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Marine geophysical investigations for offshore wind farms and submarine interconnection cables

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Abstract—**The knowledge of the marine seabed and subsoil characteristics and properties is essential for the correct development and design of any structure to be installed offshore. In this sense, geophysical techniques are indirect methods that allow obtaining high quality data useful to investigate the seafloor and therefore assure an optimum installation and maintenance of the cable route line (RPL) of submarine electrical cables connections.**

When a submarine cable route is investigated, it is planned to find if the pre-defined cable route is suitable and if there are any potential constrains that can cause problems or injuries during the installations works or during the further maintenance. Therefore, it is important to define any possible installation constrains based on the geophysical (and geotechnical) data throughout the cable route.

In this work, it is presented the methodological approach for geophysical investigations for inter-array and export cables in offshore wind farms as well as for any submarine interconnection cable between different regions. The results obtained with MultiBeam Echo-Sounder, Side Scan Sonar, Sub-Bottom Profiler and Magnetometry are presented when they indicated potential constraints that can affect these infrastructures like boulders, seabed steepness, bedrocks outcrops or unexploded ordnance and manmade objects.

I. Introduction

The need for the marine electrical interconnection between different regions and the proliferation of offshore wind farms all over the world lead to the installation of thousands of kilometres of submarine electrical cables in recent years. The correct development and design of any offshore infrastructure requires the study of the seabed and subsoil characteristics and properties.

Geociencias y Exploraciones Marítimas (GEM), a private company that develops geosciences research, has been undertaking projects related to marine electrical interconnections around Europe in the recent years (Fig. 1). Projects involved the electrical interconnection between two islands, between continent and island, and in wind farms with inter-array cables (inside the wind farm park) or export cables linking the wind farm and the shore. The experience in these kinds of marine investigations has allowed defining the most suitable geophysical techniques, the necessary equipment to be used and the vessel requirements to be considered to successfully undertake these projects. Nevertheless, experience is key to achieve the demanded technical specifications in the marine geophysical surveys for these projects often emplaced in complex working areas.

Geophysical techniques provide high-quality and high-resolution data to the marine investigation surveys resulting on the seabed and sub-seabed information. Together with geotechnical data, allow an accurate definition of soil/rock and a realistic design of the cable route and its suitability. Moreover, the potential cable constrains are a useful source of information during the installation works and for their further maintenance. This work is focussed on the hydrographical and geophysical techniques such as MultiBeam Echo-Sounder (MBES), Side Scan Sonar (SSS), Sub-Bottom Profiler (SBP) and Magnetometry (MAG). Other techniques can also be applied depending basically on the topic and the project site environment, setting and conditions.

The aim of this work is to present the application of marine geophysical techniques that are commonly used to investigate the seabed and subsoil for offshore wind farms and submarine cable projects. Examples of results and potential constraints based on the acquired experience in offshore projects are also included.

II. Methods

It is essential to determine with high reliability the surficial seabed and subsoil characteristics and properties for a proper design of the cable route and the subsequent cable installation. For assessing the seabed characteristics, usually the survey areas are divided between onshore (land or emerged area), nearshore (from 0 m to -15 m approximately) and offshore (deeper than -15 m). At each survey area different techniques, equipment, and work plans are defined.

