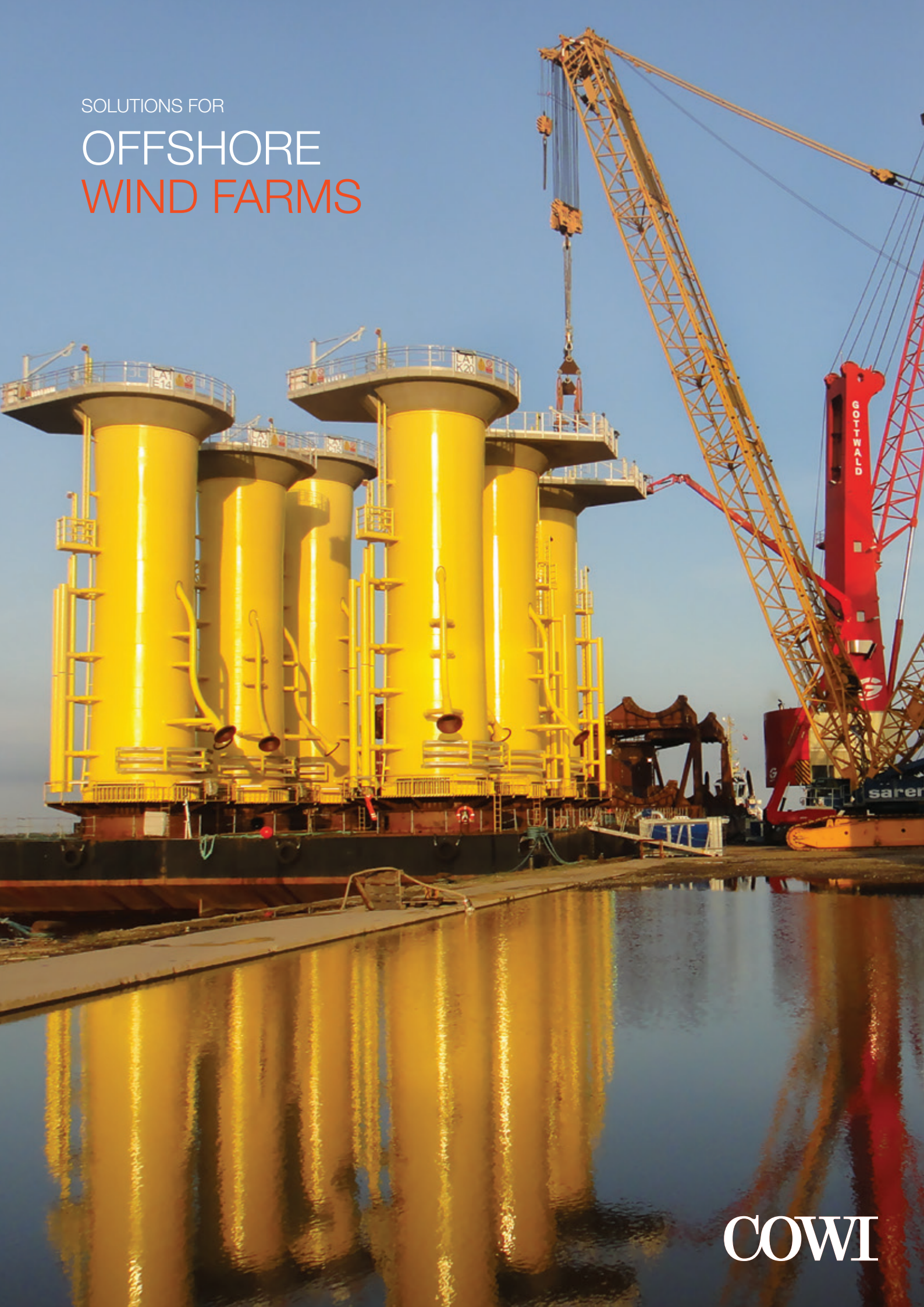
SOLUTIONS FOR

OFFSHORE WIND FARMS



COWI

Photo: Thornton

CONTENTS

COWI staff visiting a mock-up.

RELIABILITY, FLEXIBILITY AND INNOVATION

Offshore wind is a new and expanding energy source involving new technologies and a complex array of projects. COWI's mission in the industry is to reduce the risks involved in the projects, reduce the costs associated with the projects and create reliable and innovative solutions to the industry.

A fundamental driver in bringing down both cost and risk is the experience that skilled people bring to the projects. In a carefully weighted balance with the power of innovation to drive new solutions forward, this is the consultancy we provide from COWI. It is how we aim at providing reliable cost effective solutions to your projects.

We are a global civil, structural and geotechnical engineering consultancy, with extensive knowledge and experience in the Offshore Wind Industry. Our passion and expertise enable us to deliver technically excellent, high value and reliable solutions.

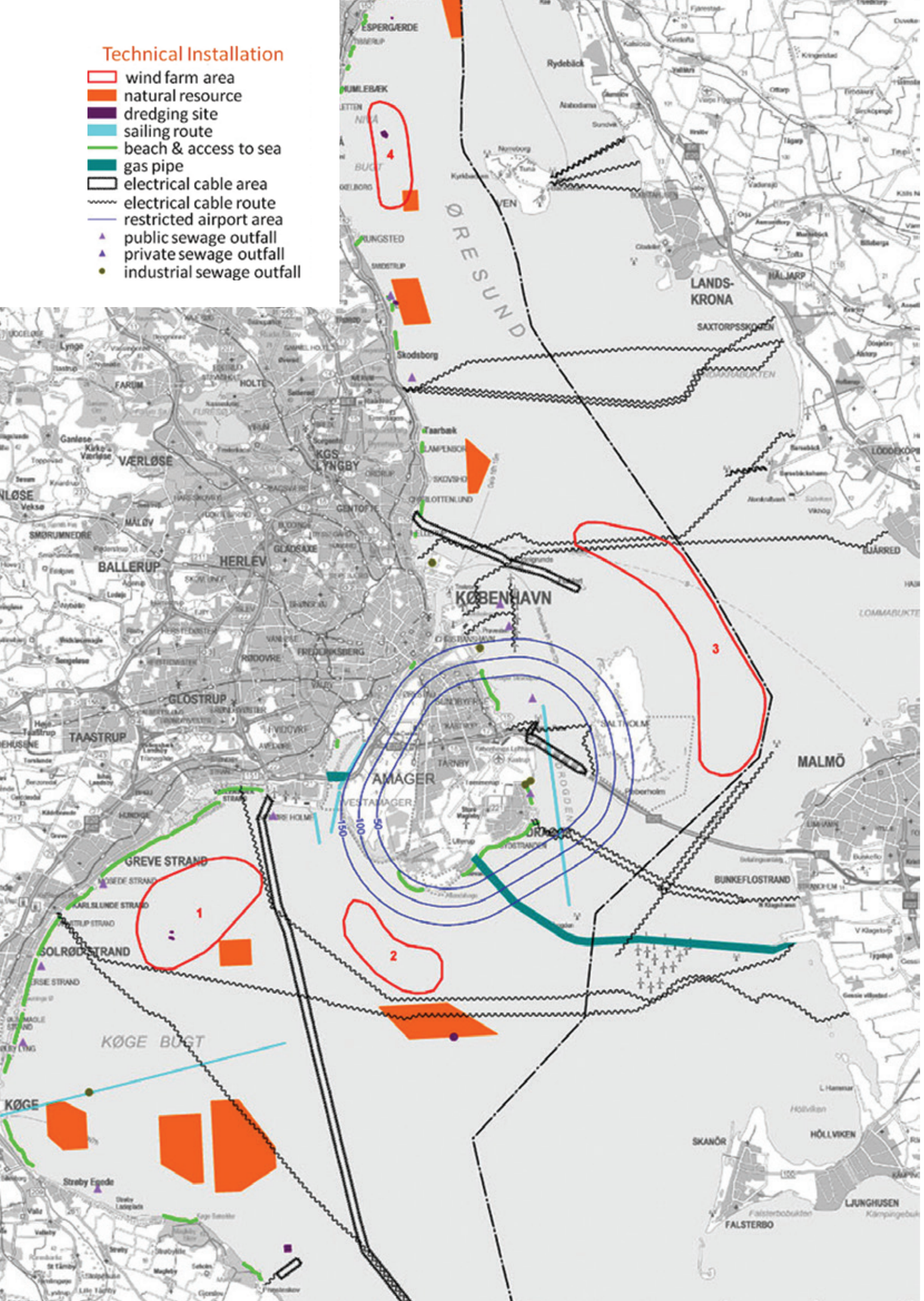
By combining global experience with local knowledge, we deliver buildable projects, anywhere in the world, for contractors and developers.

