GUIDANCE NOTES ON SITE INVESTIGATIONS FOR OFFSHORE RENEWABLE ENERGY PROJECTS

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PLEASE NOTE THAT ALL COMMENTS SHOULD BE SUBMITTED TO FinchM@rpsgroup.com BY 15TH APRIL 2005

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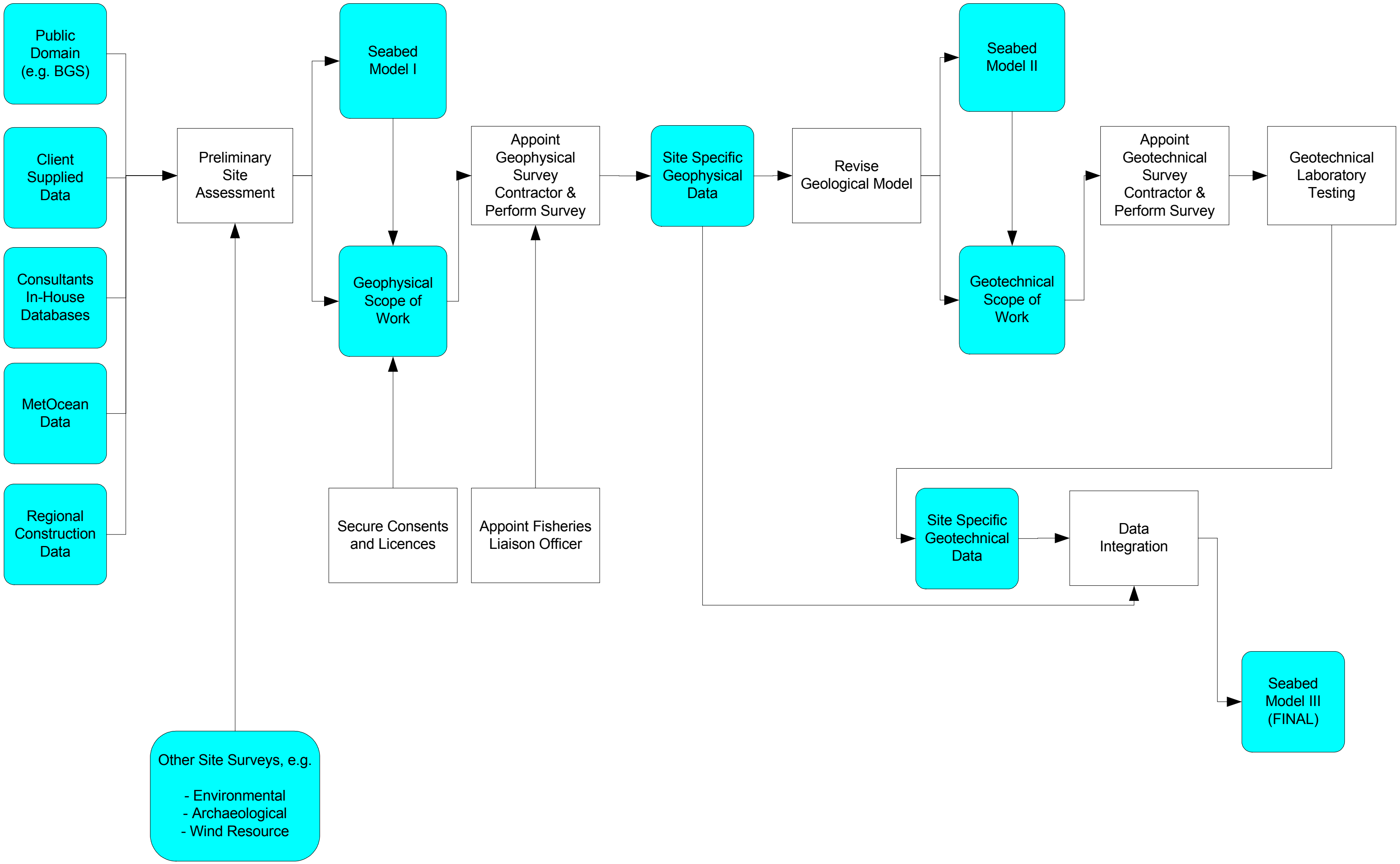
1.0 PROCESS FLOWCHART



2.0 DISCLAIMER

Members of the Offshore Site Investigation and Geotechnics (OSIG) Committee of the Society have compiled the information supplied in this document for the Society for Underwater Technology (SUT). The information within this document is based upon the shared experience and knowledge of the authors and the SUT OSIG committee and is published in good faith with the aim of promoting the highest standards of reliability and safety in the range of offshore renewable energy industries.

Whilst the SUT believes the Information to be valid, it is the responsibility of individual members, or others who may seek to rely on such information, to satisfy themselves as to the accuracy thereof.

The SUT does not accept any liability for any errors or omissions in the information or for any adverse consequences arising from its adoption.

