PO.ID 201

Foundation Monitoring Systems for optimized O&M and lifetime assessment

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Abstracts

The **Offshore Wind Infrastructure Lab (OWI-lab)** has a mutual partnership with **Parkwind** to perform **foundation monitoring**. A first monitoring system, which is installed on a monopile foundation of a 3 MW Vestas turbine at the Belwind wind farm, has now been running for almost two years. Recently two additional monitoring systems were installed at the Northwind wind farm. The **motivation** is **gaining the insights** that are crucial to **minimize construction and installations costs** of the future planned wind turbines at the Belwind concession and to **extend the lifetime** of existing structures and **reduce** their **operation and maintenance costs**.

Offshore Wind Farms

The foundation monitoring system has been installed at the Belwind and NorhWind windfarm in the Belgian North Sea.

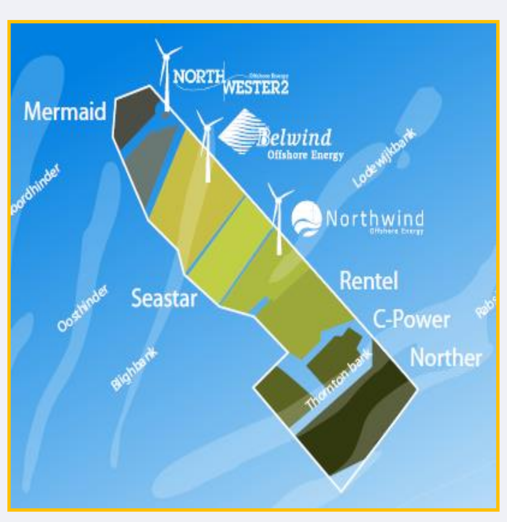


Figure 1: Belgian offshore wind-farm-concessions

Facts Belwind: 55 Vestas 3MW V90 turbines, Monopile foundations, 46 km offshore, Water Depths : 16 – 30m

Facts Nothwind: 72 Vestas 3MW V112 turbines, Monopile foundations, 37 km offshore, Water Depths: 16 – 29m

Approach

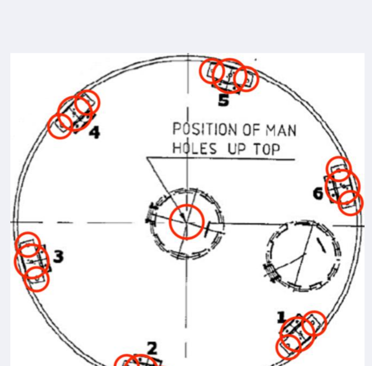
The purpose of the monitoring campaigns at the Belwind farm and the Northwind farm is to get a precise view of how the wind turbine is changing over time and what causes the changing behavior. Several parameters are being monitored, among them:

- **Loads**, **displacements**, **strains** and local **temperatures** in the grouted connection
- **vibration** and **strain** levels on tower and foundation
- resonance **frequencies**, **damping** values and **mode shapes** of the offshore structure
- **oxygen levels** and **corrosion rates** inside the monopile
- …

Grout Monitoring

The grout monitoring consists of the continuous monitoring of the loads taken by the grout connection and the relative displacement between the monopile (MP) and the transition piece (TP). Those parameters are necessary to see if the grouted connection is deteriorating. Following sensors have been installed:

- •12 displacement sensors
- •6 load sensors
- •1 temperature sensor



The most important observation made by the monitoring system was the confirmation that the transition piece was indeed slipping downwards on the monopile foundation as a result of the failing grout-connection.