We can create specialist, multidisciplinary teams with the right competencies and experience to suit the complexity of any project. We combine the specialist approachability with large company capability.

You will benefit from direct access to experienced senior staff for expert advice and project input. They can challenge concepts and will bring industry leading expertise to every project.

Our engineering culture is to design buildability in, and design risk out.

PROJECT DEFINITION



FEASIBILITY STUDIES

Developing an offshore wind farm starts by defining a basis and establishing a process whereby a concept is incrementally developed towards an actual project. We take part from the very beginning and use our experience to set the process in motion.

SCREENING PROCESS

The screening process identifies locations where offshore wind farms are technically and financially feasible and have the least possible impact on the environment and society. The following issues are considered:

- Wind energy resources
- Hydrography
- Environment
- Ease of connection to the power grid
- Sea cables
- Navigation, traffic and military interests
- Visual impact.

CONCEPTUAL DESIGN

The conceptual design phase ensures selection of the optimal type of foundation for each turbine location. This establishes a basis for the financial assessment of the wind farm, with the costs divided into:

- CAPEX – Cost of constructing, manufacturing and installing foundations
- OPEX – Operation and maintenance costs
- Decommissioning costs.

FEASIBILITY STUDY

The feasibility study assesses the financial and technical feasibility of an offshore project based on the conceptual design and site specific wind energy resources available.

COWI services include identifying sites by cost of energy. The site prospecting process consists of several phases, which are carried out for both onshore and offshore projects:

- Mesoscale modelling for creating large-scale wind atlases
- Ranking of sites based on energy potential and development costs
- Wind measurement strategy for further development of the candidate sites.

The outcome includes calculations of the production costs per kWh and an assessment of financial and technical risks associated with construction and operation.

SELECTED REFERENCES

- Assistance for setting up the first offshore windfarm project in India (FOWPI).
- Site identification for 100 MW offshore wind farm in Bohai Bay in China.
- Screening of offshore sites in the Øresund area in Denmark for 300-400 MW offshore wind farms.
- Study to estimate the average and maximum monopile weights based on the currently available project information for 1,400 MW wind farms in the Netherlands.

DESIGN BASIS

WIND RESOURCES

COWI supplies high quality analysis, measurements, wind resource studies and site-specific wind data input for the design basis for wind turbines and foundations.

Our services include:

- Initial evaluation of wind energy resources
- Planning and executing site-specific wind energy resource investigations
- Analysing site-specific data and preparing detailed wind energy resource and site condition studies for design basis
- Micro-siting using state of the art software packages
- Calculation of energy production
- Second opinion on wind studies and micro-siting.

COWI has co-founded Measnet, the international network for harmonised and recognised measurements in wind energy (measnet.com), and is one of the few companies accredited for IEC 61400-003 and Measnet quality measurements.

SELECTED REFERENCE

- Evaluation of wind and site conditions for Vesterhav Nord, Vesterhav Syd and Kriegers Flak in DK. The objective is to determine and report on the long-term wind and site conditions as well as the corresponding uncertainties at the project site.
- Met mast installation to gather data for optimising the foundation design of the 500 MW Greater Gabbard Offshore Wind Farm off the coast of Suffolk in UK.
- Met mast installation to gather data for determining the viability of a potential offshore wind off the coast of South Carolina, Palmetto Wind Research, in the USA.
- Falesrassa wind measurement campaign in Norway.

METOCEAN STUDIES

COWI offers the full suite of metocean studies for offshore wind developments and gathers the main site-specific meteorological and oceanograpic data. Furthermore, we evaluate the effets of expected climate changes (e.g. sea level rise due to global warming) as part of the metocean study. Our services include:

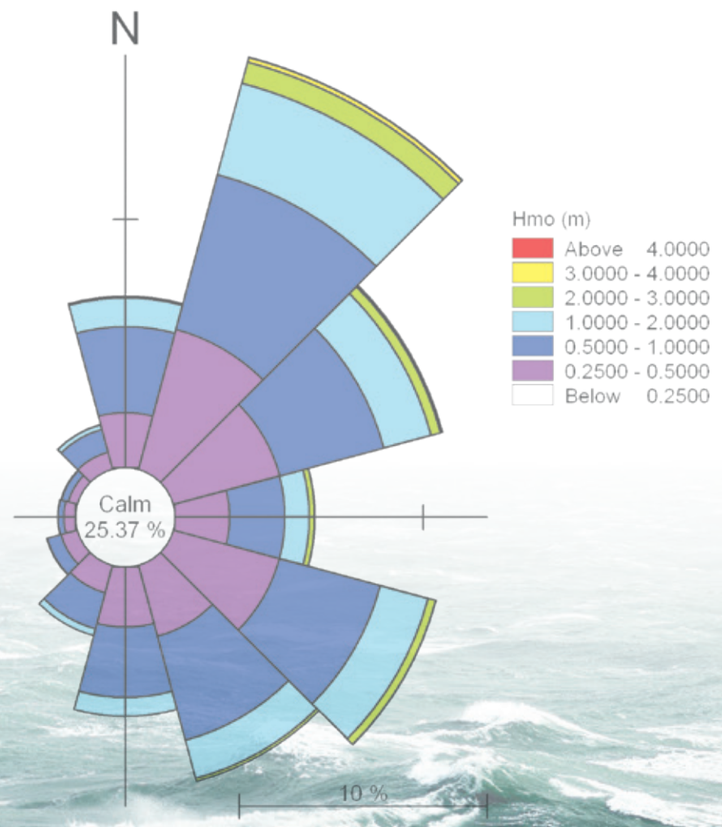
- Analysing meteorological and oceanographical data and using state-of-the-art numerical wave and hydrodynamic modelling software to define design water levels and wave conditions at each site
- Application of the DHI MIKE hydrodynamic modelling suite to model waves, current and water levels – a key part of the metocean study.

We use MIKE21 SW to model wave conditions, typically for durations of 10 to 20 years to allow full statistical analysis of design conditions. Normal and extreme current speed, as well as tidal levels and storm surges, are derived from hydrodynamic modelling MIKE21 HD for periods covering a full year and selected storm events.

Statistical analysis forms the second major part of the metocean study. This includes extreme statistics, scatter tables and joint probability analysis directly applicable to the load cases of the IEC 61400-3 standard.

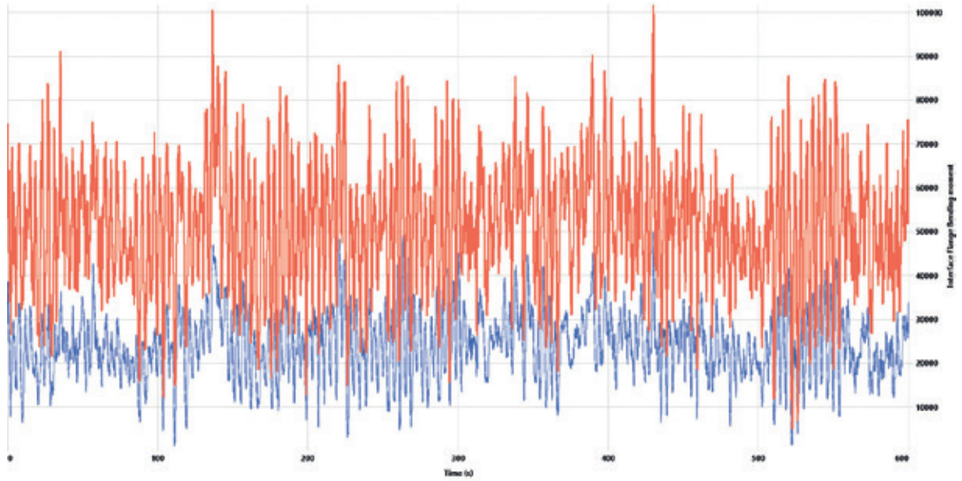
We apply time and spatially distributed wind and pressure fields as forcing of the models. Wave boundary conditions are provided from regional/global wave models and model bathymetry is derived from the global sea chart database, MIKE C-MAP, combined with site specific surveys.

