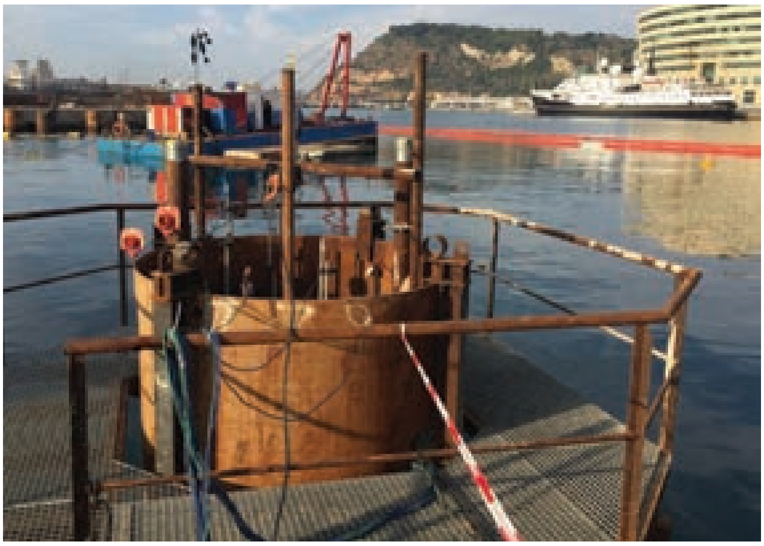
Offshore pile foundations of today

As the possibilities and uses of piled offshore foundations increase, so do the environmental, financial and technological challenges and demands. Leading providers of offshore geo-intelligence, foundation design and installation give us their take on the most cost- and time-efficient methods to overcome challenges



Bi-directional static-load test, using Fugro's Osterberg Cell (O-cell) technology at the port of Barcelona in Spain

Photo: Fugro

Ever since the first submerged pile foundation was constructed in a lake in Ohio, US, in 1891, know-how, technology and materials have been continuously developed and refined.

Previously predominantly required for the oil-and-gas industry, the need for offshore foundations has seen a significant increase with the growth of the offshore wind industry.

For the last four years, in Europe alone, an average of approximately 400 new offshore wind turbines has been erected yearly. This has created a growing pool of tools, techniques, guidelines and knowhow between the industry's leading service providers.

Cathie Associates, an offshore geoscience and geotechnical engineering consultancy, has developed a range of in-house engineering tools to understand the ground conditions and to assess pile capacity and installation design. However, it is the combination of new tools with knowledge of the traditional design practices and engineering first principles that is key to a project's success, stresses Jamie Irvine, senior project engineer at Cathie Associates.

"The key to reducing cost and risk is a good understanding of the geological conditions, combined with a good understanding of the design methodologies and engineering first principles," he says.

"It is vital to use this knowledge and to work closely with the project developer, structural designers and certification body to optimise the pile design while retaining appropriate conservatism."

When it comes to optimising offshore pile foundations, the application and combination of new techniques and design experience go hand in hand with in-depth site investigations, accurate ground models, cost-efficient installation vessels and alternative design solutions.

INAPPROPRIATE CONSERVATISM

There are several well-established design guidelines and recommended practices for offshore pile foundations.

Recently, the industry has moved towards more accurate design methods such as ICP (Imperial College pile) for axial pile design and PISA (Pile Soil Analysis) for lateral pile design.

Well-documented and implemented in commercially available software, these methods have had a significant influence on reducing the cost of offshore developments and providing a better understanding of risk.

However, the geotechnical parameters used for an input are often overly conservative, and the design procedures may not be appropriate for the anticipated soil conditions and/or construction and commissioning programme.

Key expert advice:

- Combine new technology and methods with traditional design practices and engineering first principles to avoid unnecessary conservatism and extra cost and time in the design and installation process.
- Invest in proper site investigation services, including initial desk study and scoping advice, permitting consultation, hydrodynamic oceanography, metocean measurements, geophysical and geotechnical studies, geotechnical/environmental laboratory services, and factual or interpretive reporting, to avoid cost overrun, delay, and potential failure to satisfy quality and operational needs.
- Consider alternative methods of testing pile capacity such as bi-directional testing to ensure the lowest possible costs in testing, most reliable results and avoid having to rely on unnecessarily conservative foundation designs.
- When designing foundations for larger depths, make sure everyone in the production chain has knowledge of offshore operations and look first and foremost at installation cost and challenges when choosing foundation type.

Consequently, there is still scope to further optimise the design in terms of selection of soil parameters and modification of the methods to allow for any potential advantages in the construction methods and/or timescales.

