De-risking suction bucket installation using 3D seismic surveys

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ABSTRACT

This paper presents a case study of how geo-hazards were identified using a three dimensional ultra high resolution seismic survey (3D UHRS). This innovative site investigation technique was specified for a wind farm development due to the heterogeneous site conditions and proposed foundation solution. The 3D UHRS data was used to identify and categorise geo-hazards relevant to the foundation design, such as buried channels, extent of sand pockets and potential boulders. Subsequently the results from the seismic interpretation was used to de-risk and inform the geotechnical design of the foundations.

Keywords: Shallow marine 3D seismic; Geo-hazards; Suction Buckets

1 INTRODUCTION

Ørsted recently completed a comprehensive geotechnical site investigation for the Hornsea One offshore wind farm (HOW01) in the UK sector of the Southern North Sea. The development will comprise 174 positions with 7.0 MW wind turbine generators (WTGs). The HOW01 site is located approximately 120 km off the coast of Yorkshire and will occupy an area of up to 407 km^2, the location is shown in Fig. 1. The depth to the seabed ranges from 24 m to 36 m below Lowest Astronomical Tide (LAT).

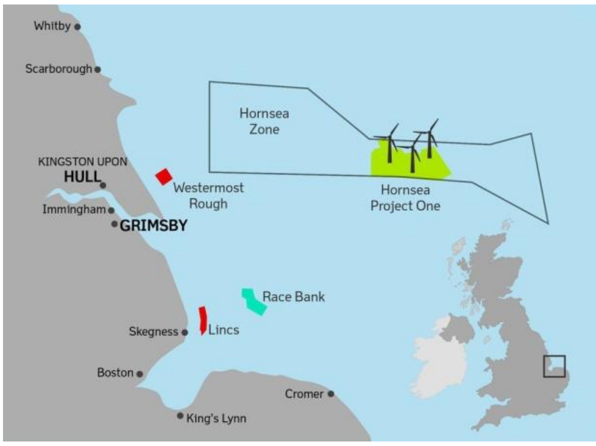

Fig. 1. HOW01 wind farm location

Suction bucket jackets were initially proposed as the foundation solution for WTGs in the western third of the HOW01 site. The SBJ foundation comprises a three-legged jacket sub-structure with each leg supported by a bucket foundation, see Fig. 2.

The site conditions at the HOW01 site and the proposed foundation type necessitated an innovative site investigation. As such, Ørsted contracted GeoSurveys (consultants in geophysics) to acquire, process and interpret a three dimensional ultra high resolution seismic survey (3D UHRS) at each of the proposed SBJ locations to assess local variability of the ground.

The interpretation of the 3D UHRS helped to identify and categorise geo-hazards which were relevant to the SBJ design.

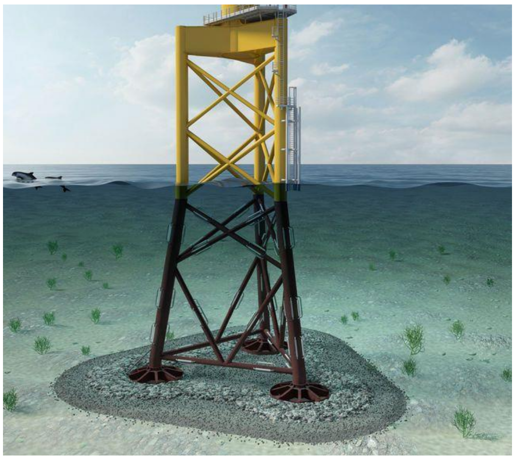

Fig. 2. Illustration of an installed SBJ foundation

2 GEOLOGICAL BACKGROUND

The upper sediments in the HOW01 area are comprised of a thin layer of Holocene sand underlain by a stiff heavily over consolidated clay sporadically interrupted by channel fill material. The stiff clay is part of the Bolders Bank (BDK) formation and the channel fill belongs to the Butney Cut (BCT) formation as described in more detail below.