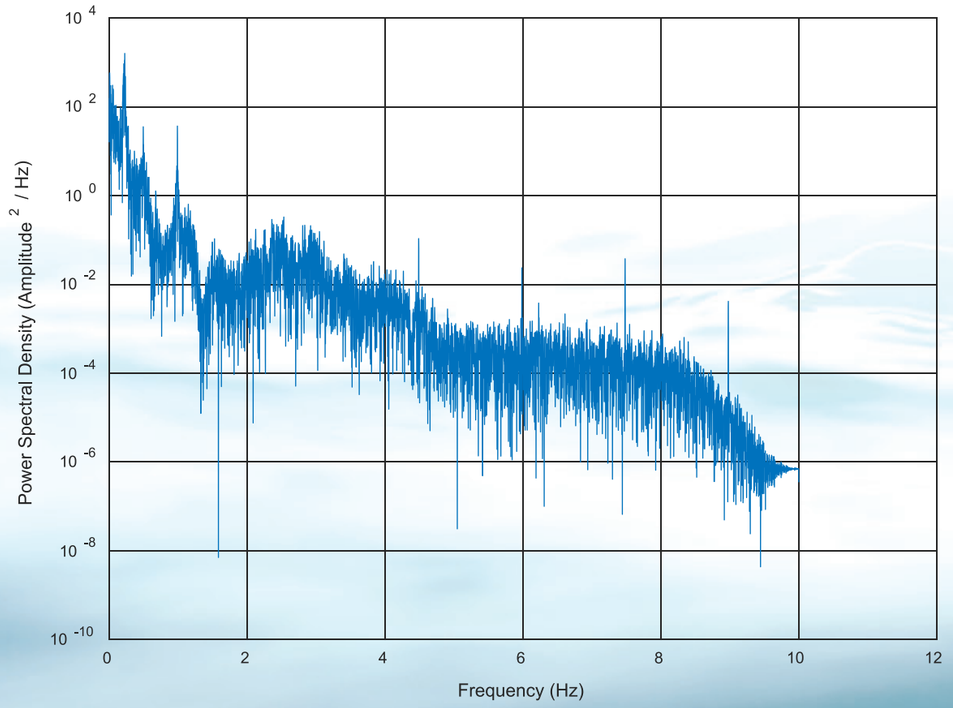
Combining this data allows us to perform metocean studies for any site, typically within three months from receipt of client-specific data.



SELECTED REFERENCES

- Analysis of metocean conditions including wind, waves, currents and water levels and preparation of the preliminary design basis for the gravity based foundation for the Storgrundet Offshore Wind Farm located in Swedish territorial waters in the southern part of the Gulf of Bothnia. For the given site three layouts of turbine positions, comprising 46, 56 and 70 wind turbine generators located in water depths from 10.5 m to 27.5 m are envisaged with 3 MW to 5 MW wind turbines.
- Metocean study for the offshore wind farm ARCADIS Ost 1 in Germany included salinity, temperature, density, seasonal variations, wind, wave, water level time series, misalignment plots and extreme analysis.
- As metocean consultant carried out the meteorological and oceanographic studies for six locations in Denmark.
- Metocean study and preliminary design basis for Suurhiekka Offshore Wind Farm in Finland.



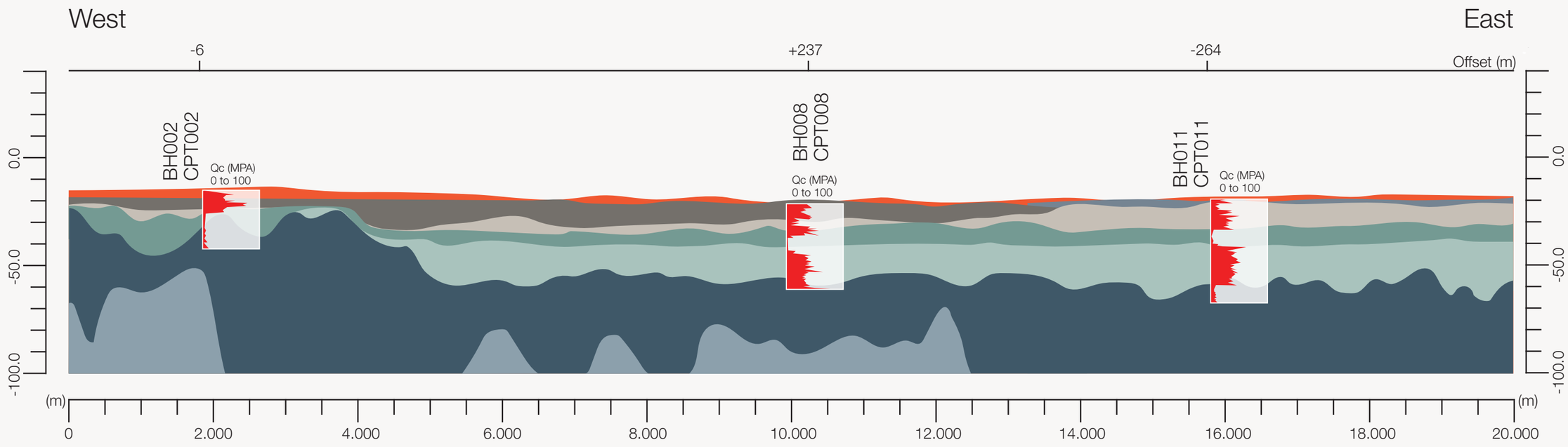


AEROELASTIC LOADS ANALYSIS SERVICES

Modern offshore wind farms are feats of engineering with sophisticated support able to withstand wind and wave forces. We provide accurate determination of the wind loads, which is essential to the efficient and safe design of foundations that can withstand decades of wind and wave conditions at sea.

We uses state-of-the-art aeroelastic computer software, e.g. Bladed and Flex5, to perform comprehensive loads and structural response analysis of support structures for offshore wind turbines according to IEC standards. Using software which incorporates turbine and foundation components in an integrated model, COWI can handle not only the entire structural design, aerodynamics, and hydrodynamics but also wind turbine controller and soil behavior as a whole. This allows a precise determination of loads and responses throughout the support structure that captures all the relevant parameters for each of the tens of thousands of combinations of environmental loads the turbines will be exposed to during their lifetime.

We apply the aeroelastic software used for optimizing support structures to extend the life of operating assets. Based on the original design and the actual site and operational conditions and combining operational data with aeroelastic modeling, COWI's specialists can accurately determine accumulated fatigue in foundations and components in operation. This information together with O&M strategies, onsite inspections, and financial modeling, lets us provide a 360 degree view of the feasibility and benefits to lifetime extension projects.



GEOSCIENCE SURVEYS

You will find support and expertise for:

- Geological desktop studies
- Geophysical surveys
- Geotechnical investigations
- Geotechnical laboratory testing
- 3D & BIM ground models.
- Geotechnical interpretive reports.

When combined: the geological studies, the geophysical surveys and the geotechnical investigations supply the soil information required for a design basis for foundation design.

We can integrate the data in a 3D model to enable full analysis, and evaluate hazards to minimise project risk.

We can assist you to ensure an efficient contractor selection process by preparing a comprehensive invitation to tender (ITT) for surveys and testing, and our significant industry experience means we can advise our clients on detailed requirements, best practice and contractual conditions.

After the survey contract award, we can manage the relationship between the client and contractor and ensure the quality of all project documentation. We can also optimise the surveys proposed by the contractor to minimise the survey time and cost, while maximising safety and data performance.

GEOPHYSICAL SURVEYS

Geophysical survey data comprise bathymetry by multibeam echosounder, acoustic imaging of the seabed by side scan sonar, vertical layering of the seabed by sub-bottom profiles and multi-channel seismic data and detection of possible metallic obstructions on the seabed by magnetometer.

Furthermore, in selected areas ultra-high resolution seismic data, or 3D seismic data, is beneficial to understand the sub-seabed layering and image sub-seabed hazardous objects or layers.

Acting as the client's consultant during calibrations, data acquisition and with operational safety assistance, COWI adds value to not only the survey performance but to the entire project.

