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Portugal first HVAC submarine power transmission cable - from engineering to construction

Premier câble sous-marin de transport d'électricité CAHT au Portugal - de l'ingénierie à la construction

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ABSTRACT: This paper presents the experience and some lessons learned from the design and construction of Portugal's first High Voltage Alternating Current (HVAC) submarine power transmission cable, offshore Viana do Castelo. The paper focuses on the ground conditions and the engineering solutions along the marine section of the submarine power cable, namely: 1) trenchless cable landing in hard rock, 2) the cable installation and protection requirements along a rocky seabed and 3) trenching in soil.

RÉSUMÉ: Cet article présente l'expérience et quelques enseignements tirés de la planification et de la construction du premier câble sous-marin de transport d'électricité à haute tension et à courant alternatif (CAHT) du Portugal, au large de Viana do Castelo. L'article se concentre sur les conditions du sol et les solutions d'ingénierie le long de la section marine du câble électrique sous-marin, à savoir: 1) l'atterrage du câble sans tranchée dans la roche dure, 2) l'installation du câble et les exigences de protection le long d'un fond marin rocheux et 3) le creusement d'une tranchée dans le sol.

Keywords: Submarine cable; offshore surveys; trenchless landfall; cable installation; cable protection; floating offshore wind.

1 BACKGROUND

The Windfloat Atlantic project is Europe's first floating semi-submersible offshore wind farm, located approximately 20km offshore Viana do Castelo, northern Portugal. The offshore wind farm consists of 3no. 8MW wind turbine generators on floating semi-submersible platforms anchored to the seabed at a water depth of around 100m, with an installed capacity of 25MW. These turbines are connected through a series of dynamic inter-array cables to the Portuguese grid offshore interconnection point through a Dry-Mate Connector (DMC) laid in the seabed approximately 20km offshore.

In 2015, the Portuguese government allocated to Redes Energéticas Nacionais (REN), the Portuguese Transmission System Operator, the responsibility for the design and commissioning of the Portuguese grid offshore infrastructure in Viana do Castelo, designed for a maximum nominal power of 200 MVA when operated at 150 kV. This comprises Portugal's first High Voltage Alternating Current (HVAC) submarine power transmission cable, 225mm diameter with three 1164 mm2 cores and approximately 17km. The connected generation power of the initial phase, already completed with the infrastructure operating at 60 kV is 25 MW.

For the design, supply and installation of the infrastructure, REN awarded in 2018 an EPC&Mcontract to Hengtong, who subcontracted the offshore works to DeepOcean, the landfall Horizontal Directional Drilling (HDD) to HDI, and the onshore switchyard to CME. Cathie were contracted by REN to support the offshore and landfall projects from early planning, leading the pre-tender design activities, providing tender support and the construction support.

The power transmission cable is laid along the seabed before entering the ~630m of HDD duct and connection to the national distribution grid. For protection, the cable was trenched into the seabed where possible or buried under a rock berm. This paper focuses on the ground conditions and the engineering solutions, namely: 1) trenchless cable landing in hard rock, 2) the cable installation and protection requirements along a rocky seabed and 3) trenching in soil.

2 GROUND CONDITIONS

2.1 Geological context

The geology along the cable route can be summarised in two major sections. Section 1 (approximately 1/3 of the cable route) closer to shoreline, characterised by the presence of exposed or sub-exposed Pre-Cambrian and Palaeozoic granitoids/schist, associated with high compressive strengths and strong NNW-SSE and WNW-ESE lineations, Figure 1. The lineations are the product of the significant folding and faulting in this area.

Section 2 is generally characterised by a minimum sediment cover of 2-3m increasing towards the west. The geology of this section consists of sub-exposed cretaceous rocks and quaternary sediments (mainly fine to coarse granular materials, sandy silt becoming silt to the West of the route).

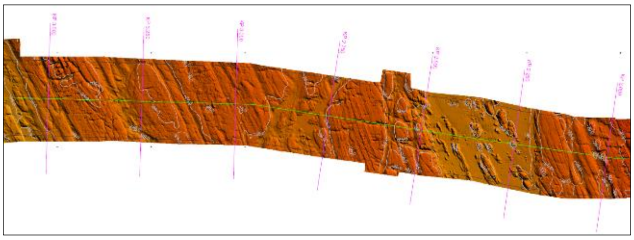

Figure 1. Bathymetry section showing rocky seabed. KP points shown every 250m.