The Holocene sand is an informal sediment unit which forms a veneer of material reworked during the flooding of the North Sea at the end of the last glacial stage. The veneer generally consists of sand which may be loose to very dense depending on local conditions.

The BDK formation is an extensive planar deposit which covers much of the southern North Sea. The formation is a basal moraine deposit from the Weichselian glaciation and it consists predominantly of stiff, reddish brown, gravelly sandy clay.

The BCT formation was deposited in a glaciomarine environment at the end of the Weichselian. In the HOW01 site it consists of both large subglacial channel infill and smaller channel infills near the seabed. The material was mainly sampled as reworked clay or sand with a significantly lower strength compared to the BDK clay.

3 DATA GATHERING

Five separate geophysical and geotechnical campaigns were completed at the HOW01 development. The 3D UHRS survey uses a system with an ultra-high resolution sparker source, utilising negative discharge technology, thus guaranteeing a stable and repeatable source signature (Monrigal et al. 2017). This resulted in a vertical resolution of less than 40 cm for the shallow stratigraphy.

The survey was conducted in the summer of 2016 from the catamaran, Bibby Tethra. The survey equipment consisted of two sparkers and four streamers placed between the two sources, as shown in Fig. 3. The spread was positioned in real-time using a Geo-Pos solution, consisting of 10 dual DGPS antennas mounted on both the sources and streamer buoys.

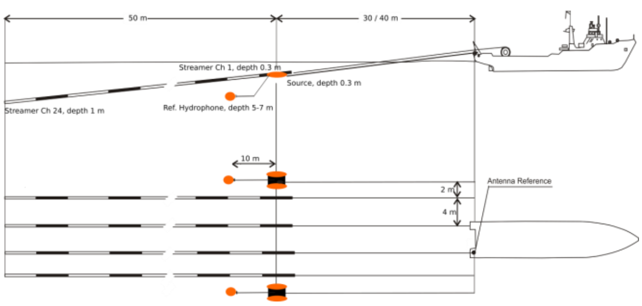

Fig. 3. The survey equipment setup

The data processing was specifically tailored for this project to improve the seismic section resolution and overall signal quality and included corrections for wave motion and tides (Duarte et al. 2017).

The area surveyed at each location was 100 m by 100 m square, with the SBJ at the centre of the square investigated. The investigation was limited to a depth of 21 m below seabed level with a focus given to the area within the SBJ footprint.

4 SEISMIC INTERPRETATION

The main focus for the interpretation was to identify the geological units and geo-hazards around the proposed foundation positions. With a particular focus on, the mapping of sandy or silty pockets, lenses or layers, buried channels and the identification of point diffractors (which may represent potential boulders), all of which could affect the SBJ installation.

In situ geotechnical data, collected from the CPTs and boreholes carried out within this area, was used to aid the interpretation.

Both non-migrated and migrated seismic data was used in the interpretation. Seismic attribute analysis, using mainly phase and envelope, allowed for a very detailed interpretation. Seismic facies analysis helped distinguish between the various formations.

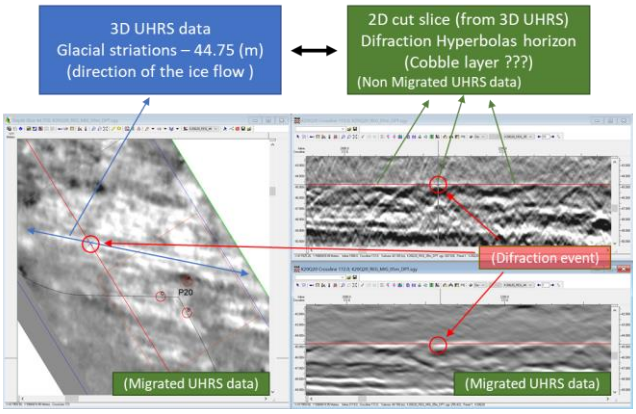

Fig. 4. 3D-URHS interpretation

Fig. 4 depicts a case where glacial striation, using 2D UHRS data alone, could be easily misinterpreted as a cobble layer. Utilizing the 3D UHRS data it was possible to interpret small scale features as changes in direction of the glacial striations.

