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NEW BAUER FLYDRILL SYSTEM
DRILLING MONOPILES AT BARROW OFFSHORE WIND FARM, UK

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ABSTRACT

With an output capacity of 90 MW of renewable electricity, Barrow OSWF is an offshore wind farm constructed in UK coastal waters. The site is located approximately 7 km south of Walney Island near Barrow-in-Furness, Cumbria, in the East Irish Sea. Steel monopiles with an outer diameter of 4750 mm and a wall thickness of between 45 mm and 80 mm provide the wind turbines foundations and vary in length between 49.5 m and 61.2 m weighing up to 452 tonnes. Installation of the monopile foundations with a penetration into the seabed of between 30.2 m and 40.7 m was carried out by a process of driving and drilling. The geology of the area beneath the wind farm site comprises sequences of medium dense to very dense sands, firm to stiff and very stiff to hard clays and weathered mudstone/siltstones. Specialist pile driving company IHC Hydrohammer BV of Holland used its 1200 tonnes hydrohammer to drive the monopiles into the subsea soil formations, whilst specialty foundation equipment manufacturer Bauer Maschinen GmbH of Germany, employed its Flydrill BFD 5500 for drilling out the core inside the monopiles to reduce frictional resistance. Main contractor for the project was Marine Projects International Ltd of Middlesbrough, UK. All construction operations were carried out from MPI's jack-up vessel MV Resolution.

INTRODUCTION

Construction of Barrow Offshore Wind (BOW) Farm site in the East Irish Sea approximately 7 km southwest of Walney Island, near Barrow-in-Furness, UK was completed in March 2006. BOWind Farm with its 30 Vestas V90-3.0 MW wind turbines now feeds clean, renewable energy into the National Grid at Heysham at an anticipated annual rate of production of 305 GWh, providing green electricity to around 65,000 homes, and forms an important building block in the Government’s plan to increase the share of the UK’s electricity generation from renewable sources to 10% by 2010 in an effort to combat the effects of global warming. With the installation of up to 61 m long 4.75 m diameter tubular steel monopile foundations weighing up to 450 tonnes in water depths ranging between 21 and 23 m, the BOWind Farm project is clearly at the cutting edge of offshore wind developments.

THE DEVELOPERS

The Barrow Offshore Wind Farm project was initially developed by Warwick Energy through their wholly owned subsidiary Warwick Offshore Wind Limited who were also granted the license for the development of the wind farm, before its development company, Barrow Offshore Wind Limited (BOW) was acquired by a consortium of European energy companies in September 2003. The new owners comprised the Danish energy group Danish Oil and Natural Gas, DONG A/S, the UK-based energy group Centrica Energy and the Norwegian electricity producer Statkraft A/S. Since the sale of Statkraft’s shares in the development company in 2004 to DONG and Centrica, Barrow Offshore Wind (BOW) is a 50/50 joint venture company between Centrica and DONG.

THE CONTRACTORS

In July 2004, Barrow Offshore Wind Limited (BOW) awarded the turnkey contract for construction of the wind farm including engineering design, procurement, fabrication, installation, and commissioning to a consortium comprising Kellogg Brown & Root Limited (KBR), the global engineering, construction and services subsidiary of Halliburton and Vestas-Celtic Wind Technology Ltd, a wholly owned subsidiary of Vestas Wind Systems A/S.
On completion, Vestas-KBR are also contracted to operate and maintain the wind farm for an initial five-year period.
The contract for the offshore construction work including installation of the monopile foundations, turbine towers, nacelles and blades, and all subsea cable laying within the wind farm as well as laying the subsea export cable to the mainland was won by Marine Projects International Ltd.

(MPI) based in Middlesbrough, Cleveland. All construction work was carried out from MPI's turbine installation vessel TIV Resolution. As the world's first purpose-built jack-up vessel, TIV Resolution provides a single-vessel solution for offshore wind turbine installation.

PROJECT DETAILS

BOWind Farm is the third large-scale offshore wind farm project constructed in UK coastal waters out of the 18 proposed under the Crown Estate's Round 1 licensing programme. It is located in the East Irish Sea approximately 7 km south west offshore of Walney Island, near Barrow-in-Furness, Cumbria.

