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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

May 2014

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Society for Underwater Technology

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

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1 Introduction

The past few years have seen a proliferation of offshore renewable energy projects including wind, wave and tidal developments. 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 impact of these risks can be exacerbated by the increasing size of offshore renewable developments.

The primary sources of information that are used to minimise and mitigate the risks posed by ground conditions and geohazards are complimentary geotechnical (intrusive) and geophysical (remote sensing) 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.

To achieve this, the guidance notes are separated into two parts:

- Part 1 – Planning – this section presents a strategy that developers are recommended to follow in the planning of ground investigations and is aimed at practitioners with minimal experience of geophysical and geotechnical investigations.
- Part 2 – Execution – this section presents key aspects that should be considered when performing such ground investigations. 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. However, they are neither intended to be a standard nor a specification and recognise that, 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 advised to engage specialist help to ensure that fit-for-purpose and cost-effective investigations are successfully achieved in a timely manner. Further, it is advised that the end-users of the ground investigation (e.g. foundation design engineers/installers, cable route developers/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 (see Section 10) and Appendix 1 comprises a list of references, standards, codes and guidelines pertaining to various aspects of offshore ground investigation. Appendix 2 comprises table of hazards, their investigation and their likely impact on a development. Appendix 3 provides several tables covering 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 a 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 project costs, project design, project schedules, construction methodologies, profitability, health and safety and can also lead to environmental damage. In the history of construction projects worldwide, there are numerous examples where unforeseen ground conditions have led to significant increases in overall project costs.

Clayton (2001) summarises very concisely why ground related risks to projects are so high by highlighting 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.
- The accuracy of many ground-related design calculations remains very poor.
- Ground conditions will affect different methods of construction in numerous and different ways.
- Construction in the ground is normally carried out 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 practical after the project commences. This will contain all identified and potential geological or geotechnical hazards and provide a structure for managing the hazards as the project progresses.

The process or methodology of risk management is not covered in these guidance notes. However, developers are recommended to consult and apply the principles contained in Managing Geotechnical Risk – Improving Productivity in UK Building and Construction (Clayton, 2001).

Typical hazards that may be present on a site for an offshore renewable project include, but are not limited to:

- Areas of soft soils (e.g. channel infill), the presence of which may affect foundation placement and installation depths and may also restrict the selection of installation vessels.
- Areas of mobile seabed, the presence of which may affect foundation behaviour, loads and installation depths and may also affect cable routing, installation and long term burial/protection.
- Very hard soils or bedrock, the presence of which may affect foundation installation methods, installation depths as well as cable routing and burial/protection options and methods.
- Rapid change in foundation conditions that may determine the selection of more than one foundation type for a development area.
- Surface or buried obstructions, boulders, unexploded ordnance (UXO), etc.
- Shallow gas, the presence of which may impact foundation stability and the safe drilling of geotechnical soil borings.
- Seismic risk and the potential for soil liquefaction.

A comprehensive table of hazards which may be encountered is provided in Appendix 2. This table is complemented by an additional table that suggests methods for investigating such hazards and provides an indication of their likely impact on an offshore renewable energy project.

3 THE GROUND MODEL

The geotechnical risk management process 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 1). 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 development area prior to the development design being finalised.

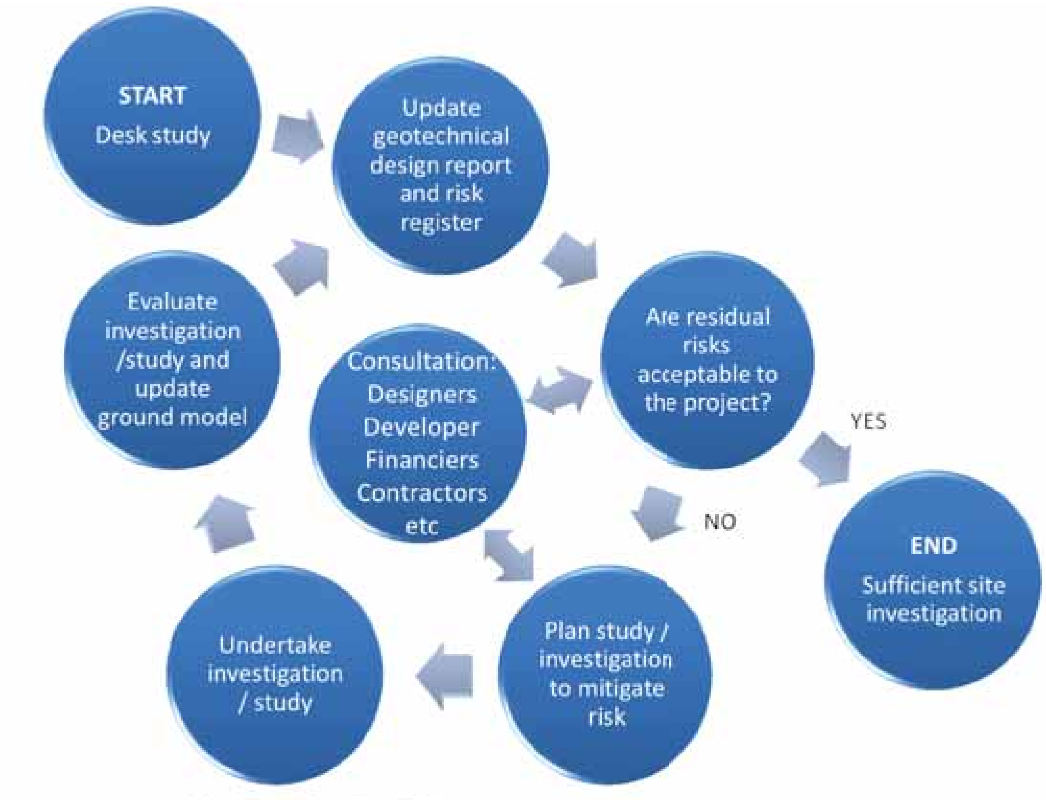

Figure 1: A typical process of understanding ground conditions

The aggregation and assimilation of all site investigation data that are collected for a project site during this process is commonly referred to as the ground model. The ground model is not a linear process developed by a single data study, investigation or analysis but is created by a continuous and iterative cycle of collecting new information, interpreting these data, updating the model, identifying the remaining unknowns and planning any subsequent investigations.

3.1 What is a Ground Model?

A ground model is a database of information that includes the structural geology, geomorphology, sedimentology, stratigraphy, geohazards and geotechnical properties of a site. Creation of a ground model is becoming 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 installation methods for a field development.

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 of all the information collated (including raw and interpreted data) in an internationally recognised format (see Section 9).
- A geotechnical risk register (see Section 2).

The ground model is a key input to geotechnical design parameters for a site and to an understanding of how these may vary across a site. Depending on the complexity of the model, this information can be presented as maps, 2D or 3D images, or in text.

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 hazard risk, a ground model will normally comprise several stages of evolution before the ground risks are considered to be acceptable. These stages are represented in Figure 1. However, 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 (e.g. Rochdale Envelope - Infrastrucure Planning Commission, 2011), the size of which will depend upon the stage of development of the ground model. 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 that is to be adopted, installation methods, the developer's attitude to risk, the speed of development that is being proposed and the stage of the development (e.g. budgetary constraints related to at-risk pre-consent spend often governs the extent and type of any ground investigation). Figure 2, below, shows the typical stages for a large offshore wind development.

