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The Importance of Fully Integrated Ground Models in the Identification and Mapping of Shallow Hazards along Export Cable Routes

J. Wilson* and K. Lehmann
Fugro GB Limited, Wallingford, Oxfordshire, United Kingdom
**jordan.wilson@fugro.com (J. Wilson)*

ABSTRACT: Offshore wind farm export cable routes (ECR) require detailed geophysical surveys and geotechnical site investigations (SI) to identify and fully characterise seafloor and sub-seafloor hazards that may constrain, or require consideration for, the design and installation of cables. Within this paper, Fugro present a case study which highlights the importance of detailed SI planning using a preliminary ground model, full integration of acquired data and the development of an ECR-specific ground model.
Along a planned ECR stretching between Dogger Bank in the central North Sea and the northeast coast of England, the integration of acquired geophysical and geotechnical data enabled the correct identification and mapping of a very low density sand (VLDS) unit. The presence of this unit was an immediate concern for design and installation; VLDS at/near seafloor possess greater potential to deform under load or be impacted by processes such as scour, which can subsequently lead to a lack of support and create spanning issues and fatigue on surface-laid cables.
At the preliminary ground model phase, the presence of the VLDS unit was unknown; the geophysical horizon marking the base of the VLDS was initially interpreted as sub-surface gravel accumulations. The presence and uncertainty around this feature led to targeted geotechnical acquisition, which ultimately led to the correct identification of VLDS through integration of acquired data. Without a fully integrated ground model, certain shallow geohazards remain unidentified and poorly constrained, which could ultimately cause significant damage and costs during, or following, installation of cables.

Keywords: Ground Model; Shallow Hazards; Export Cable Route; Geotechnical and Geophysical Integration.

1 INTRODUCTION

With the increase in demand for offshore wind, developers are increasingly planning and installing wind farms further offshore, resulting in the associated export cable routes (ECR) spanning large distances, often across areas of complex geological ground conditions. This emphasises the need to fully understand the seafloor and shallow ground conditions within the cable burial depth of interest across each offshore wind farm (OWF) development.

ECRs require a fully integrated ground model to provide the most comprehensive appreciation of ground conditions along the route corridors (Fookes, 1997, Thomas, 2017 and Smith et al 2017, SUT, 2022). A ground model can be initially developed at the desk study phase of a project to provide an early identification of potential shallow hazards. The ground model is then further developed throughout the project by integrating datasets as they become available. A fully integrated ground model combines all available datasets to present a predictive geotechnical model suitable for engineering design and installation planning.

A key component of a ground model is to identify any existing geological, geotechnical, anthropogenic and environmental hazards and communicate these to the end user. The identification and assessment of shallow hazards is an iterative process throughout the project phases that require fully integrated datasets to best detail their potential risk and impact on ECR installation and design.

In this paper, we present a case study from an ECR ground model project where detailed site investigation planning, data integration and the development of an ECR-specific ground model enabled the re-interpretation of hazards identified at an earlier, preliminary ground model phase. Without this iterative ground model process, certain hazards could remain unidentified or poorly constrained, which could lead to inappropriate cable design. This in turn could ultimately cause significant damage and costs during, or following, the installation of export cables.

1.1 Case Study

During 2023 and 2024, Fugro completed a ground modelling project for a planned ECR stretching between an offshore wind farm array area on Dogger Bank in the central North Sea and the northeast coast of England. Ground conditions across this area of the North Sea are particularly complex due to the presence of shallow, variable bedrock and complex glacial processes that have impacted the region during the Quaternary period. This project included the following phases of ground model development: preliminary ground model (which was first developed using acquired geophysical data), geotechnical site investigation planning and acquisition and a final ground model fully integrating all available site-specific data.

This case study follows the development phases of the ECR ground model, while detailing how the acquisition of different datasets enabled the improvement in interpretation around two significant shallow hazards; subsurface gravel and coarse material accumulations and very low density sands (VLDS). These shallow hazard interpretations are assessed throughout the project development phases and their implications for cable installation risks are discussed.