3.0 FOREWORD AND INTRODUCTION

"No construction project is risk free. [Geotechnical] Risk can be managed, minimised, shared, transferred or accepted. It cannot be ignored" [Ref. 1]

These Guidance Notes have been compiled by the Society for Underwater Technology (SUT) Offshore Site Investigation and Geotechnics (OSIG) Committee. The Guidance Notes are intended to set out a framework of best practice for site investigations and seabed risk management for offshore renewable energy projects.

This document is aimed primarily at site investigation for engineering design and construction purposes. Other reasons for site investigation (e.g. environmental and archaeological studies etc) are not addressed within this document.

Of necessity the current guidance notes are particularly relevant to, and focussed upon, the offshore wind farm industry – the predominant offshore renewable energy source in the world to date. They are, however, applicable to any offshore renewable energy project.

The importance of site investigation for any offshore project cannot be overstated. A site investigation is a critical step in any seabed risk management process and is vital to ensure the success of any offshore project.

The offshore environment is harsh and unforgiving and the vast majority of seabeds are complex and dynamic. Fit-for-purpose design is critical in the offshore environment where design conservatism is not a logical mitigation for seabed risk and installation problems can cause significant schedule and cost over-runs.

A recent survey of European offshore windfarm projects [Ref. 2] concluded that approximately 25% of total project capital expenditure (CAPEX) could be directly attributed to the chosen foundation system. This fact alone highlights the importance of achieving an optimum foundation solution and thus the need for a focussed and cost-effective site investigation.

A properly designed, managed and executed site investigation is critical to the success of any offshore renewables project. These Guidance Notes are intended to establish a best-practice process for achieving the maximum added value from an integrated offshore site investigation and seabed risk management system.

4.0 RELEVANT REGULATIONS AND EXISITING GUIDELINES

There are currently very few existing guidelines or recommended practice documents specifically aimed at site investigation of offshore renewable energy projects. There are, however, a number of existing documents that are relevant to the subject.

A number of nations – notably Germany, Denmark and The Netherlands - have developed regulations applicable to the construction of windfarms (and therefore, by default, offshore windfarms) which are sited within their legal jurisdiction. These national guidelines are regulatory and, as such, take precedence over any other guidelines or recommended practice (including this document) where any overlap, duplication or omission occurs.

The documents that may be relevant to site investigation for offshore renewable energy projects are listed in Table 4.1.

There are also a number of relevant documents that give guidelines with respect to laboratory testing of geotechnical samples, these include:

- British Standards Institution (1990) BS1377: Methods of Tests for Soil for Civil Engineering Purposes.
- British Standards Institution (1999) BS5930: Code of Practice for Site Investigation.
- American Society of Testing and Materials, (2005) Volume 04.08, Soil and Rock (1) D420 – D5779. Annual Book of ASTM Standards.
- EN1997, Eurocode 7, Geotechnical Design.
- International Standards Organisation: Geotechnical Investigation and Testing, Identification and Classification of Soil, Part 1: Identification and Description ISO 14688-1:2002.
- Norsk Standards 8000 to 8017.

Ref.	Title	Date	Author	Relevant Sections	Comments
1	Regulations for the Certification of Wind Energy Conversion Systems	2004	Germanischer Lloyd	Section IV, Chapter 8	Brief comments on soils and foundation issues.
2	Design of Offshore Wind Turbine Structures (DNV-OS-J101)	2004	Det Norske Veritas	1, 2, 3, 5, 10, 14, Appendices F, G, J and M	Detailed Standard.
3	Classification Notes 30.4: Foundations	1992	Det Norske Veritas	Section 1	Relatively detailed commentary. Written for oil and gas industry.
4	RP2A (WSD and LRFD), "Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms – Working Stress Design / Load and Resistance Factor Design"	WSD (2000) LRFD (1993)	American Petroleum Institute	1.4 (WSD) A.4.10 (LRFD)	Brief commentary on site investigation issues. Written for oil and gas industry.
5	Petroleum and Natural Gas Industries – Specific Requirements for Offshore Structures – Part 4: Geotechnical and Foundation Design Considerations (ISO 19901-4)	2002	International Standards Organisation	Section 6	Relatively detailed commentary. Written for oil and gas industry.
6	Guidance Notes on Geotechnical Investigations for Subsea Structures	2003	SUT OSIG	Various	Detailed Guidance Notes written specifically for subsea oil and Gas Industry.
7	Marine Soil Investigations (G-001)	2004	NORSOK	All	Detailed Guidance Notes written specifically for oil and Gas Industry. Currently DRAFT (Rev. 2).
8	Minimum Technical Requirements for the Acquisition and Reporting of Submarine Cable Route Surveys	2003	International Cable Protection Committee	All	Detailed guidance relevant to cable routes.
9	Rules and Regulations for the Classification of Fixed Offshore Installations (Part 3)	1989	Lloyds Register	Various	General advice

Table 4.1: Relevant Regulations and Existing Guidelines for Site investigation for Offshore Renewable Energy Projects

5.0 PRELIMINARY SITE ASSESSMENT

5.1 Aims and Objectives

A preliminary site assessment is the first stage in an integrated seabed risk management process – see Section 1.0 (Process Flowchart) – which encompasses all issues related to the seabed conditions at a given location.