2.2 Geophysical and Geotechnical characterisation

2.2.1 Offshore cable route

A geophysical survey of the anticipated export cable route was conducted in 2014 by GEOxyz (offshore section) and Lagoa do Ruiva Survey (nearshore section), providing multibeam echo sounder (MBES), side-scan sonar (SSS) and sub-bottom profiler (SBP) data in order to determine water depths, identifying seabed obstructions and features such as seabed sediments cover.

The nearshore survey was executed in April 2014. A zone of ~4km^2 was surveyed in the nearshore area with multibeam, where the cable was supposed to come onshore. The depth varied between +3.0m LAT and -30.0m LAT. The deepest zone was recorded in the southwestern part of the area, furthest away from the coast. This zone consists mainly of rocky outcrops.

Along the planned cable route, a corridor of 500m wide was surveyed with MBES, SSS and SBP. The first 10km of the cable route was noted to be covered with fishing gear. For this reason, side scan sonar survey was not possible in the nearshore area.

Multibeam data showed depths along the corridor varying from -10m LAT in the east, along the coast, up to -95m. Rocks were visible up to 8km from the shore, with depths up to -50m LAT. The rest of the corridor showed a smooth slope towards the west, with no rocky structures visible on the surface.

Lines for the SBP were recorded simultaneous with every multibeam or side scan line surveyed. Average penetration into the sediment resulted in 8-10m. Towards the west, the rocky structures were still visible but covered with a ~2m of sediment.

Towards the end of the corridors, rocky structures were not visible, however, in the western part of the cable route, shallow rocks were present again with only a small sediment cover. Where no rocks were visible on the surface, a mimimum of 3 meters sediment (and often more) was detected along the cable routes. Steep slopes were only visible in the rocky areas.

As part of the pre-engineering phase, an additional geophysical survey was carried out in September 2018 by MG3 under subcontract to DeepOcean, to ascertain expected free cable spans prior to finalisation of the route engineering. The scope of work involved the collection of bathymetric and geophysical data within a 200m wide corridor. The entire corridor was surveyed with MBES, SBP and seafloor dropdrown camera at certain intervals. Due to fishing activity and gear, the SSS and Magnetometer works were suspended and the MBES Backscatter Imaging was recorded as back-up in order to enable a seafloor sediment analysis.

The scope of the Export Cable geotechnical investigation, comprised a total of 32no. CPTs coupled with 32no. Vibrocore (VCs). The target penetration depth for both type of tests, was specified to be 3m to 5m below seafloor based upon the anticipated ground conditions along the cable route.

The geotechnical survey was performed by Fugro in 6 days during November-December 2016 using the MV Markab, a 63m dynamically positioned DP2 survey vessel. A 75kN Seacalf seabed CPT unit was mobilised on board of the MV Markab. Seabed CPTs were performed using a 12 tonne ROSON CPT system. Cones with a projected area of 10cm^2 and 5 tonne capacity were used for testing, with pore water measurements made on the shoulder of the cone, generally providing very good quality results, in general, all within ISO Application Class 1 (ISO 22476-1, 2022) for ground conditions comprising loose to very dense sands and soft to very stiff clays. The CPT achieved good penetrations in the sands and occasional clays were encountered along the route up to ~10km from the shoreline, from where the CPTs recorded the presence of bedrock near surface and/or rock outcrops.

Sampling operations were performed using a high performance corer (HPC). The HPC had a base frame of 2.4m x 2.8m, an overall length of 8.1m and a weight (in air) of approximately 3.1ton. The HPC was fitted with a 6m core barre allowing for the recovery of soils samples of up to 84mm in diameter.

Only basic logging of the samples was performed offshore. Laboratory testing onshore was generally performed according to the BS 1377 (1990) procedures, including:

- Basic strength and Index laboratory Tests.
- Water content and Wet and Dry Density.
- Plasticity Index.
- Particle size distribution.
- Minimum and maximum density.
- Thermal conductivity test.
- Shear box test.
- Unconsolidated Undrained Triaxial Test.

2.2.2 Landfall

An onshore geoelectrical tomography survey supplemented by seismic refraction tomography and multichannel analysis of surface waves (MASW), calibrated with boreholes, was performed by Donié Geo-Consult in order to generate a geological model for the HDD working area. Rockhead was reported at a depth of 6-8 m, slightly inclined in the direction of the sea and underlying heterogeneous anthropogenic made ground.