Fortunately, the industry and computing techniques are constantly evolving, and with tools such as OPILE, a programme designed by Cathie Associates, engineers can use the latest available techniques to avoid inappropriate conservatism, notes Irvine.

"Our engineers ensure that our tools, such as OPILE, use the latest available techniques and knowledge, whether this is incorporating the latest large-diameter lateral response behaviour into OPILE, using machine learning to optimise pile driving predictions or cloud-based solutions."

While the existing design methods provide a reasonable understanding of the capacity and installation of driven piles in conventional soils, they do not cover special soils such as carbonate sands, mica sands, weak rock or silts. Also the capacity of piles for more novel installation techniques such as drive-drill-drive and vibration is not well documented.

Thus, stresses Irvine, though automation and guidelines have allowed for significant improvements, it is the detailed understanding of the design methodology and the construction procedure that allows engineers to develop new foundation design methods for challenging soils, modify existing methods to allow for cyclic loading and to significantly reduce project costs.

He gives an example from his company's project portfolio: "In one offshore wind-farm project, a good understanding of the geotechnical parameters, design methodology and the construction programme allowed for a significant reduction in the required pile length (over 1,700m), resulting in a substantial reduction in steel weight (~3,400t), easier offshore lifting operations, reduced pile installation timescales and reduced installation risk."

ASSESS GROUND RISK

While the increase in demand has meant an increase in knowledge and technology, new projects also continue to push limits to move constructions into new waters, challenging environments and soils.

While this happens, attention to one of the most important factors in offshore foundations, ground risk, is often neglected, says Mark Richardson from Fugro, a global provider of geotechnical and survey services with many years' experience of supporting the offshore foundations sector.

Richardson has worked in marine site investigation for more than 15 years and believes the impact of an inadequate understanding of ground conditions is only just being realised.

"All too often developers and financiers focus on currency, cash flow and capital risk; on political and market factors; and on safety and environmental risks without giving adequate attention to ground risk," he points out. "With the cost of ground investigation seldom exceeding one per cent of outturn cost, the implications of problems such as cost overrun, delay, and potential failure to satisfy quality and operational needs can exceed the site investigation cost by orders of magnitude. In today's tight market conditions few developers can afford such unplanned and undesirable challenges."

Based on this fact, Fugro has recently formed a dedicated Coastal Infrastructure team to help clients manage risk by providing data acquisition, analytics and advice focused on the challenging land/water interface.

To achieve this, the team provides a range of integrated services, including initial desk study and scoping advice, permitting consultation, hydrodynamic oceanography, metocean measurements, geophysical and geotechnical studies, geotechnical/environmental laboratory services and factual or interpretive reporting.

Richardson is convinced of the benefits: "Only when these work ►

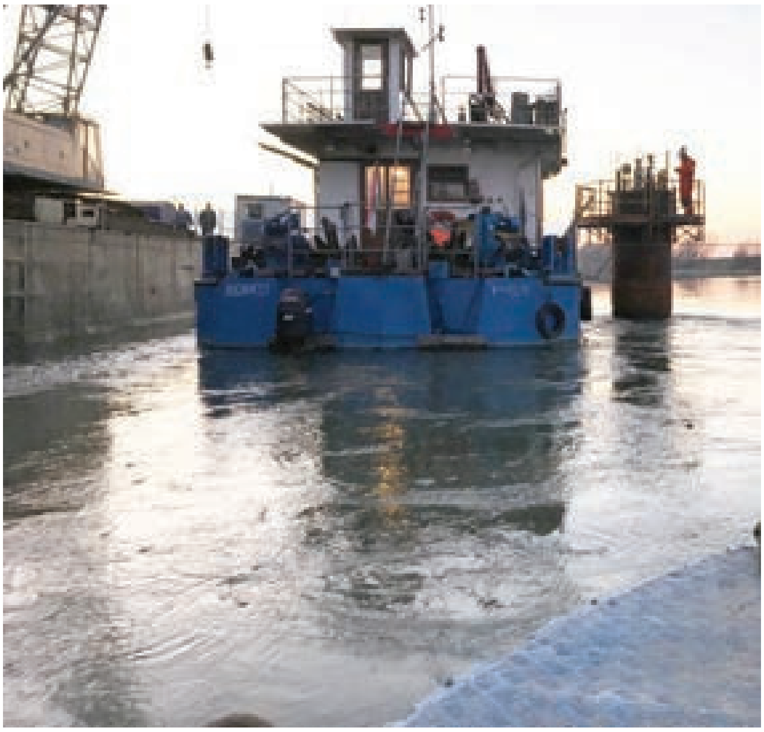


Photo: Fugro

Setting up of O-cell pile test in the Danube, where bi-directional testing was used to test pile loads in excess of 17MN phases are truly integrated via a collaborative approach, can ground risk be understood and the challenges to budget and programme properly managed."

