GeoInfo

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PS LOGGER® INSIGHTS | 01

UNLOCKING SUBSURFACE SECRETS

How Advanced Site Characterisation and PS Logging are Revolutionising Offshore Wind Development

WOOD THILSTED   everoze

Robertson Geo, Wood Thilsted and Everoze have collaborated to produce a series of literature examining how PS Logging and Advanced Site Characterisation is benefitting the offshore wind industry. The collaboration provides a much welcomed opportunity for Robertson Geo to gain an insight into how PS Logger® data impacts foundation design in offshore wind farms (OWF).

Here, Wood Thilsted are focussing on how PS Logger® data enhances seismic data depth conversion and the definition of layer based velocity functions leading to more optimised ground models, resulting in significant cost savings for developers.

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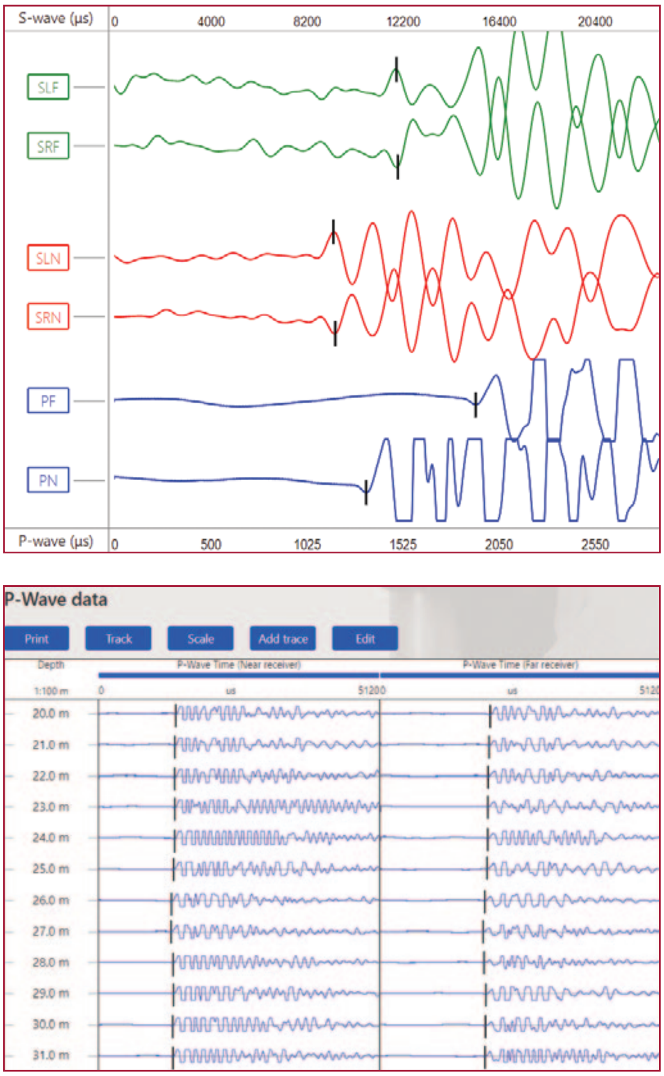
Site Characterisation Surveys

The offshore wind (OWF) industry demands a meticulous understanding of seabed and subsurface conditions. This crucial process, known as site characterisation, underpins the safe and efficient design and installation of wind turbine generator (WTG) foundations and subsea cables. A cornerstone of this process is the integration of in situ ground investigation data with geophysical remotely sensed data.

Offshore geophysical surveys, primarily utilising techniques including Single- / Multi- Channel Ultra High Resolution Seismic (S/M-UHRS), boomer, and sub-bottom profiler (SBP) systems, operate by emitting a controlled acoustic pulse, a compressional wave, into the ground through the water column. The time taken for this wave to reflect off subsurface interfaces and return to receivers at the sea surface is precisely measured and is referred to as Two-Way-Travel-Time (TWTT). By systematically acquiring and processing these seismic returns, geophysicists can construct detailed 3D images of the subsurface, revealing the stratigraphy – the layering of soils and rocks – and critically, identifying potential geological hazards (geohazards) that could impede OWF development *(Figure 2)*.

