Challenges in offshore wind farm installation

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In recent years, the construction of offshore wind farms has flourished as many countries strive to increase the share of renewable energy in their overall energy mix. Offshore wind offers some significant advantages compared to onshore developments, including stronger and more stable wind conditions ensuring a more dependable energy output, sufficient space in the national EEZs for large projects, and, last but not least, increased public acceptance compared with onshore developments.

These benefits have fueled the realization of numerous projects not only in the North Sea, but also in many other shallow-water, mid-latitude areas of the world. However, the nature of offshore wind turbine generator (WTG) foundations and offshore environmental conditions pose serious challenges for the construction of wind farms.

Today, WTG foundations are most often constructed as monopiles: large-diameter: 5 -10 m steel pipes that are rammed, or vibrated into the seafloor sediments to a depth of 30-80 m. However, several other foundation types have been used, e.g., jacket and gravity foundations and, more recently, suction buckets in conjunction with monopoles or jackets.

The decisions as regards foundation types and necessary installation depths generally depend on the local geotechnical characteristics of the encountered sediments. Foundations are designed in the appropriate dimensions for suitable installation locations depending on the findings of extensive geophysical and geotechnical pre-site surveys, which establish the geological character of the area.

Typical areas for offshore wind development, e.g., Northern Europe, were predominantly shaped by extensive glaciations in their recent geological history. The identification of widespread boulder-prone sediments in the shallow sub-seafloor is a common challenge for pre-site surveys in these areas.

Such glacial boulders usually consist of crystalline rock and are encountered in sizes of <1 m to >5 m. They were transported from the glacial source regions during glacial periods and deposited in glacial till units. Boulders may also occur on non-glaciated margins, e.g., in conglomerate layers, volcanic deposits, and subsiding beach rocks, which pose similar challenges for the installation of offshore infrastructure.

Encountering boulders during pile installation may result in damage to the foundation or to a complete refusal of the pile installation process. Pile refusal requires a significant additional remediation effort, including either the removal or abandonment of the pile. Associated stand-by costs for additional ships and backup replacement piles further increase the costs of mitigating boulder-related installation issues. Therefore, avoiding sites showing a high probability for the presence of boulders based on the findings of pre-site surveys would lead to a great reduction in installation risk and costs.

Unfortunately, conventional geophysical methods including sub-bottom profilers, single-channel seismics, and magnetic measurements cannot reliably detect and localize boulders due to their physical characteristics: limited size, non-magnetic material. As such, even extensive geophysical site surveys leave a considerable remnant risk of undetected boulder occurrences that could obstruct foundation installation and lead to an increase in costs and delays in wind farm development.

The Fraunhofer IWES Manta Ray system

In order to address this technological gap, Fraunhofer IWES, together with the University of Bremen, developed the Manta Ray system, a new geophysical tool for offshore sub-seafloor boulder surveys. This novel data acquisition system in conjunction with a highly specialized data processing procedure is capable of reliably detecting objects, i.e., boulders, on the seafloor and, most importantly, also within the marine sediments down to maximum foundation depth.

It is based on multichannel seismic principles using a custom-designed array of hydrophones for signal recording and an appropriate high-frequency seismic signal

