Offshore foundation health monitoring using resonance frequencies

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Motivation

The focus of the current research lies with monitoring the foundation structure of offshore wind turbines. The foundation is subjected to the rough offshore conditions including wave activity, the corrosive environment, currents and shifts in the sea bed.

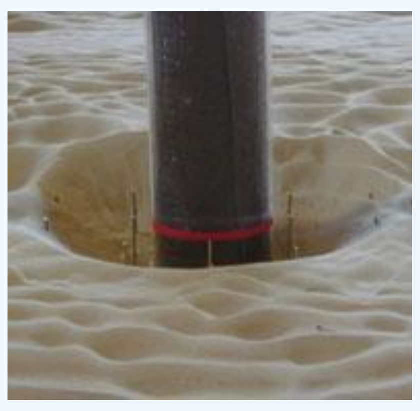

Figure 1: Example of scour near a monopile foundation

Of particular interest is **the detection of scour**, i.e. erosion of the seabed near the monopile, or any other variation that **can affect the dynamic behavior of the turbine** and thus reduce expected fatigue life.

Early detection of issues or proofs of structural integrity can reduce O&M costs and help decision making for repowering and lifetime extension.

Objectives

To develop and validate a method that :

- Is **sufficiently sensitive** to the effects of scour or other structural variations
- Is **invariant to the environmental conditions**
- **Can detect** significant deviations over time

Approach

Scour holes have a significant effect on the resonance frequencies. **With increasing scour depth the resonance frequency will decrease.**

However, as an indicator of scour it is far better to use the second order modes. Due to their greater amplitude close to the sea bed they are more sensitive to soil-related changes.

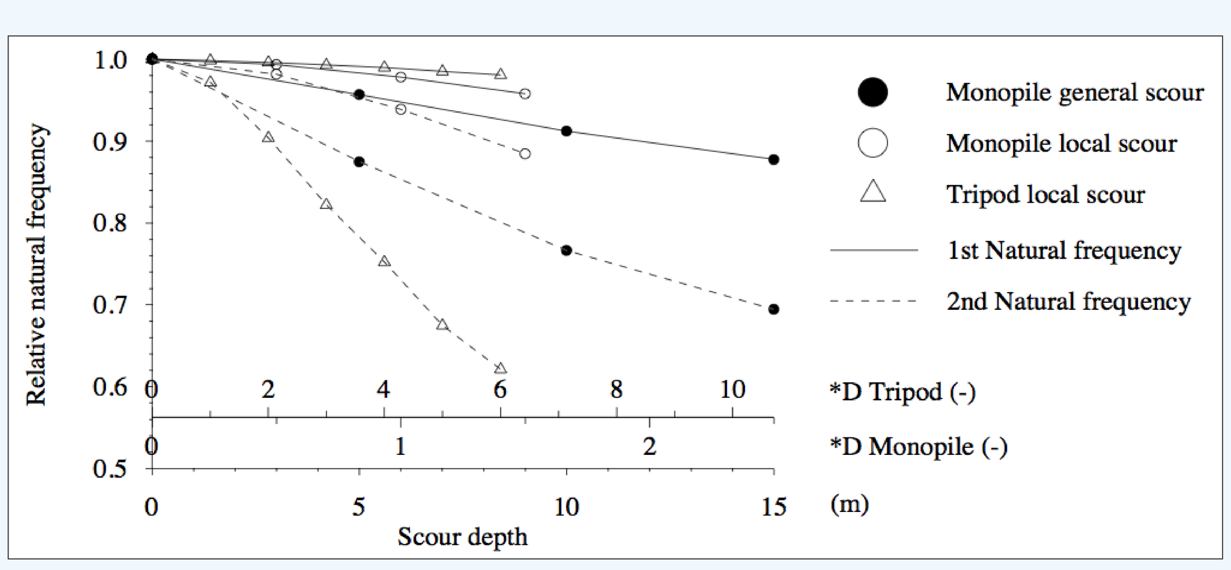

Figure 2 : The effect scour holes have on the resonance frequency demonstrates that resonance frequencies can be used to detect the onsets of scour. In particular higher order modes (2nd natural frequency) are interesting.