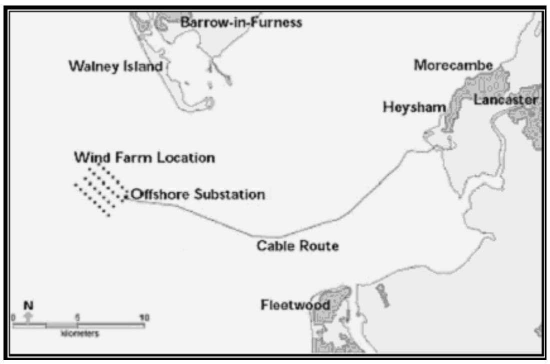

Fig. 1. General site location plan

The BOWind Farm which comprises 30 Vestas V90-3.0 MW wind turbines and one offshore sub-station is arranged in a rectangular grid of four rows of seven or eight turbines, with the longest side facing into the prevailing south westerly winds. The rows are staggered and spaced about 750 m apart. Within the rows, the turbines are spaced approximately 500 m apart. The wind farm site measuring 2.5 x 4.2 km covers an overall area of around 10 square kilometers.
The wind turbines in each row are linked by 33 kV array cables and connected to the sub-station, which is located within the south eastern corner of the wind farm area, where the electricity generated by the wind turbines is transformed up to 132 kV. A 27.5 km long single 132 kV subsea transmission cable then feeds the generated electricity into the UK grid at Heysham. According to manufacturer Nexans, the 27.5 km transmission cable, weighing around 1,600 tonnes, set a new world record as the longest 132 kV three-core cable.
Each wind turbine consists of a tapered tubular steel tower flange-bolted to a cylindrical transition piece, which is placed over the top of the monopile foundation and, after adjustment, grouted into position.
At a hub height of 75 m above mean sea level a 3-bladed rotor of 100 m diameter is mounted on each tower resulting in a total height to the vertical blade tip of 125 m above mean sea level. Tubular steel monopiles of 4.75 m diameter and varying wall thickness ranging from 45 mm to 80 mm provide the wind turbine foundations. The monopiles vary in length between 49.5m and 61.2 m, weigh up to 452 tonnes and penetrate up to 40.7 m into the seabed.

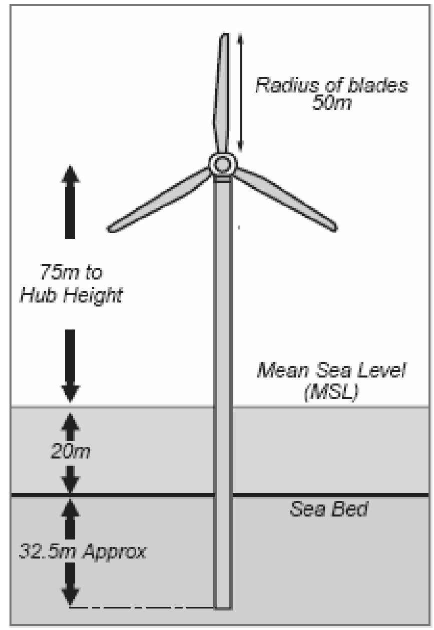

Fig. 2. Typical wind turbine

OFFSHORE CONSTRUCTION

Offshore construction of the wind farm in water depths of up to 23 m commenced at the beginning of June 2005 from MPI's purpose-built jack-up turbine installation vessel TIV Resolution and was completed at the beginning of May 2006.

Fig. 3. TIV Resolution at BOWind Farm

The wind turbines were constructed in three main construction stages:

(i) Installation of monopile foundations, followed by installation of J-tube and anode ring assembly on a submerged section of monopile, installation of cylindrical transition piece complete with integrated boatlanding accessories, ladders and access platform on top of monopile and grout connection between transition piece and monopile with ultra high performance grout.

(ii) Construction of 75 m tall turbine towers comprising lower, middle and upper sections by flange-bolting to top of the transition pieces.

(iii) Installation of pre-assembled turbine assemblies comprising nacelle, hub and two blades on top of towers, followed by installation of third blade on hub.
The subsea array cables within the wind farm area were laid between turbine construction stages (ii) and (iii) and followed by all necessary termination works. Laying of the 27.5 km long subsea export cable commenced from shore and links up with the sub-station at the south eastern corner of the field.