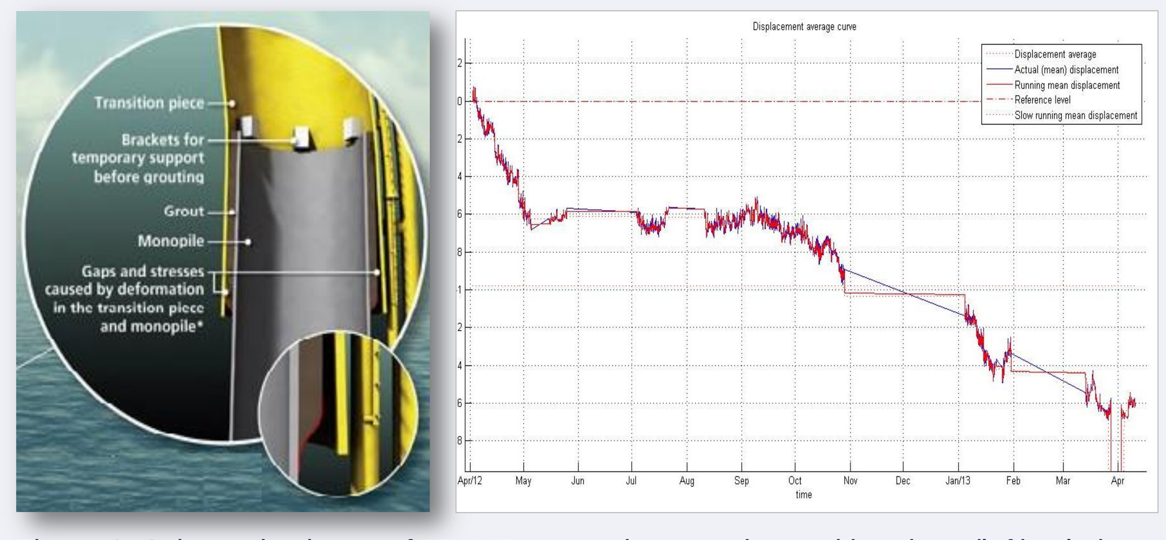


Figure 2: Schematic picture of TP, MP, grouted connection and brackets (left) relative displacement between TP and MP during monitor period (right)

Retrofit installed brackets and bearings now prevent the transition piece to completely slip downwards. The monitoring system however continues to measure the slippage of the transition piece and the loads taken by the installed brackets and bearings.

An advanced grout monitoring system has recently been installed in two turbines of the Northwind wind farm. This system will allow to measure the strains inside the grout. This will be done by using optical strain sensors embedded in reinforced bars that have been installed inside the grout during installation.

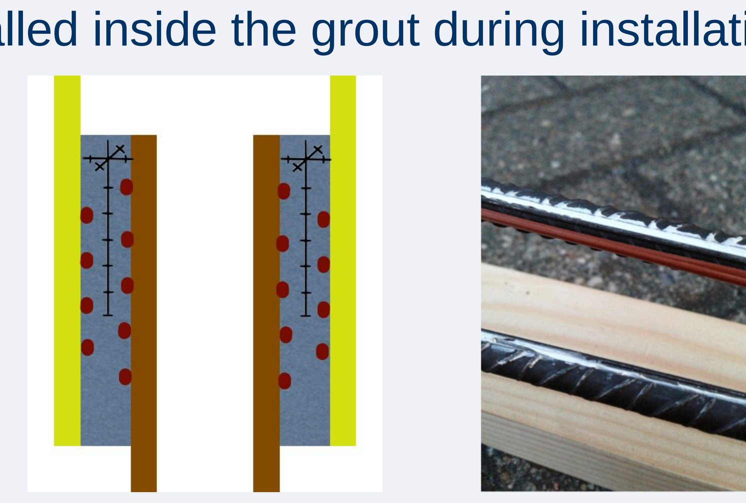


Figure 3: Setup for strain-monitoring inside the grout (left) optical fiber embedded in reinforced steel bar (right)

Dynamic Monitoring

The dynamic monitoring consists of the continuous monitoring of the vibration levels, resonant frequencies and damping values of the wind turbine structure.

