



# MARINE RENEWABLE ENERGY



Fugro provides integrated services for all phases of Offshore Renewable Energy Developments, these include:

- Desktop and Feasibility Studies,
- Site Investigations,
- Foundation Engineering
- Marine Construction Services
- Systems Performance Evaluation

Metocean services are integrated in all steps of the Project

- Desktop and Feasibility studies: collection of existing data relating to seabed and sub-seabed structure including the analyses of metocean data, geo- and man-made hazards, assessment of fishing activities, permitting & restrictions and environmental impacts. DTS provide recommendations for site location and propose preliminary soil parameters for foundation pre-selection. GIS format is currently used.

- Site Investigations: Metocean tailored measurement campaigns, geophysical surveys and geotechnical investigations (drilling, coring, in-situ testing) ) are performed from jack-up platforms and dedicated geophysical and geotechnical vessels. Specific geophysical tools (seismic refraction, resistivity) for cable route surveys are also proposed by Fugro.

- Foundation Engineering: foundations and anchoring systems design, power forecast and optimisation of installation period from modelled data.

- Marine Construction Services: real-time wind, wave, tide measurements, weather forecasts, provision of jack up / construction support vessels. Meteorological mast installations, foundations, monopile and transition piece installations. Large diameter drilling services (up to 6 metres). Pile monitoring. Measurement and monitoring of acceleration, displacement, strain load, fatigue, and performance parameters.

- Systems Performance Evaluation: real-time Metocean measurement systems, including CCTV and environmental parameters.

Fugro is a global service company that provides geotechnical, environmental, survey and positioning services on land, at sea and in the air. Organisationally, Fugro is highly decentralised. It operates through three divisions, Geotechnical, Survey and Geoscience. Fugro supports its clients in their search for natural resources and the development, production and transportation of those resources. Fugro also provides its clients with technical data and information to enable structures and infrastructure to be designed and constructed in a safe and efficient manner.



Fugro's clients operate in many different locations and under many different conditions. To be able to meet their needs in the best possible way, Fugro's organisational structure is decentralised and market-oriented. Highly-qualified specialists work with modern technologies and systems, many of which have been developed in-house. Data collection equipment includes around fifty vessels, forty jack-up platforms, hundreds of CPT (Cone Penetration Test) and drilling units, approximately fifty aircraft and helicopters, more than one hundred ROVs (Remotely Operated Vehicles), and four AUVs (Autonomous Underwater Vehicles), as well as advanced (satellite) positioning systems. Early 2009 Fugro had more than 13,000 employees stationed in over 50 countries

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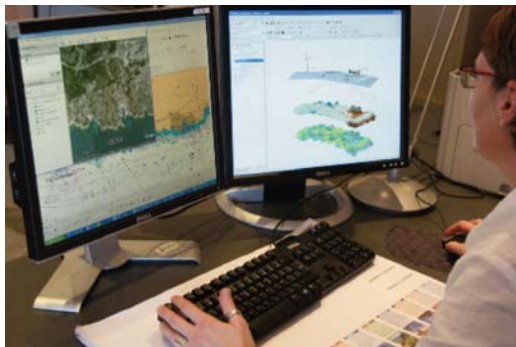


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## Desktop and feasibility studies

In the Offshore Renewable Energy domain – either for windmills or bottom-mounted turbines - the **appropriate site selection and the optimization of the structure foundations** are of paramount importance. **Desktop studies, geophysical / geotechnical investigations and feasibility studies** are successively carried out to optimize the project and to assist the client decision-making.

As a first round of information gathering, a **desktop study** is completed on a large area encompassing the proposed project site. The aim of such a study is to gather **meteorological** (wind force and direction, air temperatures, favourable / adverse weather windows, etc) and **oceanographic data** (strength and direction of waves, currents and swell, tide regime and range, etc). **Bathymetry and morphology** of the seabed is also thoroughly assessed as the geological framework is essential especially relating to the **seabed sediment consistency, sub-seabed lithology and structurology** and the **critical geohazards** that may arise from the local geology (faulting, outcrops, steep slopes, seismicity, etc).



**Man-made related activities** are then documented this include **fishing** (fishing grounds, vessels and gears used, fishing periods, resources, etc...), **shipping traffic** (main lines, ferry activity) and **leisure activities** (type and period, future developments). Other man-made related limiting factors could include the occurrence of existing structures on the seabed or in the water column (**cables, pipelines, fish aggregated devices, etc**), natural resources currently exploited or any planned project.

**Restricted areas**, either for navigation, work or installation should be carefully documented, including navigational restrictions. **Environmental factors** and protected areas will be considered.

Lastly, the **permitting** aspect of the project should not be neglected and will require an exhaustive interview of the relevant authorities for, not only the basic authorisation sand fees, but to also determine any possible delay in obtaining permits (either for survey, installation or maintenance). At the completion of this desk top study, **the most convenient site should be proposed**, balancing the favourable aspects and the limiting in view of meeting the Client requirements.