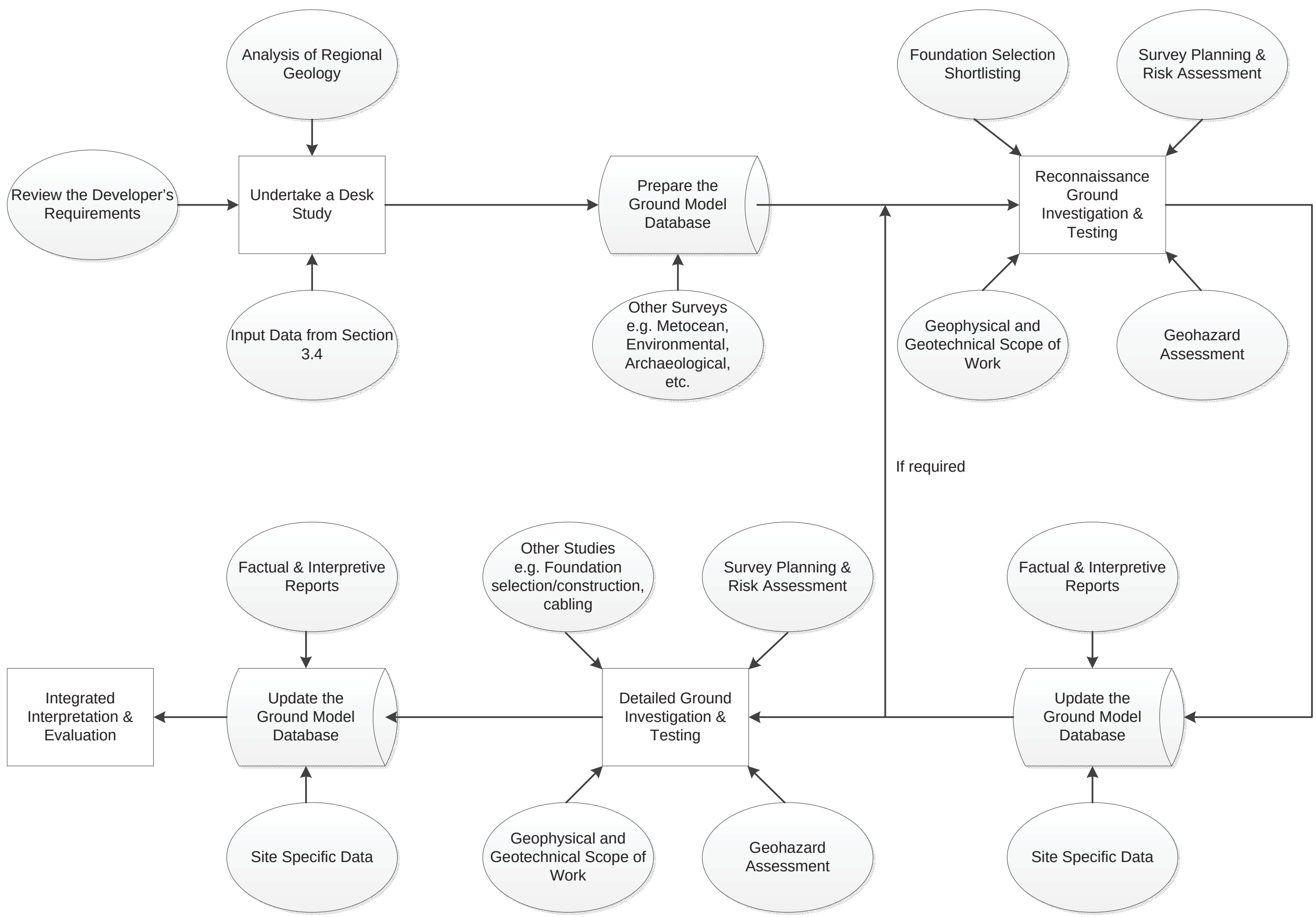

Figure 2: Example Ground Investigation Process Flowchart for an Offshore Wind Development

3.4 Desk Study

The first stage of determining the ground conditions and geological hazards that may be present on a site should always be a desk 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 study should include but not be limited to:

- Definition of the area to be surveyed.
- Geodetic datum and projection to be used.
- Vertical (tidal) datum to be used.
- Project requirements.
- License and consenting requirements pertinent to the area to be surveyed.
- Conceptual foundation selection studies.
- Assessment of shallow geological and ground conditions from all available data (published and unpublished).
- Existing geophysical and/or geotechnical data (including earthquake data) for the site.
- Existing site investigation data and reports for other nearby sites.
- Environmental issues (marine mammals, seabed ecology etc.).
- Public domain data e.g. winds, waves, tides, weather, climate, etc.
- Nautical charts (historical and current).
- 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.
- Any other local experience or knowledge.
- A hazard register including known man-made hazards (such as UXO, seabed wrecks, seabed infrastructure) and naturally occurring geohazards (such as boulders/gravel beds, soft sediment in-filled channels, bedrock, shallow gas, etc). This should include all hazards to safety, the programme and the environment, and should be updated throughout the investigations as hazards are investigated.

There is a wealth of public domain data (e.g. metocean, geological, nautical, etc.) published on the internet and in other sources that may aid the desk study and the selection of optimum survey equipment or instrumentation and techniques. However, it is recommended that the integrity of the data acquisition techniques and publication dates for these existing data be reviewed, as the use of historical, obsolete, inappropriate or positionally inaccurate data can prove to be problematic as a project progresses.

A review of up-to-date and historical nautical charts will provide indications of water depth, seabed topography, mobile seabed, existing infrastructure, and other features such as seabed wrecks, telephone or power cables, pipelines, etc., which may influence the survey design and equipment selection and the location of the proposed development. The presence of shipping lanes and other areas where operations may be constrained can also limit investigation or development activities. The range of water depths and expected nature of the shallow soils within the investigation area, when combined with the offshore renewable energy development specifications, will dictate the geophysical and geotechnical survey equipment or instrumentation selected.

Local regulatory and licence rules 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.

A review of existing site investigation data and reports for nearby sites should be conducted to identify shallow geological conditions in or adjacent to, the investigation area and to highlight any operational problems that may be expected. This will also help to determine optimum selection of survey equipment or instrumentation and techniques (see Sections 6 and 7) and specific contractor expertise.

3.4.1 Reconnaissance Surveys

Depending on the risk mitigation necessary and the scale and size of the proposed development, the desk study will typically be followed by a reconnaissance survey or surveys, using geophysical and/or geotechnical methods (see Sections 6 and 7). For smaller developments, it may be feasible to proceed directly to the detailed investigation as described in Section 3.4.2. In general, geophysical investigations normally precede geotechnical investigations and the results of the geophysical investigation are often used to aid selection of geotechnical investigation locations.

Reconnaissance surveys are performed to:

- Provide a preliminary understanding of the shallow geology and ground conditions of the area to be developed and to identify any data/knowledge gaps identified in the desk study to facilitate design and installation of a project.
- Identify possible constraints and hazards from man-made, natural and geological features which may affect 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.

The surveys will typically be used to reduce the key risks that are affecting a developer's early investment decisions within an appropriate level of financial exposure. They also enable the most appropriate method of subsequent investigation to be determined for a site. A developer must be prepared to undertake additional reconnaissance investigation(s), if the planned ones do not mitigate the risk as expected.

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.

Following the reconnaissance surveys, the developer should have sufficient understanding of the ground-based risks or hazards to enable site selection and preliminary design to take place and the necessary project investment decisions to be made.

3.4.2 Site Investigations for Detailed Design and Construction

The reconnaissance surveys will normally be followed by investigations for detailed design and construction. These investigations will, in general, be significantly more expensive than the reconnaissance surveys. Such investigations should only take place once the developer has decided on the preferred infrastructure layout, cable route(s) and type of installation vessel to be used for the development and on the foundation type to be built. Equally, they must be completed before detailed design can commence.

3.5 Ground Investigation Programme

The time line for the various investigations to be undertaken will always be project and site specific and it is not possible to provide detailed guidance on this aspect of ground investigation. However, Figure 3, below, shows an example timeline for an offshore wind project. The elapsed time shown here does not include extended time for approval procedures, adverse weather or any other unforeseen delays. It should also be noted that it is necessary for the requirement for conceptual foundation design to progress at an early stage in order to scope the most appropriate investigations.