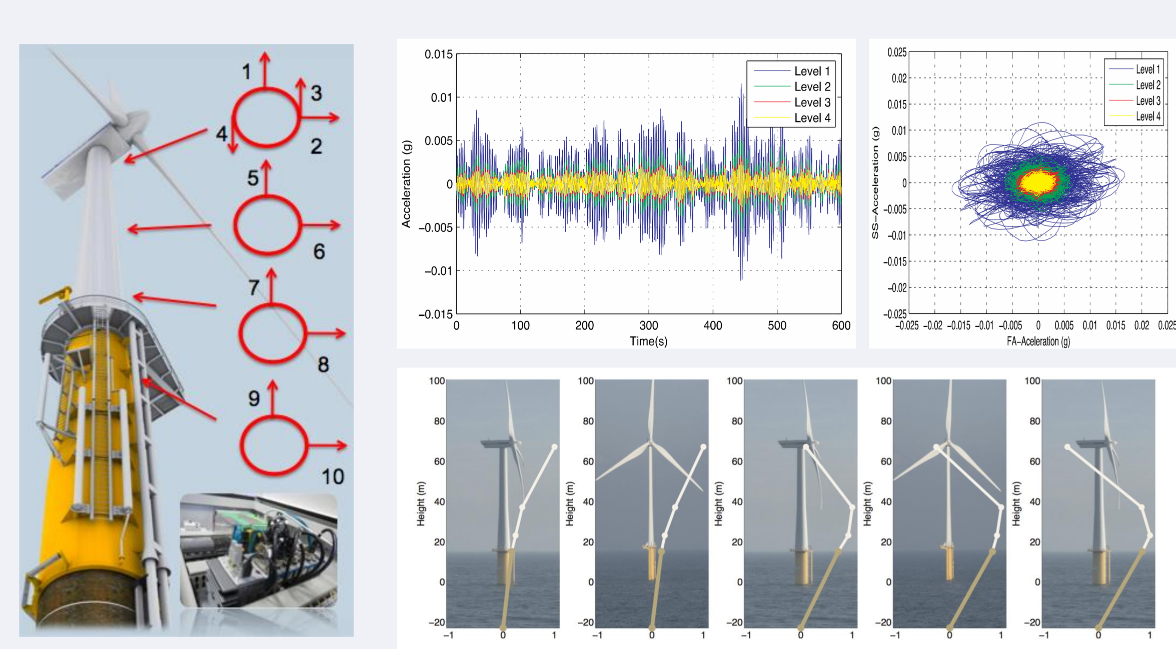


Figure 4: Measurement locations accelerometers (left) example measured vibrations during 10 minutes (top right) 5 dominant mode shapes during parked conditions

The dynamic monitoring solution is able to detect daily variations in the vibration levels due to changing ambient conditions e.g. wave periods, wind speed and wave heights. Also small changes in resonant frequencies due to e.g. tidal level are detectable. These parameters can be exploited to asess structural integrity of the offshore wind turbine and detect changes in the dynamic behavior due to e.g. scour. Real damping ratios are very difficult to predict by numerical tools and therefore measurements on existing offshore wind turbines are crucial to verify the existing design assumptions. Damping ratios are crucial for lifetime predictions as the amplitude of vibrations at resonance are inversely proportional to these ratios.

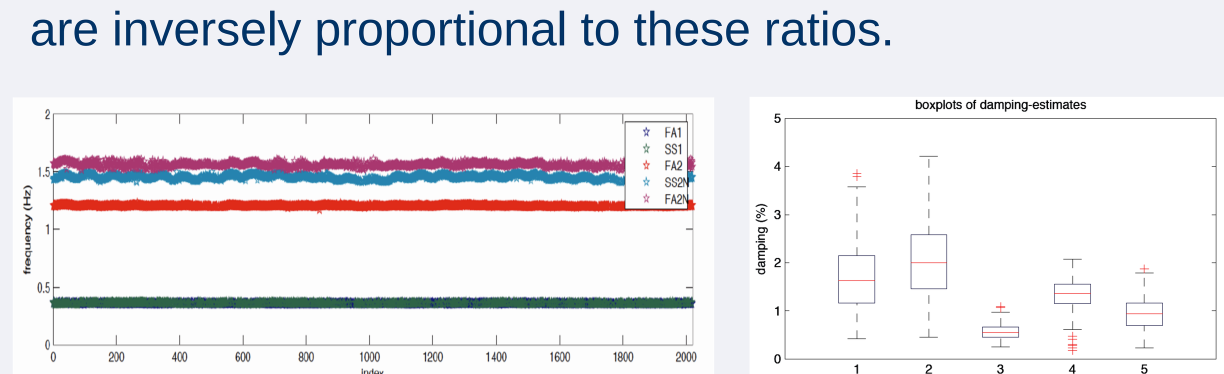


Figure 5: Evolutions of resonance frequencies of 5 dominant modes during 2 weeks of parked conditions (left) Statistics of damping values of 5 dominant modes during parked conditions with wind speeds of 0-5m/s

Corrosion Monitoring

The corrosion monitoring consists of the continuous monitoring of the corrosion rates, corrosion potential and oxygen concentration inside the monopile.