The proposed approach consists of three major steps :

- **Continuous & Automated Operational Modal Analysis** to determine the resonance frequencies
- **Removal of environmental effects through regression**
- **Long term trend analysis** and change detection

Step 1 : Determine resonance frequencies

The wind turbine is equipped with accelerometers at four levels to measure the ambient vibrations of the tower in both Fore-Aft direction and Side-Side direction.

The measured vibrations are processed through operational modal analysis to determine the behavior of the resonance frequencies over time.

At this point we have a database spanning nearly three years worth of dynamic parameters.

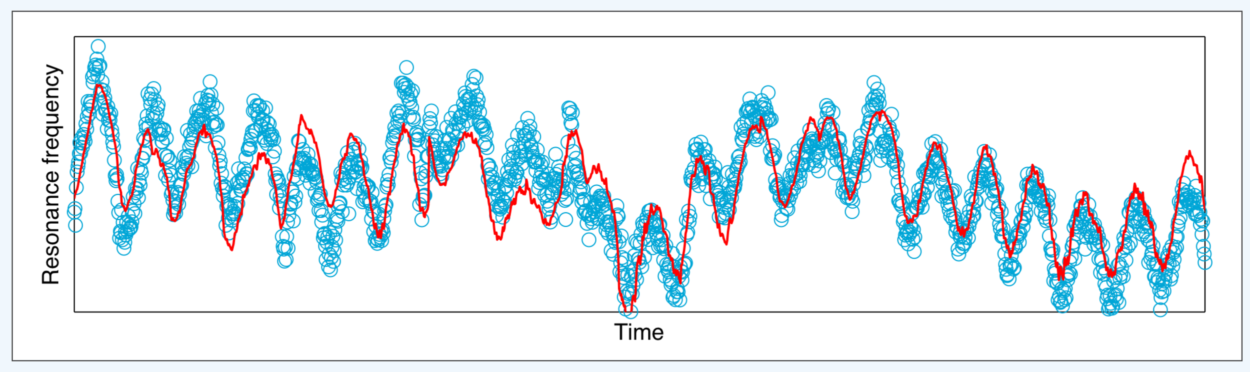

Figure 3 : Example of the behavior of the second Side-Side mode of the tower structure. A strong twice-a-day cycle can be observed linked to the tidal level. A simple regression containing both tidal as wave height can track most of these variations.

Step 2: Removal of environmental effects

The variations of resonance frequencies are mainly attributed to environmental effects such as the tidal level and wave height.