The objective of the preliminary site assessment is to demonstrate the feasibility and suitability and relative installation risk of preferred design concepts including foundations and cable routes.

A desk study alone is not sufficient for detailed engineering purposes.

However, a desk study is the best way of obtaining some information, including location of existing subsea infrastructure (e.g. pipelines and cables) which may be required for the planning of both the survey and the construction works.

5.2 Scope of Preliminary Assessment

The preliminary site assessment typically comprises a desk study to collate published data and information from previous investigations. However, in areas where little information is available, a preliminary / overview survey or investigation may be required. For example, where monitoring stations are to be installed, localised survey works may be required. Data obtained from the installation of such stations may also be incorporated into the overall site assessment.

The desk study should incorporate a review of all appropriate sources of information and the collection and evaluation of all relevant available types of data for the area of interest. The various factors that should be investigated include, but are not limited to:

5.3 Sources of Information

There are usually a number of public data sources available and sourcing of site-specific data should be undertaken wherever possible. Data sources include, but are not limited to:

- Geological databases.
- Bathymetric information.
- Geophysical databases.
- Geotechnical databases.
- Metocean data (tides, currents etc).
- Seismic data.
- Records of nearby construction.
- Data on human activities (e.g. location of existing structures, pipelines and cables, wrecks, munitions disposal site, aggregate dredging, licence areas etc).

5.4 Key Outputs

The key outputs from a preliminary site assessment are typically:

- An outline geological model for the site (including preliminary geotechnical properties).
- Preliminary definition of key geological processes and their status (e.g. active, dormant etc).
- Estimated metocean conditions.
- Identification of major geotechnical risks (with respect to the planned development) and areas of insufficient information.
- Outline scope of work for any additional survey and monitoring requirements.

6.0 ENGINEERING DESIGN CONSIDERATIONS

6.1 Introduction

This section provides a summary of key engineering considerations associated with the foundation design of offshore renewable energy projects. Design considerations are restricted to those that affect the scope of the geophysical and geotechnical site surveys.

The purpose of the summary is to enable the appropriate foundation parameters for soil strength, stiffness, stress-history, permeability and cyclic engineering parameters to be targeted in the site investigation, in addition to the minimum requirement of characterising the basic soil classification and stratification.

The summary of design considerations is not intended to be a comprehensive list. Rather, a comprehensive list of design considerations and hazards should be developed on a project-specific basis.

6.2 Structure and Foundations Concepts

A number of the design considerations are universal, in that they apply to all offshore renewable energy projects, whether surface-piercing wind turbine structures, or wave, tidal or current energy structures restricted to the water column or on the seabed. The universal considerations define the overall structure type, foundation concept and construction method.

Other design considerations are unique to each foundation concept, requiring specific ground characteristics to be targeted during the survey.

Foundation concepts for offshore renewable energy projects include deep monopiled towers, deep or shallow multiple piled frame structures and gravity based structures. Construction methods include pile driving, drilling and grouting, or suction-installation.

6.3 Engineering Design Considerations

The engineering design considerations specific to each general foundation concept – together with the universal considerations - are summarised below. They are arranged under the headings of construction, extreme loading capacity and operational performance. Decommissioning considerations are included under construction.

General Foundation Concept	Foundation Design Consideration		
	Construction	**Extreme Loading Capacity**	**Operational Performance**
All	• Temporary foundation stability of construction vessel. • Construction vessel cost and availability. • Re-positioning tolerance, i.e. can an individual unit be re-positioned in the event of an abortive installation attempt at its initial intended location? • Decommissioning requirements and removal feasibility.	• Nature of the structure to be supported and its loading, including: magnitude; direction; rate; frequency; time-dependency. • Required reliability, including individual unit reliability requirements when acting in a multiple unit development. Reflects stakeholders risk tolerances, but must ultimately satisfy regulatory requirements. • Structural fatigue. • Inspection requirements.	
Piled, Driven	• Pile drivability, governed by soil resistance, including presence of rock, cobbles or boulders. • Hammer selection. • Pile stresses, leading to direct yield and damage, or fatigue damage, during driving. • Skirt penetration of piled structure mudmats. • Pile self-weight penetration.	• Pile ultimate axial capacity. • Pile ultimate lateral capacity. • Combined pile axial, lateral and moment capacity. • Combined pile stresses. • Cyclic soil strength degradation.	• Foundation and supported structure deflections and stresses. • Definition of acceptable deflections - pile toe, mudline or turbine deflections or rotations? • Sustained tension of foundation elements (especially for shallow piles relying on suction response to resist uplift). • Seabed scour, leading to time-dependent changes in soil/structure interaction. • Cyclic soil strength degradation. • Time-dependent soil stiffness degradation, and hence change in system natural frequency.
Piled, Drive/Drill	• Open hole drilling and hole stability. • Pile self-weight penetration.		
Piled, Suction-Installed	• Pile self-weight penetration. • Soil resistance and hydraulic stability during suction penetration.		
Gravity Based	• Skirt penetration resistance. • Sliding stability and differential settlement during touchdown.	• Vertical, sliding and overturning stability. • Relative base/ soil stiffness – more base flexibility requires more complex foundation analysis.	• Foundation and supported structure deflections and stresses. • Immediate elastic and long-term consolidation settlements. • Excess pore-water pressure and dissipation under base, leading to shakedown. • Scour susceptibility. • Cyclic soil strength degradation. • Time-dependent soil stiffness degradation, and hence change in system natural frequency.