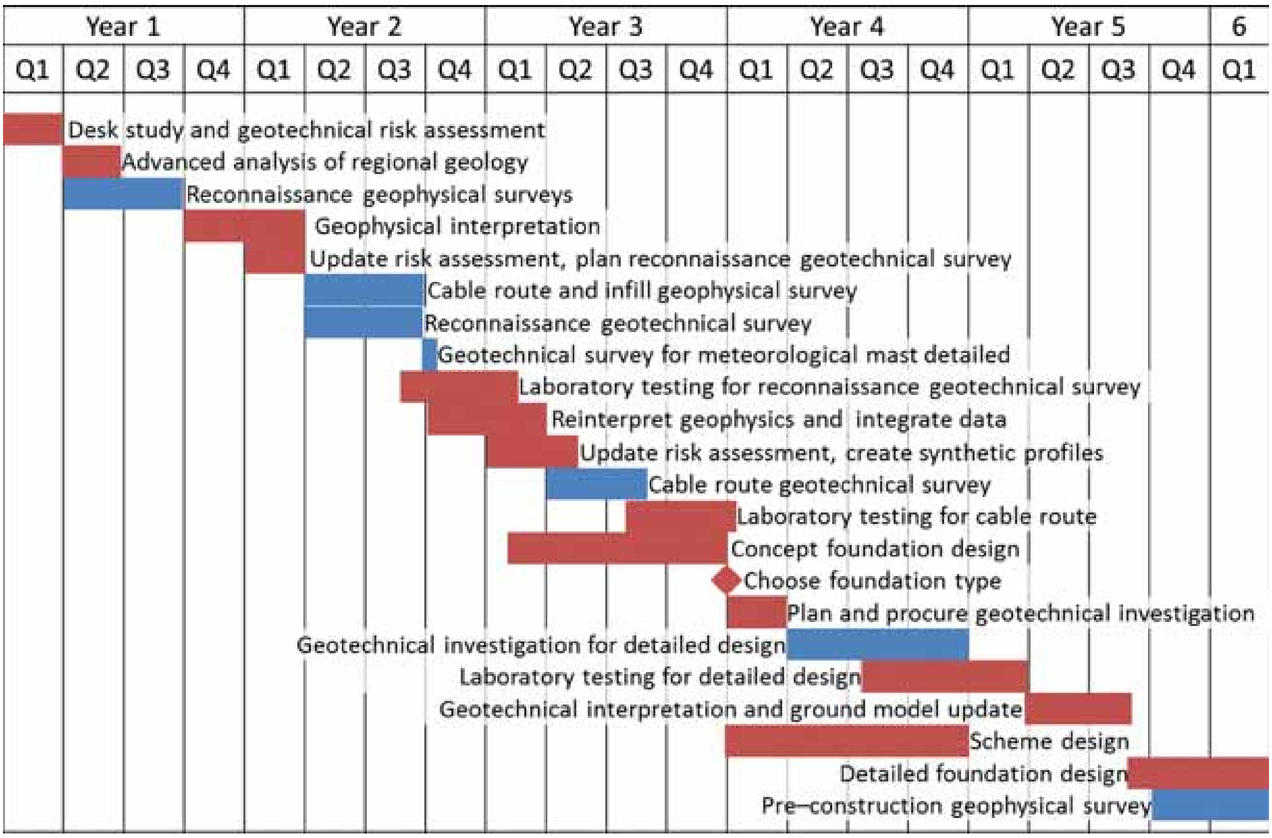

Figure 3: Example Timeline for an Offshore Wind Farm Project – Site Investigation Phase

4 PLANNING AN OFFSHORE GROUND INVESTIGATION

4.1 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.

Investigations may be designed to be multipurpose. 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 at a site. However, each purpose will have specific requirements and priorities must be defined to ensure cost benefits are optimised.

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

4.1.1 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/regulatory bodies.
- Insurers.
- Financiers/investors.
- Safety engineers.
- Geologists.
- Environmentalists.
- Archaeologists.
- Oceanographers.
- Surveyors.
- Fisheries personnel.
- Mariners.
- Public organisations/institutes.

4.1.2 Influence of Design Codes and National Standards

Developers must make themselves aware of the needs of the national codes or standards and other country-specific regulatory requirements 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 specific local legislative needs. It is recommended that developers compare legal/local requirements with these guidance notes, and where there are differences, they should apply the most appropriate guidance.

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

4.2 Types of Investigation

These guidance notes cover a number of data requirements including water depths, seabed topography, seabed and sub-seabed obstructions, seabed 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 (O&M). 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 the 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 soil conditions through a well-integrated investigation using both techniques. The benefits and limitations of these techniques are summarised in Table 1. In specific locations where earthquake activity is considered to be a risk to the development, a seismic risk analysis should be performed to ascertain ground motion parameters and to provide basic references for seismic design.

Acquisition of geophysical data primarily uses a range of acoustic-based instruments to characterise the seabed, 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 applicable to various objectives.

Acquisition of geotechnical data primarily involves making an intrusive investigation of the seabed. This generally involves the taking of samples of soils or rock, and *in situ* cone penetration tests (CPT) in which an instrumented cone is pushed into the seabed. Cone tests made with pore pressure measurements are referred to as piezocone tests (PCPT or CPTu). CPT measurements provide specific soil properties through empirical correlation 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. though use of seismic cone or P-S logging (see Appendix 3).

Following the site investigations, geophysical processing and geotechnical testing are often required at an onshore processing/laboratory 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.

More information on the benefits and limitations of these techniques when applied to an offshore renewables projects are set out below:

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	Qualitative results subject to interpretation
Continuity between specific point locations	Some systems very weather/noise sensitive
Wide range of depth of sub-bottom investigation	
Geotechnical Investigations	
Range of systems for different soils and applications	Single data point may need many locations to investigate an area
Quantitative results used for engineering design	Slower acquisition rates than geophysics
Physical measurement of soil and rock properties	
Generally, less weather sensitive than geophysics	

Table 1 Characteristics of Geophysical and Geotechnical Investigations

4.3 Scope of Investigation

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

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

Prior to any discussion on the planning of an offshore renewables project, the geodetic datum and projection and the vertical (tidal) datum for all the work associated with the project should be established. Significant cost, time and technical impacts can occur when surveys are undertaken using different geodetic data and/or tidal datums.

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

4.3.1 Generator and Substation Foundations

- The following should be considered in the planning of generator and substation foundations:
- Type(s) of structure and foundation under consideration (e.g. driven/drilled monopile, suction pile, suction caisson, gravity base structure (GBS), piled jacket, anchored floating structure, etc.).
- Likely planned extent of foundation footprint, penetration and mobilised stress depth.
- 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).
- Are the foundations limited by static or dynamic loading (cyclic strength and stiffness)?
- Uniformity of design versus optimisation of foundations for each location.
- Susceptibility to seabed mobility (scour, sand wave movement, etc.).
- Other factors or location/site specific factors identified by the foundation designer.

It is recommended that close communications be maintained between the developer and the foundation designer to ensure data suitability.

4.3.2 Installation and Maintenance

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

4.3.3 Inter-Array Cables

The installation and protection of inter-array cables often carries a significant risk on a renewables development and warrants careful consideration, to include, as a minimum, the following aspects:

- Array cable layout.
- Bathymetry and seabed gradients.
- Seabed and sub-seabed obstructions.
- Cable and pipeline crossings.
- Soil classification and engineering properties (particle size distribution, density and shear strength, thermal properties, as appropriate).
- Peat, gravel and shell content of the shallow soils.
- Seabed mobility and the consequential effect of the structures on the seabed.
- Burial protection specification – depth of lowering (DOL) from mean seabed level (MSBL), to top of cable (TOC), depth of cover (DOC) or backfill and trench cross-sectional profile.
- Potential exposed cabling over rocky seabed with anticipated protection from movement due to current or to man-made seabed activity.
- Trenchability.
- Geological substrate and its relationship with seabed bedforms.

4.3.4 Export Cables

The design issues for export cables are similar to those for inter-array cables. However, the variation in water depths and soil types 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 seabed areas and areas 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 (e.g. seismic, resistivity or refraction techniques) or a towed grapnel survey may be required to establish achievable trenching depths. The seismic, resistivity and refraction techniques referred to are beyond the scope of these guidance notes and the developer should consult a specialist engineering geophysicist if such techniques are required.

Hazards associated with vessel anchoring and fishing gear interaction with a cable are the same as for inter-array cables. However, the likelihood of such occurrence and therefore the risk to the cable is increased 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 the equipment and installation techniques available.

4.3.5 Shore Crossings (Landfalls)

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

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

In the case of geotechnical investigations, it is important to consider the protection implications for the proposed cable facility. In many instances, the prevailing 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 two kilometres, or so, offshore. Such HD drilling can be very sensitive to the soil types encountered. Careful planning of onshore and near shore geotechnical ground investigations is essential, especially where the use of mobile jack-up geotechnical 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.

4.3.6 Data Collection Structures

Developers often require ground investigations very early in a development in order to design data collection structures (e.g. met masts). Occasionally, developers attempt to advance such investigations to a detailed stage without having undertaken even a brief desk 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 structures are very similar to generator and substation foundations; albeit on a smaller scale.

It should be noted that pile driving records from the installation of a data collection structure can provide valuable input to the subsequent design of generator foundations and this information should, therefore, be included in the ground model.

Part 2 – Execution

5 GENERAL

5.1 Health, Safety and Environment

Health, safety and environment (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.

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, as such, the inspections may be required to exceed the requirements of the vessel under 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.

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 significant changes are made to the vessel or rig use or major items of survey equipment are installed and it is considered unusual for a vessel not to be inspected at least once every twelve months.

For reference, a vessel safety guide for offshore renewable energy developers has been written by RenewableUK (RenewableUK, 2012). 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.

5.2 Competent Personnel

The planning, acquisition, testing, processing, analysis, interpretation and reporting of data from site investigations require a combination of specific geotechnical, geophysical, geological, hydrographical, positioning and other specialist skills. In order that the key objectives of a ground investigation are met, it is imperative that appropriately skilled and experienced personnel are used throughout the entire project. Key factors include:

- The ground investigations should be managed by a competent specialist working for or on behalf of the developer.
- 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/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.
- It is important that all data processing, storage, testing, analysis, interpretation and reporting are overseen by experienced site investigation specialists to ensure that each constituent part of the final survey results is adequately checked and that there is optimal integration of all data.