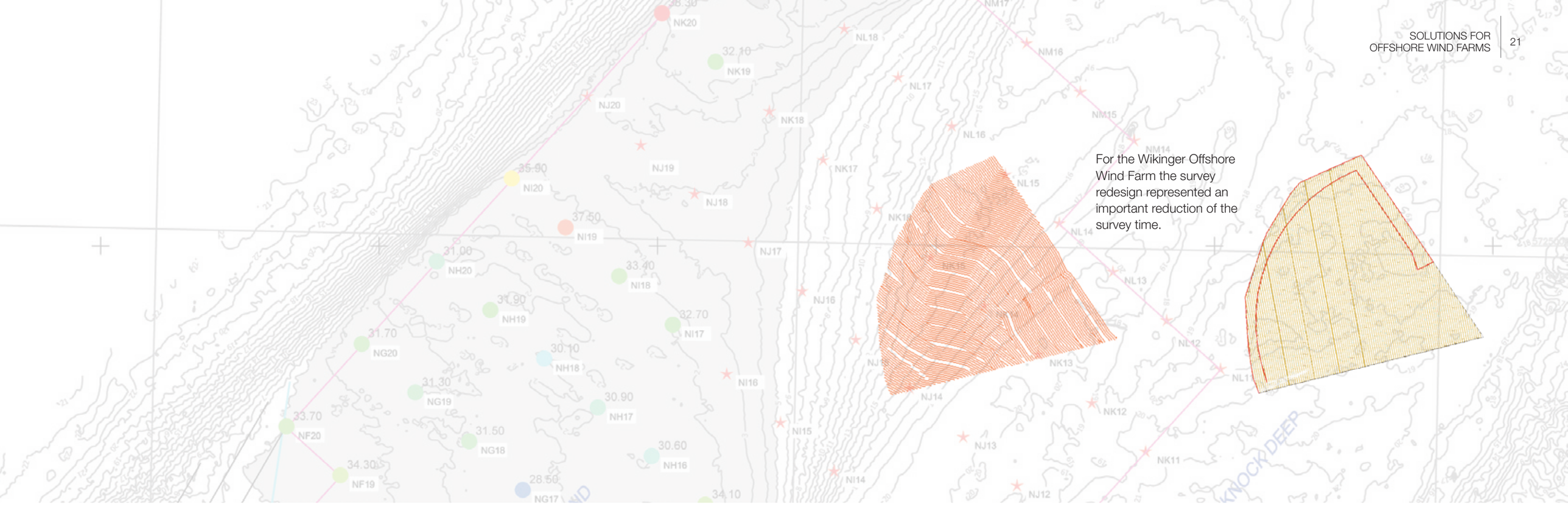
Following the survey, we check the data processing, charting and reporting to ensure that the final deliverables meet the required quality standards.

The geophysical deliverables focus on:

- Imaging the seabed and layering of soils and supporting the selection of locations for geotechnical investigations
- Supporting the creation of a geological report
- Digital data usable in 3D geological models, seabed mobility studies and geohazards risk management.

SELECTED REFERENCES

- Integrated interpretation of geophysical and geotechnical data for establishment of 3D model as well as technical assistance for invitation to tender for offshore and landfall survey, evaluation and data QA for Walney Extension Offshore Wind Farm, Inter Array and Export Cable in Irish Sea UK (for DONG Energy).
- Technical assistance for geophysical survey management for UXO survey offshore and landfall as well as EOD survey, evaluation and data QA for Race Bank Offshore Wind Farm, Inter Array and Export Cable in North Sea UK (for DONG Energy).
- Geophysical survey management and data QA for seabed and geophysical survey across the North Sea for Offshore Interconnector Cable, Viking Link (for Energinet.DK and NG).
- Site investigations in the Danish Wadden Sea for Offshore Interconnector Cobra Cable (for Energinet.DK and TenneT).



For the Wikinger Offshore Wind Farm the survey redesign represented an important reduction of the survey time.

UXO SURVEYS

COWI can also advice on the risk posed by unexploded ordnance, UXO to surveys and installation operations. Our services include:

- Comprehensive risk assessment as a basis for UXO surveying to comply with local legislation and the client's HSE requirements
- Survey, definition of clearance and buffer zones, rerouting of cables and mitigation (if needed)
- Client representation during survey and disposal of explosive ordnance in close collaboration with the selected UXO consultant.

GEOTECHNICAL INVESTIGATIONS

We provide consultancy on all aspects from site investigations to geotechnical design, including:

- Planning of site investigations, i.e. in-situ testing and sampling
- Planning of the laboratory testing campaign, ranging from traditional static testing to advanced cyclic testing,
- Consultancy during execution, e.g. as client's representative offshore and in laboratory onshore,
- Liaison with the site investigation or laboratory contractor and ensuring high quality results,
- Preparing the ground interpretative report (GIR) based on analysis and interpretation of in-situ and laboratory test results,
- Establishing 3D ground models based on geological, geotechnical and geophysical information,
- Deriving soil profiles and parameters for design.

In COWI we employ senior experts that have worked most of their life with offshore site investigations, geotechnical professors with a unique understanding of soils and their response to loading, geotechnical engineers with project management talent and a large pool of dedicated experienced geotechnical engineers at all ages and levels.

Our geotechnical experts are on the frontier on targeting and handling appropiate geotechnical programs for sampling and testing that provides the results needed as basis for an optimised design process and risk analysis.

SELECTED REFERENCES

- Supervision assistance to soil investigation for foundations for more than 100 wind turbines for Wikinger Offshore Wind Farm in Germany.
- Supervision of the detailed soil investigations for the West of Duddon Sands Offshore Wind Farm including 140 wind turbines and one substation in UK.
- Assistance in the planning and execution of laboratory testing campaign for the Hornsea 2 Offshore Wind Farm including liaison with laboratories ensuring high quality, design-targeted results as the client's technical representative (for DONG Energy).

DESIGN

Photo: Ormonde

Photo: C-Power

GEOTECHNICAL DESIGN

COWI is a frontrunner in innovative geotechnical design within jacket piled foundations, monopiles, anchored foundations, gravity based foundation concepts and suction caissons.

We develop fast and reliable software to push the boundaries of geotechnical design and our team of senior geotechnical experts and engineers understand how soil response drives the design. This includes detailed understanding of how to test, analyse and apply the optimal soil response in the design process to minimise risks.

We analyse the in-situ measurements and evaluate the soil samples taken from boreholes to assign the appropriate laboratory testing for design considering project time schedules and certification issues.

Testing experts handle the dialog with geotechnical contractors and laboratories to make sure that testing is performed to specific soils and load levels by use of correct equipment and procedures.

We introduce cyclic concepts to determine how the cyclic loading responses are investigated, analysed and included in design for the lifetime of the foundations.

Soil responses, stiffness and strength evaluations drive the optimisation of structures for installation and operation, and we support the analysis using our extensive knowledge database from projects all over the world.

Based on experience and expertise we combine the soil and load data to determine the soil-structure response for an optimised design and certification, including selection of appropriate constitutive models.

With use of finite element models in Plaxis, Abaqus or other software we include the site-specific soil characteristics in design and optimisation.

COWI's geotechnical design services include the following concepts:

- Gravity based foundation structures
- Piled foundations, jackets and monopiles
- Suction caissons
- Hybrid foundations combining foundation concepts.

The installation analysis of piled foundations allows for use of impact or vibratory driving of the piles.