One implication of uncertainty due to lacking site-specific geotechnical information and inadequate ground models is over-design. This can, for example, result in foundations that are engineered to perform far beyond their actual loading requirements, and which cost more, use more natural resources and take longer to build.

OPTIMISING PILE TESTING

The problem of over-design is not just avoided by creating a better ground model and combining experience and new technology to modify or create design methods, but also by implementing an effective pile-testing programme. Paul Cheesman, an expert on foundation testing at Fugro is an advocate of bi-directional testing.

Though the most common methodology for pile testing has, for decades, been top-down static load testing, this traditional approach presents many challenges in the marine environment and the outcomes can be disappointing, explains Cheesman. Having used numerous different methods to test a wide range of structures at sites around the world, he believes bi-directional testing can pay dividends for many projects requiring deep foundations.

"Applying the load at the pile head requires anchor piles and beams that are both expensive and difficult to construct. As a consequence, top-down testing is often restricted to smaller scale 'model' piles or is completely overlooked in favour of a more conservative design," says Cheesman. "In contrast, a bi-directional static load test, using Fugro's Osterberg Cell (O-cell) technology, eliminates the need for additional reaction systems and brings a number of other crucial advantages."

The bi-directional test works by using a hydraulically driven, calibrated, sacrificial jacking device installed within the pile shaft, to test one portion of the foundation element against the other. In effect, two static load tests are performed simultaneously, working in two directions: upwards, against skin friction, and downwards, against skin friction and end-bearing.

By conducting tests on full-size production piles rather than smaller test piles, the risk of scaling errors can be totally eliminated. Furthermore, ground conditions, not the test method, determine the magnitude of load that may be applied, and, unlike conventional top-down testing, the pile concrete or steel does not have to be brought to the test level. Instead it can be left at the top of design cut-off level, which may be below mud-line level.

Many such bi-directional tests have been carried out for major bridge construction projects, port jetties and offshore wind farms around the world. A recent example was the testing programme undertaken by Fugro for a new bridge across the Danube in Komárom, Hungary. This required static load testing of the piles, with the specific constraint that they could not extend above riverbed level.

Two preliminary test piles were required to determine the pile movements under loading. Traditional methods were ruled out on the grounds of practicality and cost.

"The O-cell method proved to be the perfect solution, and the piles were successfully installed and tested to loads in excess of 17MN allowing the designers to optimise their design," says Cheesman.

Suspection pile being installed from an anchor handling vessel. With floating foundations emerging as a cost-efficient solution at large depths, solution alternatives like driven and suction-installed piles are being considered

Photo: InterMoor

DEEP-WATER FOUNDATIONS

Cost is by far the biggest challenge when it comes to deep-water pile foundations. This is mainly due to the expenses involved in installing the piles, which by far exceed the cost of the piles themselves. As a global provider of design, fabrication and installation of subsea foundations, InterMoor has successfully worked towards reducing costs in the installation phase.

Tom Bauer, general manager, foundations, explains: "The cost to install is mostly for the construction vessel(s). A big part of InterMoor's success has come from finding innovative ways to do more with smaller, less expensive vessels. Sometimes, this means developing our own tools. It is amazing how something as simple as clever placement of lift points can make a big difference in what a certain construction vessel can do and how fast it can be done safely."

However, the cost of deep-water installation needs to be a consideration all the way through the production chain, stresses Bauer.

"This means everyone must have a working knowledge of areas like marine vessel operations, offshore lifting and handling, offshore survey, diver operations and remotely operated vehicles (ROVs)," he says.

In recent years, developers within the wind energy industry have increasingly sought to move wind farms further offshore to decrease aesthetic drawbacks and take advantage of the typically stronger and more consistent wind over the sea. At depths of more than 40m, regular pile foundations, including XL monopiles for wind turbines, become unfeasible and consequently an increased focus on floating foundations has developed.

"In this arena we see cost-efficient foundations as an enabler. This means considering solutions like driven and suction-installed piles, but also old tried and true means like drag anchors. There is an astounding variety of renewable concepts, and selecting an anchor that fits the structure type, location and quantity can make or break the economics," explains Bauer. "We're doing some interesting work with quick connection devices that can work with any foundation type. There is also renewed interest in our patented SEPLA anchor system, and we are adapting it to the renewable market. It delivers the precision and vertical load hold of a suction pile without the cost."

This goes to prove that, while there is an astounding variety and a continuously expanding range of possibilities within pile foundations, considering alternatives to piling, might, in some cases, be the key to overcoming new demands and challenges.