2 PRELIMINARY GROUND MODEL

The appraisal of seafloor and shallow ground conditions, geohazards and initial installation constraints along the ECR started with the generation of a preliminary ground model, during which an understanding of the regional geological setting and development of a depositional model was used to assess acquired route-specific geophysical data and develop a seismostratigraphic framework for the cable route.

2.1 Geophysical Data

A full suite of geophysical data were acquired along the ECR, including multibeam echosounder (MBES) bathymetry and sub-bottom profiler (SBP) data across the full width of the corridor, as well as 2D ultra-high resolution seismic (2DUHRS) data along a single survey line through the centre of the corridor.

2.2 Preliminary Interpretations

Interpretation of acquired geophysical data led to the identification of localised high amplitude reflectors along a section of the ECR. These features appeared to mark the boundary between two Holocene sand sub-units; an acoustically transparent seismic unit interpreted to consist clean sands underlain by a more stratified to chaotic seismic unit interpreted as denser, more variable sands below (Figure 1).

The reflectors were mapped as an internal seismic horizon and interpreted to reflect shallow, subsurface gravel and coarse material accumulations at the base of the cleaner sand unit. This interpretation was initially supported by the identification of similar deposits across the Dogger Bank region, where buried gravel lag deposits have been mapped (Carter et al., 2013) and the presence of localised coarse material accumulations within seafloor rippled scour depressions have been observed (Riera et al., 2023).

The interpretation of gravel and coarse material accumulations within the cable burial depth of interest was discussed with the client given their ability to affect cable trenching feasibility and performance, create variable soil conditions and geotechnical properties and constrain the penetration of geotechnical equipment and subsequently the acquisition of data.