Table 6.3.1: Summary of Engineering Design Considerations

7.0 SURVEY DESIGN

7.1 General

The objective of the site survey for offshore renewable projects is to obtain sufficient reliable seabed information on the site conditions to permit the safe and economic design of installation and permanent works.

Unexpected or poorly defined site conditions are one of the most commonly re-occurring causes of construction delays and cost escalations. By undertaking a detailed site survey – as part of an integrated seabed risk management process - the risk of delays and increased costs is significantly reduced.

Offshore renewable energy projects can be particularly exposed to seabed risk due to the relatively wide spacing of individual structures and the increased influence of metocean conditions in shallow water. In addition, projects are often located in areas where there is little or no existing knowledge of the seabed or environment.

The required level of information will vary during the development of the project. At project conception, the data available should be sufficient to demonstrate the feasibility and suitability of the preferred foundation design concepts and selected cable route corridors. As the project progresses towards detailed design and construction, the data should be sufficiently detailed and robust for design purposes and to allow contractors to provide optimised pricing for supply and installation contracts.

The site investigation programme should therefore be undertaken in progressive stages. Planning for each stage should be carried out based on the results from previous findings in order to optimise the extent of investigation work. Factors such as vertical and horizontal uniformity of ground conditions and the project specific design requirements should be directly reflected in the extent of the site investigation undertaken.

At each stage of development, it is important to evaluate the geotechnical risk as part of an integrated risk management procedure for the project. As the project develops, one of the aims of the site survey should be to reduce the identified risks.

There are two basic components to any site investigation – a geophysical and a geotechnical survey.

In general the results of a geophysical survey will provide information on:

- Water depth.
- Bathymetry.
- Near surface soil conditions and their lateral variation.
- Debris or man-made hazards across the proposed site.

A geophysical survey cannot provide specific information on soil types or actual geotechnical parameters.

A geotechnical survey provides actual soil samples ("ground truth") that can be physically tested to give site specific geotechnical information. This information can then be integrated with the geophysical data, and the results of the desk studies (i.e. integrated into the seabed risk model), to yield a site specific geotechnical model for the proposed development site.

The following sections describe the various issues that should be considered when designing a site survey for an offshore renewable energy project.

7.2 Licences, Permits and Consents

This document is not intended to be limited to the UK, however, the following sections are included as an example of requirements for typical site investigations.

The majority of renewable energy projects in the UK to date are located within 12 miles of the coastline. As such these sites are classified as coastal or nearshore projects and are subject to the same health & safety and licensing requirements as near and onshore civil engineering projects.

The following sections give an overview of relevant regulations that may apply and licences that must be obtained.

7.2.1 CDM Regulations

The CDM Regulations (Construction (Design & Management) Regulations 1994) identifies all duty holders that can contribute to the health & safety of a project, summarised as:

- Client
- Designer
- Contractor
- Planning supervisor

The following nominated personnel should be appointed:

- Planning supervisor to co-ordinate and manage health & safety during the design and early stages of preparation / construction.
- Principal contractors to co-ordinate and manage health & safety issues during the construction or site investigation phases as appropriate.

One of the Planning Supervisors duties is to ensure that a pre-tender stage health and safety plan is prepared before construction begins. It is the planning supervisor that completes and issues an F10 form to the Health and Safety Executive prior to the start of the works.

The Principal Contractor has to develop the Health and Safety plan prior to work commencing and keep it up to date during the works.

Additional information can be obtained from the HSE web site at www.hse.gov.uk

7.2.2 Mandatory Licences and Consents

Depending on the scope of work of the project one or more licences / consents must be obtained for the site investigation before any work begins on site. The licences / consents required for the site investigation fall under one or more of the following acts:

- Food & Environment Protection Act (1985).
- Coastal Protection Act (1949).
- Telecommunications Act (1984).