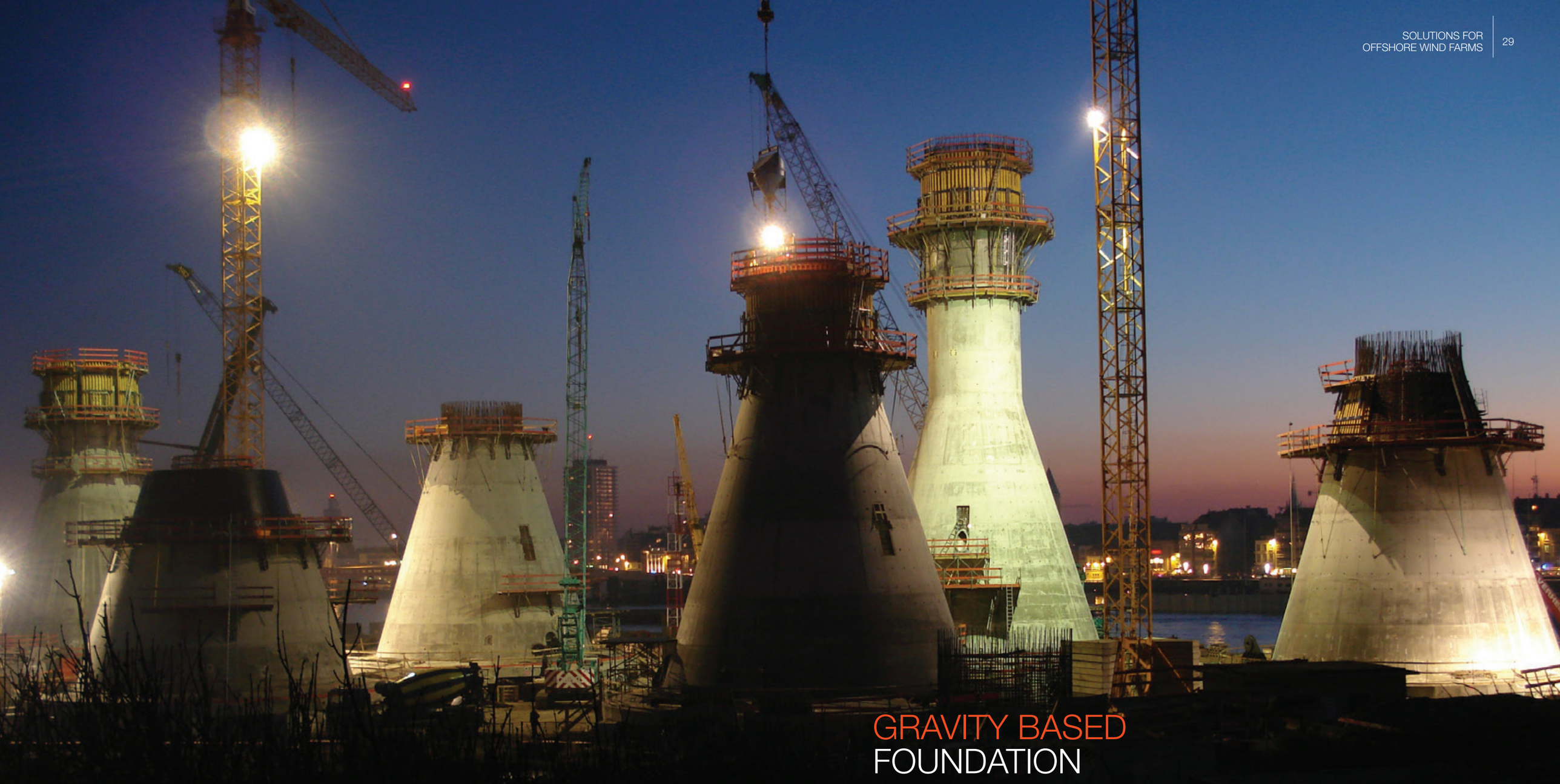
MONOPILE FOUNDATION

With 175 monopiles, designed to carry the Siemens 3.6 MW turbines, the London Array is one of the largest operational offshore wind farm in the world, when completed in 2012. Monopiles of 4.7 m and 5.7 m in diameter have been installed in water depths between 0 m and 25 m. With a total length of up to 85 m, these foundations are amongst the largest ever built.

A consortium of DONG, E.ON and Masdar commissioned Aarsleff | Bilfinger Berger Joint Venture (ABJV) as contractor to undertake fabrication and installation of the steel foundations. To carry out the detailed design of the steel foundations, ABJV engaged COWI as lead in a joint venture with IMS GmbH, COWI-IMS JV.

The offshore wind farm is located on and between the sandbanks of Kentish Knock and Long Sand representing depth variations of up to 25 m. The soil includes both sand profiles, stiff London Clay profiles and mixtures including also gravel layers. With layers potentially prone to liquefaction, also the soil represents a challenge to the design.

The project was one of the first to introduce a new design of grouted connections and improvements in the geotechnical calculations of soil structure interaction to allow for an optimised design.



GRAVITY BASED FOUNDATION

COWI carried out the detailed design of the foundations for Thornton Bank phase 1, which comprises 6 turbines, 30 MW.

The wind turbines are founded at -21.5 m to -27 m TAW and soil conditions are generally sand of medium grain size. The pre-stressed concrete foundation structure is composed of a cylindrical shaft on top of a conical base on top of a conical base transferring the loads from the wind turbine directly to the base slab.

The base diameter is 23.5 m and the shaft diameter is 6.5 m, matching the diameter of the turbine tower.

The foundation structures are prefabricated on land and installed at sea by a heavy lift crane on a pre-installed gravel bed. The weight of the concrete structure is about 2,700 tonnes.

Photo: Iberdrola Wikinger Project

JACKET FOUNDATION

The Wikinger Offshore Wind Farm is located in the German part of the Baltic Sea about northeast of the island of Rügen, covering an area of approximately 34 km². The wind farm is expected to deliver up to 350 MW.

The joint venture of COWI A/S and IMS Ingenieurgesellschaft mbH, led by COWI, supervised the geophysical and geotechnical investigations for the first BSH release (permit from the Federal Maritime and Hydrographic Agency), and supervised the detailed geotechnical investigations for the second BSH release.

COWI-IMS conducted a feasibility study of the turbine foundation types, investigating concepts for monopiles and jacket foundations. Based on this study, the basic detailed design of the chosen jacket foundations for the 70 turbines were undertaken. Subsequently, construction support was provided to Iberdrola during the fabrication and installation phase of the project.

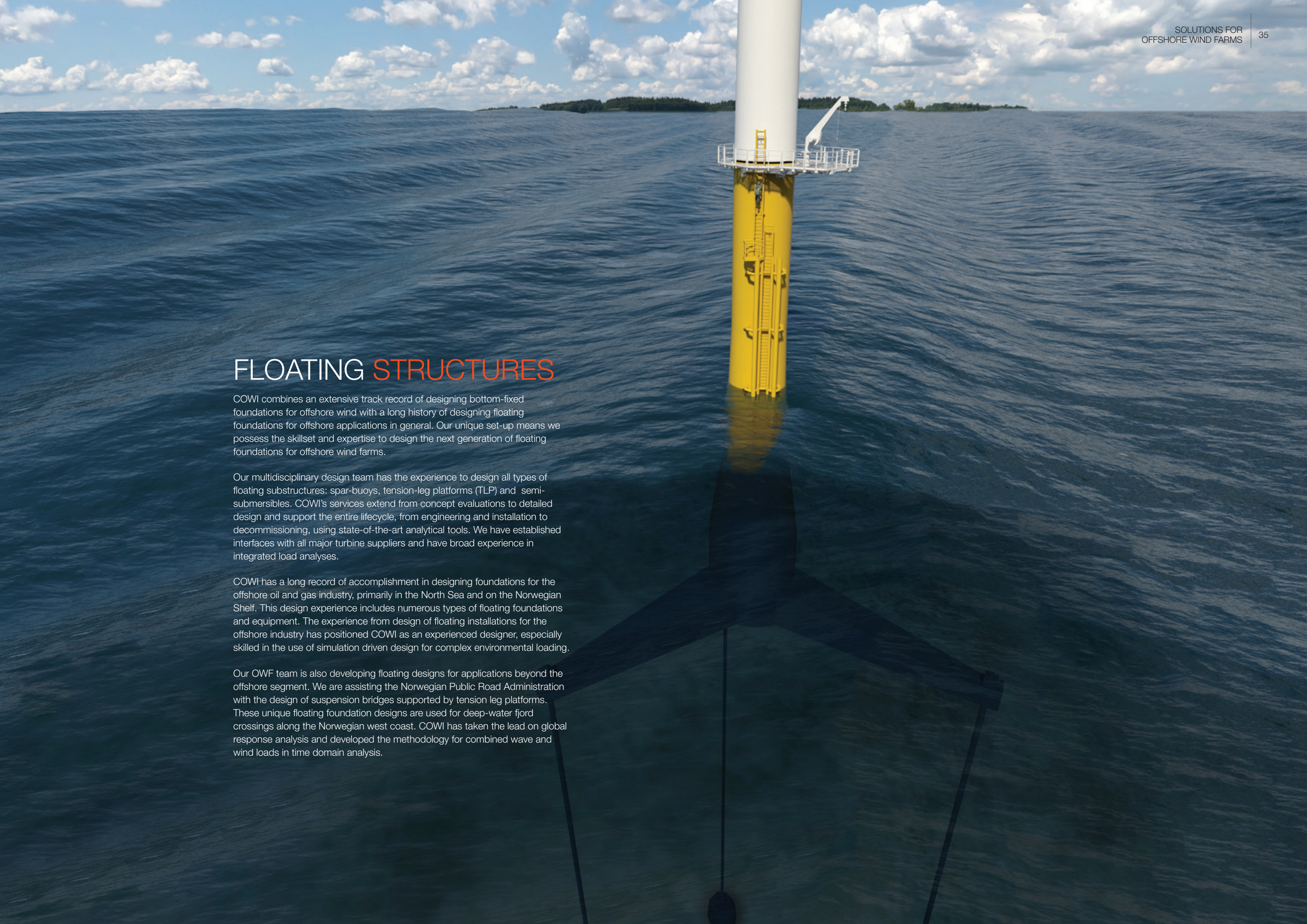
COWI has completed the detailed design of more than 150 jacket foundations for offshore wind farms. This, combined with a long history from oil and gas jackets, ensures our clients get the right expertise where jackets are the preferred design solution, covering all disciplines needed for concept or detailed design of jacket structures, including foundation design. COWI combines deep theoretical knowledge, advanced analysis and applied engineering expertise to establish world-class solutions for our clients.

OFFSHORE SUBSTATIONS

Horns rev 3 consists of 49 wind turbines with a total output of 406.7 MW, enough to supply 425,000 Danish households for a whole year.