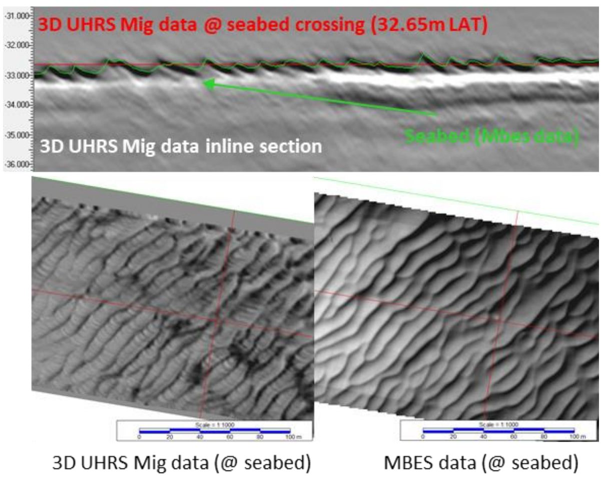

Fig. 5. 3D seismic correlation with bathymetry

Comparing bathymetry data with the 3D seismic data, see Fig. 5, it became apparent that even the sandwaves on the seabed were resolved in the seismic data and that the positioning was accurate enough to align the undulations between the two datasets. This helped to provide extra confidence on the geo-hazard interpretations.

5 GEO-HAZARDS

The 3D UHRS data helped identify geo-hazards which otherwise could not be identified as efficiently or thoroughly using intrusive in situ investigation techniques or other geophysical methods.

5.1 Buried Channel

A small buried channel was identified from the interpretation of the 3D UHRS data. The in-situ testing had identified a soft clay deposit across an SBJ footprint, but this appeared as a horizontal layer due to the positioning of the in situ tests. Thus, the nature of the geo-hazard was not identified in the initial ground model. However, the channel was clearly visible from the 3D UHRS results, see Fig 6 and Fig 7.

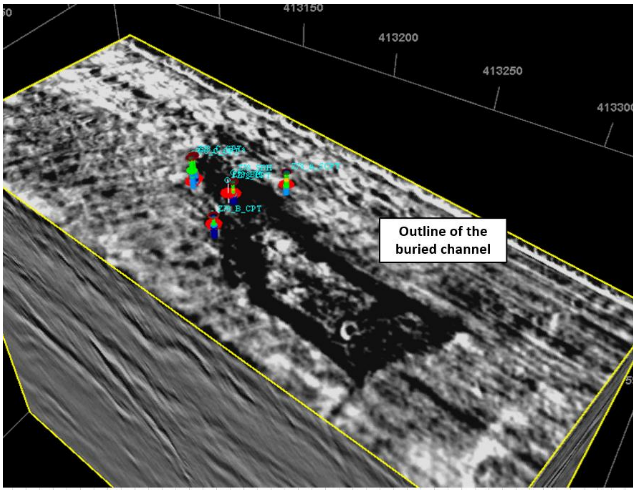

Fig. 6. Outline of the buried channel identified using the 3D-UHRS

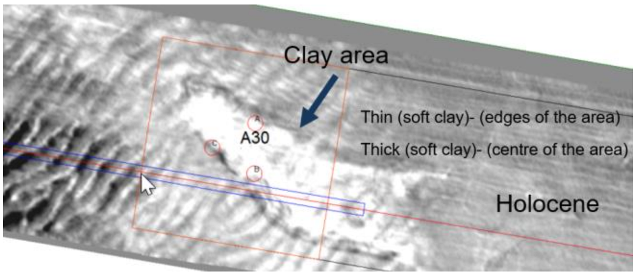

Fig. 7. Plan view of the buried channel identified using the 3D-UHRS

5.2 Boulders

The identification of point diffractors (PD) or other potential boulder related anomalies was carried out using a manual picking procedure, with a resolution ± 0.2 m. The PD were identified using migrated seismic data and seismic polarity information, see Fig 8.