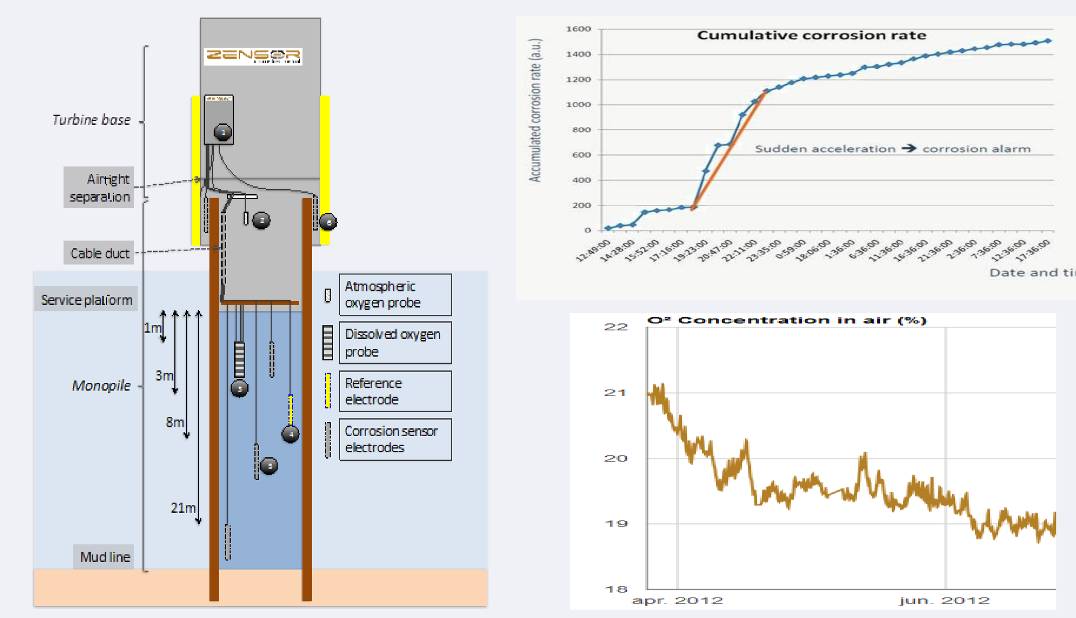


Figure 4: Measurement setup corrosion monitoring inside monopile (left) example measured corrosion rate (top right) example measured oxygen level (bottom right)

Corrosion management inside the monopiles has been based on the assumption that no oxygen is present within the confined space of the monopile. The monitoring-setup at Belwind has however been able to detect that the level of oxygen inside stays high. Based on installed electrodes that are lowered inside the monopile structure measurements of corrosion rates at multiple depths are conducted. These measurements confirmed that active corrosion is present inside the monopile. It is currently being investigated how the corrosion management for these type of structures needs to be adapted and how the presented monitoring system can play a crucial role within this.

Life Time Assessment

Continuous monitoring of stresses is essential for life time assessment. Direct measurements of the stresses at the e.g. the mud-line, 30 meter below the water level are expensive and practically unfeasible. In this case a response estimation techniques will be used to estimate the response at unmeasured locations by combining a limited set of response measurements (accelerations, strains, etc.) and a Finite Element (FE) model. The FE model will be updated based on the dynamic properties identified by the dynamic monitoring system.

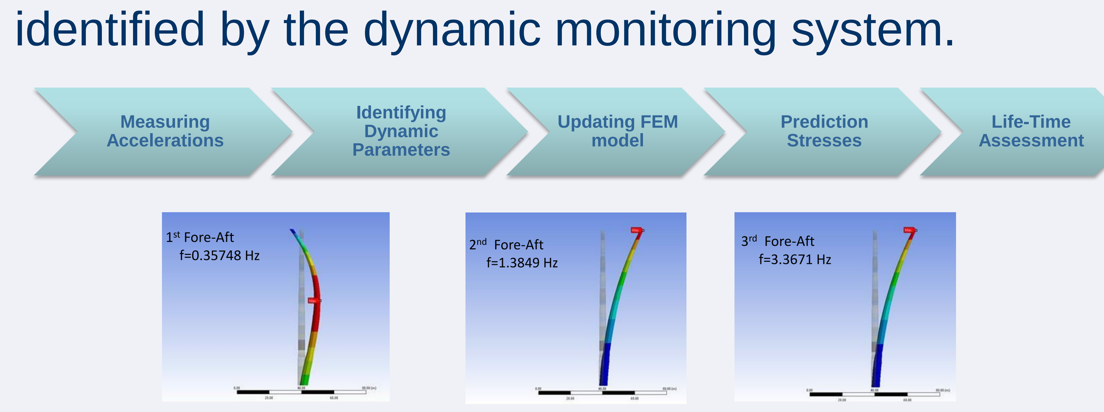


Figure 6: work-flow for life-time assessment (top) First 3 tower modes from FE-model

O&M Optimization

The final step is to combine the output of the foundation monitoring system with the weather data and the business plan to achieve an optimal and informed decision to plan O&M activities on the foundations.

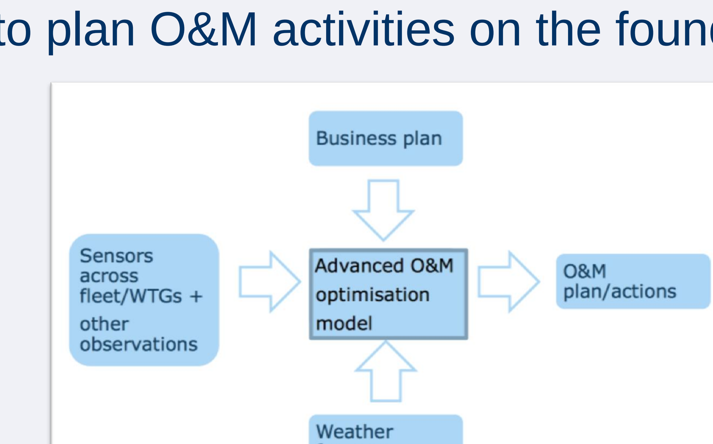


Figure 7: Building-blocks towards O&M optimization

Acknowledgements

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