Geotechnical surveys for OWF are typically conducted following geophysical surveys. Current DNV guidelines recommend WTG locations to have one in situ test per foundation location prior to installation. In some cases this will be a push-CPT (Cone Penetration Test), which can be performed rapidly and cost effectively. Other WTG locations utilise heave-compensated, dynamically positioned drill-ships to rotary drill boreholes *(Figure 3)*. A wide range of data gathering techniques can be deployed on these boreholes including PS Logging, CPT, Seismic CPT, pressure meter and core sampling for laboratory testing. The PS Logger® data (P and S wave velocity profiles) allows more accurate velocity models to be developed for seismic data and ground models.

Figure 1: PS Logger® waveforms and data examples.



The Challenge of Seismic Time-Depth Conversion

While seismic data provides an invaluable spatial understanding of the subsurface, its fundamental unit of measurement is time (TWTT). Consequently, initial ground models are built in the time domain, with the vertical axis representing travel time. For these models to be directly applicable to engineering design, which operates in the depth domain, a crucial transformation is required: time-to-depth conversion.

In its simplest form, time-to-depth conversion involves multiplying the compressional wave velocity (Vp) of the subsurface materials by the One-Way-Travel-Time (OWTT) – half of the measured TWTT. Historically, a significant portion of offshore wind farm development has occurred in relatively benign environments: shallow coastal waters in geologically stable regions, such as the UK Southern North Sea and Irish Sea. Under these favourable conditions, with readily available survey vessel capacity, accommodating project timelines, and less acute economic pressures, the intricacies of depth conversion often took a backseat. Simplified approaches, relying on analogous single average velocities ranging from 1500 ms^{-1} to 1700 ms^{-1} from the seabed to the target depth, were commonly employed within the conversion calculation. This often resulted in significant depth uncertainties, potentially averaging 5m to 10m at any given location within the ground model, even considering typical monopile lengths ranging from 30m to 40m within the subsurface.

However, the landscape of offshore wind development is undergoing a significant shift. New lease areas are being awarded in more challenging, marginal continental shelf environments, characterised by deeper waters and increasingly complex ground conditions. Simultaneously, development timelines are being compressed, and competition for Power Purchase Agreements (PPAs) and Contracts for Difference (CfDs) has intensified. Even supply chain constraints, particularly in the geotechnical survey vessel market, are becoming more pronounced.

In this evolving context, the time-to-depth conversion of geophysical seismic data emerges as a significant source of uncertainty in the ground modelling process. This uncertainty, if not adequately addressed, can propagate through the entire project lifecycle, impacting everything from detailed design to installation. Conversely, a more constrained model with higher certainty in ground conditions facilitates a reduction in the project design envelope, enabling more targeted ground investigations, optimised foundation sizing, and refined logistical planning, ultimately reducing the overall "cone of uncertainty" and supporting more accurate site definition and design.

The traditional way of dealing with the uncertainties associated with the ground conditions, related to wind turbine foundation design, is to conduct a 2-stage ground investigation campaign, where geophysical and geotechnical investigations are first carried out to give a regional understanding of the wind farm site, colloquially known as GP1 and GT1 respectively, and these are used to produce the ground model. This ground model is then used for all the site planning work, with a heavy reliance on the geophysical data to define the 3D ground model in between the widely spaced geotechnical investigation points, boreholes or CPTs or usually a mixture of both.

Acknowledging that most turbines are then placed within the site boundary based on maximising the wind resource, whilst avoiding any identified geohazards, other no-go zones or deep areas, the ground model is then used to check that the geotechnical conditions will be suitable for wind turbine foundation design. Significant uncertainties may be carried into the FEED or the detailed design before the next round of site investigation is carried out. The next round of survey work, known as GP2 and GT2 for the second geophysical and geotechnical surveys respectively, is used to get 'on the money' geotechnical information, typically required to reduce the uncertainties sufficiently to carry out detailed design.

