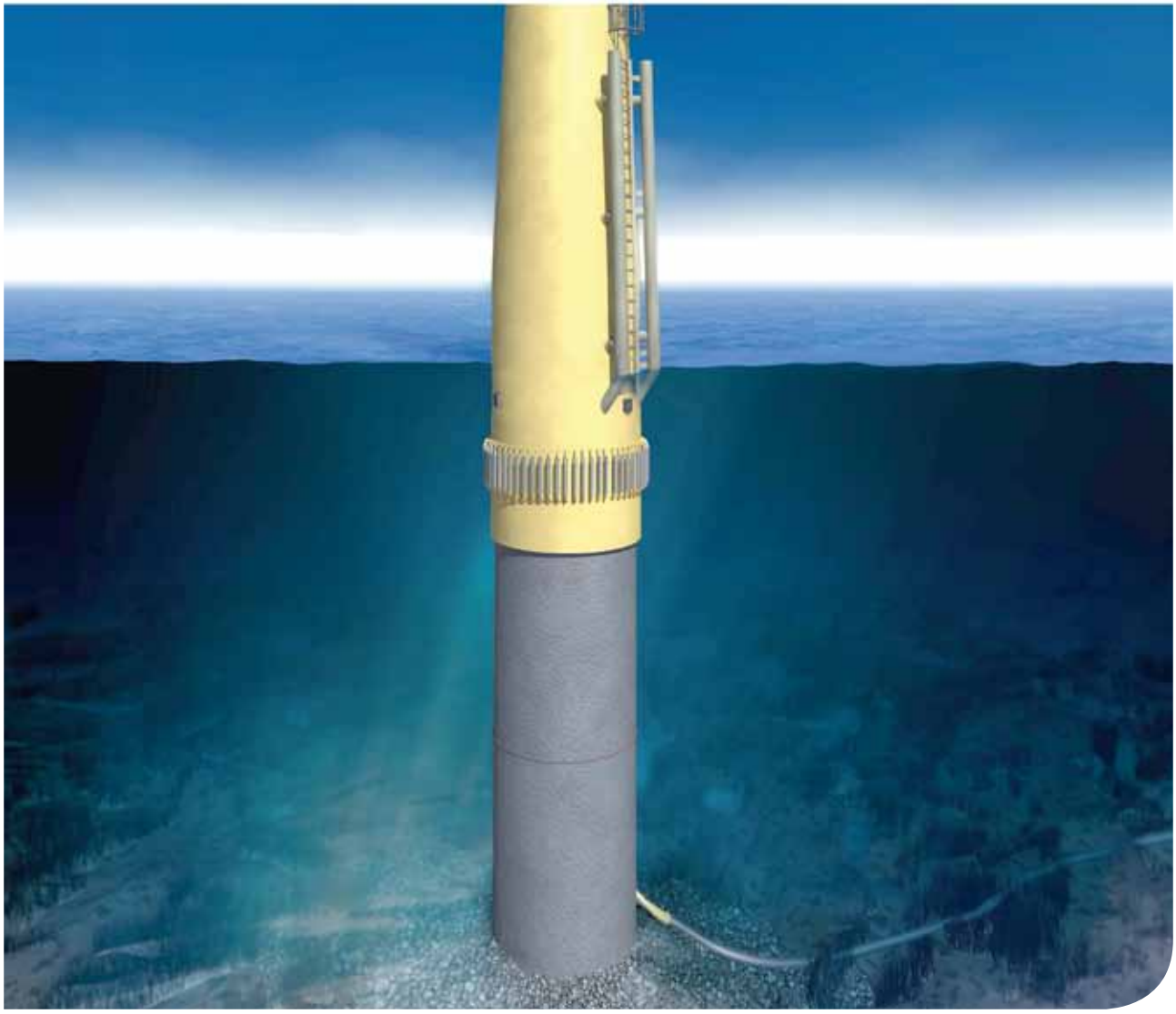