5.3 Developer's Offshore/Onshore Representative

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. These personnel act as independent witnesses of all activities onboard. Further, depending on the contractual set-up, it is common for the DOR to represent the developer in commercial aspects of the survey (including weather downtime, data acceptability and any contractual issues) and to monitor 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 support offshore, where appropriate.

It is very important that the DOR has experience of:

- Health and safety management.
- Geotechnical design.
- Offshore working.

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 uneconomical and/or unsafe campaign. Experience of foundation design is particularly important in order to be able to modify and amend scopes of work on a 24 hours basis. Relying on onshore support for foundation expert guidance can result in poor decisions being made overnight or at weekends when the support may not be immediately available.

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

5.4 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

- Previous experience of the contractor in the area of operations and the techniques and equipment required.
- Whether or not the vessel/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/rigs with survey/drilling equipment permanently installed.
- Good HS&E record and a demonstrable HS&E culture.
- Where the vessel/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/rig suitability for efficient and safe operations in the area during the proposed time frame of the investigation.
- Weather sensitivity of the vessel and its in-water equipment deployment and retrieval capabilities.
- Vessel/rig suitability to operate survey/drilling equipment to meet the objectives of the investigation.
- Vessel/rig accreditation and audits for compliance with regulatory requirements.

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 practical and safe.
- In specific circumstances, the vessel should be capable of acquiring soil samples to provide near "real-time" ground truthing of shallow geophysical data in the field.
- Autonomous Underwater Vehicles (AUVs) 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.

Geotechnical vessels/rigs

- All geotechnical investigations require a working platform from which to perform the investigation. In shallow water and in the near shore environment, jack-up platforms 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) 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 20-25m, they can be more limited by drill-pipe flexibility and 'watch circle' constraints. Alternatives to vessels with drilling rigs are seabed 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 seabed 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. The seabed CPT drive and deployment system can typically weigh in excess of 20 tonnes and a safe deployment system is imperative. Where penetration below seabed exceeds the water depth, additional CPT rods will have to be added during the test in which case a safe working platform above the seabed unit needs to be available.
- In areas where bedrock is encountered and there is a requirement to sample the bedrock in addition to the superficial deposits, secondary drilling systems are often required.
- 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 bedrock exposed, 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 seabed surveys (e.g. for UXO or unlisted man-made hazards, or in environmentally sensitive areas) and sub-seabed surveys (e.g. for geohazards such as shallow gas) are required, either by the contractor or by regulatory requirements and these need to be scheduled sufficiently in advance.

Reference, as an example, should be made to the vessel safety guide for offshore renewable energy projects prepared by RenewableUK (2012).

5.5 Data and Information Management

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 seabed footprint. Data can include the following:

- Raw survey data including positioning, bathymetry, side scan sonar, magnetometer, single channel sub-bottom profiler, multi-channel sub-bottom profiler, CPT, geotechnical borehole, grab sample, shallow gravity core and seabed camera/video footage 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 appropriate consideration is given during the planning stage of any project as to how these data will be recorded and managed.

5.5.1 Geospatial Data Provision

Geographical Information Systems (GIS) are rapidly becoming the de facto method for storing and distributing the geospatial data relating to renewable energy projects. 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.

Effective management of spatial data allows seamless integration of workflows between site investigation outputs, desk studies and engineering phases of renewable projects. It is strongly recommended that contractors and developers utilise GIS for survey, ground investigation and ground model data management and delivery.

5.5.2 Standards

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 standards and guidelines for the expression of geospatial features and metadata. A metadata record is a standalone 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 coordinate 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 the oil & gas and renewables sectors.

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/consultants should liaise with the developer with regard to specific policies for data standards.

In terms of data specification, the Open Geospatial Consortium, or 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 standards. Generally, best international practice follows ISO 19115:2003 – "Geographic information – Metadata" which defines the scope of metadata. However, ISO/TS 19139:2007 "Geographic information Metadata - XML schema implementation", which is derived from ISO19115:2003 actually defines how 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 (http://inspire.jrc.ec.europa.eu/index.cfm).

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 is in compliance with the Marine Environmental Data & Information Network (MEDIN) data guidelines and metadata standards. The MEDIN standards cover a range marine data types and have specific data guidelines for site investigation and geophysical investigation. MEDIN compliant geospatial data must follow the data standard guidelines (*www.oceannet.org/marine_data_standards/*). MEDIN specify a metadata standard (*www.oceannet.org/marine_data_standards/medin_disc_stnd.html*), where the metadata schema is based on ISO19115:2003, includes all core INSPIRE metadata elements and the XML conforms to ISO19139:2007 for xml implementation.

5.6 Offshore Data Processing, Analysis and Interpretation

Consideration should be given to processing, analysis and interpretation of the geotechnical and geophysical 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 on the proposed work scope. Further, it 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 such 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-coordinated process to those that continue such work subsequently 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 focussing on the wrong priorities.

5.7 Developer/Contractor Liaison

When planning and conducting ground investigations, it is essential that effective communications between the developer, contractor and any developer's representative(s) are 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 to the appropriate parties should be made.

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 enable this, early liaison is essential.

6 GEOPHYSICAL INVESTIGATION

6.1 General

The literature contains considerable information on the equipment and techniques used for geophysical and geotechnical data acquisition, processing, testing and interpretation for ground investigations for offshore oil and gas projects. In essence, the equipment and techniques are largely similar to those used for offshore renewables projects. Hence, it is not intended in this document to duplicate this and reference is, therefore, made to the guidelines listed in Appendix 1; particularly the OGP Guidance notes for the conduct of offshore drilling hazard site surveys, and ISO 19901-8 Marine soil investigations. (At the time of writing the geophysical content of this latter document is under preparation).

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 type, size and area of the development, the range of foundation options and the uniformity and type of seabed and shallow soils conditions likely to be encountered. The desk study (see Section 3.4) provides essential information to assist this scoping work. The geophysical investigation should provide relevant information on all geohazards, water depths, seabed features and obstructions and the shallow soils and geology over the area to be surveyed to a depth below which the underlying conditions will not influence the safety or performance of the structures being considered.

A geohazard is a geological state, feature or process that presents a risk to humans, property or environment. Geohazards 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.

Geological features including shallow gas, infilled channels, rock head, very dense sands, geological faults etc., are investigated by the geophysical survey (sub-bottom profiling methods) indicated below. 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 associated operations rather than as a global geohazard. For example, gas present in the shallow soils/geology 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. See Tables 2a and 2b in Appendix 2 for additional information.

6.2 Geophysical Equipment and its Application

Table 2 summarises the characteristics of the main types of geophysical equipment used together with comments on their typical usage:

Data requirement	Suggested primary instruments	Comments
Water depth and seabed topography	Multi-beam echo sounder (MBES) (preferably) or single beam echo sounder (in shallow water – where complete MBES coverage is impractical)	Bathymetry systems should be suitable for, and set up to accurately record, water depth data across the range of water depths expected over the ground investigation area. The bathymetry system should be hull-mounted (preferably) and used in conjunction with suitable motion sensors to compensate for vessel movement. Water column sound velocities should be determined at the start and end of the survey and at appropriate intervals during the survey. Statistical analyses of the MBES data should be undertaken and, coupled with repeated sampling of a single point throughout the survey period, be used to verify the results of the MBES for any gross measurement errors. Survey line spacing should be selected to ensure >100% coverage by the MBES (except in the case of reconnaissance surveys where less than 100% may be acceptable). Where it is not practical to use MBES (e.g., in very shallow water) a single beam echo sounder may suffice, with line spacing chosen that is appropriate to the variability of the bathymetry. Water depths should be corrected for vessel draft and tidal levels and should be referenced to an appropriate local tidal survey datum (e.g., lowest astronomical tide (LAT), mean sea level (MSL), etc). 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. IHO SO44, IHO 2008) 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.
Seabed features and/or obstructions	Side scan sonar	A dual channel, dual frequency (preferably), side scan sonar (SSS) should be used, to provide an acoustic image of the seabed with suitable coverage across the entire investigation area, preferably allowing sufficient overlap to obtain data at the nadir (the acoustically blank area directly under the SSS fish). The dual frequencies of operation should be selected to achieve appropriate seabed coverage and resolution for all data users. Where MBES data are acquired (see above), it is recommended that backscatter data from seabed returns be logged and processed for use in seabed characterisation and integrated with SSS data. For detailed inspection of relevant seabed sonar contacts, additional SSS lines should 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 on the data and to allow computer-aided analysis and subsequent mosaics to be made of the seabed. Such mosaics should be output as a geo-referenced, high resolution image, to be used as part of the revised ground model.
Shallow soils/ geology	Sub-bottom profiler (single and/or multi-channel)	A suite of acoustic/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: • the depth of interest below seabed • the nature of shallow soils/geology that are likely to be encountered • the desired resolution of the data that are to be used for mapping the shallow soils/geology 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