Additionally, an offshore geophysical exploration in the planned landfall area was performed with MBES, SBP and electrical resistivity tomography techniques by Donié Geo-Consult and SSS and Seismic Reflection (with a boomer) by Instituto Hidrográfico. The aim of the investigation was to create a geological model for the cable landing area.

At least two to three critical sections with lengths of up to 100 m and apparently strongly fragmented hard rock were identified. On the last 100 m before the exit point, a remarkable resistivity minimum linked to a very rough surface of fractured rock according to the SBP results was identified, Figure 2. The Echo Sounder detected a strongly fractured rock surface with open fissures pointing in two main directions (NW-SE and WSW-ENE).

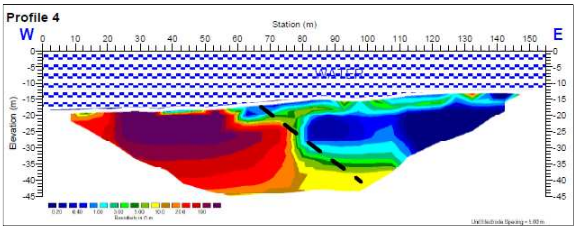

Figure 2. Geolectrical tomography of punchout area (red, high resistivity; blue low resistivity).

In 2018, a total of seven onshore rotary percussive boreholes were drilled by GeoSonda, six boreholes to a maximum depth of ~10.5m at the footprint of the switchyard building, and one borehole at the location of the HDD entry point, with total depth of 40m.

The borehole descriptions at the HDD entry point identified an upper layer of made ground, with cavities overlying solid rock composed of various types of schists, with subvertical schistosity.

Additionally, laboratory testing from five representative samples at different depths and lithologies were obtained from borehole S7 including:

- Point Load Test
- Uniaxial compressive test (UCS)
- Micro-Deval
- Cerchar Abrasivity
- D.R.I. (Drilling rate index).

Abrasivity results revealed very to highly abrasive samples, particularly in quartzitic schist. In general, medium to high D.R.I index values were obtained. Maximum values from the UCS tests ranged between ~39-80 MPa in quarzitic schist and ~12-61 MPa in andalusite schist. It was noted that the lowest values correspond to fractures along discontinuities during the test.

3 ENGINERING SOLUTION

3.1 Contractual cable burial and protection requirements

The governing basis for the design was protection for a minimum 30 year service life against fishing activity and 1:10,000 year anchoring events.

REN specified different protection requirements over two characteristic sections: rocky section (Section 1) and buried section (Section 2).

For Section 1, defined as rocky outcrops with thin or absent sediment cover, closer to shore, it was envisaged that cable armour and pinning/rock dumping compliant with environmental restrictions was required.

For Section 2, defined as minimum sediment cover, it was envisaged a minimum Depth of Cover (DoC) of

1.5m, and greater where appropriate, to guard against a 1:10,000 year anchoring damage event in accordance to Cable Burial Risk Assessment) methodology (Carbon Trust, 2015) where sufficient sediment existed.

3.2 Cable route

DeepOcean initially reviewed the GEOxyz geophysical data and the geotechnical data from Fugro 2016 to ground-truth the geophysical report and build a conceptual ground model. The cable corridor was then optimised and the route further surveyed by DeepOcean in 2018. The following items were considered in order of priority for route engineering:

- Permitted Operational Corridors.
- Avoidance of anchoring zones. An anchoring area was noted to be present to the south of the corridor. An exclusion boundary was drawn around the outside of this zone to ensure no operations were planned there.
- Avoidance of bedrock outcrops and minimisation of rock spans where possible.
- Avoidance of Archaeological excludion zones. A number of contacts with potential for archaeological content were identified. All the contacts had a 50m buffer applied to make sure that none of these buffers come within the cable corridor.
- No field infrastructure, crossings or boulders were reported to be within the corridor. Preliminary research indicated the UXO risk along the corridor to be very low.

The export cable route was designed from the Transition Joint Bay on land through the HDD westwards to the DMC. Approximately 8km consisted of subsea rock placement and ~9km corresponded to seabed trenching to a burial depth of 1.5m. Water depths along the route range from Landfall to a maximum of approximately -94m LAT.