The substation has 12 incoming 33 kV cables and one 220 kV export cable which will transport the electricity from the offshore wind turbines to the electrical grid onshore. The number of transformers in the topside is 3 and the total operating weight of the topside is 2,200 tonnes. The topside is supported on a 4-legged jacket with a total weight of 1,100 tonnes. The jacket has one pile per leg and the total weight of the piles is 500 tonnes. The substation was installed in 2016.

COWI designed the layout plans, structural design for both topside and jacket, electrical design, HVAC, mechanical, and fire & safety. COWI was involved in all project phases from concept design to certification and installation.



FLOATING STRUCTURES

COWI combines an extensive track record of designing bottom-fixed foundations for offshore wind with a long history of designing floating foundations for offshore applications in general. Our unique set-up means we possess the skillset and expertise to design the next generation of floating foundations for offshore wind farms.

Our multidisciplinary design team has the experience to design all types of floating substructures: spar-buoys, tension-leg platforms (TLP) and semi-submersibles. COWI's services extend from concept evaluations to detailed design and support the entire lifecycle, from engineering and installation to decommissioning, using state-of-the-art analytical tools. We have established interfaces with all major turbine suppliers and have broad experience in integrated load analyses.

COWI has a long record of accomplishment in designing foundations for the offshore oil and gas industry, primarily in the North Sea and on the Norwegian Shelf. This design experience includes numerous types of floating foundations and equipment. The experience from design of floating installations for the offshore industry has positioned COWI as an experienced designer, especially skilled in the use of simulation driven design for complex environmental loading.

Our OWF team is also developing floating designs for applications beyond the offshore segment. We are assisting the Norwegian Public Road Administration with the design of suspension bridges supported by tension leg platforms. These unique floating foundation designs are used for deep-water fjord crossings along the Norwegian west coast. COWI has taken the lead on global response analysis and developed the methodology for combined wave and wind loads in time domain analysis.

SCOUR

The offshore wind foundations are often placed in hydrodynamically severe environments. Scour occurs when the foundations are placed on erodible beds exposed to current and waves and can pose a threat to the structural stability of the structure.

COWI has extensive experience in scour assessment with our experts at the forefront of developing new methodologies through their work with leading universities and research institutes.

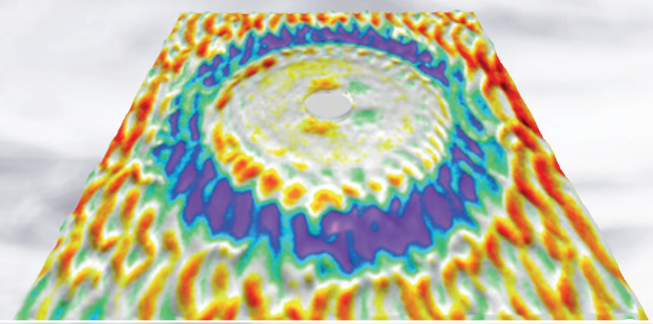
COWI is a member of the Joint Industry Project HaSPro (Hand Book Scour Protection Methods) which establishes best practices in scour protection design. This project includes design tools for designing traditional rock protection, but also innovative methods using concrete and alternative materials. Our scour protection studies comprise:

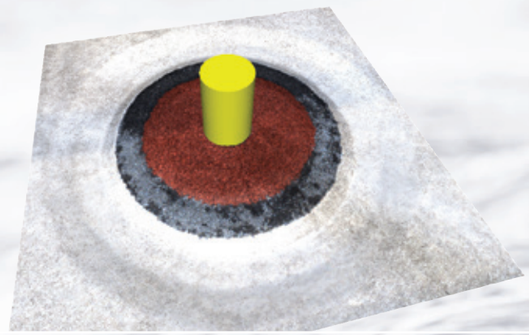
- Scour assessment addressing the need for scour protection
- Design of scour protection, notably classic two-layer systems but also single layer systems
- Filter stability and mitigation of winnowing
- Edge scour assessments and falling apron design
- Assessment of interim stability in the construction phase.

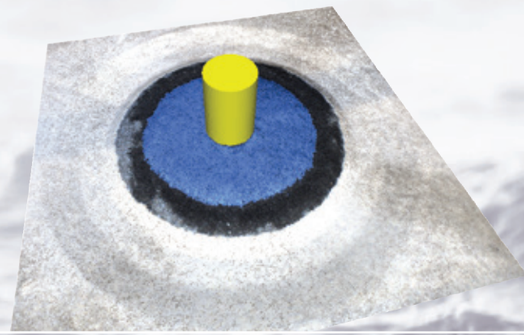
We collaborate with clients to develop safe, cost effective and buildable solutions.

SELECTED REFERENCES

- DanTysk Offshore Wind Farm with 80 monopiles equipped with internal cabling, steel working platform and scour protection in Germany.
- Scour protection for 83 gravity based foundations, including exposed gravel bed/filter layer in interim stage for the Fécamp Offshore Wind Farm in France.
- Scour protection for 42 monopile foundations, including monitoring specifications and impacts from seabed variability for the Belgian Rentel Offshore Wind Farm.
- Scour protection design for a 130 MW offshore wind farm located 3-6 km off the West coast of Taiwan.







CORROSION PROTECTION DESIGN

Steel structures, such as monopile or jacket foundations, are exposed to severe corrosion in the offshore marine environment.

A corrosion protection system is needed to meet the service life requirements, normally 20 to 30 years. The system must protect both primary and secondary steel in all environmental exposure zones: atmospheric, splash, submerged, mudline or embedded in the seabed.

Designing corrosion protection systems is a specialist field which interfaces with most of the other design disciplines. In particular, the cathodic protection system requires close collaboration between disciplines to determine the optimal position of the anodes. The distance to infield cables, drag forces on the foundation and corrosion protection requirements all need to be taken into account.

We verify the design of the corrosion protection system with boundary element modelling, to ensure all steel surfaces are protected.

Our approach is to design corrosion protection systems which minimise the need for operation and maintenance interventions.

SELECTED REFERENCES

- Detailed design of monopile foundations for Merkur Offshore Wind Farm in Germany.
- Detailed design of the Hohe See foundations in accordance with the requirements of BSH, covering corrosion protection design.
- Tender design for gravity based foundations for the Fécamp Offshore Wind Farm in France.

LOW VOLTAGE FOR FOUNDATIONS AND M&E DESIGN FOR OFFSHORE SUBSTATIONS

The output cables from the turbines are linked to an offshore transformer station (called a substation) from where a high voltage cable leads the power ashore.

We design the entire structure for offshore substations and all low voltage installations, employing state-of-the-art mechanical and electrical engineering (M&E) tools.

Our design team works in close collaboration with all project stakeholders to ensure that the design satisfies their requirements.

We have extensive experience in the design of electrical and mechanical systems and design in compliance with the latest standards and regulations, always open for third party review.

The basis for our design is a comprehensive understanding of the requirements for an offshore facility. Our design team pays attention to aspects such as:

- High system reliability
- Fire, health and safety
- Space management for special equipment such as high voltage systems
- Serviceability and system design life time
- Environmental conditions such as wind and wave impact, humidity and corrosive atmosphere
- Serviceability and system design life time
- Personal and operational safety during installation, operation and maintenance.

We develop the low voltage design in 3D, ensuring full coordination with all other disciplines and with special focus on accessibility, clash check and requirements for safe operation of the facility

SELECTED REFERENCES

- Conceptual, basic and detailed design of 3 substation topside structures consisting of including two 400 MW transformer substations (at Horns Rev C and Kriegers Flak B) and one 200 MW transformer substation (at Kriegers Flak A).
- Detailed electrical design for offshore substation for 207 MW wind farm Rødsand 2 in Denmark.
- Offshore substation detailed electrical design of 34 kV and 132 kV equipment as well as protection relays. Design, procurement, supervision and commissioning and onshore grid connection for 300 MW Walney 1 and 2 in UK.
- Tender design for the 288 MW substation for the Rentel Offshore Wind Farm.
- Low voltage tender design for the Borsseele Wind Farm in Holland.
- Design of external and internal low voltage equipment for Hohe See Offshore Wind Farm in Germany.
- Low voltage design for the Merkur Offshore Wind Farm in Germany.
- Low voltage design for the Rentel Offshore Wind Farm in Belgium.
- Low voltage design for two offshore wind farms in Taiwan.