## Site Investigations

In a second phase of the project, detailed geological, geophysical and geotechnical information, on the selected site, should be obtained to support the recommendations for the structure foundations. A basic **geophysical survey** will provide full coverage of the site using analogue tools such as **multibeam echo-sounders** and **side scan sonars**, to refine the **bathymetry** of the area and the **seabed morphology**. The major asset of this analogue geophysical survey is to map the seabed heterogeneities (outcrop and hard material patches), the **surficial sediment figures** (excessive slope gradient, sand waves, ribbons and furrows) and the **obstructions**. The analogue survey can be advantageously completed by a **magnetometric survey** in order to locate **potential buried unexploded ordnances**.



Investigation of the sub-seabed layers is achieved by carrying out **reflection seismic survey** with various tools depending on the required depth of penetration: sub-bottom profiler to +/- 10m, sparker or boomer to +/- 60m. For deeper investigation (100- 200m), **Ultra High Resolution multi-channel digital seismic** is the ideal tool. The aim of a reflection survey is to assess the layer thickness, series structure and seismic facies related to lithology. Initial sampling is through a grab sampler or piston corer during the geophysical surveys. These data are required for surficial ground truthing and calibration of geophysical data. Geotechnical investigations for foundation engineering involve **heavier means and combine in-situ testing and deep penetration drilling/sampling**.

Using specialised vessels like the **Fugro Commander**, Fugro provides resources to rapidly carry out deep (**40m**) **PCPT** (PCPT screening) at the facility locations in order to provide initial geotechnical design data at an early stage, and allow clients to focus their drilling budgets economically i.e. where PCPT has not reached required depths or identifies geotechnical difficulties. PCPTs are typically employed for Wind Energy facilities with high numbers of installations.

Once the PCPT screening has been completed, and detailed geotechnical drilling needs have been identified, Fugro can supply **geotechnical drilling solutions** for all **water depths, ground conditions and metocean exposure expectations**.

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During geotechnical drilling Fugro can carry out **borehole drilling (coring or soils boring)** in order to provide further geotechnical data using **wireline geophysics (P&S wave seismic velocity logging included)**, **downhole WISON CPT and WIP sampling, high pressure dilatometer.**

Final choice for a vessel or jack-up platform is based upon the metocean and ground condition assessment and Fugro offers all types of marine support with a range from:

- Shallow water (5 – 20m), and relatively sheltered: **medium to large jack-up rigs**
- Medium water (12 – 30m), and moderately sheltered: **Fugro Commander DP vessel, 4 points anchoring vessels**
- Deeper water (25m – ocean depth), fully exposed: **one of Fugro's dedicated geotechnical drill ships: Bucentaur, Bavenit or Gargano.**



To provide data for **cable burial assessments, cable protection design, and optimum economical route to shore facility**, Fugro undertakes **shallow seabed CPT / Vibrocoring sample recovery**, the latter in order to conduct **thermal conductivity testing especially**. In the inter-tidal zone and onshore landing areas Fugro can carry out **geotechnical investigations (boreholes, trial pits, land CPT)**

In addition to standard geophysical and geotechnical campaigns, **specific survey tools** can be proposed for a detailed sub-seabed layers classification. The principle of these surveys is to characterize soil layers by parameters which can be directly correlated with physical or mechanical soil parameters. This covers **electrical resistivity (related to porosity), compression waves velocity (related to sediment compactness) and shear waves velocity (related to small strain modulus Gmax)**. Those survey tools are limited to 15m penetration and have a low daily production rate.

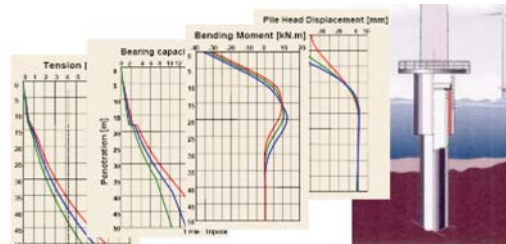
## Foundation Engineering

Design of structures foundations and soil/foundation/structure interactions analyses are key phases for offshore Renewable Energy systems. These systems are in essence installed in locations where the environmental loads are severe and the consequences on the foundation design and on the related costs may compromise a project development.

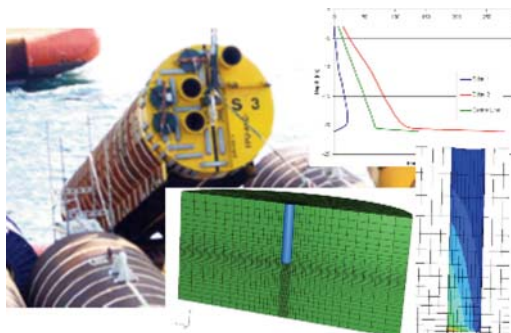
The **dynamic response and fatigue behaviour of the soil-foundation system** may also be a critical aspect and should be carefully investigated.