The risks are clear – site layout work is done based on the 'regional' surveys, where some geotechnical units may not have been sampled, and considerable uncertainly on depth to each geotechnical unit will be present, increasing with distance from the nearest borehole. The more complex and varied the terrain, the larger the uncertainties become.

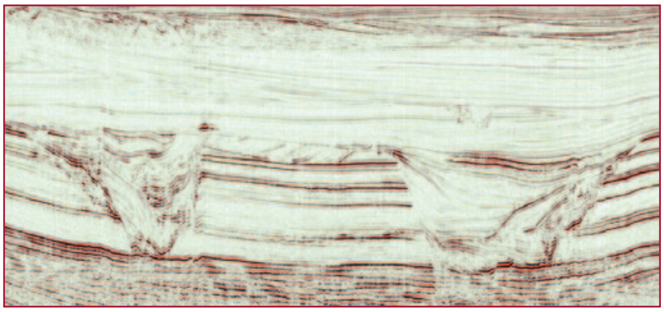


Figure 2: Example of MUHRS section from confidential project site.

The Solution: PS Logging Integrated Ground Model Refinement

Recognising the critical importance of accurate ground models, Wood Thilsted champions a data-driven approach to site characterisation, leveraging advanced techniques like PS logging to significantly refine the time-to-depth conversion process and unlock substantial downstream benefits for OWF developers.

As highlighted, refining the ground model leads to a cascade of positive impacts, mitigating risks and positively influencing project economics. To achieve this refinement, a more precise understanding and tighter constraints of P-wave velocities within the subsurface are paramount. This is where tools like the PS Logger® come into their own.

Figure 3: Geotechnical Survey Vessel. *(Copyright: Geoquip Marine)*

The PS Logger® is a downhole geophysical tool deployed within boreholes drilled during geotechnical site investigations. By strategically deploying the PS Logger®, we obtain critical in situ measurements that act as "ground truthing" data for the broader geophysical interpretation. Importantly, the PS Logger® measures the travel time of both compressional (P) and shear (S) waves between two receivers spaced a known distance apart (typically one meter). This direct measurement of travel time over a fixed distance provides a highly accurate determination of the subsurface velocity at discrete depth intervals – completing the fundamental relationship of Distance = Speed x Time.

By integrating these crucial in situ velocity measurements obtained from the PS Logger® with the regional-scale understanding provided by the seismic data, a far more accurate and representative velocity model of the subsurface can be constructed. This allows for:

- **Spatially Varying Velocity Modelling:** Recognising that subsurface velocities are not uniform across an entire offshore wind site, which can span tens of kilometres and encompass multiple geological regimes.
- **Layer-Based Velocity Functions:** Accounting for the distinct velocity characteristics of different soil and rock layers, which are influenced by a complex interplay of factors such as composition, mineralogy, burial history, and water content.

The primary aim is to accurately recreate the three-dimensional distribution of subsurface velocities, thereby significantly reducing the vertical component of error in the depth-converted ground model.

For further information on how Wood Thilsted and Robertson Geo can optimise your site characterisation strategy, please contact info@woodthilsted.com.

BACKGROUND TO THE COLLABORATING COMPANIES:

ROBERTSON GEO

Robertson Geo are one of the world's leading suppliers of downhole geophysical logging equipment, establishing a customer base, across 45 years, in more than 160 countries. As OEM for the entire product range, design, development and manufacturing takes place in the main North Wales base supported by sales offices in Hong Kong and USA.

Geophysical probes, winches, surface acquisition units and accessories are available for sale or rental, all backed up by a comprehensive warranty and support package. Equipment is designed to be reliable and robust and is field tested by Robertson Geo Services (RGS) engineers in real world conditions prior to launch. Rigorous manufacturing processes, conformance testing and calibration regimes, operating under an ISO9001 quality framework, ensures that the highest quality data is consistently achieved from all probes.

Innovation in design continues to be key to the success with Robertson Geo having benefited from many development initiatives with leading UK and overseas universities. Expansion continues with a recent move to modern larger premises, necessary to accommodate the team of experienced professionals and ambitious graduates and specialists. The expert in-house software team develops firmware, acquisition software and the flagship modular processing software GeoCAD®.