Fig. 4. J-tube and anode ring

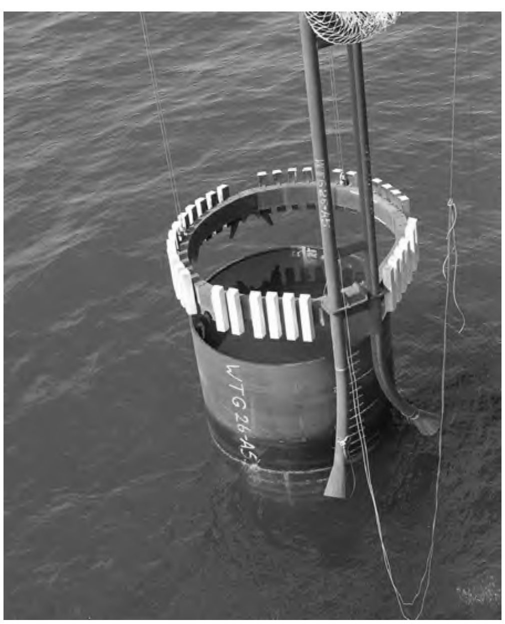

Fig. 5. J-tube and anode ring being placed over monopole

Fig. 6. Transition piece

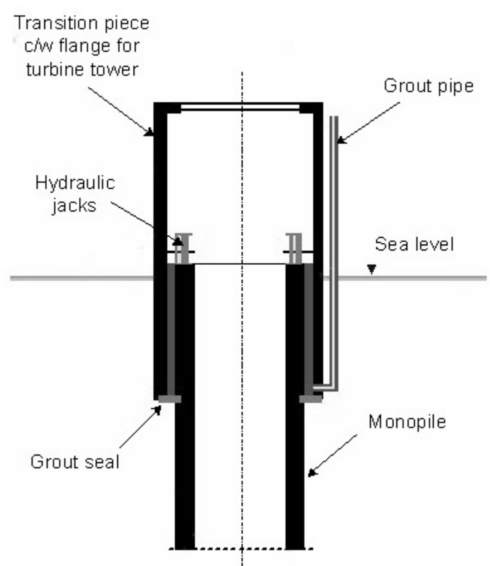

Fig. 7. Grouted connection between monopile and transition piece

GEOLOGICAL CONDITIONS

The geology of the area beneath the BOWind Farm site comprises variable sequences of superficial sediments and till or boulder clays of the last glaciation, the Devensian period, as well as proglacial clays.
In the northern half of the site these comprise predominantly medium dense to dense to very dense gravelly sands inter-bedded with silts and firm to very stiff to hard clays. The southern half of the site is characterized by firm to hard clays interbedded with layers of very dense sands, underlain by very

stiff to hard formations of completely weathered mudstone/siltstone and weak to moderately weak siltstone/sandstone.

Whilst these conditions are generally suitable for pile driving, formations such as completely weathered mudstone/siltstone and weak to moderately weak siltstone/sandstone at elevations well above the toe levels of the monopiles particularly in the southwestern sector of the site, have the potential to result in refusal of monopiles during driving.

INSTALLATION OF MONOPILES

Up to four monopiles were loaded onto TIV Resolution at MPI's operational supply base at Harland and Wolff Shipyard in Belfast, together with four transition pieces and associated equipment and taken to site for installation.

After the vessel has been manoeuvred into position by its high-powered dynamic positioning system, the monopiles were first raised into the vertical position or 'upended' with the help of a purpose-built upending and guidance system located at the stern of the vessel. The system was designed and fabricated by Gusto B.V. of Holland.

Fig. 8. Monopile being lifted into position

Fig. 9. Monopiles on deck TIV Resolution

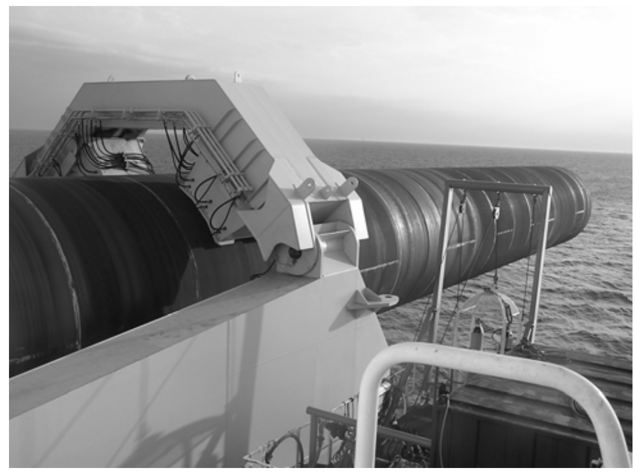

Fig. 10. 'Upending' the monopole

After upending the pile the vessel jacked-down at low tide and placed the monopile on the seabed.