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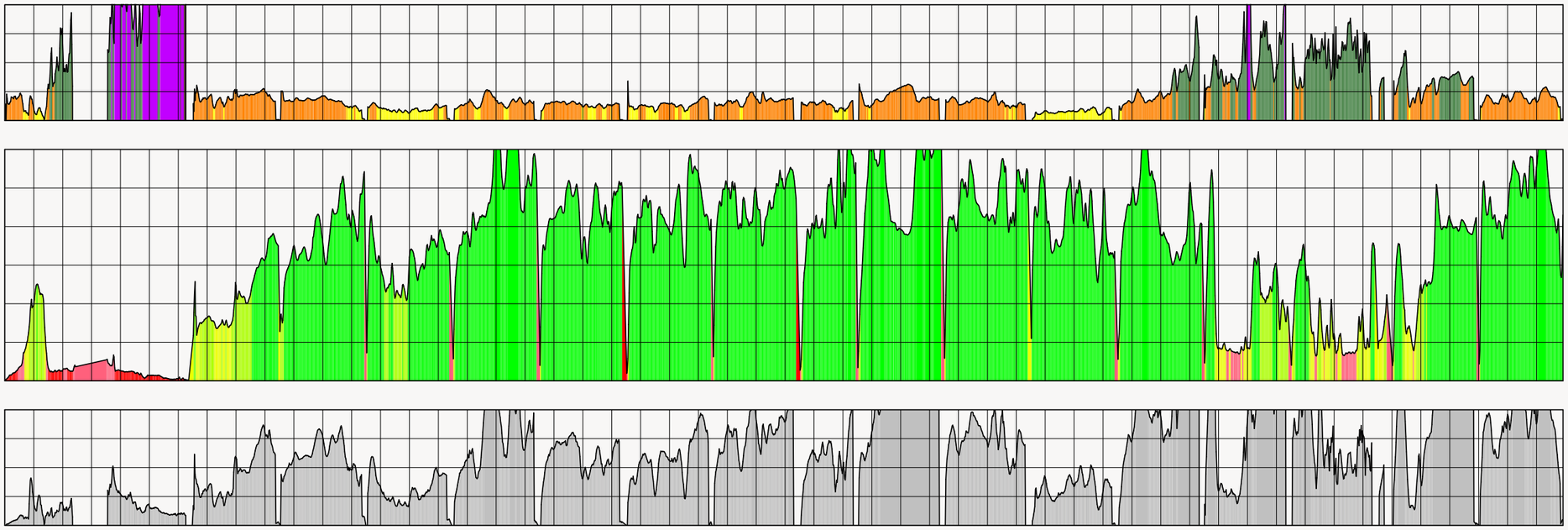

LEG PENETRATION AND SITE SPECIFIC ASSESSMENTS

COWI carries out leg penetration assessments (LPA) and site specific assessments (SSA) for jack-ups used for wind farm installation, maintenance and accommodation. In the last decade we have carried out leg penetration assessments for offshore wind farms in the Baltic, Irish and North seas.

LEG PENETRATION ASSESSMENTS

COWI's LPA provides the predicted penetration of the spud can into the seabed, based on the available geotechnical data. Penetration graphs are prepared using our in-house leg penetration analysis program, which can perform analyses on the basis of both SNAME and ISO 19905. The main risks investigated are punch-through, scour induced punch-through, deep penetration and squeezing.

COWI's LPA services include:

- Indicative LPA's for entire sites. These evaluate soil risks, group the locations according to risk and include indicative penetration predictions which are representative for each group.
- LPA's for entire sites or specific locations (e.g. harbour locations) assessing leg penetration and geotechnical risks for each location.
- Recommendations for safe operational distances in order to avoid damage to nearby structures, such as wind turbine foundations, quay walls, offshore pipelines and cables.

The SSA assesses a jack-up vessel's operability in elevated mode for a given location, and identifies risks related to jacking up on site. The assessment is carried out in accordance with recognised standards such as ISO 19905-1 and SNAME 5-5A, and, when relevant, in compliance with Renewable UK guidelines.

Project and site specific data, such as ground conditions, environmental loading, water depth, air gap and variable deck loading, are closely investigated by our experienced team of structural, geotechnical and marine engineers. The storm survival mode is the base case for the SSA; we check whether the unit can survive a design storm with a 50-year return period.

COWI's SSA services include:

- Dynamic structural response analysis
- Overturning stability analysis
- Analysis of structural capacity of legs and leg-to-hull connections
- Analysis of foundation integrity based reaction from the SSA
- Advice on seasonal and directional limitations to allow for operation at site when the unit fails to fulfil requirements for all-year omni-directional conditions
- Determination of weather window limitations for operating mode
- Creating and maintaining an analytical model database of the client's vessel fleet to allow for fast results.

SELECTED REFERENCES

- Supervision assistance to soil investigation for foundations for 23 offshore wind turbines for Thornton Bank phase 2 in Belgium.
- Supervision assistance to soil investigation for 12 locations to characterise the area for Wikinger Offshore Wind Farm in Germany.
- Supervision assistance to soil investigation for foundations for more than 100 wind turbines for Wikinger Offshore Wind Farm in Germany.
- Supervision of the detailed soil investigations for the West of Duddon Sands Offshore Wind Farm including 140 wind turbines and one substation in UK.
- Supervision of geotechnical investigations containing boreholes and CPTs from jack-up for the offshore wind farm just east of Frederikshavn with 5 wind turbines. COWI is acting as client's representative.

Photo: Alpha Ventus

DESIGN OF TEMPORARY PHASES

COWI provides engineering and analysis for transport and installation of a wide variety of foundations for the offshore wind sector. We can support our clients in the whole process of moving the foundation from the fabrication site to completed installation offshore. Our services include:

BARGE TRANSPORTS
- Seafastenings and grillage design
- Load-out analysis

LOAD-OUT TO INSTALLATION VESSEL
- Lifting/up-ending analysis
- Design of local lifting points/interface to lifting tools.

INSTALLATION
- Design of lift rigging
- Vessel motion response analysis
- Lifting analysis
- Site specific assessment/Leg penetration assessment (SSA/LPA)
- On bottom stability analysis.

PILE DRIVING
- Pile driving assessment
- Ultimate limit state (ULS)
- Fatigue assessment
- Pile refusal assessment
- Pile tip buckling assessment.

SELECTED REFERENCES

- Design of pre-piling template for Norwind Installer, considereing all aspects of the marine operation.
- Installation analysis of suction bucket jacket for DONG Energy considering installation from both jack up and floating vessel.
- Marine operations analysis and design of seafastening and grillage for installation of suction bucket for Fred Olsen Windcarrier.
- Transport, lift and installation analysis of jacket foundations for the Thornton Bank Offshore Wind Farm.
- Design of jacket lifting tools for the Ormonde and Alpha Ventus offshore wind farms.

CABLE ENGINEERING

Our services comprise the complete engineering package for the power connection from an offshore windfarm to the existing transmission grid, from pre-feasibility studies to commissioning and related to the main power components as:

- 33-66 kV offshore inter-array cable systems connecting the turbine generators and the offshore transformer platforms
- Medium and high voltage components on the offshore platforms
- Internal power cable systems on the offshore platforms
- Offshore and onshore export cabling connecting the windfarm to existing grid substations.

The engineering package also includes upfront assessments of the prevailing grid code requirements to ensure that the output can be exported through the transmission network without restrictions. Typical studies cover:

- Load flow and fault analysis, contingencies, transient and dynamic analysis
- Verification of the wind farm's grid code compliance for owners and investors
- PQ and UQ capability diagrams, dynamic and transient stability, fault ride-through capability, voltage and frequency regulation and harmonic analysis
- Insulation coordination studies, development and validation of simulation models, and grid code compliance by on-site tests and measurements.

COWI provides:

- Design of optimal cable routing, burial assessment, burial protection level and installation methods offshore and onshore
- Assistance to our clients when cable systems cross sea defence areas or environmentally sensitive areas where open excavation is prohibited or when horizontal drilled ducts are required
- Assistance to our clients obtaining right of way and identification of suitable trenching and cable burial methods including burial assessment
- Determination of ampacity (current rating) and installation methods for export cables at landfall (horizontal drilling, open cut etc.).
- Design of offshore platform cable deck arrangement, power components and auxiliary systems
- Design of onshore substation buildings and outdoor switchyard arrangement.

SELECTED REFERENCES

- Detailed electrical design for substation for 207 MW for the Rødsand 2 Offshore Wind Farm in Denmark.
- Offshore substation detailed electrical design of 34 kV and 132 kV equipment as well as protection relays. Design, procurement, supervision and commissioning and onshore grid connection for 300 MW Walney 1 and 2 in UK.
- Offshore substation detailed electrical design of 34 kV and 132 kV equipment as well as protection relays and SCADA. Design, procurement, supervision and commissioning and onshore grid connection for 165 MW Nysted in Denmark.
- Outline design of 33 kV cable systems interconnection WTGs and onshore substation including power components and arrangement of 33/132 kV onshore onshore substation. Nearshore Windfarm Sejerø and Smålandsfarvandet, 2x200 MW.
- Outline design of 33 kV offshore inter array cable system, offshore platform cable deck arrangement and 33 kV switchgear for 600 MW Krigersflak Offshore substation.
- Power System Study and Conceptual design study of 33kV system Horns Rev 3 Offshore Wind Farm (400 MW).