Data requirement	Suggested primary instruments	Comments
		would typically include: • shallow sub-seabed (0m-5m) ; inter-array and export cable protection/burial depths • intermediate sub-seabed (5m-10m); anchoring and small structure foundations • deeper sub-seabed: (10m-100m); large structure (e.g., piled foundations) Profiler seismic source systems that are commonly used include: • pinger • chirp • sparker • boomer • small airgun Data from the first four systems listed are normally recorded in single channel mode, for shallower investigations, whereas data from the latter three systems are recorded in either single or multi-channel ultra-high resolution (UHR) mode, to obtain deeper information. 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-seabed geology that are required for foundation assessments. A summary of the characteristics of the sub-bottom profilers listed (including their likely sub-bottom penetration) are presented in Table 3 below. 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.
Unexploded ordnance (UXO)	Magnetometer/ gradiometer supplemented by side scan sonar and sub-bottom profiler	UXO is a specific high risk seabed or sub-seabed obstruction. If the desk-based UXO threat and risk assessment reveals that the offshore renewable energy site has a significant risk of UXO being present, then an appropriate phase of site investigation should be designed to acquire data to detect and identify them. The majority of UXO surveys 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 seabed. Such systems can only detect UXO items that have an associated ferrous metal casing or magnetic signature. Owing to the rapid reduction in magnetic field effect 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 seabed. This requirement precludes widely spaced survey lines and renders it impractical to magnetically survey for UXO over large investigation areas. Hence, such surveys should only be undertaken when i) energy structure layouts and cable routes are in an advanced stage of planning and/or ii) geotechnical soil boring/CPT locations or anchor spread layouts are known, in order to focus on limited areas of interest. Other sensors may be required to identify UXO prior to deciding further action. These may include using high resolution sonar, such as 3D mapping and/or imaging sonar and/or the use of ROVs equipped with cameras and other imaging tools. It is recommended that specialist UXO personnel be used to assess any risk and aid survey design, as appropriate.
Beach topographic and subsurface profile		Land topographic surveys are undertaken using total survey stations or laser scanning. Subsurface profiling is undertaken using seismic reflection, refraction, MASW techniques, with low power (eg sledgehammer, weight drop) sources and geophone arrays.

Table 2 Geophysical Data Requirements/Instruments Used

The picture below (courtesy of Osiris Projects) shows a schematic layout of equipment commonly used for offshore geophysical investigations.

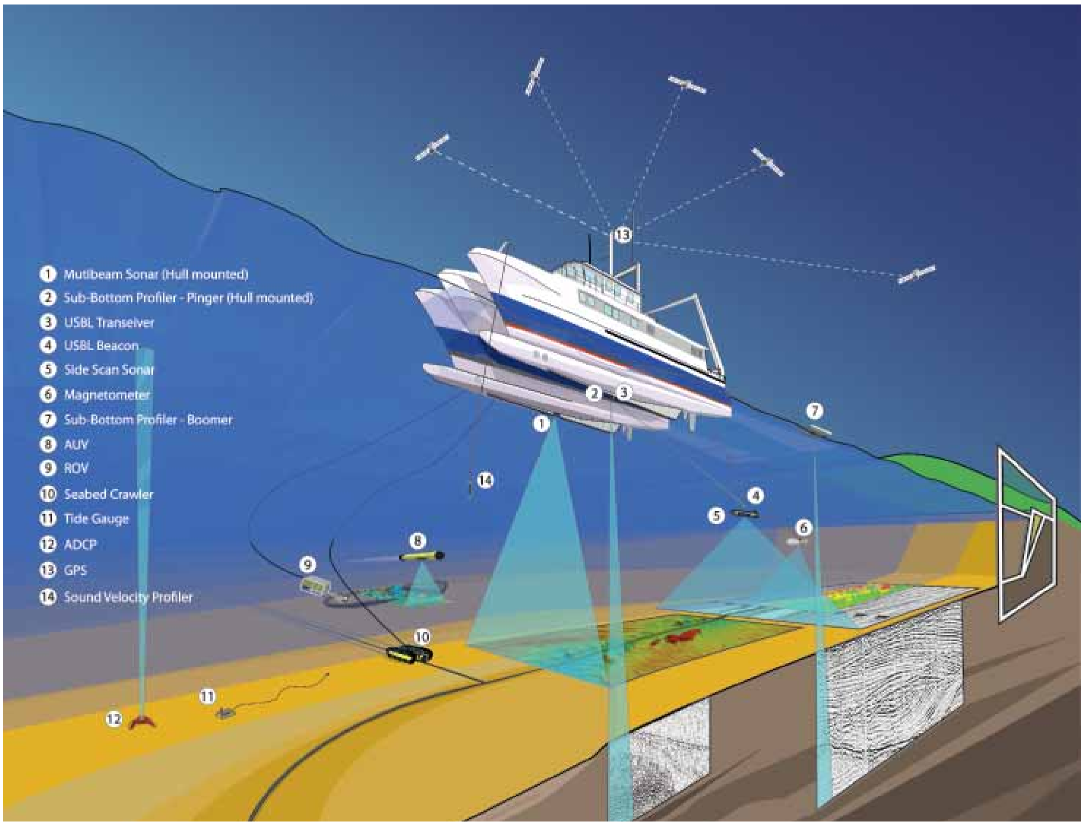

Figure 4: Schematic layout of equipment commonly used for geophysical investigations (courtesy of Osiris Projects)

6.3 Sub-bottom Profiling Systems

Table 3 details the characteristics of commonly used sub-bottom profiler equipment:

Sub-bottom Profiler	No. of channels	Approximate frequency range (Hz)	Expected sub-bottom penetration (metres below seabed)
Pinger	Single	2,000-7,000	Up to 50 in soft soils, typically 5-10
Chirp	Single	2,000-8,000	Up to 50 in soft soils, typically 5-15
Sparker	Single/Multi	50-4,000	Up to 100, typically 50, multichannel up to 300m
Boomer	Single/Multi	300-3,000	Up to 60, typically 30
Single 10 cu.in. airgun	Multi	20-500	Up to 500 in soils and soft rocks, dependent on water depth

Table 3 Sub-bottom profiler characteristics

Increased sub-bottom seismic penetration requires systems with higher power output. This usually results in reduced geological layer resolution resulting from the necessary use of lower acoustic frequencies to achieve the greater penetration. System selection should always consider this penetration/resolution trade-off in achievable data.

6.4 Time/Depth Conversion – Seismic Velocities

It is important to recognise that seismic data are recorded in the time domain and seismic reflections that are used to image the seabed and sub-bottom geology need to be converted to depths using derived seismic velocities. Ground models are likely to contain variable geological provinces with different geological settings and processes encountered both vertically and laterally. The implication of this is that single seismic (p-wave) velocity models (commonly used in offshore site investigations) for depth conversion of seismic (time domain) data into depth data are 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.

7 GEOTECHNICAL INVESTIGATION

7.1 General

The geotechnical investigation should provide all the necessary soils and rock data to allow detailed design and installation of the project. For example, this may include data for the founding of installation vessels (including jack-up rigs), foundation design & installation, and cable routing, burial and/or protection.

To add maximum value to the seabed 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 survey is to add to and further develop the ground model for the site, determine the vertical and lateral variation in seabed conditions and to provide the relevant geotechnical data for foundation design, for planning installation activities (including foundations for the installation vessel), operations and maintenance and for planning cable protection and/or burial.

7.2 Scope of Geotechnical Works

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 seabed and sub-seabed 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 to be used. Depending on the homogeneity of the site geology and/or confidence in the ground model, this will not necessarily require information to the full foundation depth at every structure location.

Vessel selection (see Section 5.4) is critical to gaining high quality data in a timely and cost effective manner. Depending upon the specific site environmental conditions, fixed platforms (jack-up rigs) and anchored or dynamically positioned vessels can be used. In the case of floating plant, the use of motion compensated drilling equipment is recommended. Appropriately equipped vessels can also deploy seabed drills and shallow sampling or CPT equipment for applications such as cable route surveys.

The advantages and disadvantages of various vessel/drill platform types are provided in Table 4 below.