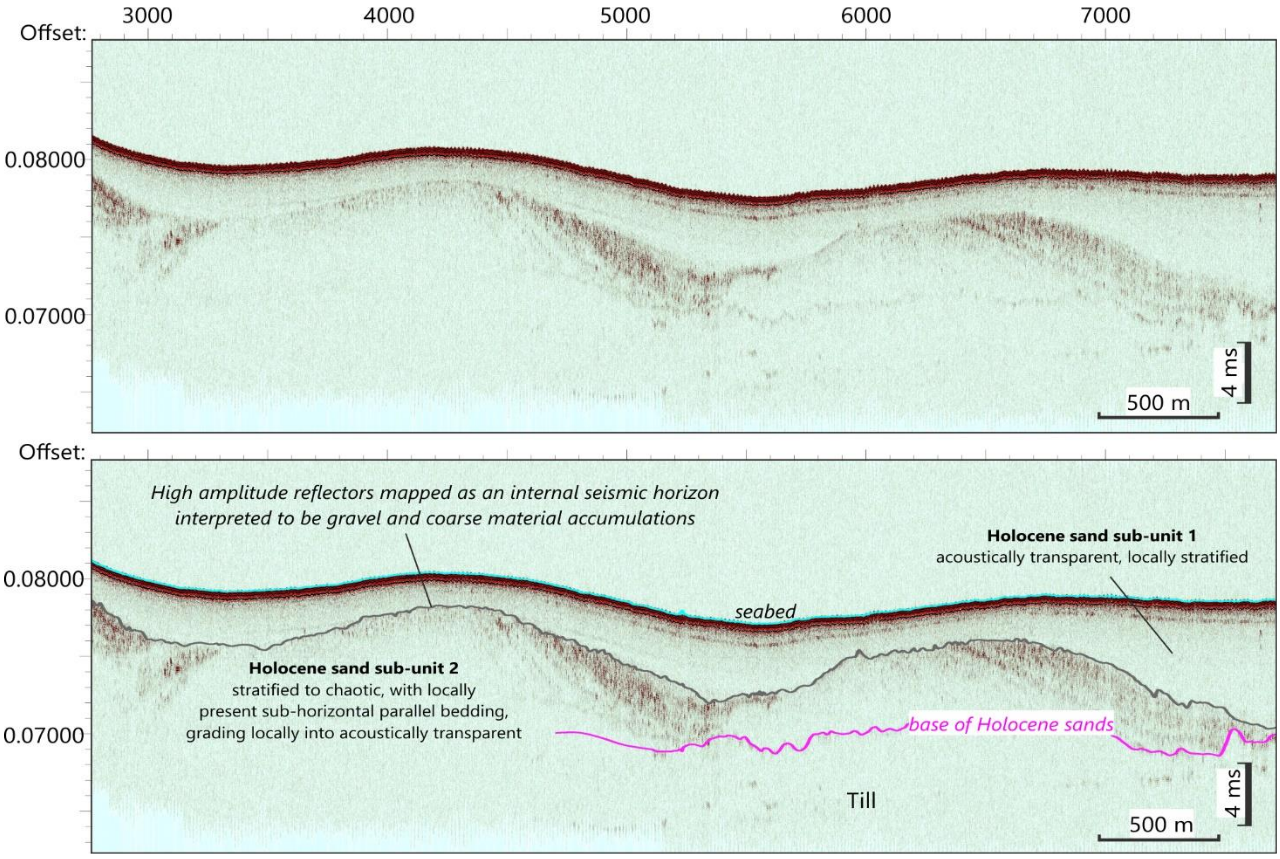

Figure 1 – Preliminary geophysical interpretation of SBP data showing initially interpreted gravel and coarse material accumulation horizon

3 GEOTECHNICAL DATA ACQUISITION AND INTEGRATION

The results of the preliminary ground model were used to plan the acquisition of geotechnical data. Mapped seismic units, geological features and shallow hazards were targeted for geotechnical sampling and testing with the aim of further characterising the ground conditions and fully constraining the presence of previously identified features within the cable burial depth of interest.

The areas of ECR where subsurface gravel and coarse material accumulations had been mapped were a particular focus, with an increased number of geotechnical locations being sited at a reduced spacing to fully constrain these features.

In total, 154 seabed cone penetration tests (CPT) and 122 vibrocores (VC) were acquired along the ECR. Geotechnical data were reviewed and unitised as part of the fully integrated ground model development. Geotechnical units were defined based on changes in primary soil type and/or subtle changes in secondary soil constituents or geotechnical properties such as cone resistance, undrained shear strength or relative density.

3.1 Identification of Very Low Density Sands (VLDS)

The unitisation of both CPT and VC data led to the identification and definition of a VLDS unit at/near seafloor which characteristically possessed very low cone resistance (average 0.0 to 1.2 MPa) and very low relative density (0 to 35% - classified as very loose to loose sands) (Figure 2). This unit was relatively clean with an average fines content of 6%. This VLDS unit was present in 51 geotechnical locations, locally present from seafloor to a maximum depth of 5.65 m below seafloor (BSF). In 6 geotechnical locations, the VLDS unit was gravelly at the base.

The presence of VLDS within the cable burial depth of interest was an immediate concern to the project:

- VLDS possess greater potential to deform under load or be impacted by processes such as scour, which can subsequently lead to low axial capacity, a lack of support and create spanning issues and fatigue on surface-laid cables;

- 'Loose sands' may be more prone to processes such as liquefaction (wave-induced), which can also lead to lack of support for surface-laid cables;
- 'Loose sands' are classified as an unconventional soil, which, in accordance with ISO 19901-9 (ISO, 2019), require extra caution, additional consideration and special handling and treatment when sampling;
- Amongst other parameters, VLDS may affect trenching feasibility and performance of trenching tools. In some instances, the presence of VLDS may be a positive for jetting and trenching.