When released from the hydraulic grips of the upending frame, the pile penetrated the upper soft marine deposits to a depth of 3 to 4 m under its own weight of up to 452 tonnes. During this process the monopile was guided by another purpose-built pile guide cantilevering out from the stern of the vessel

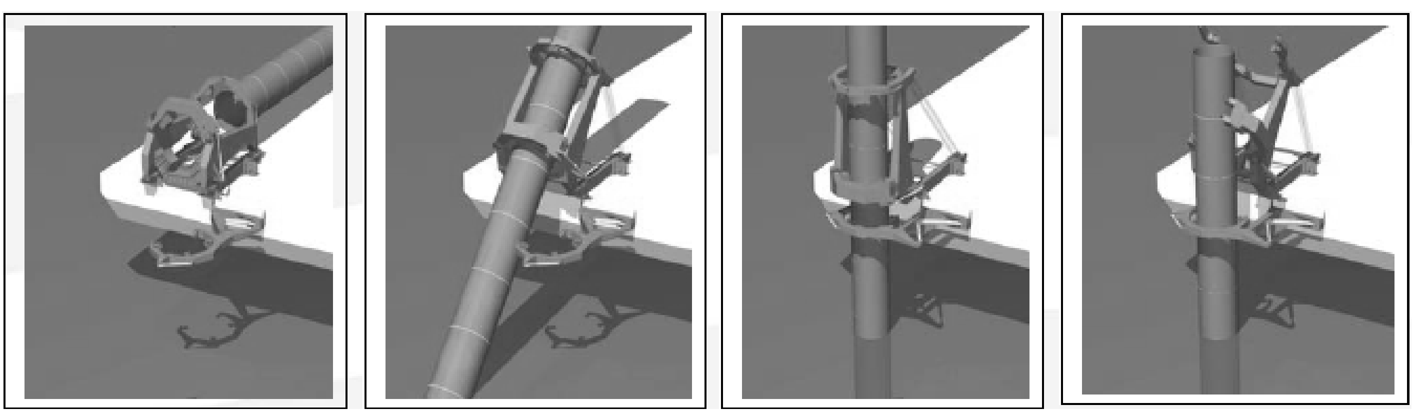

Fig. 11. Monopile Upending and Guide System (Reproduced by kind permission of Gusto B.V. Holland)

Fig. 12. Upended' monopile (Reproduced by kind permission of Gusto B.V. Holland)

PILE DRIVING PROCESS

As the ground conditions across the wind farm site described above are generally suitable for pile driving, the monopiles were driven to their pre-designed terminal penetration with the use of an S-1200 Hydrohammer supplied by pile driving specialist IHC Hydrohammer BV of Holland.

The hydraulically operated IHC S-1200 Hydrohammer with a combined weight of 286 tonnes houses a solid one-piece steel ram weighing 60 tonnes and is capable of producing a maximum net energy of 1200 kNm per blow at a maximum blow rate of 24 blows per minute. A pressurized gas buffer above the main piston gives the ram an acceleration of up to 2 g during its downward movement, which reduces the actual stroke required and thus increases the blow rate of the hammer. A bell-shaped pile sleeve incorporating the solid steel anvil, anvil housing, anvil ring and pile guide or skirt with a total weight of 135 tonnes is flange-bolted to the base of the lower housing of the cylindrical Hydrohammer and acts as piling guide for the Hydrohammer. The Hydrohammer is suspended from the main 300-tonne crane on board TIV Resolution and placed over the top of the pile, overlapping the head of the pile by a length of about 3 m.

During pile driving essential parameters were recorded, such as penetration generally in 250 mm intervals, number of blows per 250 mm penetration, total number of blows over time, energy per blow and total energy used.

The majority of monopiles have been driven to their terminal penetration without difficulty by the IHC S-1200 Hydrohammer. Only nine refused further driving and thus required drilling to facilitate full penetration by subsequent driving.