Vessel Type	Advantages	Disadvantages
Jack-up	• Provides stable platform • Offers dual 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	• Sites need to be assessed in advance for punch through and leg penetration • Have limited water depth capability • In general, need additional vessels for moving and supply • Can only move when environmental limits are not exceeded • No accommodation on small jack-up rigs in shallow water, which can lead to crew change issues
DP vessel with heave compensated drill or seabed CPT	• Fast moving between locations and fast set-up • Heave compensation allows operations to proceed in marginal sea-state conditions • Track record and experience in oil and gas operations, with high productivity	• In general, higher per diem cost than other options • Limited number of vessels in operation

Anchored vessel	• Can offer more stability in high current areas • Minimum water depth for operations is less than for DP vessels	• Longer periods for anchoring and set-up • Increased weather sensitivity during anchor deployment and when on station as susceptible to weather heading changes • Anchor type may need to be changed for some locations • Unable to anchor with rock outcrops at seabed surface
Seabed drill	• Reduced pipe handling • Lower HS&E risk with no personnel intervention when operating • Ability to operate in strong currents	• May produce lower quality data in highly variable soil conditions • Limited down-hole *in situ* testing options • Requires a DP vessel to deploy with appropriate deck space and launch and recovery system • Limited number of systems and experience in operation

Table 4 Advantages and Disadvantages of Various Vessel/Drill Platform Types

7.3 Data Coverage

Due to the widely varying nature of the applications of the ground investigation data and, in the case of large wind farm sites, their large areal extent, it is sometimes not possible to acquire such data at every precise foundation location or at closely-spaced intervals along all proposed cable routes. As a result, the ground model, developed from the available and acquired data, can be used to provide an interpreted 3D model of the seabed and underlying soils to depths of interest.

Where ground truthing is not available, it is important to recognise that the ground model will only be based on seismo-stratigraphic information. Where a good degree of ground truthing is available and the model is appropriately constructed and maintained, the ground model can be used, with caution, to assist engineering design where detailed point sample data are not available. In general, geophysical data provide remotely sensed, wide area information for input to the model; geotechnical data provide multi-purpose specific point sample data to, amongst other things, ground truth the geophysical data.

The spacing of sampling and testing locations, particularly during any reconnaissance phase, will depend on the lateral and vertical variability in ground conditions revealed by the desk study and any reconnaissance geophysical survey data available at the time of investigation. The number, depth and position of the boreholes and CPTs for the reconnaissance geotechnical investigation should be sufficient to inform the prospective foundation designers of the regional ground model. The distribution should be based on geotechnical provinces previously developed during the desk study phase and other historical data, unless available geophysical survey coverage suggests otherwise.

For the detailed final preconstruction 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 preconstruction 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 foundation conditions show significant variation that warrants the consideration of more than one foundation type and/or there are specific certifying authority or classification society requirements that are to be satisfied.

During the scoping of the geotechnical investigation consideration should be given to project-specific factors such as those detailed in Section 4.3 and including:

- Size, location and foundation type of all the proposed seabed structures.
- Complexity of ground model.
- Presence and distribution of geotechnical hazards.

- Variability and uncertainty in geotechnical properties.
- Uncertainty regarding final layout of structures.
- Position of inter-array and export cables.
- Installation vessel or methodology (e.g. jack-up rigs).

Each project should be reviewed separately and an appropriate sampling and testing programme determined by a competent geotechnical engineer. However, as a guide, a best practice geotechnical survey work scope is suggested in Table 5 below.

Foundation structure type	Best practice geotechnical work scope
Monopile	For a pile that does not rely on end bearing, a continuous CPT (from seabed 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. Down hole geophysical logging and *in situ* stiffness measurements may also be used.
Monopile in rock or combination of soil/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. Down hole geophysical logging and *in situ* stiffness measurements may also be used.
Jackets and tripods, substations	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/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. Down hole geophysical logging and *in situ* stiffness measurements 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 of the rock. 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-up installation and O&M vessels	Further sub-surface investigation may be required where there is significant variability in soil conditions or very hard or very soft soils are encountered and/or the possibility of punch through is predicted in the area where these vessels will be located.
Anchored or tethered foundations	A borehole with samples/CPT or a seabed CPT at each anchor location. The investigation depth is dependent upon the geology.

For further details see text in this section 7.3. Note, guidance from adopted code/certifying body and advice from a competent geotechnical engineer should be sought in developing the work scope.

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.

Refer to Figure 5 for indication of foundation structure types

Table 5 Example Best Practice Geotechnical Work Scope for Different Foundation Types and Construction Vessels

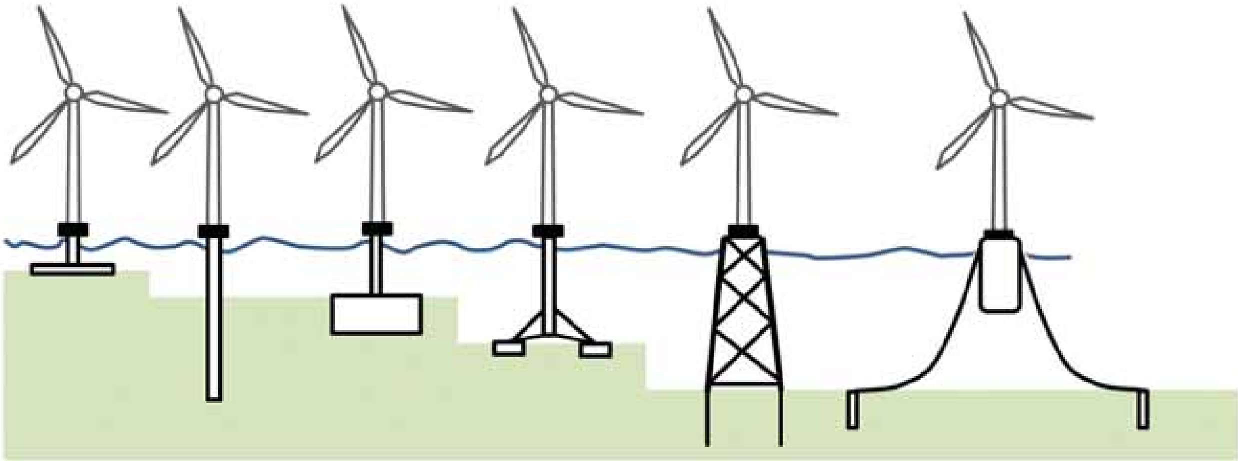

Figure 5: Structure and Foundation Types for Offshore Renewable Developments

The termination depths 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. For instance, foundations for substation structures may need deeper data than those for turbines. High quality data near to seabed may be of importance – for example, where jack-ups are used, or for laterally loaded foundations or to define scour likelihood.

Where soil conditions are likely to vary over the footprint, or where 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.

In deciding the final geotechnical scope of work, the following factors, amongst others, should be considered:

- Whether or not the risks from acquiring fewer boreholes/CPTs, in terms of soil strength, can be accommodated by using more conservative design parameters for in-place analyses.
- Whether or not acquiring less boreholes/CPTs may increase the risk of installation problems (e.g. pile refusal at less than target depth) or whether or not such risks can be accommodated by, for example, utilisation of larger pile driving hammers and possibly corresponding thicker pile wall section.

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

Consideration should also be given to the acceptable level of sample disturbance. Depending on the design methodology and the 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.

Where bedrock is present beneath 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 seabed currents may be sited on bedrock; although pockets of infill sedimentary material may remain. Gravity base foundations, in particular, require detailed knowledge of the localised seabed roughness which can cause uneven contact. In addition, visual data can be collected using remotely operated vehicles (ROVs) to examine seabed features and 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. Bedrock may be exposed nearby, onshore, and investigation of this can be used to supplement offshore data.

Additional sampling or *in situ* tests may also be required away from structure or foundation locations to define the extent of any geotechnical hazards and reduce the level of uncertainty and associated risk, particularly if any relocation of the structure is to be considered. This could also apply to areas where stability of the installation vessels is considered to be a risk.

Consideration should be given to wire-line geophysical logging, seismic cone and pressuremeter testing to enhance the quality of the survey data.

For cable routes, a sufficient number of samples should be obtained from, and *in situ* tests conducted in, each surface seabed unit along the routes to identify and classify the material, to assess the requirements for burial and protection, and to assess thermal properties. Sample or test spacing and number may vary depending on the complexity of the near-surface soil conditions, and the presence and frequency of geological features that may influence the cable installation method. Sampling and testing is normally required to extend below the target burial depth to obtain information on thermal conductivity, electrical resistivity and organic content. Consideration should be given to site investigation requirements for directional drilling for landfalls and also to greater depth of penetration for cable routes around shipping channels that may not be covered by conventional cable route investigations.

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/challenges that arise.

7.4 Geotechnical Information Required

The geotechnical data relevant for structural foundations and cable installation design includes, but is not limited to:

- Description and index classification.
- Strength parameters (for different failure modes, monotonic and cyclic).
- Soil modulus and damping parameters.
- Permeability and consolidation parameters.
- Liquefaction potential.
- Thermal conductivity.
- Chemical composition.

