Introduction to Offshore Geophysical & Geotechnical Site Investigation for Offshore Renewables
Industry Overview

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CONTENTS

• What is offshore site investigation?
• Why do offshore site investigations?
• Site investigation tools/process
• What happens when things go wrong?
• Seabed risk management?
• Who uses offshore site investigation data?
• Why is data integration important?
A Few Definitions

• Site Investigation:

   The ACT of acquiring quantitative and non-quantitative data to identify and describe submarine soils, shallow geology and geohazards

• Engineering Geophysics:

   The ART/SCIENCE of investigation and analyses of submarine soils, shallow geology and geohazards using high frequency sound and other non-seismic geophysical remote sensing methods

• Geotechnical Engineering:

   The ANALYSES of intrusive data on submarine soils and shallow geology for the purposes of engineering design for structural foundations etc

• Geohazard:

   A potential SOURCE of harm or loss causing human injury, damage to the environment, damage to property or a combination of these
Generalised Site Investigation Process

- Desk Study
- Geophysical Survey
- Data Processing, Interpretation & Laboratory Analyses
- Geotechnical Survey

Integrated report(s) for engineering design – Ground Model
Typical site investigation process flow

1. Perform desk study to develop initial ground model
2. Assess project requirements for geophysical and geotechnical data from different stakeholders
3. Perform Geophysical Survey
4. Update ground model and determine scope of geotechnical investigation based on survey results and engineering requirements
5. Perform Geotechnical Survey
6. Update Ground Model
7. Is Data enough to meet requirements and manage ground risks?
   - Yes: END
   - No: Perform additional Geophysical Surveys
8. Perform additional Geophysical Surveys
9. Perform additional Lab testing, PSHA, and/or additional Geotechnical Surveys
What is a Ground Model?

• A ground model is a database of available information such as the structural geology, geomorphology, sedimentology, stratigraphy, geotechnical properties and geohazards of a site
• Creation of a ground model is an industry standard approach to collating all available site information. This resource is used to identify all relevant unknowns and project hazards, to direct investigations and to inform the foundation design and selection of installation methods for a field development
• Creation of the ground model is not a linear process developed from a single data study, investigation or analysis, but from a continuous and iterative cycle of collecting new information, interpreting these data, updating the model, identifying the remaining unknowns and planning any subsequent investigations
• The ground model remains live throughout the project from initial inception through to decommissioning
Why do Offshore SI?

- Engineering design & hazard identification
  - Feasibility and conceptual studies
  - Foundation analyses for:
    - Wind turbines
    - Jack-up rigs
    - Sub-sea structures (eg tidal machines)
- Moorings & anchors for floating structures
- Unexploded ordnance (UXO)
- Cable route selection
  - Burial & trenching assessments
- Installation
- Operations & maintenance
Potential benefits of Offshore SI?

- Reduce Project Risk
- Identify project opportunities and limitations
- Fit-for-purpose design
- Minimise cost
  - Construction
  - Installation
- Seabed risk management
  - Quantify
  - Manage
- Insurance?
Geophysical investigations can provide?

- Water depths
- Seabed features and obstructions
- All geohazards
- Other hazards (e.g.: pUXO, wrecks, debris, etc.)
- Environmental restrictions
- Shallow soils and geology over the area to a depth below which the underlying conditions will not influence the safety or performance of the structures being considered (both turbines and cables)
- In-field and interconnector power cable burial depths
- Post-installation dynamics, both geological and environmental
Geophysical survey schematic
Geophysical survey vessel
Multi-beam Echo Sounder

A multi-beam echosounder is a device to determine the depth of water and the nature of the seabed. Most modern systems work by transmitting a broad acoustic fan shaped pulse from a specially designed transducer across the full swath across track with a narrow beam along track then forming multiple received beams that are much narrower in the across track (around 1 degree depending on the system). From this narrow beam, a two-way travel time of the acoustic pulse is then established utilising a bottom detection algorithm. Using the speed of sound in water for the full water column profile, the depth and position of the return signal can be determined from the receive angle and the two-way travel time.
Multi-beam Echo Sounder
Bathymetric image
Side scan sonar
Side scan sonar - operation