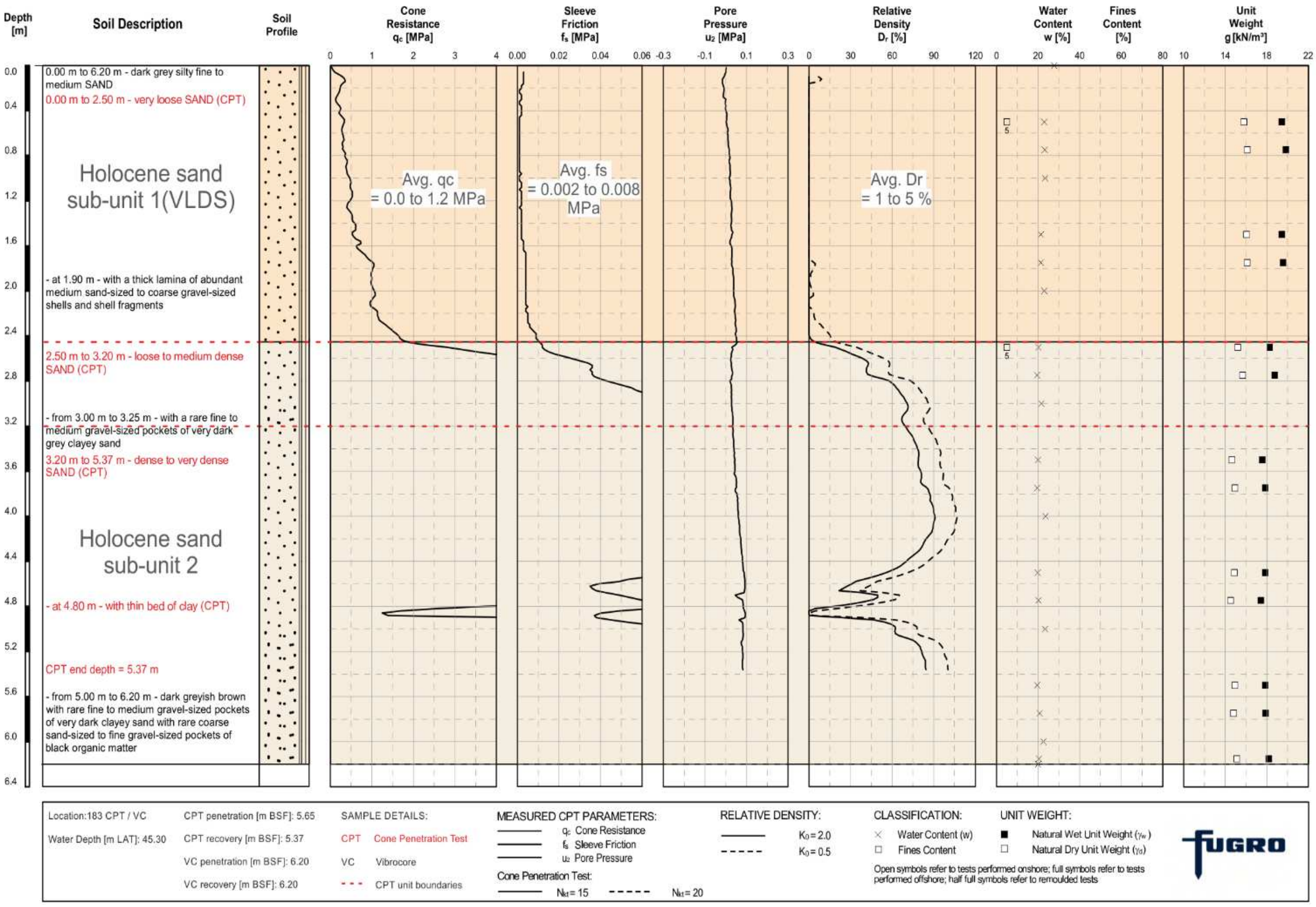

Figure 2 – Example of integrated CPT and VC geotechnical log highlighting the presence of the VLDS unit. Average cone resistance, sleeve friction and relative density values calculated using measured CPT data specific to this geotechnical unit

4 FULLY INTEGRATED GROUND MODEL DEVELOPMENT

The integration of acquired geotechnical data with the SBP and 2DUHRS geophysical data and defined seismostratigraphic framework enabled the development of a fully integrated ground model for the ECR. Only following this full integration did the presence, lateral extent and variability in thickness of sampled VLDS along the ECR become clear.

The full integration of data enabled the Holocene sand sub-unit 1 (Figure 1) to be correlated to the VLDS identified in geotechnical data (Figure 2). The base of the VLDS unit correlated well with the mapped internal seismic horizon initially interpreted to represent gravel and coarse material accumulations. However, geotechnical data did not support the presence of laterally extensive gravel and coarse material accumulations; only 6 geotechnical locations out of 51 that sampled both the VLDS unit and the internal horizon showed slightly gravelly to very gravelly sands at the base of the VLDS. Furthermore, CPT data showed the base of the VLDS unit is abrupt, with a clear increase in relative density and cone resistance in the sand unit below (Figure 3).