7.5 Key Outputs

The key outputs from the investigation should include, but not be limited to:

- Refined ground model, integrating the geotechnical and geophysical data, and including the determination of the lateral and vertical variability in ground conditions.
- Idealised ground profile at each structure or foundation location.
- Factual and interpreted geotechnical parameters to allow determination of bearing capacity, vertical displacements, drivability, punch-through, liquefaction potential and scour and erosion.

To achieve these key outputs, data must be acquired from *in situ* and laboratory data. The following table provides guidance on the site tests which are commonly used to acquire this information.

Data required	Suggested equipment	Comments
Shallow seabed samples	Vibrocorer, box corer, gravity corer	Seabed samplers can be deployed from non-specialist vessels using an A-frame or over-side crane deployment. Some operate from frames lowered to the seabed. Others are dropped and use gravity or vibration to penetrate the seabed
Continuous soil profile	CPT using seabed or down-hole equipment. Seabed CPT thrust capacity of 200kN is recommended for deep push CPTs. For shallow penetration, 50kN is generally acceptable along cable routes. In down hole mode, thrusts of 60kN to 90KN 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/CPT	Drilling equipment combined with sampling tools and down hole CPT. 76mm 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-up platforms or seabed drilling units
Continuous sampling in rock or very hard soils	Rotary coring. Core size of at least 76mm is recommended	Wire-line coring equipment can be used with the main drill or by using a supplementary drilling system
Down-hole 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/rocks**	Pressuremeter/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 measurement
Thermal conductivity	Heat-flow probe or laboratory-based needle probe	Heat-flow probe measures the *in situ* thermal conductivity in shallow soil depths with an array of thermistors. Alternatively, laboratory-based samples can be tested with a needle probe
Permeability	CPT dissipation test	Laboratory testing may also provide information on permeability

Table 6 Types of Sampling and *in situ* Test Data

8 POSITIONING

Surface positioning of the survey vessel/rig should be based on augmented global navigation satellite system (GNSS), e.g. differentially corrected GPS (DGPS) or clock and orbit corrected GPS (also referred to as precise point positioning (PPP)). Absolute horizontal positioning accuracy is correlated with the level of augmentation provided and typically ranges from +/-3m for standard DGPS through to +/-0.15m for PPP. The objectives, accuracy requirements and scale of the investigation should be considered in assessing the positioning system performance specification. Standard or dual frequency DGPS should be appropriate for the majority of offshore surveys. It is recommended that two fully independent surface positioning systems should be used for quality control purposes and redundancy should component failure in a system occur.

GPS, or spinning mass, ring laser or fibre optic gyros, 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 tow-fish or subsea vehicles is being undertaken using USBL systems (see below). Heading accuracy of better than +/-0.5° x secant latitude for gyros and +/-0.5° for GPS is readily achievable using modern systems and should reflect the minimum specification.

The correct use of GNSS positioning and solutions are critical to the success of an offshore site investigation. It is recommended that the GNSS are installed, verified and operated in line with the Guidance Notes for GNSS Positioning in the Oil and Gas Industry, issued jointly by OGP and IMCA (see Appendix 1). This describes good practice in, among others, offshore survey and related activities for the oil and gas industry.

Where optimal vertical absolute accuracy is a requirement, as may be required in support of borehole operations or where bathymetry is to be reduced using a VORF (Vertical Offshore Reference Frame) model, real time kinematic (RTK) GPS positioning may be used. This assumes that the investigation area is within VHF/UHF radio transmitting range of a fixed based station at a precisely known location and altitude. 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. Vertical accuracies of better than +/-0.1m are achievable using these approaches.

Bathymetry may be reduced to the required vertical datum using qualified VORF mode, if available for the site, that precisely relate satellite datums to hydrographical datums such as mean sea level (MSL) and lowest astronomical tide (LAT).

Where towed sensors are being used, such as side scan sonar or sub bottom profiler, the position should be determined using a vessel mounted acoustic positioning system. Typically this will be an ultra-short base-line (USBL) system, which consists of a hydrophone that transmits and receives a signal from a beacon mounted on the towed system. By observing the time delay of the signal and observations of the speed of sound in water together with the phase angle of the returning signal, a range and bearing to the beacon is calculated and positioned. For optimum performance the system must be appropriately installed, calibrated and operated and may deliver relative accuracies of better than 0.5% slant range between the hydrophone and beacon. It is recommended that contractors adhere to the relevant guidelines described in IMCA document S 017 (2011) - Guidance on vessel USBL systems for use in offshore survey and positioning operations.

In shallow waters, less than 15m, it may be impractical to use a USBL system, in which case layback methods and position calculations may be considered. In some operations, e.g. positioning of a plough or a cable-tracking seabed 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.

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

9 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 to convey the results of the ground investigation effectively to the end-users listed in Section 4.1.1.

Offshore renewables ground investigations can be very large, incorporate a number of different phases and utilise several different contractors and vessels or rigs over a prolonged time period. As such, it is essential to establish a co-ordinated, consistent and rigorous approach to data interpretation and subsequent integration in the early stages of the project; preferably at the planning phase (see Section 4).

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

Report deliverables may be provided in both digital media (GIS compatible) and paper forms. Integrated digital methods of compiling, presenting and delivery of 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. The OGP has published a seabed survey data model (SSDM) to define an industry standard GIS data model for seabed surveys (see Appendix 1). This model can be used as a deliverable standard between developers and contractors, as well as a data model for managing seabed survey data within developers.

Careful consideration should be given to the reporting requirements during the site investigation, 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 progress whilst the ground investigation progresses, provided the risks of using partial results are well managed.

10 GLOSSARY

Term	Definition
Acoustic ground discrimination system	Automated seabed classification system based on backscatter data from a single or multi beam echosounder. Usually requires site specific calibration.
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.
Autonomous underwater vehicles	A self-propelled, untethered underwater vehicle that is able to be programmed to fly along a predefined survey track at a predefined height above the seabed to collect data from sensors installed on it.
BAT probe	*In situ* gas-water saturation measurement.
Bathymetry	Variation in water depth across a given site. (The measurement of) water depth.
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.
Boomer	Marine seismic energy source that operates by the rapid movement of a restricted metal plate using an electrical pulse applied to a coil.
Borehole	Boreholes 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.
Chirp System	Energy source used in sub-bottom profiling that emits a frequency modulated pulse over a specified range of frequencies.
Consolidation parameters	Geotechnical soil parameters used in compressibility analyses, typically defined by onshore laboratory testing of recovered seabed samples.
CPT	Cone Penetration Test. *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	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 height of soil or other backfill material measured directly above the top of cable.
Digital terrain model	Digital representation of a mapped surface usually defined by xyz values for defined cells.
Dredging	The removal of seabed soils – e.g. perhaps to prepare the seabed for installation of foundations.
Dynamic positioning	Thruster system installed on a vessel to maintain position without anchoring.
Electrical resistivity	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.
Fall cone test	A test used to measure the liquid limit and undrained shear strength of soils other soil parameters.
Geodetic datum	Geodetic datums define the size and shape of the earth and the origin and orientation of the coordinate systems used to map the earth. Position co-ordinates must be referenced to the geodetic datum to which they relate.
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.
GIS	Geographic Information System. A system that captures, stores, analyses, manages, and presents data that are directly linked to the coordinates of the data's origin.
Grab sample	Seabed samples acquired by mechanical or hydraulic grab methods.
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.
Heat-flow probe	A heat flow probe is used to measure thermal conductivity.
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. For example 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 0.5m into the soil before being activated and can be deployed from seabed or a borehole.
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.
Jack-ups	A type of mobile platform with a floating hull and is capable of moving its legs to raise itself over the surface of the sea.
Lab vane	A vane apparatus used in a laboratory to measure the undrained shear strength of soil.
Liquefaction	The process by which soil loses its strength due to an increase in pore pressure during single or repeated loading. The process by which soil loses its strength during loading.
Lowest astronomical tide	Lowest tide level which can be predicted from astronomical factors (solar and lunar effects). Ignores factors that are due to meteorological conditions.
Magnetometer	An instrument to measure magnetic field strengths 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.
Mean sea level	Average height of sea surface midway between high and low tide.
Mudmat	Flat plate or grillage used as a gravity base foundation.
Multi-beam echo sounder	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.
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. 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.
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.
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.
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.
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 offshore and is usually supplemented by higher quality testing in the laboratory.
Pressuremeter/dilatometer	*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-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 sub seabed.
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 metre sub-seabed. Operationally more complex than reflection, as requires sensors to be deployed on seabed; usually used to obtain data nearshore.
Resistivity techniques	Survey methods using electrical resistivity instruments.
Rotary coring	A technique for obtaining cores that is 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.