The Marine Consents and Environment Unit (MCEU) is an alliance between the Department for the Environment, Food and Rural Affairs (DEFRA) Marine Environment Branch and the Department for Transport Ports Division. The MCEU provides a central facility for receipt of applications and the subsequent administration of all marine works.

The MCU 5 application form is appropriate for both geophysical and geotechnical site investigation applications.

The Marine Consents and Environment Unit (MCEU) should be contacted for guidance on applications for relevant licences and consents at either www.defra.gov.uk or marine.consents@mceu.gsi.gov.uk

It should be noted that prior to the start of the site investigation notices to mariners and the appointment of a fisheries liaison officer will usually be required.

7.3 Geophysical Survey

7.3.1 Objectives

- To provide an accurate bathymetric chart of the development area and cable routes.
- To chart natural seabed features and any obstructions, debris or wrecks.
- To produce isopach charts to show sediment thickness of the upper, loose, and any mobile material, and of any other significant reflector levels which might impact on the engineering design.
- To locate any structural complexities or geohazards within the shallow geological succession such as faulting, accumulations of shallow gas, buried channels etc.
- To provide detailed geological interpretation to show facies variations and structural feature changes via appropriate maps and sections.
- To design a geotechnical sampling and testing programme following the completion of the geophysical survey.
- To produce a comprehensive interpretative report on the survey results obtained to assist design of the offshore foundations / structures and cable burial.

7.3.2 Geophysical Survey Design

Final survey design will depend upon the requirements of the survey, water depths and any other physical restrictions. Typically for an echo sounder, side scan sonar, and a sub bottom profiler data should be recorded along survey lines spaced at 50m intervals with cross lines every 250m. Swathe data should be recorded along lines spaced no less than 3 times water depth. It is also advised that magnetic, resistivity and electromagnetic data be recorded along lines as closely spaced as is feasibly possible.

7.4 Geotechnical Survey

7.4.1 General

The geotechnical survey should provide all the necessary seabed data to allow detailed design of the project including foundations and cable routing, burial and protection. To add maximum value to the seabed risk management process the geotechnical survey data should be correlated with the preliminary site assessment and the findings of the geophysical survey. The aim of the survey is to confirm the geological / geophysical model for the site, determine the vertical and lateral variation in seabed conditions and to provide the relevant geotechnical data for design.

7.4.2 Scope of Geotechnical Survey

An experienced marine Geotechnical Engineer should be involved in preparing the survey scope and technical specifications. The extent of the geotechnical survey 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 conditions.

The geotechnical survey should provide relevant information to a depth below which the underlying conditions will not influence the safety or performance of the structure.

The survey would normally comprise a series of sampling locations and *in situ* tests (e.g. cone penetration tests), combined with a programme of laboratory testing. The requirements for sampling and testing are different for foundations and cables.

7.4.3 Data Coverage

The spacing of sampling and testing locations will depend on the lateral variability in ground conditions revealed by the desk study and geophysical survey phases. The number, depth and position of investigation locations should be a product of a rational engineering exercise, incorporating the owners / developers risk acceptance criteria, the robustness of the design and the degree of homogeneity anticipated across the site.

In selecting appropriate spacing, consideration should be given to project-specific factors such as:

- Size, location and foundation type of any seabed structures.
- Complexity of geological model.
- Presence and distribution of geotechnical hazards.
- Variability and uncertainty in geotechnical properties.

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

For single structures (e.g. meteorological masts etc), one borehole to a sufficient depth below the expected influence of foundations is recommended.

For multiple structures / foundations, an absolute minimum of one sample point located at each corner of the development site may suffice in certain circumstances (Ref. DNV-OS-J101), however, depending on the nature of the proposed foundation concept and variability in seabed conditions, it may also be necessary to undertake sampling or *in situ* testing (e.g. cone penetration tests) at more frequent intervals or at each structure / foundation location.

Where seabed conditions are found to be highly variable or where difficult foundation conditions are identified locally, it may be necessary to carry out more than one sampling or *in situ* test at each structure / foundation location. Additional sampling or *in situ* tests may also be required away from structure / foundation locations to define the extent of any geotechnical hazards and reduce the level of uncertainty and associated risk.

For calibration of *in situ* tests, it is important to locate a number of sample locations adjacent to *in situ* tests.

For cable routes, a sufficient number of samples should be obtained from each surface seabed unit along the routes to identify and classify the material and to assess the requirements for burial and protection.

Because of the exploratory nature of the geotechnical survey, 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 survey are being achieved in the most cost-effective and optimised manner. Those specifying survey services should bear this in mind. A geotechnical engineer representing the owner or developer should be present during the survey to ensure that the objectives of the survey are fully met.