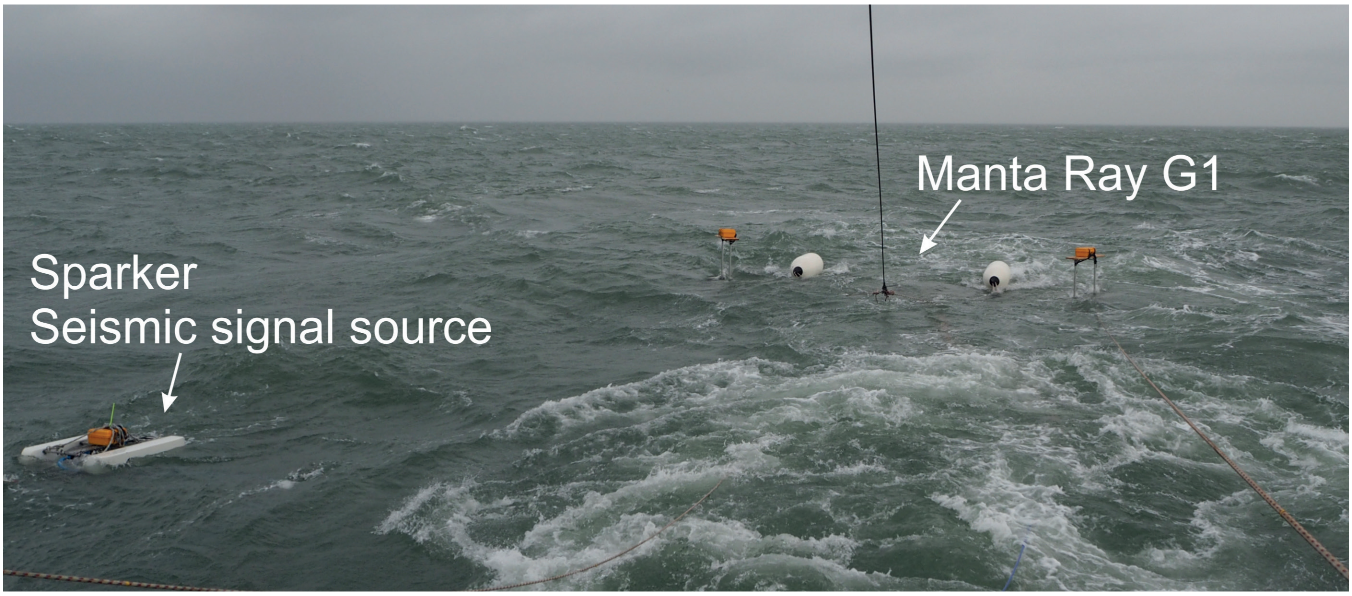

Fig. 2: The Manta Ray prototype during sea trials in the North Sea

source. While conventional seismic methods commonly image sub-surface structures utilizing reflected energy, the Manta Ray system images diffracted energy. Diffractions are caused by individual objects (e.g., boulders) in the sub-surface, whereas reflections are generally caused by laterally extensive surfaces, such as boundary surfaces between sediment units.

Therefore, the accurate recording, processing, and interpretation of the acquired seismic diffraction data allows the Manta Ray system to map individual objects in the sub-seafloor. Objects are reliably detected down to a depth of approximately 100 m below the seafloor in shallow water areas of the North and Baltic Seas, covering the foundation depths of bucket foundations as well as large monopiles. Simultaneously to the acquisition of seismic diffraction data, the Manta Ray is capable of acquiring ultra-high-resolution (UHR) 2D seismic reflection data, used for a detailed geological interpretation of the survey area.

The combination of high-precision positioning systems, a custom-designed survey strategy, and an effective data processing routine results in a high-resolution seismic diffraction and UHR seismic reflection dataset for subsequent interpretation. Data analysis is based on proprietary processing algorithms to identify and localize objects confidently in various geological units.

The versatile interpretation workflow integrates the statistical analysis of seismic diffraction data and a stratigraphic interpretation of geological units from the seismic reflection data. The results comprise the locations and burial depths of identified objects including localization error estimates and a geological interpretation of identified