RGS provide a worldwide borehole logging service across all business sectors and environments with specialities in underground working and marine geotechnics. Commissioning and training, anywhere in the world, is facilitated by the RG Academy utilising the expertise of experienced RGS engineers. Marine geotechnics, dominated by the demand for OWFs, is expanding exponentially with the PS Logger® probe, seeing deployment on more than 80 OWF projects globally, now considered an essential part of site characterisation.

The PS Logger® is a full waveform shear wave probe that reliably captures P and S waves in both soil and rock formations. The probe was initially developed in Japan where it was widely used for Geotechnical and Earthquake engineering and later adopted on major projects overseas. By the turn of the millennium the probe was gaining acceptance for geotechnical investigations and with the advent of OWFs take up increased exponentially.

The PS Logger® probe uses a powerful integral hammer and strike cylinder source with hydrophone receivers for P waves and geophones for S waves. The PS Logger® records six channels of full waveform data at each static depth point, two for P waves and four for S waves (two sets, horizontally opposed). Uniquely, this receiver arrangement means the probe is tuned by design to attenuate unwanted signals on each channel, isolating the desired signals *(Figure 1)*. This clarity of signal, from which P and S velocities are easily derived, is fundamental to the success and increasing adoption of the PS Logger®.

WOOD THILSTED

Wood Thilsted are a team of world-leading experts covering every discipline of offshore wind engineering and are already supporting delivery of over 8GW of projects across four continents. The team are world leaders in their fields working together to create innovative, efficient solutions for their clients.

The specialist Advisory team provide end to end services ensuring clients successfully navigate the complexities of their offshore wind projects, covering market intelligence, site screening, bid support, financial planning, delivery optimisation, procurement strategy, contract management and project due diligence.

The Engineering Services team of industry leading multi-disciplinary professionals cover all phases of windfarm development, from feasibility through development, engineering and installation to operation.

The feasibility phase is where initial engineering work is performed. The boundary conditions (e.g. wind, wave, geology, etc.) of the project site are investigated and critically reviewed. This also identifies risks and hazards that may be potential threats to the project.

At the development phase the broader team become involved to get into the project detail. This means looking at and reducing project risks by analysing the site, the soil, seismic data and more, optimising wind farm layouts, considering foundation design options and installation concerns as well as identifying opportunities for innovation and general improvement.

Engineering Services have designed some of the most cost-effective foundation designs for many of the largest offshore wind projects in the world. This is achieved through a holistic in-house approach to design, which means that all the information is available whenever it is needed, delivering a more efficient process. Having all these inputs readily available leads to a full understanding of the design and supply chain constraints which results in efficient structural design and project cost savings.

For the installation phase, the team have access to the right tools, knowledge, technology and understanding of partnership working to make sure fabrication, transport and installation run smoothly.

Throughout the operational life of a windfarm the integrated team can monitor and accurately assess the structural integrity and efficiency of every turbine, via structural health monitoring systems, potentially adding additional years to the operating life of a windfarm.

EVEROZE

Everoze is an employee-owned consultancy, specialising in renewables, storage and wider energy flexibility. Everoze's unique strength is bridging the gap between the technical and the commercial, helping clients accelerate the transition to a decarbonised energy system. Everoze operates in energy markets globally, with a strong presence in Europe and Asia Pacific.

Everoze is a trusted advisor to some of the biggest brands in the sector and work closely with their clients to make projects, companies and technologies futureproof and financeable. Everoze offers:

- Due Diligence on Demand: Working smarter to rapidly evaluate risk and opportunity for investors, lenders and sellers.
- Project Support: Applying experienced eyes to improve asset performance and add value to project development. Everoze has worked with a number of major developers, providing technical teams to support global bids and projects.
- Strategic Support: Deploying effective people with the right industry know-how to address technical, commercial and strategic challenges, Everoze has worked with industry bodies such as RenewableUK, the Crown Estate, and the Offshore Wind Growth Partnership, helping to inform industrial strategy and grow companies within offshore wind. Everoze has also worked with several supply chain companies, supporting innovation and technology development in the sector.