Sample disturbance	Changes to material properties by disturbance of the soil that has occurred during the process of sampling, transportation and testing.
Scour	The process by which the seabed soil is removed from around structures due to the action of currents and waves.
SDI	Spatial data infrastructure - a means to manage, interrogate, integrate, and visualise project data 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 multi-channel) 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.
Side scan sonar	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	Instrument for measuring water depth immediately below a survey vessel, will produce a single line profile of data, 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.
Sparker	Seismic source produced by an electric spark discharge in water.
Stratigraphy	A branch of geology that studies rock layers and layering (stratification) primarily used in the study of sedimentary rocks and also soils.

Suction caisson/suction pile/ suction bucket/ suction can suction caisson/ Suction pile/ suction bucket	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.
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.
Top of cable	Depth to the 12 o'clock position on a cable, usually measured relative to LAT.
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 surveys to identify and remove seabed obstructions.
Tripods	A structure supported by three separate foundations.
Unconsolidated undrained triaxial compression	Relatively quick measurement of undisturbed soil shear strength.
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.
Vibrocorer	Seabed continuous sampling device typically up to 6m long that penetrates the seabed using force exerted by a vibrating motor mounted on top of a coring barrel.
Water column sound velocity profile	The vertical distribution of acoustic velocity, measured using a instrument lowered or dropped from a survey vessel, to enable accurate conversion of signal travel time to depth when measuring bathymetry.
Wire-line logging tools	Various geophysical tools lowered into a borehole to measure soil or rock properties.

APPENDIX 1
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APPENDIX 2
TABLES OF HAZARDS, THEIR INVESTIGATION AND THEIR LIKELY IMPACT ON AN OFFSHORE RENEWABLES ENERGY DEVELOPMENT

Table Appendix 2a: Key Features of Constraint, Hazard or Concern, to be Assessed by Means of Site Investigations

<table>
<tr><th colspan="3">Key features to be assessed by means of survey and geotechnical investigations</th></tr>
<tr><td>Man-made features:
• Pipelines: on or buried below the seabed
• Communications cables
• Wrecks, including ships aircraft & submarines
• Wellheads and abandoned well locations
• Unexploded ordnance (UXO) and related debris, previously deployed or dumped
• Navigation or metocean buoys
• Archaeological remains
• Miscellaneous debris
• Power and umbilical lines & cables
• Waste, chemical or other dumping grounds
• Jack-up rig footprints
• Rock dumps
• Scour protection material
• Gravel extraction areas
• Export and intra-array cables
• Wind turbines, wave, tidal arrays
• Manifolds and templates
• Platforms: active, abandoned, or toppled
• Anchorage</td><td>Natural seabed features:
• Seabed topography and relief
• Seabed sediments
• Sand: banks, waves, and mega-ripples
• Glacial features including iceberg plough marks, flutes and moraines
• Rock outcrops, pinnacles and boulders
• Seabed channels and scours
• Peat
• Gravel beds
• Hard grounds / cemented sands
• Submerged forest or terrestrial palaeo-landscape
• Unstable or steep slopes
• Gas vents and pockmarks
• Collapse features
• Fluid expulsion features
• Chemosynthetic communities
• Fault escarpments
• Reefs
• Mud: flows, gullies, volcanoes, lumps, lobes
• Slumps
• Diapiric structures
• Gas hydrate mounds</td><td>Subsurface geological features:
• Sedimentary sequences
• Stratigraphy
• Buried infilled channels
• Hard grounds / cemented sands or buried land surfaces
• Gravel beds
• Boulder beds
• Rock head or igneous intrusion near seabed
• Peat
• Erosion and truncation surfaces
• Shallow water flow zones / loose sands
• Glacial features incl. drumlins, loess and moraines
• Faults - tectonic or glacigenic
• Shallow gas charged intervals
• Gas chimneys
• Salt or mud diapirs and diatremes
• Buried slumps and mass transport complexes
• Gas hydrate zones and hydrated soils</td></tr>
<tr><td colspan="3">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.</td></tr>
</table>

Table Appendix 2b: Feature/Hazard Investigation Methods and Effect on Renewable Energy Developments

Features of constraint, hazard or 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 3rd party damage; historic or sensitive feature with protection obligations. Location or distribution of such features can require device relocation or field redesign	Safety hazard; obstruction to cable or its installation, protection by burial, operation or longevity; soil strength effects; litigation hazard from 3rd party damage. Location or distribution of such features can require cable route relocation or layout redesign	Location, identification and avoidance by means of side scan sonar, multibeam and single beam echosounder, magnetometer, shallow sub bottom profiler, drop- or ROV-deployed camera	N/A
Natural seabed 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 redesign	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 redesign	Location, identification and mapping by means of side scan sonar, multibeam and single beam echosounder, magnetometer, 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 its 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 installation methods required or suitable. Such factors affect optimisation of array and cable location.	Single and multi-channel seismic reflection profiler systems. Resistivity and seismic refraction systems for cable route investigations	Geotechnical boreholes, CPT systems, vibrocorers,

APPENDIX 3
GEOTECHNICAL TESTING METHODS TABLES

Table Appendix 3a: Conventional 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>Geological description</td><td>Geological logging</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td><td></td><td>3</td><td>4</td><td>4</td><td>4</td></tr>
<tr><td rowspan="3">Soil classification</td><td rowspan="3">CPT</td><td rowspan="3">5</td><td rowspan="3">5</td><td rowspan="3">3</td><td rowspan="3">2</td><td>Grain size (sieve)</td><td>5</td><td>3</td><td>4</td><td>1</td></tr>
<tr><td>Water content</td><td>1</td><td>5</td><td>5</td><td>1</td></tr>
<tr><td>Atterberg limits</td><td>N/A</td><td>5</td><td>5</td><td>1</td></tr>
<tr><td>Soil density</td><td>CPT</td><td>3 to 4</td><td>2</td><td>3</td><td>2</td><td>Unit weight and water content measurement</td><td>1 to 2</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td rowspan="7">Soil strength (undrained shear strength)</td><td>CPT</td><td>N/A</td><td>3 to 4 (a)</td><td>3</td><td>2</td><td>Unconsolidated undrained (UU) triaxial compression</td><td>N/A</td><td>5</td><td>5</td><td>3</td></tr>
<tr><td>In situ vane</td><td>N/A</td><td>4 to 5</td><td>2</td><td>1</td><td>Consolidated triaxial compression</td><td>N/A</td><td>5</td><td>4</td><td>1</td></tr>
<tr><td rowspan="5">T bar</td><td rowspan="5">N/A</td><td rowspan="5">5</td><td rowspan="5">3</td><td rowspan="5">1</td><td>Small T bar</td><td>N/A</td><td>5</td><td>3</td><td>1</td></tr>
<tr><td>Fallcone, pocket penetrometer, Torvane, lab vane, direct simple shear</td><td>N/A</td><td>2</td><td>2</td><td>2</td></tr>
<tr><td>Unconfined or uniaxial (UCS) testing</td><td>N/A</td><td>1</td><td>3</td><td>5</td></tr>
<tr><td>Point load testing (PLT)</td><td>N/A</td><td>1</td><td>3</td><td>4</td></tr>
<tr><td rowspan="2">Friction angle (drained shear strength)</td><td rowspan="2">CPT</td><td rowspan="2">3 to 4</td><td rowspan="2">2</td><td rowspan="2">3</td><td rowspan="2">2</td><td>Consolidated triaxial compression,</td><td>5 (b)</td><td>5</td><td>2</td><td>2</td></tr>
<tr><td>direct shear (shear box), direct simple shear</td><td>4 (b)</td><td>1</td><td>2</td><td>2</td></tr>
<tr><td rowspan="2">Sensitivity</td><td>CPT</td><td>N/A</td><td>2</td><td rowspan="2">2</td><td rowspan="2">2</td><td rowspan="2">Fall cone, lab vane, triaxial</td><td rowspan="2">N/A</td><td rowspan="2">5</td><td rowspan="2">3</td><td rowspan="2">1</td></tr>
<tr><td>In situ vane</td><td>N/A</td><td>3</td></tr>
<tr><td>Consolidation characteristics and permeability</td><td>CPT (piezocone)</td><td>1</td><td>3 (c)</td><td>3</td><td>2</td><td>Oedometer</td><td>2 (b)</td><td>5</td><td>4</td><td>2</td></tr>
</table>

Table Appendix 3b: Special Testing Methods

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

Table Appendix 3c: Seabed Sampling Equipment

Seabed 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
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

Down-hole 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

Suitability Scale

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