The integration of the geophysical and geotechnical data therefore enabled an improved understanding of the correlation between the VLDS and the internal seismic horizon, leading to the initial interpretation of 'gravel and coarse material accumulations' within the shallow subsurface being reconsidered. The mapped high amplitude reflectors at the base of the VLDS unit were now considered to reflect a change in density between the two Holocene sand units. This is supported by the change in geophysical characteristics (Figure 1). An example SBP image with associated geophysical and geotechnical data integration for the VLDS is shown in Figure 3.

Following data integration, a shallow cable route soil zonation to 3 m BSF was developed along the ECR to divide up the ECR into areas of similar geotechnical conditions. The VLDS unit was assigned its own geotechnical zone due to its unique geotechnical properties and potential risk to the project. The VLDS was present in over 18% of the ECR making it a significant unit within the cable burial depth of interest with respect to project shallow hazards and installation risks.

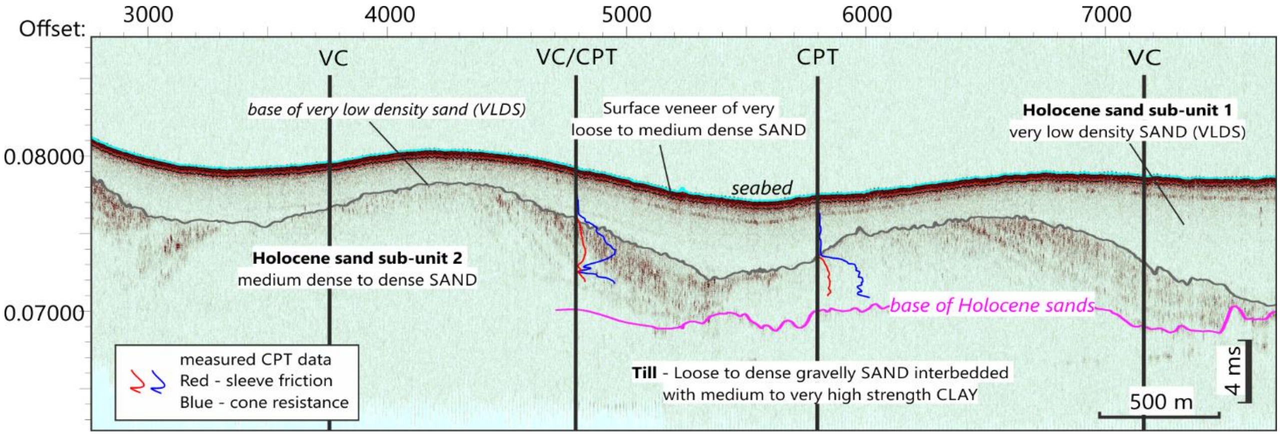

Figure 3 – Detailed geophysical and geotechnical interpretation of SBP data showing very low density sand (VLDS)

5 CONCLUSIONS

In this case study, preliminary interpretations from geophysical data alone did not identify the presence of the VLDS unit, let alone facilitate the understanding of its lateral and vertical extent, geotechnical properties or subsequent risk to the project. The preliminary interpretation of gravel and coarse material accumulations based on acoustic characteristics within SBP and 2DUHRS data was, in hindsight, a false interpretation which greatly overexaggerated the extent, thickness and concentration of gravel and coarse material along the ECR. The preliminary interpretation therefore did not identify the potential for VLDS along the cable route which could have significant implications for cable design and installation.

The case study presented within this paper highlights the importance of a fully integrated ground model to best provide the most comprehensive appreciation of seafloor and sub-seafloor ground conditions. A complete, integrated set of geophysical and geotechnical data along geologically complex ECRs is vital in fully characterising ground conditions along the entire length and width of ECR corridors. Without this, shallow hazards may not be fully constrained and may remain unknown.

AUTHOR CONTRIBUTION STATEMENT

J. Wilson: Conceptualization, Data curation (equal), Formal Analysis (equal), Investigation (equal), Methodology (equal), Visualization (equal), Writing- Original draft and reviewing and editing (equal).
K. Lehmann: Data curation (equal), Formal Analysis (equal), Investigation (equal), Methodology (equal), Writing- Original draft and reviewing and editing (equal).

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