HSE AND RISK ASSESSMENT

As part of our project execution an HSE management system will outline a health and safety action plan - a living document that is maintained and revised during the project to ensure that HSE considerations are a part of all project phases.

Furthermore, the HSE management system will describe targets and the basis of the HSE ambitions during design, execution and maintenance, including organisation, communication, distribution of work and responsibilities.

An HSE manager will be appointed to coordinate the project HSE activities.

Design risk workshops are conducted with various design groups, and designers will work together to point out parts of the project that need specific focus.

The design risk assessment will be documented in a design risk matrix.

The hierarchy of mitigation principles, as stated in EU Directive 89/391/EEC, will be used as a basis of mapping risks.

Execution of the issues listed in the DRA matrix are monitored regularly by the HSE manager and finally in each phase in combination with the HSE check of the design.

The HSE manager liaises with designers to carry out HSE design check of selected design documents, assessed to be significant in relation to HSE performance. The purpose is to follow up and check that HSE measures are properly integrated in the design and that the design is consistent with the objectives and success criteria for the project and with requirements of applicable occupational health and safety legislation.

EXAMPLES OF RELEVANT FOCUS AREAS FOR THE WIND FARM PROJECTS:

- Boat landing/access
- Rest platforms and other platforms
- Fall from height incl. fall arrest system
- Hazardous/toxic gasses
- Transportation and handling of heavy elements
- Evacuation and rescue.

PROJECT FOLLOW-UP

Photo: London Array

MONITORING, OPERATION AND MAINTENANCE

OPERATION FROM DAY ONE
To ensure full and safe operation, operation and maintenance (O&M) should be carried out from day one of the service life. However, it is never too late to start taking care of your offshore wind farm assets.

Optimally, wind turbine structures are designed with due consideration for service life aspects such as durability, access and efficient operation and maintenance.

COWI has the experience and expertise to tackle any O&M challenge and provides and installs monitoring systems for structural load measurement.

SERVICE LIFE DESIGN
To achieve a long service life, the offshore wind farm design must take into account durability and access, and provide the right O&M instructions for the management of the wind farm. The goal is to avoid major maintenance work during the service life.

Durability design, together with corrosion protection plans, ensure the target service life of an offshore wind farm with the minimum life cycle costs. An access strategy ensures efficiency in operation, inspection and maintenance, and an O&M manual allows the owner to take over and manage the offshore wind farm efficiently from day one.

Our team will produce a practical manual, adapted to local laws and regulations. With a manual in hand, an O&M management system can be specified. This allows for effective electronic offshore wind farm maintenance management, and may even be developed into a full management system with easy access to as-built data. To optimise O&M, a structural health monitoring system dedicated to some of the wind turbines may support O&M with data.

SELECTED REFERENCES

- Planning, procurement and installation of a structural load measuring system for one monopile foundation at Race Bank.
- Extension Offshore Wind Farm in UK.
- Measurement equipment including strain gauges on the foundation have been installed on an offshore wind turbine at Nysted Offshore Wind Farm in Denmark and several analyses have been carried out in order to determine the loads on the turbine caused by waves and wind.
- Planning, procurement and installation of structural load measuring system for one monopile foundation at Borkum Riffgrund 2 Offshore Wind Farm.

INSPECTION

DRONE INSPECTION
Drone inspections offer a new way of working, making it possible to perform fast, inexpensive screenings of large areas.

The drone method offers higher efficiency, saves time and money, reduces traffic interference and minimises risk compared to more traditional methods.

COWI employs a team of highly skilled drone pilots and inspectors with global experience. Our advanced drones make it possible for the inspectors to operate a separate live camera feed, which they can control independently. This ensures that no areas are missed and any damage or defects are registered as the inspectors monitor the structure themselves.

STRUCTURAL HEALTH MONITORING
A structural health monitoring system (SHMS) is essential for optimising inspection and maintenance. COWI's SHMS provides a safe and cost-efficient way for OWF managers to operate the structures with minimal down time.

For structures where a structural monitoring system is considered necessary, COWI can carry out initial analysis for recognised hazards and deterioration mechanisms to map out the requirements for the SHMS.

Our experts are currently researching monitoring strain, deflections and accelerations from drone platforms, thereby reducing the cost of installing permanent sensors and enabling all wind turbines within an OWF array to be monitored.

ROPE ACCESS TEAM
It is essential that inspectors have access to all parts of a structure so that any damage can be detected. It can be difficult, time consuming and expensive to access all parts of the foundation using traditional methods, such as temporary platforms and boat-based inspection. In contrast, rope access is relatively quick, low-cost and efficient.

COWI has an international IRATA-certified rope access team of qualified engineers with an established record of inspection experience in corrosion, steel coating and concrete.

PROJECT EXECUTION

Photo: Petri & Betz

COPILOD AND COSPIN

COPILOD (COWI PIle Offshore Designer) is a proprietary software platform for analysis of wave and wind loaded piles with a focus on primary steel and monopile foundations.

COPILOD was developed during the course of numerous offshore wind projects and has matured into a central tool for structural design and design documentation for any design stage between tender and detailed design.

The central part of COPILOD is its project-specific database, where all relevant data is stored consistently, including input data and calculation results.

COPILOD consists of the following modules:

- ULS stress and buckling design checks according to various codes and standards
- FLS design checks for damage-equivalent sectional forces and Markov matrices according to various codes and standards
- Natural frequency analysis
- Generation of structural steel drawings directly using data out of the central project-specific database
- Generation of overview drawings directly using data out of the central project-specific database
- Generation of design documentation, e.g. appendices for design reports comprising relevant information on pile geometry, soil conditions and calculation results.

COSPIN (COWI SOIL PILE INTERACTION)
COWI Soil Pile INteraction (COSPIN) is a state-of-the-art tool for analysis of wave and wind-loaded piles, primarily for offshore wind turbine foundations.

COSPIN consists of a number of modules which allow easy design of laterally and axially loaded piles. It handles every aspect of the design process, from initial design soil profiles in simple ASCII-format to vast data amounts stored in a central project-specific database shared with COPILOD.

The routine has the most widely used standard soil-pile response curves incorporated. However, the open user interface allows easy input of modifications as well as custom curves. Pile deflections, soil utilization rates and internal forces are easily calculated.

RELIABILITY
In order to ensure data consistency throughout the design process a central project-specific database is used interacting with the software tools.

FLEXIBILITY
All software tools can be easily adapted to project-specific needs based on their project-specific setup.

INNOVATION
Latest technical developments can easily be incorporated into the software tools based on their modular structure.

Photo: Bladt

COWAL
(COWI WAVE LOADER)

One of the major load components on offshore wind turbine foundations is the hydrodynamic load due to waves and current. COWI has developed the software tool COWAL (COWI WAve Loader) which is a tool for load calculations on offshore structures.

COWAL provides the time and spatial hydrodynamic loads based on a Morison formulation. COWAL also includes advanced features like diffraction effects and wave breaking taking into account the overall geometry of the structure as well as secondary elements like boat landings, ladders, anodes and J- tubes. Marine growth is also taken into account when calculating the loads.

Requirements given in governing standards by DNV-GL and IEC are incorporated in COWAL.

In most projects, the hydrodynamic loads are exchanged with the turbine provider as input to a complete dynamic model. COWAL delivers load time series in any format specified by the turbine manufacturer.

COWAL applies either regular nonlinear waves (based on the stream function theory) or irregular waves (based on a wave spectrum) to model a given sea state. COWAL can also embed a nonlinear regular design wave in an otherwise irregular sea state.

SELECTED REFERENCES

- Calculation of wave loads for the integrated load analysis using COWI's in-house program COWAL for the Hohe See Offshore Wind Farm in Germany.


Together with our customers,
we create coherence in tomorrow's
sustainable societies through
our unique 360 approach.
Explore us more at
www.cowi.com/offhorewind

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POWERING YOUR 360° SOLUTIONS
COWI is a leading consulting group that creates value for customers, people and society through our unique 360° approach. Based on our world-class competencies within engineering, economics and environmental science, we tackle challenges from many vantage points to create coherent solutions for our customers – and thereby sustainable and coherent societies in the world.

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