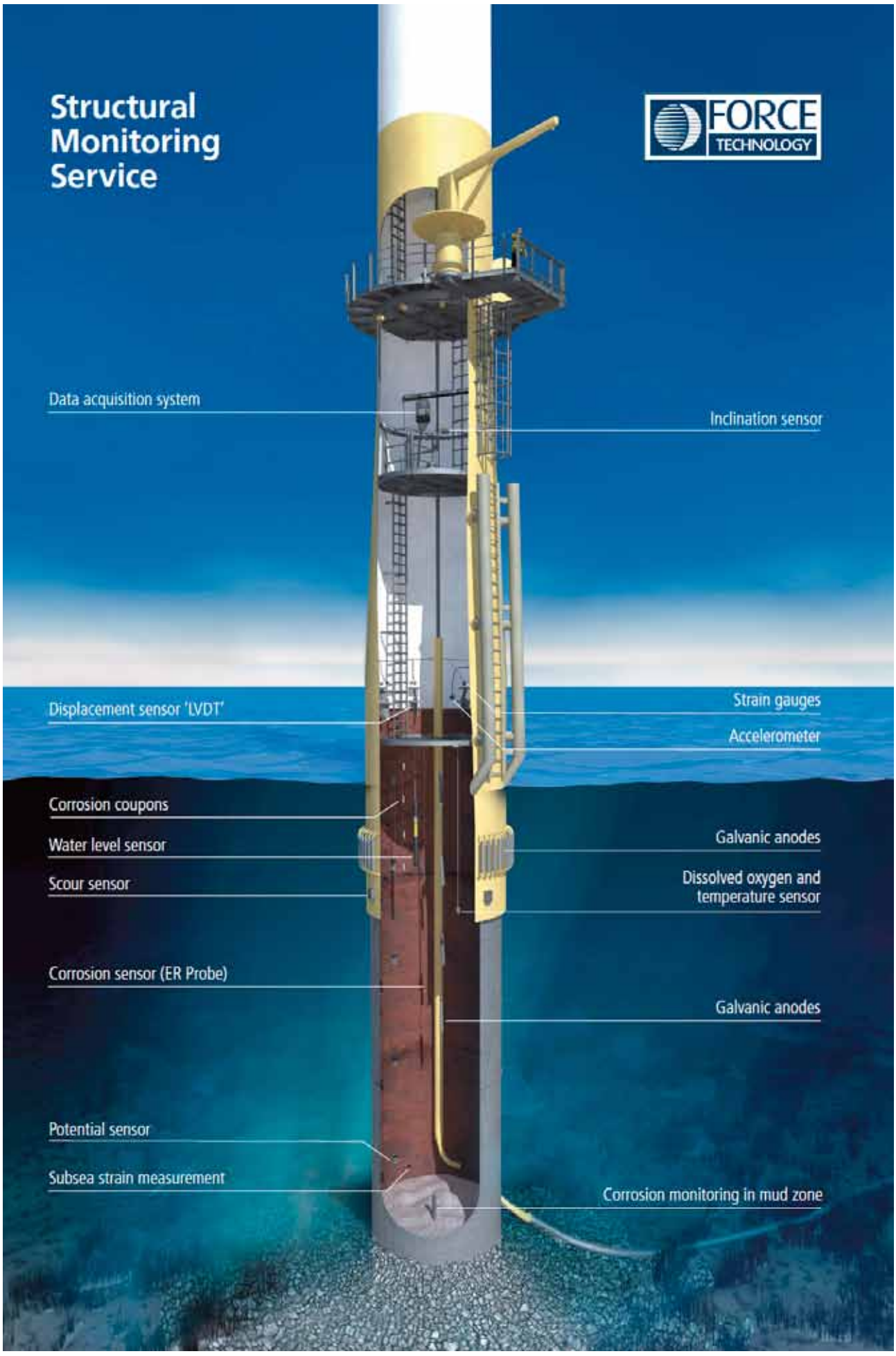
Online Monitoring of sub-structure