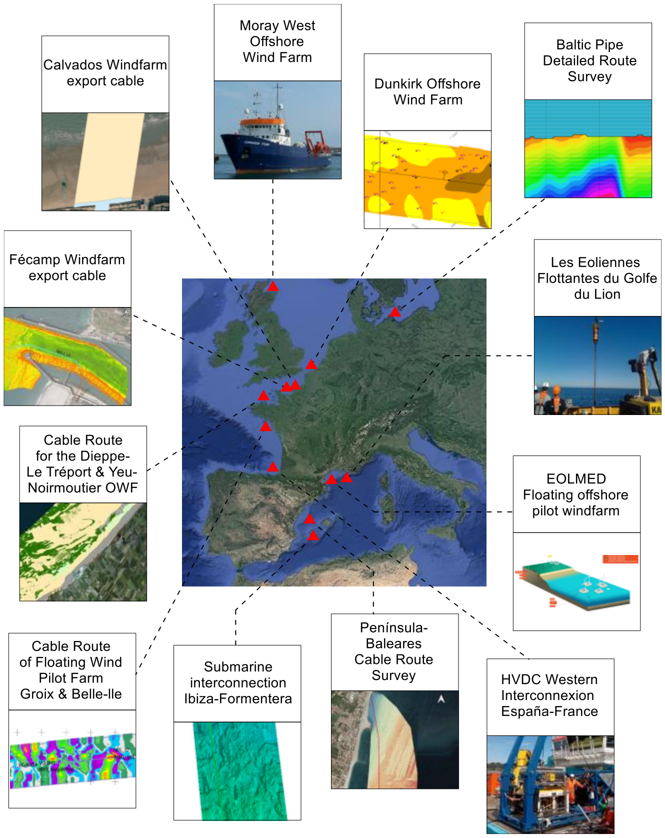

Figure 1. Submarine cables and wind farm projects undertook by the company Geociencias y Exploraciones Marítimas (GEM) in the recent years

A specific line plan is well-defined, previously to field works, considering each data acquisitions techniques, the equipment, the depth of the survey area and the desired resolution. Previously to the geophysical surveys, it must be ensured that all the equipment is calibrated, verified and that data is acquired correctly as well as to confirm that the methodology for data acquisition is adequate for the project site. The nearshore and offshore techniques are briefly explained in the following paragraphs [2].

MBES is used to obtain a high-resolution bathymetric map of the seabed that allows to characterise the seafloor topography and relief. Bathymetry surveys provide seabed information that can be used to determine, for example, the seabed gradients, the sediment mobility, or seafloor stability by comparing different data acquisition times.

SSS creates images/sonographs of the seafloor. The SSS data is used to define the seabed morphology and if there are different type of sediments, the sedimentary features or the identification of natural or manmade objects on the seafloor that can result on a constrain for the cable such as boulders, debris, channels and unidentified submerged objects (USO) that can be potential unexploded ordnance (UXO).

Seismic survey is accomplished through a SBP and is used to identify the geological structures and the seismic stratigraphy of the subsurface (shallow geology) with high-resolution. With the SBP data, the sediment thickness, the depth of the rock and hard or cemented sediments can be defined which is important for cable burial engineering.

The MAG is used to identify any magnetic anomaly in the subsoil or shallow geology, being natural or anthropogenic. It can recognize objects up to several meters buried on the seafloor depending on the survey requirements. The MAG data is key to ensure a safety cable installation.

To guarantee the security during the geotechnical campaign and during the cable installations works, an UXO study using the technics mentioned is undertaken to identify any possible unexploded objects or artefacts present throughout the corridor.

When the geotechnical campaign and the laboratory works are finished, all data are integrated, and a definitive global ground model is developed. The ground model is key for the seabed investigations because it provides a useful and complete package of information about the surface but also about the shallow geology. Thereafter, the suitability of the cable route is studied and the potential installation and maintenance constraints.

III. RESULTS AND CONCLUSIONS

The cable route suitability is examined by using the obtained ground model with the combination of all techniques and interpretations. To install and protect the cable, consideration must be taken to those issues that could impose limitations on these operations. Some examples of potential installation constraints are shown in the following sections:

A. *Seabed gradients*

High seabed slopes/gradients can cause hazards for the cable during installation or post-installation maintenance activities (Fig. 2). Typically, the seabed gradients are classified in function of the slopes as: very gentle (<1˚), gentle (1˚-4.9˚), moderate (5˚-9.9˚), steep (10˚-14.9˚) and very steep (>15˚). Some burial or installation equipment (i.e. ROV jetting, plough, trencher) are not suitable for stable and safe operations on steep or very steep seabed slopes. Figure 2 shows an example of a beach rock detected with the MBES and SBP that crosses a cable route. The beach rock was composed by two parallel ridges with 6.5 m of maximum height. In this case, the MBES provides information about the seabed topography (Fig. 2 left) and the seabed gradients

(Fig. 2 right) of the ridges that were up to 15˚ and therefore, classified as very steep being dangerous for the cable installation. Moreover, the SBP (Fig. 2 down) give information of the internal structure of the beach rock showing the reflectors of the two ridges made up of cemented sediments outcropping and separated by soft sands between them.