7.4.4 Information Required

The geotechnical data relevant for foundation design should include, but not be limited to:

- Description and index classification.
- Strength parameters.
- Deformation properties (e.g. consolidation parameters).
- Permeability.
- Stiffness and damping parameters.

7.4.5 Key Outputs

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

- Refined geological model including the determination of the variability and lateral extent of any variation in ground conditions.
- Idealised ground profile at each structure / foundation location.
- Geotechnical parameters to allow detailed design.
- Identification of geotechnical hazards and quantification of risk.

8.0 INTEGRATION OF SURVEY DATA

8.1 General

To maximise the value of the data acquisition exercise it is essential that all field and laboratory data are:

- Evaluated critically.
- Presented clearly.
- Summarized succinctly.
- Fully integrated with all other available data set.

To achieve this it is important that a minimum standard of data presentation is adopted. The following sections describe proven good practice and recommend some minimum standards. All interpretation and reporting should be subject to Quality Assurance procedures to the standards of ISO 9000 or equivalent.

For more comprehensive guidance, reference can be made to NORSOK standard: "Common Requirements – Marine Soil Investigations". Ref. G-CR-001 Rev. 2, May April 2004.

8.2 Core, Sample and Borehole Logs

These should clearly show the soil type variation with depth and include as a minimum:

- Graphical soil symbol column.
- Detailed written description of the soil type, its strength or density, constituent parts and any soil structure and / or inclusions and how these characteristics vary with depth. (Descriptions should adhere to terminology laid down in the relevant national or international standards).
- Moisture content, wet and dry density test results.
- Undrained shear strength measurements in clay.
- Angle of shearing resistance (friction angle) in sand.
- Atterberg Limits in clay.

8.3 CPT/PCPT (CPTU) Results

Measured and derived parameters should be plotted graphically against depth at a convenient scale such as 1cm to 1m and include:

- Cone resistance.
- Sleeve friction.
- Excess pore pressure.
- Friction ratio (ratio of sleeve friction to cone resistance).
- Pore pressure ratio (ratio of excess pore pressure to cone resistance).

In addition, interpreted logs of the CPT's or PCPT's should be presented in a format similar to the core log in order that it might be clearly understood by non-geotechnical engineers. The interpreted log should incorporate:

- Graphical soil symbol column.
- Detailed description of the interpreted soil types (using the same standard terminology as the core logs).
- Graphical plot of interpreted shear strength for fine-grained (clay) soils.
- Estimated values of relative density and angle of shearing resistance (friction angle) for coarse-grained (sand) soils.

Where there are no site specific geotechnical samples available it should be clearly stated that all derived parameters are preliminary estimates only.

8.4 Special In-situ Test Results

The results of non-standard tests should be presented in a clear and simple format, preferably including graphical representation, together with an explanation of the results and their implications.

8.5 Laboratory Test Results

Each individual laboratory test result should be presented graphically where appropriate, and in a format that complies with the relevant national or international standard. All results should also be summarised in tabular form. Any interpretation of results should be clearly highlighted.

8.6 Interpretation and Design Parameters

The interpretation and correlation of laboratory and in-situ test data should be performed by a competent geotechnical engineer and the results presented as ranges of recommended geotechnical design parameters for each relevant location.

8.7 Integration of Results

It is essential that suitably qualified personnel carefully integrate the results of all available data including geophysical and the geotechnical surveys. Often the most valuable way to integrate the data is to revise the preliminary site assessment (desk top study) in light of the data acquired during the site investigation, interpretation and laboratory testing phases.

It is important that both geophysical and geotechnical specialists are involved in this process to maximise the value of the site investigations. Only in this way can the full value of the various components of the site assessment be fully realised and misleading interpolation between individual sample and test locations avoided.

9.0 EQUIPMENT SELECTION AND DATA ACQUISITION

9.1 General

It is important that suitably qualified personnel evaluate all proposals put forward for site investigation techniques.

9.2 Geophysical Equipment and Data Acquisition

The following are issues that should be considered when developing a specification for a geophysical survey for an offshore renewables project.

9.2.1 Vessel

The survey vessel should have been purpose built or suitably converted to undertake the required survey operations in the designated geographic area and water depths.

The vessel should be capable of remaining safely at sea for a minimum of 12 hours per day in the designated survey area and equipped to meet International safety and environmental requirements.

Sufficient certified and suitably located handling machinery should be provided for the safe and efficient deployment and recovery of survey equipment.

The vessel should be equipped with suitable communication equipment and navigation and steerage control aids.

9.2.2 Positioning

Positioning should be carried out in a controlled manner such that co-ordinates are derived with sufficient accuracy to meet the needs of the project.

DGPS should be used for positioning control and preference should be given to systems that operate in RTK mode using a shore based station at a known datum position.

9.2.3 Gyro Compass

A precision survey gyro compass should be provided.

9.2.4 Sidescan Sonar

A dual channel sidescan sonar system should be supplied which should be towed at the optimum height for the water depth encountered.

