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Different jacket foundation installation methods for three offshore substations

Différentes méthodes d'installation de fondations de type jacket pour trois sous-stations électriques offshore

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ABSTRACT: Following the world demand for clean energy, the development of Offshore Windfarms (OWF) has been in constant growth with more challenging sites being considered for the construction of these OWF. Three Offshore Substations (OSS) of three different OWF located off the North and West coast of France, are installed on four-legged jackets founded on piles. For each of the OSS, the installation method of the pile foundations was different due to the soil conditions found on site: Rock Socket Drilling (RSD), Drill and Grouted (DG) and Drive-Drill-Drive (DDD). For all the three OSSs a pre-pilling template was deployed on the seabed. For the RSD method, for each pile a casing was oscillated into the seabed. Afterwards the rock socket was drilled to target depth and the casing retrieved after grouting. Then the pile was installed in the socket and the annulus between the pile and socket was grouted. For the DG method, first a pile was driven to the shallowest hard layer. Next a socket was drilled to target depth and the pile inserted. Afterwards, the inserted pile was grouted in the socket and in the driven pile. For the DDD method, first the pile was driven until initial refusal. Then a pilot hole was drilled and afterwards the pile was driven to target depth. In this paper, a more detailed description and challenges of these installation methods are discussed.

RÉSUMÉ: Suite à la demande mondiale d'énergie propre, le développement des parcs éoliens offshore (OWF) n'a cessé de croître et des sites de plus en plus difficiles sont envisagés pour la construction de ces OWF. Trois sous-stations offshore (OSS) pour trois parcs éoliens offshore différents situés au large des côtes nord et ouest de la France ont été installées sur des jackets à quatre pieds fondés sur des pieux. Pour chacun des OSS, la méthode d'installation des fondations sur pieux était différente en raison des conditions de sol rencontrées sur le site Forage de la roche (RSD), Forage et coulis (DG) et battage-forage-battage (DDD). Pour les trois méthodes OSS, un gabarit de préforage a été déployé sur le fond marin. Pour la méthode RSD, un tubage a été oscillé dans le fond marin pour chaque pieu. Ensuite, la cavité rocheuse a été forée jusqu'à la profondeur cible et le tubage a été récupéré après injection de coulis. Le pieu a ensuite été installé dans l'alvéole et l'espace annulaire entre le pieu et l'alvéole a été jointoyé. Pour la méthode DG, un pieu a d'abord été battu jusqu'à la couche dure la moins profonde. Ensuite, une alvéole a été forée jusqu'à la profondeur cible et un deuxième pieu a été inséré. Ensuite, le pieu inséré a été jointoyé dans l'alvéole et le pieu battu. Pour la méthode DDD, le pieu a d'abord été battu jusqu'au refus initial. Ensuite, un trou pilote a été foré et le pieu a été battu jusqu'à la profondeur cible. Dans cet article, une description plus détaillée et les défis de ces méthodes d'installation sont discutés.

Keywords: Pre-pilling; driving; drilling; grouting; offshore.

1 INTRODUCTION

Three Offshore Wind Farms (OWFs) located off the North and West coast of France were planned to be constructed and be commissioned by 2023. For each of these OWFs an offshore substation (OSS) needed to be installed. The OSSs are installed on a four-legged jacket with 26m x 26m footprint, which were founded on four piles. The piles were installed prior to the installation of the jacket (pre-piling) using a piling template deployed on the seabed. The installation method for the piles of each of the OSSs was different and the selection was based on the soil conditions found specifically at the OSS locations: Calcarenite overlying sand (Site 1), sand overlying chalk interbedded with flint layers (Site 2) and sand/clay overlying calcarenite and calcilutite (Site 3). The presence of rock at these sites presented a challenge for the pile installation as the standard/normal installation method (drive only) would not have been able to install the piles at these sites.

The piles were installed using the jack-up platform (JUP) "Sea Installer". A picture of the JUP, at Site 2, is shown in Figure 1.

Figure 1. Jack-up platform Sea Installer at Site 2.

2 SOIL CONDITIONS

Rock is present at the three sites. However, the characteristics and depth at which the rock occurs varies between them. The general soil conditions at each of the sites and soil profiles, up to the pile embedment depth, considered for installation assessment, are described below, and depicted in Table 1, 2 and 3.

At Site 1, rock (calcarenite) is found at seabed, with thicknesses around 19m. The rock presents Unconfined Compressive Strength (UCS) values ranging from 2MPa and 24MPa.

Table 1. Soil profile at Site 1.

Stratum Type	Top depth (mbsb*)	Bottom depth (mbsb*)	Range of UCS (MPa)
Calcarenite	0.0	18.8	2.2-24.0

Note: *mbsb – meters below seabed

At Site 2, a thin layer of sand overlies the rock. The rock consists of low to medium density chalk becoming high density with depth. Several flint layers/cobbles were detected within the chalk at different depths below seabed level, the first occurrence being at 13.9mbsb.