Structural Monitoring Service

FORCE TECHNOLOGY



Why Condition Monitoring in the structure?

Preventive maintenance, also known as planned or scheduled maintenance, is the most commonly used maintenance strategy within the offshore industry today.

When using preventive maintenance on your offshore assets, you assume that the lifetime of your turbine is known, and that you can perform overhauls in time, so that the turbine will not fail.

In reality it is not always as easy as this. As other parts in the turbine fail randomly, concerns about the offshore foundations have been seen lately, and the financial loss when corrosion or fatigue failure in the structure occur is significant in this part of a turbine, and much higher than the investment required for an online condition monitoring system.

Condition Monitoring is installed for systematic data collection and evaluation to identify changes within the structural part of your turbine, so that remedial action may be planned in a cost-effective manner to maintain reliability.

Condition Monitoring using **dedicated techniques (critical areas) to detect changes in operating conditions**. Many failure modes have measurable responses and develop over a period of time. These are the ideal applications for Condition Based Maintenance.

Condition Monitoring **gives early warning of potential failure.**
If the measured parameters are well chosen and properly measured and analyzed, valuable information will be gained for maintenance planning purposes, and severe variations can be taken care off immediately.

Condition Monitoring **gives information about the nature of the failure.**
From this a prognosis can be determined. The rate of sampling and access to maintenance history on the machine may have an influence on the quality of the final decisions made.

Condition Monitoring **evaluates corrective action.**
Collected data will be of great benefit for any design correction or optimization of the existing engineering design.

Summary

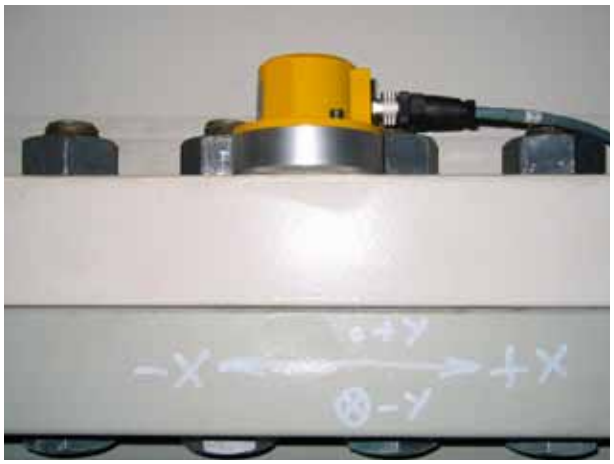
Condition Monitoring when used to drive reliability improvement offers diagnostics, information and data for Root Cause Analysis and equipment redesign, along with verification of defect or design correction. Condition monitoring applied proactively is a context embracing world class reliability maintenance concepts when using Condition Based Maintenance.

Strain/stress measurement

Strain measurements may be of interest for several reasons: E.g. to clarify whether the design load assumptions are correct, to calculate the fatigue load of the transition piece and foundation, to determine the eigenfrequencies of the structure etc.

In accordance with these reasons, strain gauges are often installed at locations on the structure identified as fatigue critical or with high risk during the design stage. At these locations, strain - i.e. stress - is measured and analysed, e.g. stress cycles are counted by rainflow counting to track the fatigue damage accumulation over time. Following sensors can be offered:

- Strain gauges



Acceleration and inclination

The dynamic behavior of a structure is often extracted from strain measurements. However, continuous dynamic monitoring - i.e. monitoring of the vibration levels, resonant frequencies and damping values of the fundamental modes of the foundation structure - is also possible by measuring accelerations.

Furthermore, measuring the inclination at well-defined locations may also bring valuable knowledge about the structure.