9.2.5 Analogue Sub-Bottom Profiler

An analogue, sub-bottom profiler should be provided. This may be either a surface tow boomer, sub tow boomer, pinger or chirp system depending upon the expected water depth and anticipated sediment type.

9.2.6 Swathe Bathymetry System

A swathe bathymetry system should be provided that is suitable for the water depths and conditions likely to be encountered. The system should also include devices for continuous measurement of roll / pitch and heading for direct input to the swathe bathymetry system.

9.2.7 Magnetometer

A Caesium Vapour type magnetometer should be provided capable of obtaining maximum survey depth and will be used to detect any metallic objects. A base station magnetometer should be established in an area of low magnetic gradient and field values logged during the marine acquisition period.

9.2.8 Magnetic Gradiometer (Option)

A vertical or horizontal gradient gradiometer may be utilised in place of a standard magnetometer. The two sensors will be separated by no less than 1 meter with both sensors should be synchronised to 1ms or better.

9.2.9 Geo Electrical System (Marine Resistivity)

A geoelectrical system may be supplied capable of providing resistivity data to a depth of 10m below seabed. Electrode geometry should be chosen to optimise resolution and depth of penetration.

9.2.10 Data Storage

It is important to ensure that all data is securely stored during the acquisition, processing, analysis, interpretation and reporting phases of the surveys.

9.3 Geotechnical Equipment and Data Acquisition

The following are issues that should be considered when developing a specification for a geophysical survey for an offshore renewables project.

9.3.1 Vessel / Working Platform

Any geotechnical survey requires a working platform from which to perform the seabed sampling and / or testing. There are two generic types of platform; nearshore jack-up rigs that are founded on the seabed and dedicated drillships that are typically dynamically positioned but can, in certain circumstances, be anchored to the seabed.

The choice of working platform (e.g. jack-up rig or dedicated drillship) is normally based on the water depth across the proposed development. In general dedicated drillships can be used in water depths greater than 20m. Where water depths are less than 20m it is common to deploy a jack-up platform as a working platform.

There are several drillships and jack-up rigs available from specialist geotechnical contractors and nearshore construction companies on a worldwide basis. It is important to note that each unit will have strengths and weaknesses when considered against a particular workscope for a given development (see Section 11: Contractual Issues)

9.3.2 Sampling / Testing Equipment

This section evaluates the suitability of different *in situ* and laboratory tests for determining the required parameters for foundation design. The evaluation has been divided into conventional tests that are normally used in standard investigations and special tests that may be considered for specific design topics. Conventional tests and special tests are presented in Tables 9.3.2.1 and 9.3.2.2 respectively. The level of suitability / applicability is indicated on a scale of 1 to 5, where 1 is Poor and 5 is Very Good.

Similarly, an evaluation of sampling equipment is presented in Tables 9.3.2.3 and 9.3.2.4.

Soil Parameters	In-Situ Testing			Laboratory Testing		
	Type of Tests	Applicability Sand	Applicability Clay	Type of Tests	Applicability Sand	Applicability Clay
Interpolation of soil layering in between cores/borings/CPT's	Seismic reflection, (sub-bottom) profiling	3	3	N/A	N/A	N/A
Soil classification	Seismic reflection profiling CPT/PCPT*	2 4	2 4	Grain size, Water content, Atterberg limits.	5 2 N/A	3 3 5
Soil density	CPT/PCPT*	3 to 4	2	Unit weight and water content measurement	1 to 2	5
Soil strength (Undrained shear strength)	CPT/PCPT* In-situ Vane	N/A N/A	3 to 4 (a) 4 to 5	Unconsolidated triaxial compression, Consolidated triaxial compression, Fallcone, pocket penetrometer, Torvane, Labvane, Direct Simple Shear	N/A 5 (b) N/A	3 to 4 5 2
Friction angle (Drained shear strength)	CPT/PCPT*	3 to 4	2	Consolidated triaxial compression, Direct Shear (Shear box), Direct Simple Shear	5(b) 4	5 1
Sensitivity	CPT/PCPT* In-situ Vane	N/A N/A	2 3	Fall cone, labvane	N/A	5
Consolidation characteristics and permeability	PCPT*	1	3(c)	Oedometer	2(b)	5