The Cable Lay Vessel (CLV) OY Connector was used to support most offshore activities, namely rock and sandbags placement, cable lay and trenching activities. The Fall Pipe Vessel (FVP) Simon Stevin was used for the rock placement activities.

3.3 Landfall

HDD with forward reaming solution (drilling from onshore to offshore) was selected for the landfall with the use of HDI HK400 drilling rig (400t), Figure 3. The solution consisted of drilling an initial pilot hole, subsequently enlarged by a forward reaming operation, prior to the installation of a 24‘‘ steel pipeline through which the export cable was later on pulled-in.

Based on the findings from the offshore geophysical investigation, the initial HDD design trajectory was anticipated to cross an area of strongly fractured rock at exit point. The HDD trajectory was then adjusted to avoid this area and achieve an exit point 35m closer to shore.

Initial pilot hole with 12’’1/4 drill bit was aborted after 170m due to magnetic interferences afecting direction control. This pilot hole was plugged with cement grouting and abandoned. A second sucessfull pilot hole, approximately 625m long, was performed with a 9’’7/8 drill bit and with the assistance of a gyroscope to avoid magnetic interference.

Reaming was then performed in two steps, 26’’ performed to a length of 617m, and 36’’ performed to a length of 597m. Punch-out operations were performed following the same 26’’ and 36’’ drilling steps. First attempt was made with the drill bit and the 26’’ and 36’’ tools connected, in order to minimize amount of drilling fluid at sea. Shearing of a drill pipe occured during drilling; the contractor successfully engineered fishing gear to recover the drill bit, allowing to resume reaming with 26‘‘ and 36‘‘ performed separately.

Figure 3. Forward reamer and launching pit.

The final stage of the installation consisted of the installation of a 24’’steel pipeline welded on-site and pushed into the reamed hole. A messenger wire was installed at the completion of the job to allow later connection for the cable pull-in activities.

Due to the HDD exit changes to a shallower depth, approximately 40m cast iron half-shells (bend restrictors) were installed and connected to the HDD exit with diver support. Each section of half-shells incorporated a messenger wire connected to the main HDD pull in messenger wire. Thethered 4t rock bags filled with high density (3050 kg/m^3) angular quarry rock were placed over the shells to provide stability against combined wave and current loading under extreme hydrodynamic conditions assumed for 1:50 year return period conditions.

3.4 Cable installation and protection requirements

3.4.1 Rocky seabed

A significant portion of the route along the rocky seabed involved placement of the cable on an irregular seabed with NNW-SSW ridges and NNE-SSW erosional channels, with anticipated cable free-spans. Pre-installation of rock bags and sandbags at pre-determined locations was adopted to provide support to the Export Cable, minimising free-spans along the lay route, Figure 4. After cable laying, the cable was mechanically protected by engineered rock placement.

Figure 4. Rock bags.

A Cable Protection System (CPS), consisting of half shells secured with carbon steel banding, was fitted to the portion of the cable to be laid in the rocky seabed during the cable spooling on the CLV carousel at Leixões Port in Portugal, with the purpose to provide abrasion and protection during rock placement operations.

For the cable section closer to the Port of Viana do Castelo anchorage (500-600m south of the cable route), the rock berm was designed to further protect the cable from anchoring associated with inclement weather conditions or anchor drifting in a northward direction, Figure 5. The rock berm was designed to protect against a 4000t vessel which based on the IACS rules would typically comprise an anchor of 1500kg.

Given the very low probability of an anchor strike of any size along the remaining of the cable route, assessed in the CBRA study, the rock berm design was governed by protection from fishing gear interaction and to maintain hydraulic stability.

Based on the varying governing design conditions along the route, the total rock placement length of the rocky area was subdivided into different sections, depending on the water depth. Two different rock gradings (LMA 5/40 and 1-8'') were adopted in combination with varying berm geometries and side slopes to obtain hydraulic stability. For the area adjacent to the anchorage area, a wider rock berm (1.5m) and a higher cover (total armour + cushion 1.5m) was adopted. A specific rock density of 3050kg/m³ (HD) was targeted.

For the shallowest section the rock installation placement was subject to the FPV draft limitations and was executed with the Inclined Fall Pipe system with the support of a survey support vessel. For the remainder of the rock placement scope the Fall Pipe ROV (FPROV) was used with survey systems onboard the FPV.