Following sensors can be offered:

- Accelerometer
- Inclinometer

Differential settlement measurement

In some cases it may be advantageous to measure vertical/ horizontal displacement or load. For instance monitoring the loads absorbed by a grout connection between transition piece and foundation, some relative displacements and/or some loads may be measured. A few examples:

- Measurement of vertical displacement of transition piece relative to foundaton.
- Measurement of contact force applied to the stoppers (if displacement may become critical and there is contact between stopper and monopole).

Following sensors can be offered:

- LVDT (Linear displacement sensor)
- Optical laser sensor (Linear displacement)
- Load cell

Dissolved oxygen

Many foundations have been designed under the assumption that no replacement of seawater occurs in the closed compartment. However, experience has shown that seawater may enter the monopiles to a varying degree through e.g. the J-tube gasket.

The renewal of oxygen should preferably be monomonitored using a dissolved oxygen probe because this substance represents the driving force for corrosion. Systems for permanent monitoring have been supplied to several offshore wind farms.

Inspections using a specially designed measurement rack are also offered for "depth profiling" of dissolved oxygen and other key environmental parameters of the water column inside foundations.

Cathodic protection

Monitoring of the cathodic protection (CP) is often requested due to uncertainties about regional and tidal effects on the outside, and effects from site-dependent microbiology, sediment composition and aeration of seawater on the inside. FORCE Technology can provide specially designed probes that ensure that the protection criteria are met, thereby avoiding over-protecting the structure which could cause hydrogen damage or excessive gas evolution. CP monitoring is based on potential measurement with durable reference electrodes and/or probes measuring the actual corrosion rate of the protected steel. The protection current running between the structure and the sacrificial anodes is also recorded as this parameter provides valuable information about development in corrosive conditions as well as anode consumption. FORCE Technology has installed permanent monitoring systems in foundations in several offshore wind farms.

Mud Zone Corrosion

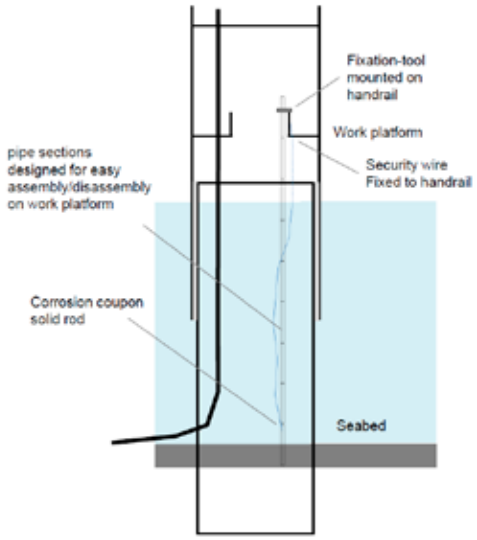
The mud line inside monopile foundations may represent a risk of highly localised corrosion due to the combination of bacterial activity in the mud and macro galvanic elements between the oxygen-containing bulk media and the oxygen-depleted mud zone. There is no straight forward and standardized way of measuring corrosion in mud lines, and exposure of simple coupons may overlook critical effects.

FORCE Technology provides specially designed probes such as full-length corrosion coupons or real-time monitoring devices that assess the risk of macro galvanic effects, microbial corrosion (MIC) or hydrogen-induced stress cracking (HISC).

Corrosion monitoring

This monitoring system allows continuous monitoring of the corrosion rates, corrosion potential and performance of cathodic protection systems inside the monopile foundation. Important environmental parameters are measured as well for correlation with the obtained corrosion data.