Table 9.3.2.1 Conventional Testing Methods

* Note: The abbreviation CPTU is sometimes used in place of PCPT

Soil Parameters	In-Situ Testing			Laboratory Testing		
	Type of Tests	Applicability		Type of Tests	Applicability	
		Sand	Clay		Sand	Clay
Interpolation of soil layering in between borings/CPT's	Instrumented plough	3	3	N/A	N/A	N/A
	Seismic refraction profiling	(d)	(d)			
	Electrical resistivity profiling	(d)	(d)			
Soil density and stiffness	Electrical resistivity probe	2 to 3	1	Small strain effective stress testing	3 to 4 (e)	1
	Nuclear density probe	1 to 2	2 to 3			
	Seismic cone	3 to 4 (e)				
Soil strength and deformation	Pipe model test Plate load test	3 to 4	3 to 4	Direct simple shear	4 (b)	5
Rate effects / cyclic behaviour	Seismic Cone	3 to 4	3 to 4	Direct simple shear - static/cyclic	4 (a)	5
				Consolidated triaxial – static/cyclic	5 (b)	5
Permeability	PCPT* - dissipation tests BAT probe Piezoprobe	1	4	Special permeability tests	5 (b)	N/A
Thermal conductivity	Heat flow probe	4	4 to 5	Transient method	5 (b)	5
				Steady state method	5 (b)	5
				Mineralogy and porosity	4	4
Corrosion potential	Electrical resistivity cone	4	4	Electrical resistivity	4 (b)	4
Gas content	BAT/DGP (Deep Gas Probe)	4	4	Geochemical	5	5

Table 9.3.2.2 Special Testing Methods

* Note: The abbreviation CPTU is sometimes used in place of PCPT.

Type of Equipment *	**Sample Quality**		**Recovery (relative to length of sample tube)**	
	Sand (g)	**Clay**	**Sand**	**Clay**
Gravity Corer/Piston Corer	2	3	1	3 to 4
Vibro Corer	2 to 3	2 to 3 (g)	3 to 4	2 to 3
Grab Sampler	1 to 2	1	1 to 2	2
Box Corer (i)	1 to 2	5	1	5

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

Table 9.3.2.3 Seabed Sampling Equipment

Type of Equipment	**Sample Quality**		**Recovery (relative to length of sample tube)**	
	Sand (g)	**Clay**	**Sand**	**Clay**
Hydraulic Piston Sampler	3 to 4	5	3	5
Hydraulic Push Sampler	3 to 4	4 to 5	3	5
Hammer Sampler	2 to 3	2 to 3	3 to 4	3 to 4
Rotary Coring (j)	1	2 (i)	1	3 (I)

Table 9.3.2.4 Downhole Sampling Equipment

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) Potentially good – still to be proven, resistivity in particular requires very careful correlation with samples and / or in-situ testing
e) If in-situ shear wave velocity and laboratory shear wave velocities for different densities are available.
f) It is normally not possible to take undisturbed samples in sand
g) Poor in soft clays (but can be improved if controlled self-weight penetration of barrel is achievable, i.e. no vibration used.)
h) Recovery is limited to 0.5m and suitable only for very soft to firm clays and loose clayey/silty sands
i) Normally only used in rock or very hard clay.

10.0 REPORTING

Report formats should be designed for ease of assimilation by non-geoscience specialists. Wherever possible the data should also be summarised graphically.

The depth, below seabed, to the top or base of critical near surface strata should be presented in the form of contour (isopach) plots if sufficient data are available.

The variation of critical design parameters should be plotted, against depth below seabed, to show actual values, upper and lower bound envelopes and recommended mean.

It is very important that any and all limitations of the data are clearly highlighted and their potential affect on any engineering design and construction made clear to the end user of the data.

11.0 CONTRACTUAL ISSUES

The selection of a contractor to undertake a given survey for an offshore renewable project is a complex process that should be managed by competent professionals with significant experience of the offshore site investigation business.

Any site investigation for an offshore renewables project will typically have three key objectives:

i. Quality (i.e. to maximise survey data quality).
ii. Schedule (i.e. to minimise the duration from contract award to presentation of final results).
iii. Cost (i.e. to minimise the total cost of the survey and interpretation / presentation of results).

It is difficult – but by no means impossible, given the right expert advice and support - to achieve all three of these objectives for a given offshore survey.

When evaluating a particular survey proposal it is important to address a number of issues including:

i. What is the probable weather downtime for the proposed working platform / vessel and equipment and how could this affect the schedule and overall cost of the survey?
ii. What contractual agreement best suits the various (often conflicting) survey objectives (cost-plus, lump-sum, target price etc)?
iii. Is the project able to accommodate a reduction or increase in workscope whilst maintaining an acceptable level of quality and overall cost?

It is important to note that a given survey for a given development may have very specific objectives and these should be balanced against each other to derive the best solution for a particular development, contractor and client.

As with any contract it is critical that there is no ambiguity with respect to what has been agreed and who is responsible for each part of the site investigation process.

12.0 REFERENCES

1. “Managing Geotechnical Risk – Improving Productivity in UK Building and Construction”, Clayton, C.R.I., DETR and the Institution of Civil Engineers, 2001.

2. “Dynamics and Design Optimisation of Offshore Wind Energy Conversion Systems”, Kuhn, M., Delft University Wind Energy Research Institute (DUWIND), 2001.

3. “Marine Soil Investigations”, G-001, REV. 2, NORSOK, 2004.