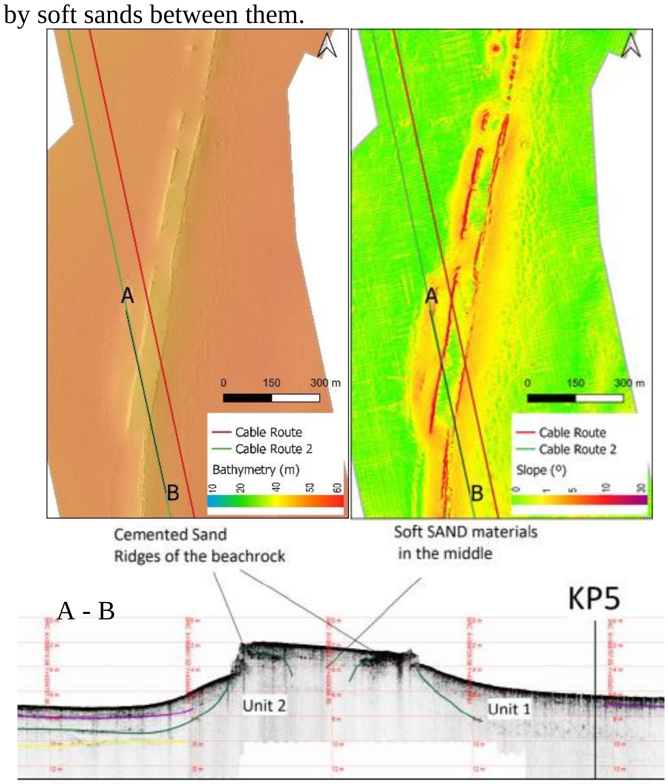

Figure 2. Examples of a beach rock crossing a cable route that causes high seabed gradients that constituted an important constraint for the cable route. Above, bathymetry (left) and slope gradient map (right). Below, SBP data showing the shallow geology profile.

B. *Boulders, wrecks, and anthropogenic debris*

The presence of obstructions could jeopardize or delay the cable installation. Boulders or any feature identified over the seafloor should have different implications in cable installation according to their dimensions. For example, boulders can damage the burial equipment or reduce the burial equipment's capability to reach the required burial depth (Fig. 3.1). Therefore, they are classified distinguishing their largest axis (d) as: small (d < 0.3 m), medium (0.3 > d > 2 m) and big (d > 2 m).

Wrecks and other anthropogenic debris are also constraints when installing the cable, as it can be suspended from the seabed and represent a rough threat to the cable. In Figure 3.3 is represented a wreck that we found close to a cable route, in this particular case it was far enough to not be considered a hazard.

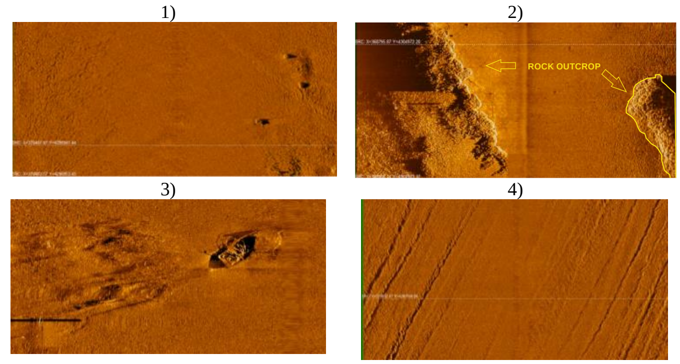

Figure 3. Examples of different constraints identified by the SSS. 1) isolated big boulders; 2) rock outcrop surrounded by sandy material; 3) a wreck; 4) trawl marks originated from fishing activity.

C. *Mobile sediments*

Mobile sediment can cause two types of constraints when installing a cable: the cable can be buried more than expected, causing overheating, or the cable can be left exposed, leaving the cable vulnerable to be damaged. Bedforms (i.e., dunes or sand waves) or landslides are typically indicators of sediment mobility. Figure 4 shows an example of mega-ripples of 1.5 m high and 150 m apart crossing the cable route. Because the MBES provides information of the seafloor for a specific moment, ripples mobility and migration should be studied [2].

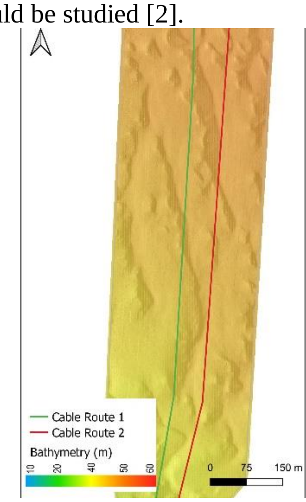

Figure 4. Examples of mega-ripples seen in the bathymetry indicating mega-ripples field crossing the cable route.