The migrated seismic data shows higher energy at migrated hyperbola apexes. These anomalies are usually caused by seismic diffraction behavior related to impedance contrast and will depend on the size and shape of the acoustic contrasting bodies. For similar impedance contrasts, bodies with larger sizes yield wider reflections of stronger amplitudes.

The seismic polarity was used to characterize the nature of the PD. The acoustic wave acceleration or deacceleration was correlated to changes in material stiffness, hence changes from harder to softer bodies and vice versa, could be interpreted from the signal polarity.

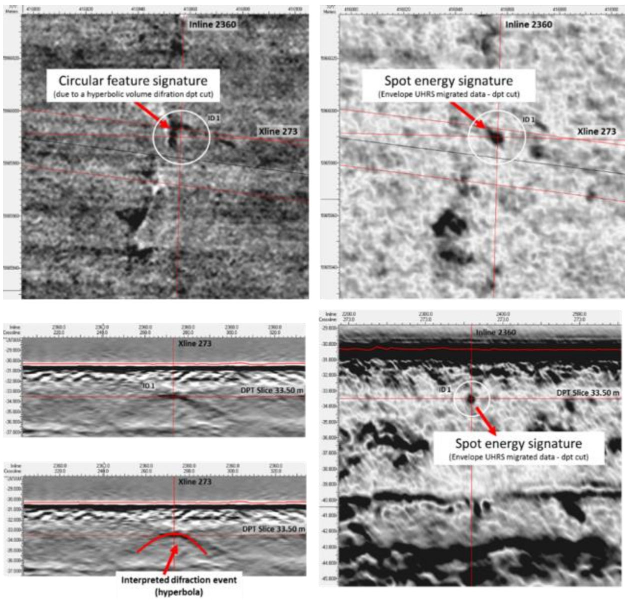

Fig. 8. Identification of point diffractors

5.3 Sand Units

The till at HOW01 was extremely chaotic in nature and the CPT data did not give a good indication of the extent of any sand pockets. However, by cross correlating the CPT data with the 3D UHRS the extent of the sand pockets could be mapped, see Fig 9.

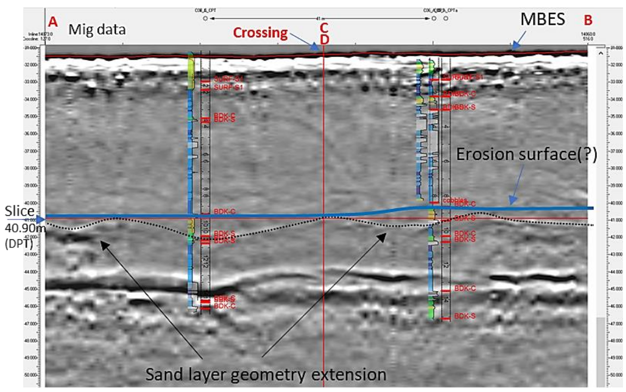

Fig. 9. Example categorisation of sand layers

6 ENGINEERING IMPLICATIONS

The individual suction bucket dimensions for each SBJ is determined by results from the installation assessment and in-place capacity assessment (Sturm 2017). Therefore, detailed location specific geotechnical information is required to carry out the design. The 3D-UHRS de-risked the suction bucket design by identifying geo-hazards that could affect either the installation or in-place performance of the buckets.

6.1 Installation Assessment

For the installation assessment, the key geo-hazards identified by the 3D UHRS were the sand layers/lenses and potential boulders, see Fig 10.