Table 2. Soil profile at Site 2.

Stratum Type	Top depth (mbsb*)	Bottom depth (mbsb*)	Range of UCS (MPa)
Sand	0.0	0.4	-
Chalk	0.4	28.5	1.0-4.0

At Site 3, the rock (limestone: calcarenite and calcilutite) is found at around 7mbsb depth overlain by a thin layer of sand and a thick layer of clay.

Table 3. Soil profile at Site 3.

Stratum Type	Top depth (mbsb*)	Bottom depth (mbsb*)	Range of UCS (MPa)
Sand	0.0	0.9	-
Clay	0.9	7.0	-
Calcarenite	7.0	18.8	2.2-24.0
Calcilutite	18.8	21.1	3.5-6.0
Clay	21.1	23.1	-
Calcilutite	23.1	28.9	6.0-9.0
Calcarenite	28.9	31.0	12.0-20.0

The layering considered for these soil profiles, is based on the boreholes performed at the centre of the jacket. The top level of the different stratum types was expected to show some variability between the borehole and the pile locations. Due to this variability, especially for the shallowest flint layer at Site 2 (where driving refusal was expected) and the calcarenite layer at 28.9m depth at Site 3 (where the piles needed to be founded to ensure the pile capacity), contingency measures had to be foreseen to ensure the integrity of the piles (safe driving) and that the piles would reach the necessary embedment depth to obtain the pile design capacity. These measures are explained in Chapters 4.2 and 4.3, respectively.

3 PILE DESIGN

The general pile dimensions for the three sites are given in Table 4, Table 5 and Table 6, respectively.

Table 4. General characteristics of the installed piles at Site 1.

Pile section	Pile length (m)	Pile embedment (mbsb)	Pile diameter (m)	Bottom WT* (mm)
1	9.5	4.5	2.3	80
2	9.5	9.0	2.3	60

*WT – Wall Thickness

Table 5. General characteristics of the installed piles at Site 2.

Pile section	Pile length (m)	Pile embedment (mbsb)	Pile diameter (m)	Bottom WT* (mm)
Driven	16.5	13.5	3.0	75.0
Insert	28.5	28.5	2.4	50.0

Table 6. General characteristics of the installed piles at Site 3.

Pile length (m)	Pile embedment (mbsb)	Pile diameter (m)	Bottom WT* (mm)
35.0	31.0^{+}	3.0	100

Note: $^{+}$ Including 2m contingency length due to variability of the top level of the calcarenite found at 28.9mbsb

4 INSTALLATION METHODS

Based on the soil conditions described in Chapter 2, for the three sites, three pile installation methods were used:

- Site 1 Rock socket drilling (RSD)
- Site 2 Drill and grouted (DG)
- Site 3 Drive-drill-drive (DDD)

Although the installation method was different, all methods used a piling template as a piling guide for placing the jacket piles within tolerances into the ground. One single piling template was custom-made for the projects as the jacket footprints are identical. A picture of the template while being tested is shown in Figure 2.

Figure 2. View of the template used.

The drilling equipment consisted of a Wirth PB 928 for site 1 and LD2500 for sites 2 and 3.

For Sites 2 and 3, adding to the drilling operations, driving operations were necessary as part of the installation method. For that purpose, IQIP impact hammers S-800 and S-2000, for site 2 and 3 respectively, and a follower, were used. A picture of the impact hammer and follower is shown in Figure 3.

4.1 Rock socket drilling – Site 1

Due to the presence of rock at seabed and up to 19mbsb, the installation method chosen for Site 1 was rock socket drilling. This method consisted of deploying the piling template and stabbing a casing in the template sleeve. The casing was then oscillated into the seabed. Afterwards, the drill rig was mounted directly on the top of the casing and the BHA was lowered inside the casing, enabling the rock socket to be drilled to target depth. The drilling methodology is based on the reverse circulation drilling (RCD) process. After drilling operations were completed, the BHA and drill rig were recovered and put back on deck and the casing was cut just above the seabed, leaving the casing shoe (sacrificial) to stabilize the top rock layer. Finally, the pile was lowered into the drilled socket and the annulus between the socket and the pile was grouted. Ultimately, the casing was removed and the template recovered. A view of the drilling set-up (BHA and drill rig) and the oscillator is shown in Figure 4.

Figure 3. Impact hammer and follower.