The rock material was mostly sourced from a quarry in the North of Spain, with some additional LMA5/40 material being sourced from Southwest Norway. The total rock weight required to create the berms protecting the cable was approximately 131,000t and involved 5 loadings at the Ferrol Port in Spain.

Figure 5. Rock berm construction operations (FPV).

3.4.2 Trenching in soil

The CBRA study concluded that there was a very low probability of an anchor strike along the buried section and the statistical analysis indicated that an unburied cable would be within REN specified target annual failure frequency of 1:10000 year. The recommended level of protection for the trenched section of the cable route was therefore governed by potential fishing gear interaction. Based on the shallow geological conditions along the route and on the varying penetration of different types of fishing gear in the region, a Minimum Depth of Cover (DoC) for protection against fishing of 0.5m was recommended by DeepOcean. For the trenching operations the following criteria was agreed:

- Target trench depth of 1.5m DoC, with results considered acceptable without further review for DoL between 1.0m and 1.5m.
- DoC between 0.5m and 1.0m: further review required between REN and DeepOcean to agree if further actions would be required based on a specific assessment of depth and lengths. This

was evidenced by an offshore field memo assessment of the TSS350 cable tracker survey results.

- DoC less than 0.5m: 2nd trenching pass required to try and achieve the above requirements.

During the pre-lay grapnel run (PLGR) along the proposed cable lay route, the grapnel train caught several fishing gear, long-lines and mono-filament tangle nets, which could prove hazardous for ROV operations during the cable lay and post-lay burial operations.

Cable trenching was completed between ~KP7.15 and ~KP16.4, with a transition zone between KP7.197 and KP7.212 where the cable was lowered into the seabed and also protected by extending the rock berm from the rocky section. From the start of trenching to approx. KP9 the trench depth was locally reduced due to the presence of bedrock within the trenching profile.

Considering the anticipated ground conditions and target burial objectives, DeepOcean selected their T1 tracked subsea jet-trencher, capable of independently loading and unloading laid product from the seabed, then digging a trench using hydraulic power whilst simultaneously burying the product behind it, Figure 6. The T1 was fitted with 3.5m jet swords which could extend to 2.2m below the seabed with the aim to lower the cable to target depth in one pass. An average speed of 200m/h was envisaged. The nozzle configuration was selected to optimise the trencher performance, with an output of 750m^3/h at 4 to 5bar.

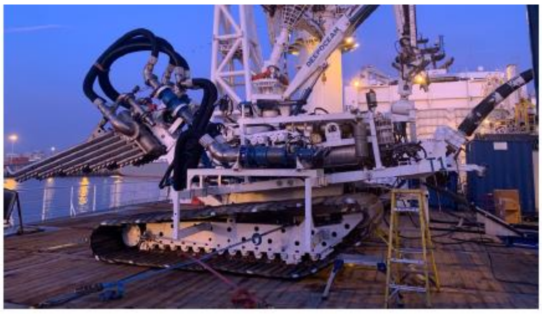

Figure 6. T1 DeepOcean Jet trencher.

Extremely low strength clay, with thickness between 0.40m and 0.6m, was noted at seabead between approx. KP14 and approx. KP15.3, overlying sand. For this section, trafficability was anticipated to be potentially difficult and several methods were employed to reduce the effective bearing pressure of the trencher and to maintain traction, namely through locking the trencher in the bullet, crane assistance to reduce the overall weight, and fitting of grousers.

At limited sections of the route, the DoC did not meet the requirements upon the trencher first pass. Following thorough review of results and consideration of potential risks and benefits of a second pass, limited sections of 1-8’’ rock grading were installed to provide suitable cover where required.

At the western end of the static cable a transitioning out trenching profile was adopted until reaching the DMC position, Figure 7. A total of 31 2t rock bags were subsequently installed over the DMC and the area of exposed cable to the east of the DMC.

Figure 7. Dry-mate connector deployment.

4 CONCLUSIONS

This paper presented the experience and some lessons learned from the planning and construction of Portugal’s first HVAC submarine +ower transmission cable, offshore Viana do Castelo. Operations included trenchless construction of the landing area, rocky seabed routing and free-span management, CPS fitting and deployment, rock berm construction, seabed trenching and DMC deployment and protection. The cable was successfully designed and installed and is currently operational.

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