Fig. 13. IHC S-1200 Hydrohammer

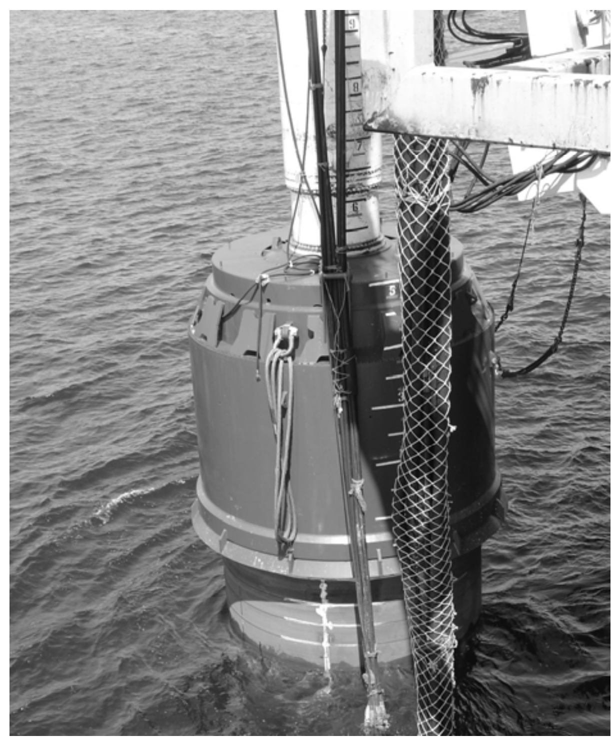

Fig. 14. IHC S-1200 Hydrohammer driving a monopile

DRILLING PROCESS

Drilling was required every time a monopile reached refusal or required unacceptable levels of energy to achieve further penetration. The geological conditions which necessitate drilling, as described above, are particularly prevalent in the southwestern corner of the BOWind Farm site, where the highly to completely weathered siltstone/mudstone formations and the underlying moderately weak to weak siltstone/sandstone formations occur at their highest elevations and had to be penetrated by up to 12 m. In this area the final toe elevations of some of the monopiles extend to a maximum depth of -56.2 m CD.

The aim of drilling out the core from inside monopiles that refused above their final elevations is to reduce both frictional and end resistance. By drilling the soil material out from inside the tubular steel pile, the skin friction acting on the internal surface of the monopile is eliminated over the drilled out length. Although this will reduce the total combined frictional resistance, it is unlikely to reduce the pile's driving resistance sufficiently to achieve terminal penetration by subsequent pile driving, if the pile has refused in the weathered siltstone/mudstone or weak mudstone /sandstone formations. The standard criteria for measuring refusal is a blow count of 150 blows per 250 mm penetration, although this figure may be increased depending on driving conditions. It is also important to recognise that it may be necessary to temporarily exceed the specified number of blows to overcome any pile setup when trying to restart pile driving after drilling.

If refusal has occurred, the pile bore must be advanced a sufficient distance ahead of the pile toe to enable stress release to occur enabling the annulus underneath the base of the pile to be displaced during subsequent pile driving.

DRILLING WITH THE NEW BAUER FLYDRILL BFD 5500

Specialist foundation equipment manufacturer Bauer Maschinen GmbH, a member of the Bauer Group of Germany, was awarded the contract for supplying its Flydrill System BFD 5500 to MPI, together with full technical supervision and operational support.

In contrast to fixed pile-top drilling systems, such as the top drill RC (Reverse Circulation or air-lift) system, the Flydrill System BFD 5500 is a highly versatile 'mobile' pile-top drilling system for applications in kelly mode in all types of soil and weak rock as well as in RC mode for drilling rock sockets in hard rock.

The Flydrill System BFD 5500 in its current form is a completely new concept for drilling large diameter holes for a wide range of applications both on land and offshore, although its particular field of operation must clearly be seen in the offshore environment. Integrating the power packs fully into the setup by mounting them on a platform immediately adjacent to the rotary drive of the Flydrill without the need for an 'umbilical cord' was an essential part of the design concept which aimed at a truly 'mobile' top drill capable of being suspended from a crane, placed on top of an isolated monopile in the sea and operating fully independently from any other power source on deck of the support vessel. This concept and the absence of an umbilical cord also requires a fully integrated remotely controlled operating system which enables the Flydrill to be operated via a radio-controlled link by way of a control panel with joystick controls. The operation is supported by Bauer's sophisticated B-Tronic® electronic monitoring, control and recording system, which has been specially adapted for offshore drilling and comprises an onboard industrial micro-computer c/w touch-sensitive screen for visualisation of all essential operating functions, a radio transmitter and receiver for transmission of all operating signals for immediate processing and storage on a RAM card for subsequent evaluation and documentation.