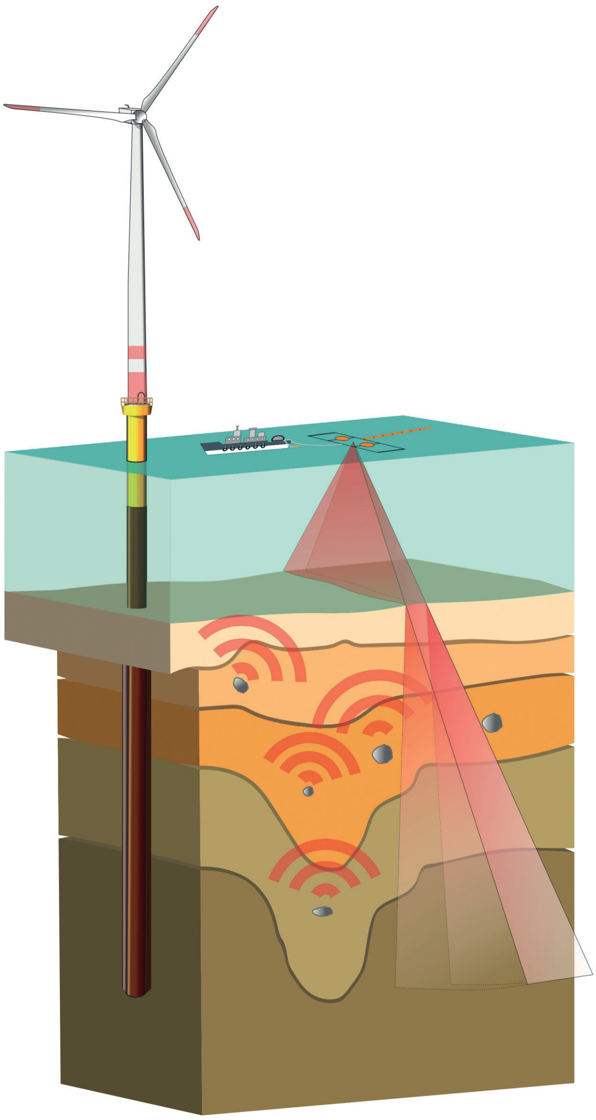

Fig. 1: The new Manta Ray system uses diffracted energy to map boulders in the sub-seafloor to full installation depths in various geological units

objects within their respective sedimentary units. These results may be used not only to avoid areas of high boulder risk, but also to find optimized low-risk locations in the immediate vicinity via micro-siting of the planned installations.

State-of-the art boulder detection surveys for offshore wind farm areas

The Manta Ray system has been deployed in a number of sea trials in the German North Sea and Baltic Sea sectors in order to validate the method. Recently, it showed its potential during the successful implementation of a first commercial survey for wind farm installation de-risking. A Manta Ray survey, followed by subsequent data processing and interpretation, resulted in the confident mapping of boulder occurrences over the full installation depth.

Typical survey work using the Manta Ray targets limited areas around planned WTG locations (e.g., 100 x 100 m). The data acquisition time needed for one such location is between 6 and 12 hours, depending on the overall survey layout, vessel mobilization, and other campaign constraints. Due to the high achievable survey speeds of up to 5 knots and swath imaging capabilities of the Manta Ray, efficient full field surveys are also possible but should be included in the planning process at an earlier stage than de-risking surveys for individual WTG-foundations.

Data processing and interpretation are carried out in close cooperation with the client to ensure result-oriented work and individually designed deliverables. Processing times are in the order of several weeks owing to sophisticated data processing procedures and careful interpretation of results. The final results allow the client to ensure the safe, time-efficient, and cost-efficient construction of offshore infrastructure