The foundation design process in the Fugro engineering companies begins with a full and extensive **integration of all soil data** acquired during the various surveys, complemented by the **soil laboratory test results**. The objective of this phase is to establish a **geological and geotechnical soil model** which will be utilised for all design and interaction analyses. The soil model will assess the spatial variability of the stratigraphic layers. It will identify and characterise all features and heterogeneities which may affect the behaviour of the foundation. **Soil design parameters** including static resistances and stiffness shall be defined in the soil model for all significant soil layers. Whenever possible, the soil design parameters are established using **geostatistical methods** and the reliability of each parameter is calculated. Cyclic, dynamic and fatigue soil parameters are also determined from **advanced laboratory testing** such as cyclic triaxial and resonant column.

During the early stages of the project, Fugro advises the project developer on the choice of the best suited type of foundation, using the desktop study results complemented if possible by preliminary soil investigation. Preliminary foundation sizing is also performed.



The final foundation design and soil/foundation/structure interaction analyses are performed once the full soil model has been set up. It necessitates a **very close cooperation between the geotechnical engineers and the structural engineers**, particularly for the dynamic response analyses.



The Fugro Geoconsulting group has a full range of well established design methods and tools which covers all standard foundation types: drilled and grouted piles, driven tubular steel open piles, gravity concrete bases, suction emplaced caissons or anchors, any type of temporary or permanent mooring system. These methods are based on recognized analytical procedures as well as on sophisticated numerical analyses for complex configurations.

Fugro soil mechanics engineers have the skills to develop **new methods and numerical tools** for all innovative foundation solutions proposed by the developer.

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Fugro's expertise and assistance also applies for foundations and cables installation e.g.:

- pile driving predictions and installation monitoring,
- evaluation of suction pressures required for caisson penetration and supervision of installation,
- assessment of cable burial conditions, selection of adapted burial tools, prediction of performance rate.

Fugro is one of Europe's foremost specialists in the field of challenging marine construction with 30 years experience in the operation of jack-up platforms. The in-house fleet now comprises 15 platforms ranging from 40 – 4,000 tons. Each of these jack-ups can be used as a stable working platform for construction operations in the harsh marine environment. Fugro strength lies in a proven capability to design and build project-specific equipment which has been used on several occasions to complete world first engineering achievements, e.g. Fugro Seacore constructed Europe's first offshore windfarm in Sweden in 1997 and have just completed the world's largest vertically drilled marine riser shaft at approximately 6 metres diameter.



Fugro specialist activities are always centred around its capabilities as an overwater drilling contractor and always include highly detailed planning and engineering and close liaison with the clients to ensure success. A large proportion of projects involve the installation of large diameter monopode foundations, e.g. offshore wind turbines, meteorological masts and marine current turbine foundations.

## Metocean

Marine structures require information on the environment in which they will operate, specific to the particular energy source they seek to harness, whether it is winds, currents or tides. Fugro can provide this information throughout the life of a renewable energy installation.

Right from the feasibility stage of a project, Fugro can provide information on the region's climatology, while a review of the existing wind, wave, current and tide level data for the site can provide early screening for suitable areas and concepts. As the project takes shape more detailed data will be required for designing the structure:

- What are the 100-year extreme values for wave heights or wind speeds?
- What is the best time of year for installation?
- What is the forecasted power output from the installation?

Fugro's expertise lies in providing cost-effective solutions through statistical analyses using a combination of carefully-tailored measurement campaigns and hindcast data. During installation, Fugro can provide real-time data on important parameters, such as wave conditions or tidal height that can be crucial to a successful installation, as well as weather forecasts to help with the planning of the installations. Once the installation is operational, real-time measurement and structural monitoring systems, including CCTV and environmental parameters, provide essential data on the performance of the site and its operation and any strain or fatigue. Specific metocean concerns for the marine renewable energy sector are outlined below.

## Wind Energy

Wind conditions at the site are critical to the turbine's performance as well as its structural integrity. Current, tide and wave interactions around the prime locations for wind turbines (e.g. offshore sandbanks, reefs and mudflats) are known to be complex. In extreme situations, current and wave conditions at the site may result in scouring and erosion at the turbines' foundations. Where existing data is sparse or non-existent Fugro can supply the sensors to measure these factors and monitor conditions after the installation.



## Wave Energy

Fugro maintains an extensive global database of wave data from buoys, platforms, satellites and numerical models. These data have been integrated globally into our WorldWaves package. In conjunction with state-of-the-art models these data can be used to optimise the location of the wave energy generators within the local bathymetry. While it is often sufficient to use existing data sources and models for feasibility studies, it is usually essential to make at least a few months of sitespecific measurements to ensure that wave criteria used for engineering purposes are fully validated. In particular, measurements during the winter months are essential for validating statistics towards the extremes of likely conditions.

## Tidal Current Energy

number of depth-averaged current velocity models are available worldwide and it would be appropriate to access these data to provide an early indication of the feasibility of projects. These data would probably be sufficient to test whether the general location of a generator site is viable. Moving beyond the feasibility stage, it is recommended that site-specific measurements be made for energy output calculations, to determine the financial viability of the project, and for the engineering design. And, as with the installation of any structure offshore, Fugro can provide real-time information on the waves, tides and currents to help ensure a successful and safe outcome.

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