Side scan uses a sonar device that emits conical or fan-shaped pulses down toward the seabed across a wide angle perpendicular to the path of the sensor through the water, which may be towed from a surface vessel or be incorporated in an autonomous underwater vehicle (AUV). The intensity of the acoustic reflections from the seabed of this fan-shaped beam is recorded in a series of cross-track slices. When stitched together along the direction of motion, these slices form an image of the seabed within the swath of the beam. The sound frequencies used in side-scan sonar usually range from 100 to 500 kHz; higher frequencies yield better resolution but less range.
Seabed sonar image
More normal side scan sonar image
High resolution seismic profiling

A sound source (boomer, sparker, chirp, airgun, etc.) is fired at regular intervals. Sound radiates concentrically and is reflected from ‘geological’ interfaces and received on an array of hydrophones (marine microphones) and recorded on a suitable recorder. These data when suitably processed provide a 2D or 3D (dependent on equipment deployment) representations of the geological strata below seabed. Depth of survey ranges from a few cms to 1000’s of metres dependent on the size and frequency of the sound source and the geological environment. Lower frequencies = deeper penetration and lower resolution (ie the ability to differentiate geological layers). Reflection travel paths are recorded in two-way time. This necessitates conversion to depth using the equation distance = velocity (of the sediments through which the sound passes) x time elapsed. Such data can be acquired and recorded single channel and multi-channel.
Seismic sources

Airgun

Chirp profiler

Sub-bottom boomer/sparker
High resolution seismic image
High resolution seismic image
UXO risk mitigation process

UXO are typically located either on seafloor or buried in the upper few metres of the seabed. To detect them a combination of Side Scan Sonar, Multibeam echosounder and a Magnetometer systems are used.

Final risk mitigation is to investigate magnetic anomalies which cannot be avoided. Hereafter a UXO specialist signs off on the process being follow through all phases = ALARP certificate.
Some advantages/limitations - geophysics

<table>
<thead>
<tr>
<th>Advantages:</th>
<th>Limitations:</th>
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<tbody>
<tr>
<td>• Wide range of data acquired simultaneously from one vessel</td>
<td>• Remote sensing tool that requires ground truthing</td>
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<tr>
<td>• Large areal coverage in short time - efficiency</td>
<td>• Results subject to interpretation</td>
</tr>
<tr>
<td>• Continuity between specific point locations</td>
<td>• Some systems very weather/noise sensitive</td>
</tr>
<tr>
<td>• Wide range of depth and type of sub-bottom investigations</td>
<td>• Ground conditions can limit usefulness (e.g. biogenic gas blanking)</td>
</tr>
</tbody>
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Geotechnical site investigation provides

The geotechnical data relevant for structural foundations and cable installation design include, but are 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
# Primary types of sampling and in-situ testing

<table>
<thead>
<tr>
<th>Data required</th>
<th>Equipment</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seabed sediments</td>
<td>Vibrocore, gravity core</td>
<td>Non-specialist vessels</td>
</tr>
<tr>
<td>Continuous soil profile</td>
<td>CPT using seabed of downhole equipment. Seabed CPT thrust capacity of 200kN recommended. 50kN OK for cable routes. Downhole CPT thrusts 60-90kN typical</td>
<td>CPT electrical instrumented cones measure cone end resistance, sleeve friction and excess pore water pressure providing near continuous interpreted soils profile</td>
</tr>
<tr>
<td>Discontinuous sampling</td>
<td>Rotary drilling with sampling tools and downhole CPT. 76mm sample size is standard for soil sampling</td>
<td>Drilling from a vessel with heave compensation or from static jack-up or seabed drilling unit</td>
</tr>
<tr>
<td>Sampling in hard soils/rock</td>
<td>Min. 76mm rotary coring</td>
<td></td>
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Geotechnical drilling vessel
Geotechnical jack-up drilling rig
Vibrocorer for shallow sampling
Geotechnical drilling

Geotechnical engineer analysing geotechnical core sample
Piezocone penetrometer testing

PCPT measures point end resistance, sleeve friction and pore water pressure etc. Empirical correlations enable soils parameters to be derived.
Geotechnical testing results example
## Some advantages/limitations - geotechnics

### Advantages:
- Physical measure of soil properties
- Quantitative results used for engineering design
- Range of systems for different soils and applications
- Generally, less weather sensitive than geophysics

### Limitations:
- Single data point - may need many samples to investigate an area
- “Slower” acquisition rates than geophysics
- Compared to geophysics, limited depth of investigation
# Oil & gas vs offshore wind