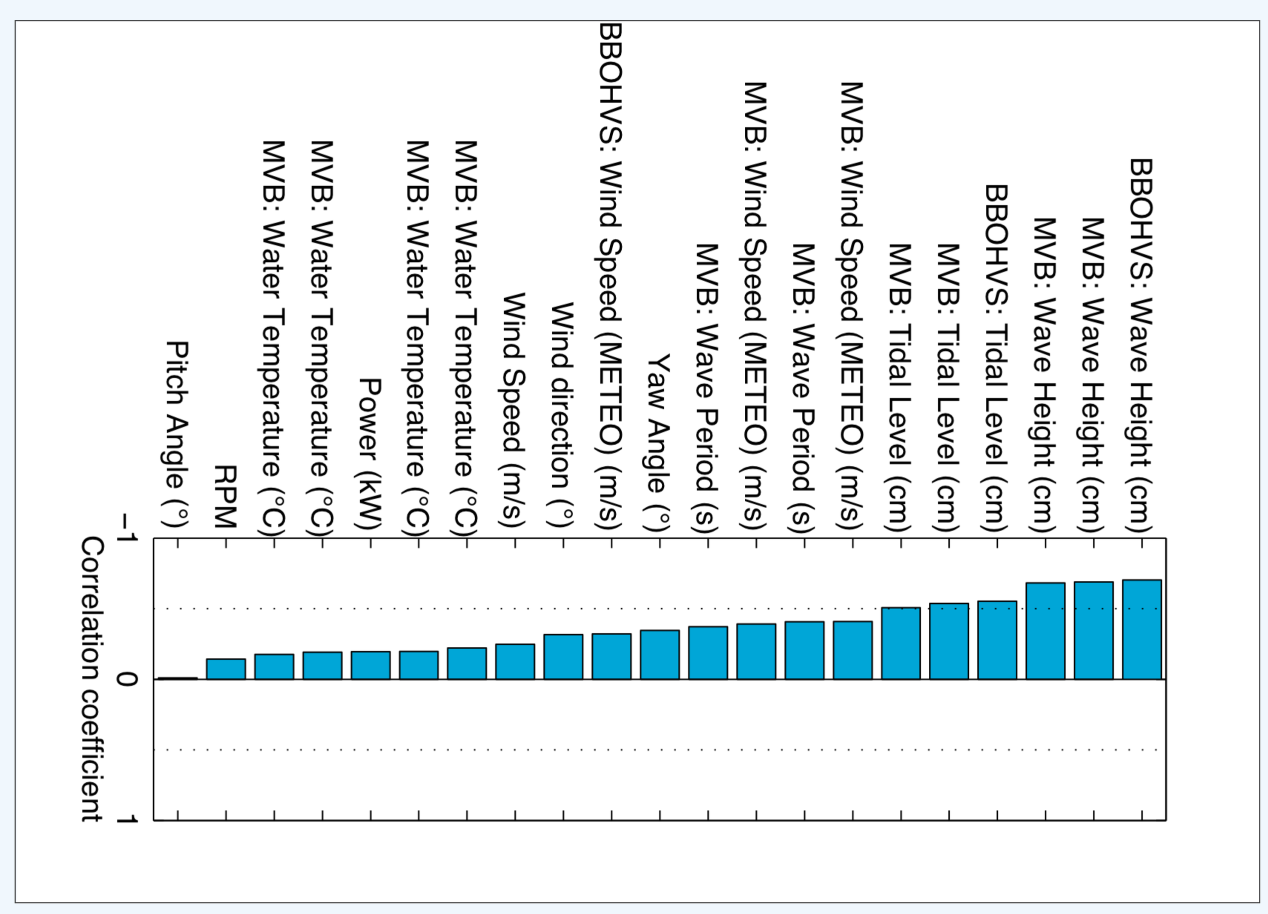

Figure 4 : Resonance frequencies are affected by an array of environmental conditions.

By applying a simple model to the data **we can model most of these environmental variations and remove their effect** all together. However, also less straightforward parameters have an effect on the resonance frequency.

In Fig. 3 a model is plotted that considers both the tidal level and the wave height. While this captures most variations it is not able to capture all deviations. A dependency on the yaw angle remains within the data.