D. *Stiff/hard sediments*

The risks associated with the presence of hard soil involve possible difficulties in reaching an appropriate burial depth to protect the cable from external hazards (i.e. Fig. 3.2). These areas must be considered when assessing the most appropriate burial techniques. In Figure 5 there is an example of the isopach map (up) of soft sediment over stiff sediments obtained from the SBP (down) where the soft sediments are indicated as Unit 1. In this case, the hard soil present at shallow depths is an obstacle for reaching the required cable burial depth.

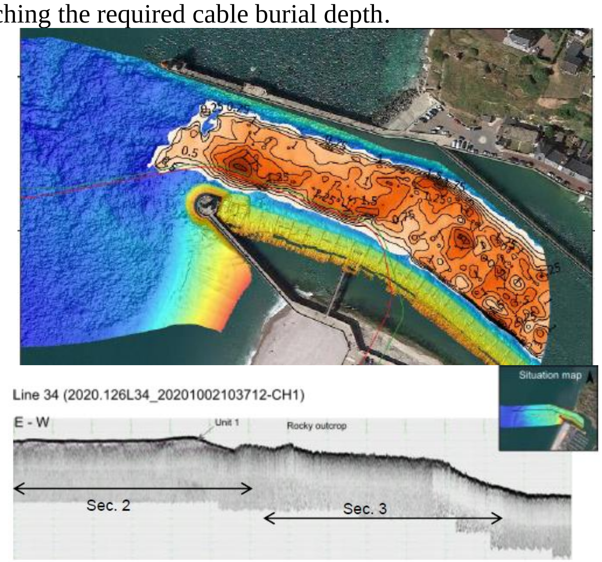

Figure 5. Examples of soft sediments represented by the isopachs in contact with the stiff sediment/bedrock. Below, an SBP profile from the same area where sand is identified as Unit 1.

E. Cables and pipelines/crossings

To simplify cable and pipeline crossing design, the best option would be to cross them as perpendicularly as possible. This will minimize risks in future cable repair and maintenance operations. Figure 6 shows an electrical cable detection with SSS (up) and with the magnetometry (down) that crosses almost perpendicularly the cable route. This type of crossings is optimum and desirables.

F. Fishing Activity

Fishing is an activity to consider, particularly, demersal fishing. This activity could result in snagging or damage of a buried/protected cable. It should be noted that the minimum burial depth to protect cables from fishing tackle should consider cases when a fishing vessel perform multiple passes, resulting in greater penetration. Figure 3.4 shows an example of trawl marks identified with the SSS.

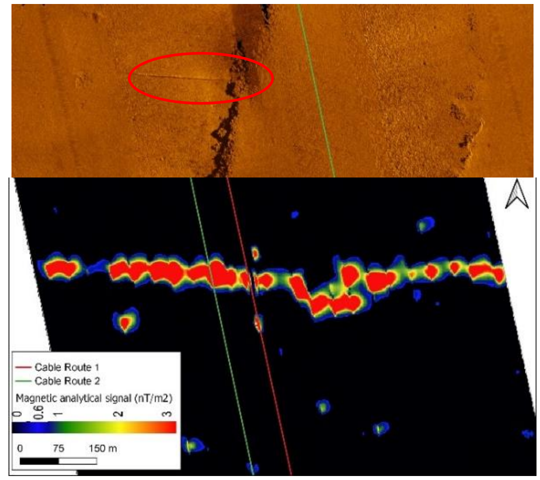

Figure 6. Examples of cable crossing a cable route. Above sonar image, below is represented the magnetic anomaly of the observed cable crossing**.**

G. Unexploded Ordnance (UXO)

Most of the countries that are leading the installation of wind farms and submarine cables in Europe where highly affected during the First and the Second World Wars and concentrate a high number of debris from artillery shells or bombs dropped from aircrafts in the seafloor or buried inland [23]. The UXO survey results includes the verification that the cable route and the locations of the geotechnical points where tests will be undertaken are optimum and safe.

In conclusion, the ground model obtained integrating the geophysical and geotechnical techniques is useful to investigate the submarine seabed and asses properly the cable routes. Particularly, MBES, SSS, SBP and MAG technics are key to identify potential cable installation and maintenance constrains and guarantee the security during the works. Examples of constrains shown are steep gradients because of beachrock outcrops, boulders on the cable route, debris or manmade objects like wrecks, stiff sediments, fishing activities that can lead the cable vulnerable to be damage and bedforms that can leave the cable exposed or over buried.

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