Fig. 15. Flydrill BFD 5500 with KB 4400 reaming bucket

The unit uses Bauer's specially extended ProDat® software program for enhanced processing, evaluation and documentation of all relevant machine operating and process related data in the form of a continuous monopile installation record with detailed diagrammatic illustrations. This record also serves as Quality Assurance and Control document.

The Flydrill BFD 5500 comprises Bauer's most powerful rotary drive KDK 480 which produces a torque of 462 kNm at 320 bar; two hydraulic crowd cylinders each producing a crowd pressure of 40 tonnes; two heavy-duty hydraulic power packs HD 460 each with an installed power of 260 kW and an hydraulic output of 450 l/min at 320 bar; a clamping device

Fig. 16. B-Tronic monitoring, control and recording system inside crane dab

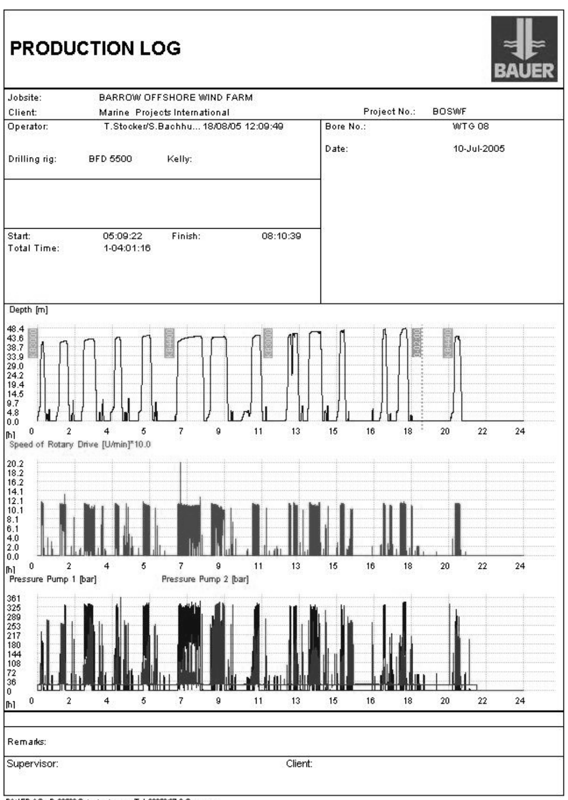

Fig. 17. ProDat® monopile report

consisting of three hydraulically operated heavy-duty clamping units delivering a clamping force of 32 tonnes each; a specially designed triple telescopic kelly bar KB/BFD480/3/65 with an overall extended length of 63.9 m, a nominal drilling depth of 65 m and an outer diameter of 559 mm; a 3.0 m diameter pre-drilling bucket KB 3000 c/w centraliser; and a 4.4 m diameter reaming bucket for reaming the pre-drilled 3.0 m pre-bore to the required full internal diameter of the monopile.

The three main components of the Flydrill system are stored on the main deck in specially designed tool stands, which also provide the necessary sea fastenings. In preparation for drilling, the kelly bar is inserted into the rotary drive of the Flydrill and secured by a heavy-duty spherical support bracket which carries the Flydrill platform c/w rotary drive, power packs and clamping device. The unit is then suspended from the main hoist of the 300-tonne crane, lifted over the pre-drilling bucket and connected by inserting the kelly stump into the mating kelly box at the top of the bucket and locked by a specially designed heavy-duty lock ring.

After lifting the entire unit off the tool stand, the Flydrill is mounted on top of the tubular monopile and clamped to the top of the tubular steel pile with the help of three hydraulic clamps which transfer not only the torque produced by the rotary drive into the monopile, but also the crowd force generated by the crowd cylinders. Finally, the drill string is lowered onto the seabed and drilling begins.

Fig. 18. Flydrill BFD 5500 drilling on top of a monpile

The drill spoil is collected inside the heavy-duty drilling bucket, carried to the surface as the drill string is withdrawn and de-clamped from the top of the pile, and then dumped directly into the sea. To avoid obstructing subsequent cable laying operations, a dumping area is designated for each monopile location.