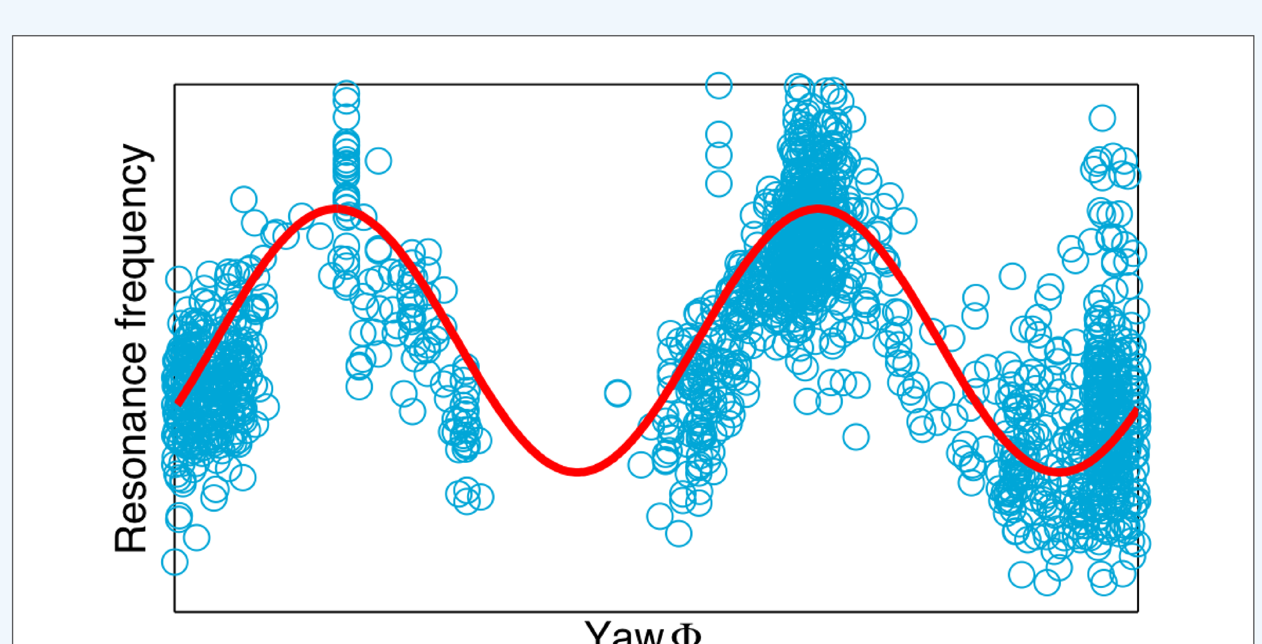

Figure 5 : Although the initial model was able to capture several variations in the resonance frequency a yaw-dependency remains. Seemingly the turbine is stiffer in one direction compared to the other.

This implies that the applied method is sufficiently sensitive to detect variations in the stiffness of the turbine. The true cause of these **stiffer angles** was determined by plotting the stiffest angles for all modes on top of a blueprint of the considered turbine.

This revealed that all Fore-Aft modes and all Side-Side modes had stiffest angles related to the J-Tube of the transition piece (TP). That served as a local bracing and thus stiffening of the turbine. Note that as for Side-Side modes the motion is orthogonal to the yaw-direction and thus the stiffest angle is also orthogonal to the yaw-direction at which the highest resonance frequency was determined.

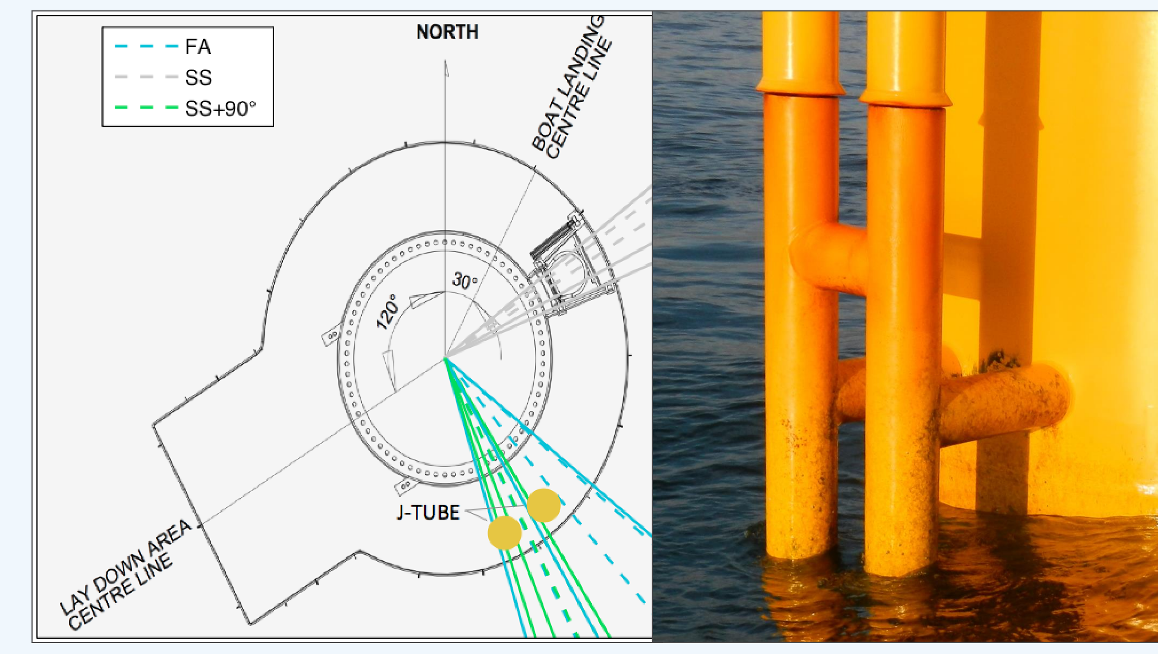

Figure 6 : (Left) Detected stiffest angles for all modes are close to the J-tube. (Right) Detail of the J-tube at the investigated turbine. This auxiliary structure is bracing the TP.

Step 3: Trend detection

A model is trained based on the data of one period of parked conditions in 2012. After modeling the influence of tidal level, wave height and the J-tube is removed.

This model is then used to predict the resonance frequencies in 2013 during a new period of parked conditions.