- H_2 sensor
- H_2S sensor
- Air temperature sensor
- Reference electrode
- pH meter
- Water temperature sensor
- Water level sensor
- Dissolved O_2 sensor



ER corrosion rate measurement

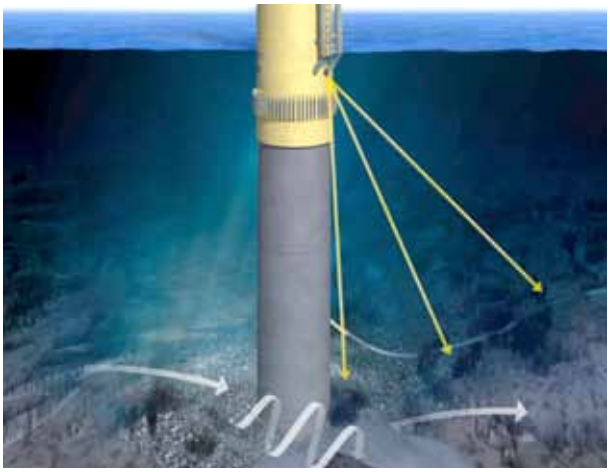
Real-time rate corrosion measurement inside monopiles is offered both for unprotected structures relying on oxygen depletion as well as structures protected by anodes (cathodic protection CP). Well-proven probes based on electrical resistance (ER) are provided for this purpose having a resolution of 0.006 mm/year at daily readings. The technique gives early warning in case of deviating conditions, such as malfunction of CP, acidification or excessive seawater ingress. Apart from corrosion rate, the ER probes provide indirect measurements of the temperature from the resistance measurement of the reference element. The system can be designed to special requirements and integrated with the SCADA system of the operator.

Scour and seabed characteristics

Changes in seabed level (scour) are measured in real-time and relayed back from the field from the sensors.

The Scour monitor is an inexpensive, yet powerful way of getting vital data about dynamic changes over time in bottom elevation around a wide range of physical structures, including monopiles.

FORCE Technology supply services in mounting the devices to the turbine, installing external batteries and initiate the system for getting use of the data immediately after installation. For online data transmission we can supply adaption and integration to the acquisition system or directly to the SCADA system of the windfarm.



Acquisition system

FORCE Technology installs a complete, generic PC-based acquisition system built on a multi-purpose, expandable data logger. In addition, the acquisition system holds several interfaces to dedicated third-party logging systems, e.g. ER- and scour monitoring systems. The acquisition system can be offered as a "stand-alone" system, where communication via WAN, LAN or a traditional GSM modem connection may be used, according to the conditions and requirements on site. As an option, the system can be integrated to the SCADA system of the wind farm, if requested.