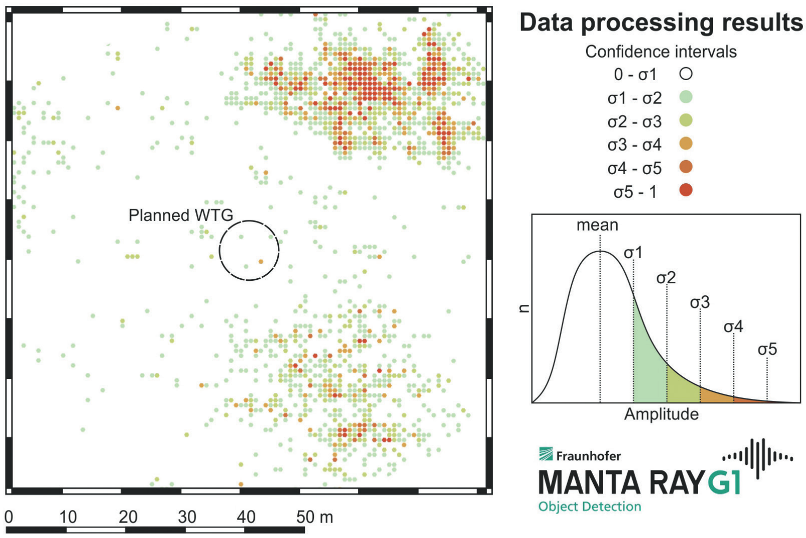

Fig. 3: Data processing results for a WTG location showing different levels of diffraction energy observed in individual grid cells

through the de-risking of construction sites with regard to boulder occurrence.

Future applications of the Manta Ray system

Besides the de-risking of WTG positions for boulder occurrence, the de-risking of cable corridors and other offshore infrastructure projects such as platform construction and dredging operations are other possible applications for the Manta Ray system. The system can be easily adjusted to the sizes of boulders that are of interest for individual projects as well as the depth below seafloor that is targeted.

The success of the Manta Ray system has prompted Fraunhofer IWES to pursue further research and development projects into the new method. Upcoming activities target various topics relevant to the offshore surveying and wind industry. One important challenge is the mapping of installed offshore cables, including depth-of-burial measurements, in order to confirm installation success and perform periodic monitoring during cable operation.

Additionally, unexploded ordnance (UxO) pose a serious threat for any seafloor activities in many marine areas. Fraunhofer IWES plans to further develop the Manta Ray system to detect buried UxO, which have proven difficult to image using conventional surveying systems, especially in the case of non-magnetic UxO.

Conclusion

This new boulder detection methodology is a significant addition to the Fraunhofer IWES portfolio, which focuses on the validation of wind energy in all of its aspects through research and development together with various industry partners. The successful implementation of a geophysical mapping tool for boulders down to the installation depths of typical WTG foundations is a major step forward in de-risking offshore wind developments and facilitating wind farm construction.

The efficient investigation of sub-seafloor object occurrence that is made possible with the Manta Ray system significantly lowers costs during pre-site surveying, compared with time-consuming geotechnical surveys or seafloor-based measurements, and simultaneously increases the safety and speed of foundation installation. Further research based on the Manta Ray system at Fraunhofer IWES will contribute to continued improvements to the method, the survey design, and data analysis, further heightening the methods' utility for the offshore industry.

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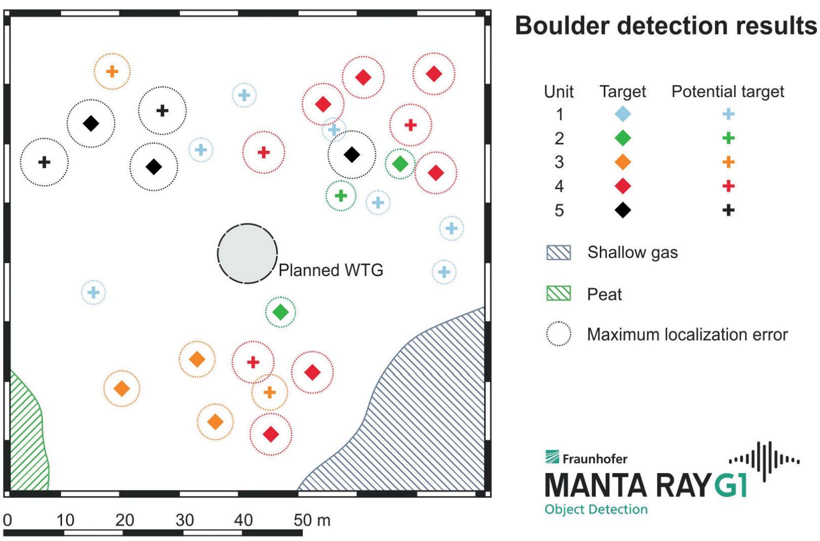

Fig. 4: Interpretation results showing encountered targets in different geological units with maximum localization errors