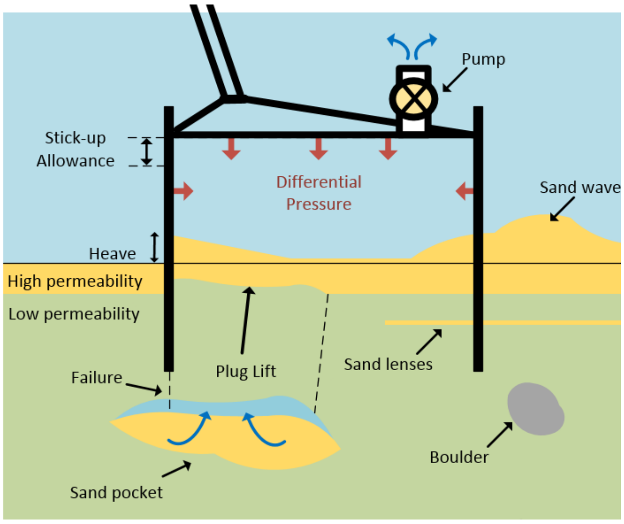

Fig. 10. Illustration of bucket installation

The identification and categorisation of sand pockets and sand lenses was used to assess the installation resistance and the potential for plug lift. Plug lift is a rapid lifting of the internal plug in relation to the external soil column. Generally, it is caused by a cut-off to the flow after the tip penetrates a low permeability layer leading to high hydraulic gradients (sand into clay), or by high suction pressures and low reverse end bearing capacity (clay overlying sand). The interpreted extent of the sand layers allowed the designers to gauge the plug lift risk on a site specific basis and implement mitigation measures to reduce the risk of plug lift occurring.

The detailed identification of PD (potential boulder related anomalies) allowed the designers to assess the risk of boulder strike for each bucket and identify potential boulder free micro-sited locations. The risk was based on the size, location and clarity of the PD.

In addition, at certain locations, the sand wave height, confirmed with the 3D URHS, led to the bucket stick-up (a key design parameter) being increased to accommodate the uneven seabed.

6.1 In-place Assessment

For the in-place assessment, the 3D UHRS was used to provide additional localized soil information and to ensure that the local soil conditions were in accordance with the design assumptions.

Given the localised chaotic nature of the soil conditions at HOW01, the 3D UHRS was predominantly used to confirm that the site conditions assumed in the design were present at each SBJ location. Whilst the soil profile described by the in situ tests were directly used in the design of each foundation, the 3D UHRS results provided additional confidence that the soil conditions were in accordance with the design assumptions. At locations where ‘micro-siting’ was required (i.e. where the structure’s location was moved within a 50 m radius from the original planned position), the 3D URHS was used to create “pseudo” CPT profiles which provided the designers with additional flexibility should micro-siting be required.

Finally, at one particular location (described in Section 5.1) where a buried channel was identified, a redesign was undertaken which took into account the updated ground model.

7 CONCLUSIONS

The site conditions and proposed foundation solution at the HOW01 development called for an innovative site investigation. A three dimensional ultra high resolution seismic survey (3D UHRS) was carried out at each of the proposed SBJ locations to assess local variability of the ground. The results of the 3D UHRS were used to identify and categorise geo-hazards relevant to SBJ design, such as buried channels, extent of sand pockets and potential boulders. This information was then used to de-risk the SBJ design. Although the 3D UHRS results provided valuable design information, the data analysis is intensive and time consuming. Extensive lead in times should be planned to allow adequate time to appropriately analyse the large volume of data created during these campaigns.

REFERENCES

Duarte H., Wardell N., Monrigal O. (2017). Advanced processing for UHR3D shallow marine seismic surveys. Near Surface Geophysics, 15, 347-358.

Monrigal O., de Jong I., Duarte H. (2017). An ultra-high-resolution 3D marine seismic system for detailed site investigation. Near Surface Geophysics, 15, 335-345.

Sturm, H. (2017). Design aspects of suction Caissons for offshore wind turbine foundations. In Proceedings of TC209 Workshop (Foundation design of offshore wind structures): 19th International Conference on Soil Mechanics and Geotechnical Engineering, Seoul, South Korea, 20 September.