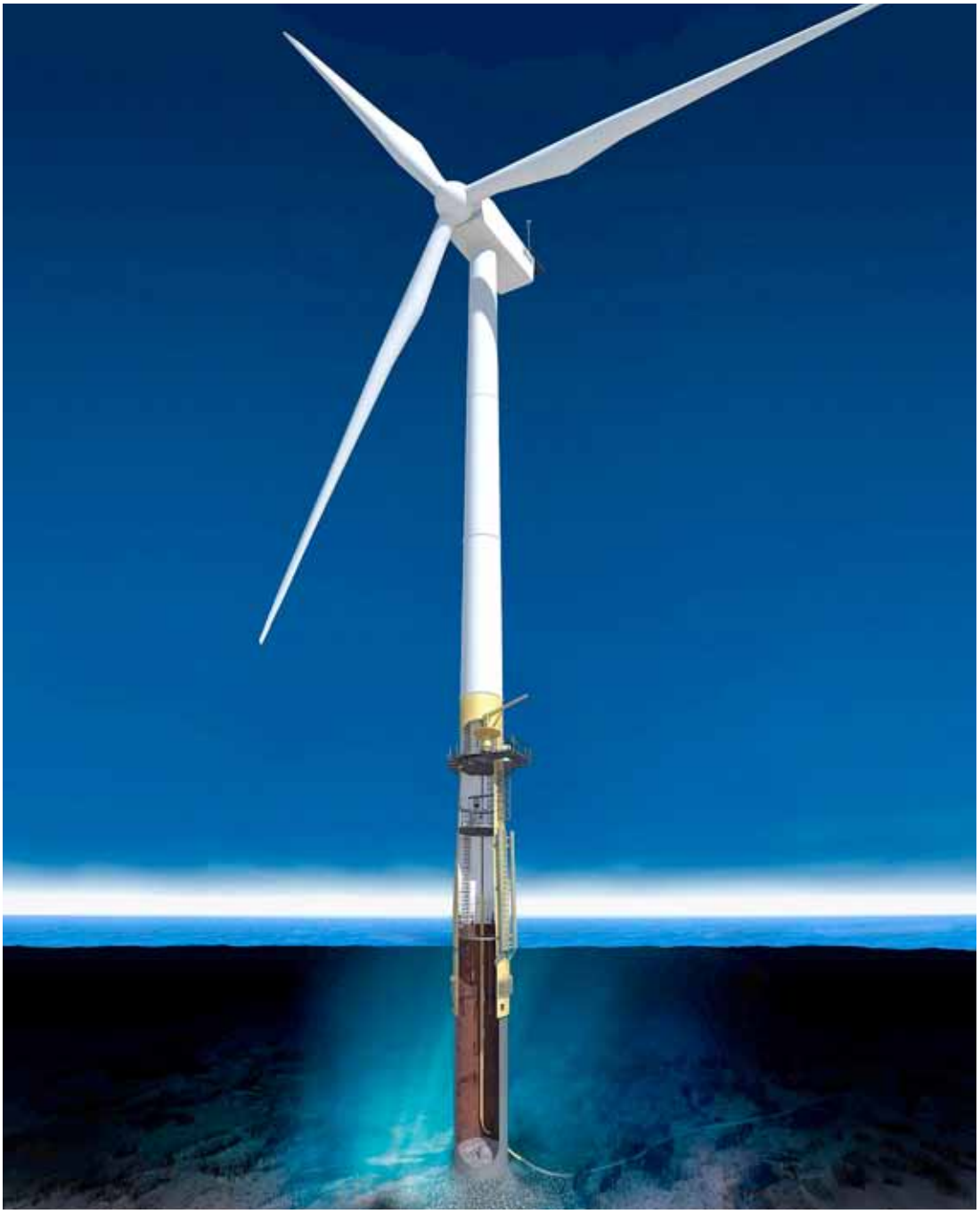
All measurements are, by default, stored or transferred as raw data. However, FORCE Technology also offers automatic post processing of the data, e.g. counting of stress cycles by rainflow counting to track the fatigue damage accumulation over time. The acquisition system is designed for installation above the airtight compartment.

Customized solution

FORCE Technology offers customized full service solutions of the Condition Monitoring Systems, starting from preliminary studies to design and guidance related to selecting locations of interest using appropriate sensors and instrumentation to suit individual project requirements for the installation of the monitoring system on-site, collecting and analyzing data and customer reporting.

Our data is quality controlled and presented according to the client's requirements. Performance of evaluation of e.g. fatigue life either with reference codes or by means of fracture mechanical calculations can also be offered if required.

	Online Monitoring of sub-structure	Strain measu-rement	Displace-ment (grout)	Accele-rometer	Incli-nation	Hydro-gen	Water level	Disolver oxygen (DO) + temp	pH	Corro-sion	Effiency of CP system	Anode current	Erosion of sea-bed	Wave hight	Water current
Date	Offer														
2009	Lost	X		X											
2009	Delivered	X													
2010	Delivered	X	X		X										
2011	Delivered	X	X		X										
2011	Delivered	X													
2012	Delivered	X													
2012	Delivered	X													
2012	Delayed									X					
2012	Delayed	X	X	X	X					X	X			X	X
2012	Delivered	X	X		X		X	X		X			X		
2012	Lost	X	X		X	X	X			X	X		X		
2012	Delivered									X					
2012	Lost		X												
2013	Offered	Sub													
2013	Delivered								X		X	X			
2014	Offered	X	X		X		X			X			X		
2014	Offered	X	X					X							
2014	Offered	X													
2014	Offered								X			X			
2014	Offered					X		X	X	X	X	X			



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