**Oil and gas**
- Bespoke Projects
- Smaller areas of seabed
- Often deeper water & remote
- Limited number of piles
- Shallow and deep geohazards
- Mature clients
- Exploration drilling risks
- <5% costs in foundations
- Often floating installation vessels

**Offshore wind**
- Industrialisation
- Very large areas of seabed
- Shallower water & closer to shore
- 100’s of piles
- Infield and export cable routes
- Shallow geohazards
- UXO issue
- Less mature clients
- Utility procurement
- Approx. 30% cost in foundations
- Often jack-up installation vessels
Fixed vs floating wind turbines – bathymetry around the UK
Example of Inch Cape offshore windfarm scale

Inch Cape Offshore Wind Farm
- 150 km²
- 12 km from shore at nearest point
- 72 WTG ~ 700 MW output
- Export cable ~ 80 km to East Lothian

Courtesy M Finch
Offshore wind turbine foundations
Increasing offshore wind turbine size
SI risks to offshore wind development

These include:

- Water depths & seabed conditions
- Seabed and shallow soils suitability for turbine foundation design and cable installation/burial
- Identification of hazards and geohazards to field development
- Environmental constraints and impacts
- Bottom-founded rig issues
- Installation of wind turbines and infield and interconnector power cables
- Operations & maintenance
Jack-up rig for windfarm installation
Jack-up rig punch though
Punch through analysis

![Diagram showing punch through analysis with various curves and labels indicating depth and bearing capacity.]
Jack-up geotechnical drilling rig
Harsh environment
Power cable lay vessel
Submarine power cable burial
Submarine power cable lay
Why are ground related risks so high?

Summarised by Clayton 2001:

• Properties and distribution of ground materials predetermined
• Soils and rocks created by many processes out of wide variety of materials
• Accuracy of many ground-related calculations remain poor
• Ground conditions affect different methods of construction in many different ways
• Construction in the ground normally carried out early in a project

Why do things go wrong?

Many reasons including:

• Geophysics is a remote sensing tool subject to interpretation and ground truthing
• Lack of or poor planning resulting in inappropriate surveys, data processing, lab analyses, data interpretation
• Insufficient budget – SI occurs in early phase of project
• Communication
• Natural world is highly variable
• Minimal data integration
• Human factors
Data integration

Geophysics

Integration

Geology

Geotechnics

GIS
Seabed Risk Management - Process

1) Define Risk
2) Reduce Risk
3) Mitigate Risk
4) Manage Risk
Minimise Risk early in the Project Life Cycle
So who uses SI data?

- Developers
- Foundation designers
- Foundation installers
- Site investigation contractors
- Cable route developers and installers
- Certifying authorities, warranty agencies or regulatory bodies
- Insurers
- Financiers or investors
- Safety engineers
- Geologists
- Environmentalists
- Archaeologists
- Oceanographers
- Surveyors
- Fisheries personnel
- Mariners
- Public organisations
What can an offshore SI provide?

• Little in isolation - integration essential (iterative process)
• Definition of soil types and distribution
• Geohazard identification
• Design Parameters / Conditions for Design & Planning Contingencies
• Risk mitigation

A badly planned & executed SI can be at best somewhat useless and at worst utterly catastrophic
What you won’t get!

• Absolute certainty
• Answers to all your problems
• Compensation for poor design
• Indemnity against claims
How important is an appropriate site investigation?

As the Italian design engineers of the Tower of Pisa found out – you pay for a site investigation whether you do one or not!

“AND WE CAN SAVE 700 LIRA BY NOT TAKING ANY SOIL TESTS.”
Key points:

- Geophysical site investigation is a remote sensing tool.
- Acoustic measurement is in two-way time. Conversion to depth = velocity of sound through sediment/water column x time / 2.
- Geotechnical site investigation is an intrusive method required to ground truth geophysical data and to provide engineering properties of the shallow soils.
- An holistic approach is required to investigate a development site INTEGRATING geophysics, geotechnics, geology etc etc.
- Attention to SI is required as early as possible when developing a site.
- The GROUND MODEL is an iterative model that requires updating throughout the lifecycle of a project.
- Site investigation represents a significant proportion of the overall cost of an offshore renewables project.
Site investigation guidelines

In 2014, the OSIG committee of the SUT produced the first guidance notes for offshore renewables. Over the past 18 months these have been updated and the revised guidance notes are due to be published in 2021.
Thank you for listening. I hope you are enjoying the course.

Do you have any questions?