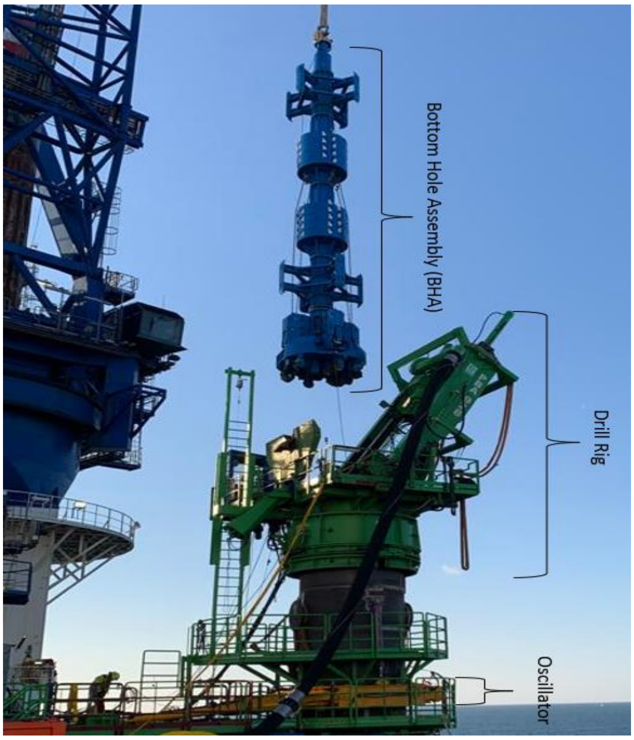

Figure 4. Bottom hole assembly, drill rig and oscillator.

4.2 Drill and grouted – Site 2

Due to the presence of high-density chalk, it was estimated that the pile could not be driven up to target depth. It was also considered that the presence of the flint layers would pose a risk with regards to pile tip damage. Hence, the drill and grouted installation method was chosen.

The drill and grouted method consisted of driving a 3m diameter pile up to the top of the shallowest flint layer (13.9mbsb) with an 800kJ impact hammer. In the case the shallowest flint layer was encountered at depths shallower than the expected 13.9mbsb, and to ensure that the driven pile would have sufficient embedment depth for loads to be transferred from the driven to drilled and grouted casings, a drilling spread was mobilized for a drive-drill-drive contingency. After driving the 3m diameter pile, a casing was stabbed and supported on the template. Then the drill rig was mounted directly on top of the casing and the BHA was lowered inside the casing and a socket was drilled to target depth (the drilling method was the same as for Site 1). Afterwards the BHA and the drill rig were recovered on deck. Finally, the pile was lowered through the driven pile into the drilled socket and the annulus between the socket and the pile and between the insert and driven pile were grouted. At the end, the casing and the piling template were recovered.

4.3 Drive-Drill-Drive – Site 3

At Site 3, due to the presence of rock with UCS values up to 24MPa below 7mbsb depth, it was estimated that the pile could not be driven to target depth with an impact hammer, unless a pilot hole was drilled to reduce the shaft friction and end bearing. Hence the DDD method was considered for this site. The method consisted of driving the pile with a 2000kJ impact hammer through the template sleeve, until refusal (top of calcarenite) occurred. Afterwards a casing was installed, and the drill rig was mounted directly on top of the casing. The BHA was lowered inside the pile and a pilot hole with 80% of the outside diameter of the pile was drilled up to 29mbsb (the drilling method was the same as the one mentioned for Site 1 and Site 2). Then the drill rig was recovered and put back on deck. Afterwards, the pile was driven to target depth with the 2000kJ impact hammer. At the end, the piling template was recovered.

In the case that the stratum required to ensure pile capacity, expected at 29mbsb depth, would be at deeper depths, pile length was increased and a pile cutting spread was mobilized on board. At the end three out of the four piles were cut.

5 PILE DRIVING MONITORING

Hard driving conditions were expected at Sites 2 and 3. The axial stresses on the pile, and particularly at the pile tip, were to be limited to prevent the risk of pile tip damage by means of pile driving monitoring. The instrumentation consisted of two deep-sea underwater accelerometers and four deep-sea underwater strain transducers per pile. Sensors were bolted on the pile external shaft at 5m from the top. All jacket piles on both sites were instrumented.

Monitoring measures the compressive stresses at sensor level. Based on a Safe Tip analysis done prior to installation (defining a safe driving criterion), the stresses at pile tip were estimated. The driving criterion consisted of intervals alert function of a compressive stress limit, taken 80% of the steel yield stress: pre-alert limits (80% of stress limit), alert limits (90% of stress limit) maximum limits (equal to stress limit).

At the sites, the stresses remained below the alert limits which allowed for safe driving operations to take place and mitigate the risk of pile damage.

6 CONCLUSIONS

Soil conditions offshore are becoming more challenging, preventing the use of the "standard" drive only installation method to be used. Also, the fact that there is rock on site does not mean that one method should fit all rock sites. The type of rock, and more particularly the strength and layering encountered at the sites, have a major impact on the method chosen to install the piles.

For the three sites here presented, where rock occurs within the embedment depth of the piles, an active cooperation between designer and installation contractor led to the selection of the optimal design and installation method, that allowed for a safe and economical installation of the piles.

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