In contrast to the RC air-lift drilling system which uses water as its medium for bringing spoil to the surface and dumping it in a generally uncontrolled manner into the sea with the potential of widespread pollution, the deployment of the Bauer Flydrill System BFD 5500 in FD kelly mode with drilling buckets offers an environmentally friendly method of spoil disposal. As excavated drill spoil is brought to the surface inside a bucket, water is allowed to drain freely as soon as it is raised above the water level inside the monopile.

Fig. 19. Flydrill BFD 5500 with KB3000 just before exiting pile

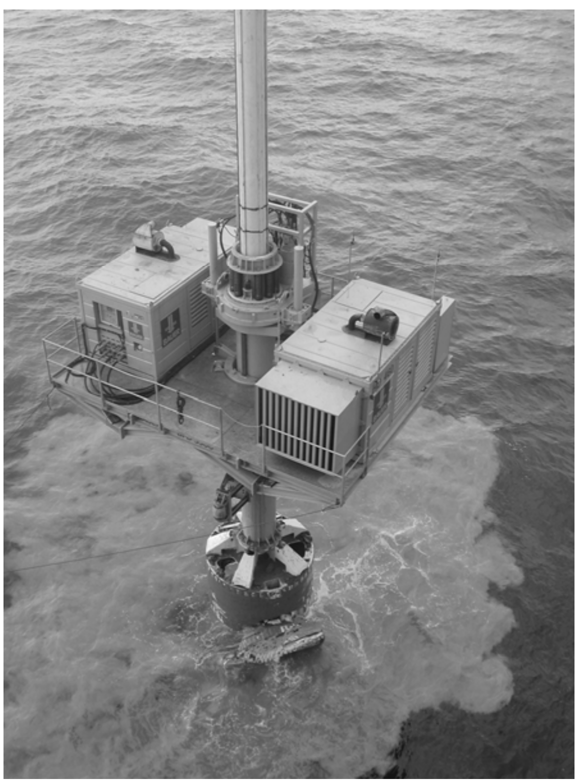

Fig. 20. Flydrill BFD 5500 with KB 3000 dumping drill spoil

To enable the maximum of free water to escape, the bucket is left suspended inside the pile for a short period of time before it is lifted clear of the pile and the spoil dumped in the designated area.

The twin trip mechanism for opening the hinged bottom gate of the bucket is activated by an actuator ring underneath the rotary drive using the crowd cylinders. Prior to dumping, the Flydrill is lowered just above sea level for controlled dumping of the drill spoil and to dampen the movement of the bottom gate after its release.

Drilling with the Flydrill System in kelly mode also enables bulk sampling and visual inspection of drill spoil brought to the surface inside the drilling bucket to be carried out for the purpose of comparative soil classification and strata verification.

Fig. 21. KB 3000 Pre-bore bucket just above sea level

Fig. 22.Flydrill BFD 5500 with KB 3000

Fig. 23. Flydrill BFD 5500 returning on deck for soil sampling

On completion of the pilot bore to a depth of about 5 m, the 3.0 m pre-bore bucket is returned to its tool stand and the 4.4 m reaming bucket picked up by the Flydrill for reaming out the 3.0 m diameter pre-bore to the full internal diameter of the monopile. This cycle of drilling in alternating sequence continues until the bore has been advanced to its specified elevation. Progress rates of up to 1.0 m/hour were achieved in the stiff to very stiff to hard clays and silts and dense sands and 0.35 to 0.65 m/hour in the underlying completely weathered mudstone /siltstone and moderately weak to weak siltstone/sandstone formations.

CONCLUSION

This paper describes a new drilling system for the installation of large monopile foundations for offshore wind turbines in difficult soil conditions in which a combined pile driving and drilling operation is required to achieve final target penetration. In contrast to fixed pile-top drilling systems using the reverse circulation or air-lift drilling technique, the new Flydrill offers a highly versatile ‘mobile’ pile-top drilling system for application in kelly mode. Integrating the power packs fully into the setup without the need for an umbilical cord has enabled the Flydrill to be suspended from a crane, placed on top of an isolated monopile in the sea and operated fully independently from any other power source on board the support vessel. All operations are carried out by a fully integrated remotely controlled operating system via radio-controlled link. Deployment of the Flydrill in kelly mode with large-diameter drilling buckets offers an environmentally friendly method of spoil disposal.