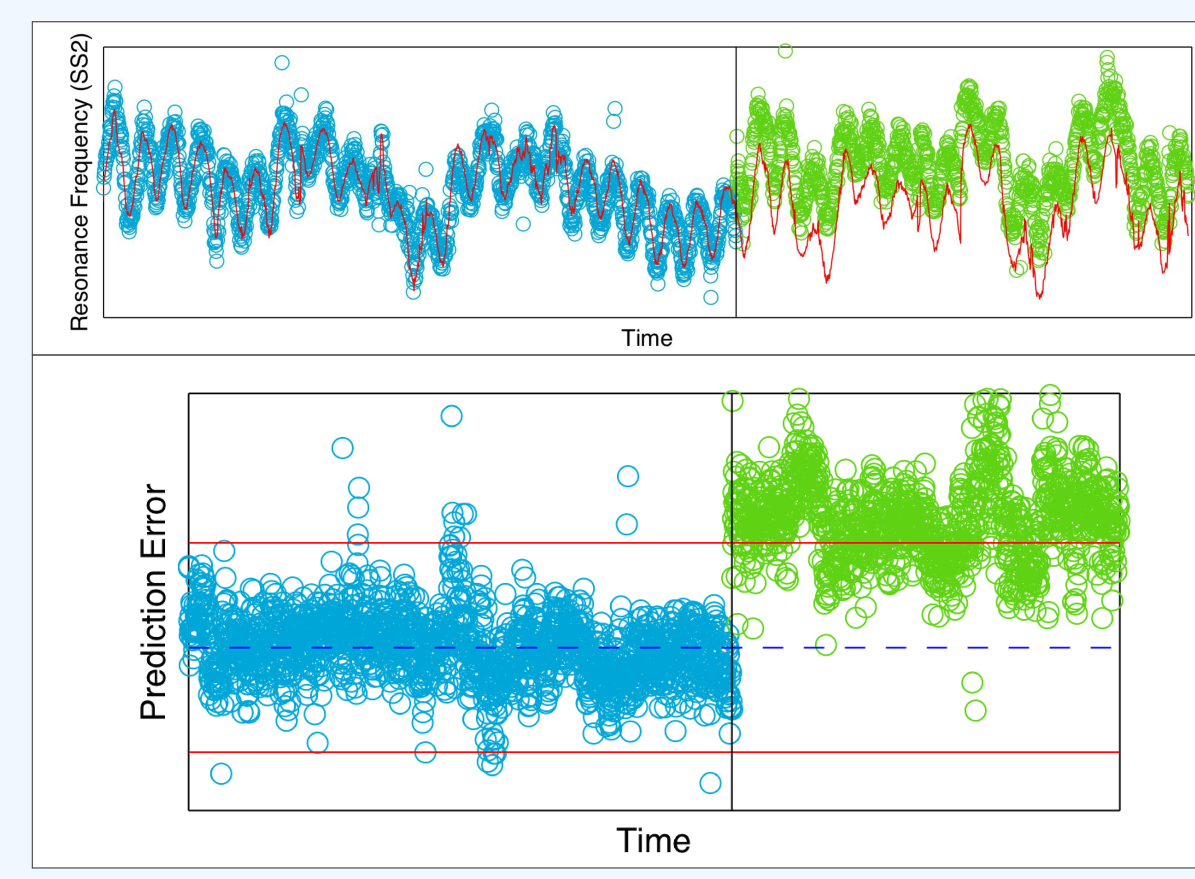

Figure 7 : (Top) Resonance frequencies measured in 2012 are used to train a model. This model predicted the resonance frequencies for a period in 2013. (Bottom) The actual resonance frequencies in 2013 were significantly (>3 Sigma) greater than those predicted.

The model reveals a significant stiffening of the turbine over the course of one year. Possible explanations are the passing of a sand-dune or more likely a **stiffening of the sandy soil** at the monopile.

A method that would not remove these environmental effects would not have been able to detect this evolution.

Conclusions

A structural health monitoring methodology was developed based on a continuous monitoring of the resonance frequencies.

This approach is in concept sensitive to the onsets of scour and variations in the seabed.

First results showed that the method was sufficiently sensitive to detect the variations of the resonance frequency over time due to tidal and wave-action. Moreover the bracing effect of the J-tube was also visible. These effects were successfully removed by applying a regression model to the data.

The long term data analysis reveal a stiffening of the turbine most likely due to soil stiffening.

Acknowledgements

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