

## Abstract

The **Offshore Wind Infrastructure Lab (OWI-Lab)** develops short- and long-term **monitoring solutions** for offshore wind turbines. The **motivation** is gaining the insights that are crucial to **minimize construction and installation costs** of future offshore wind farms and to **extend the life time** of existing structures and **reduce their operation and maintenance costs**.

The main goal of this poster is to share the results of an extensive design verification campaign. The results will allow improvement of current standards, ultimately reducing the cost of offshore wind energy.

## Objectives

In **design verification** the resonance frequencies of the fundamental tower modes are identified using a mobile measurement system and state-of-the-art operational modal analysis techniques. The obtained frequencies are compared with the as designed values.

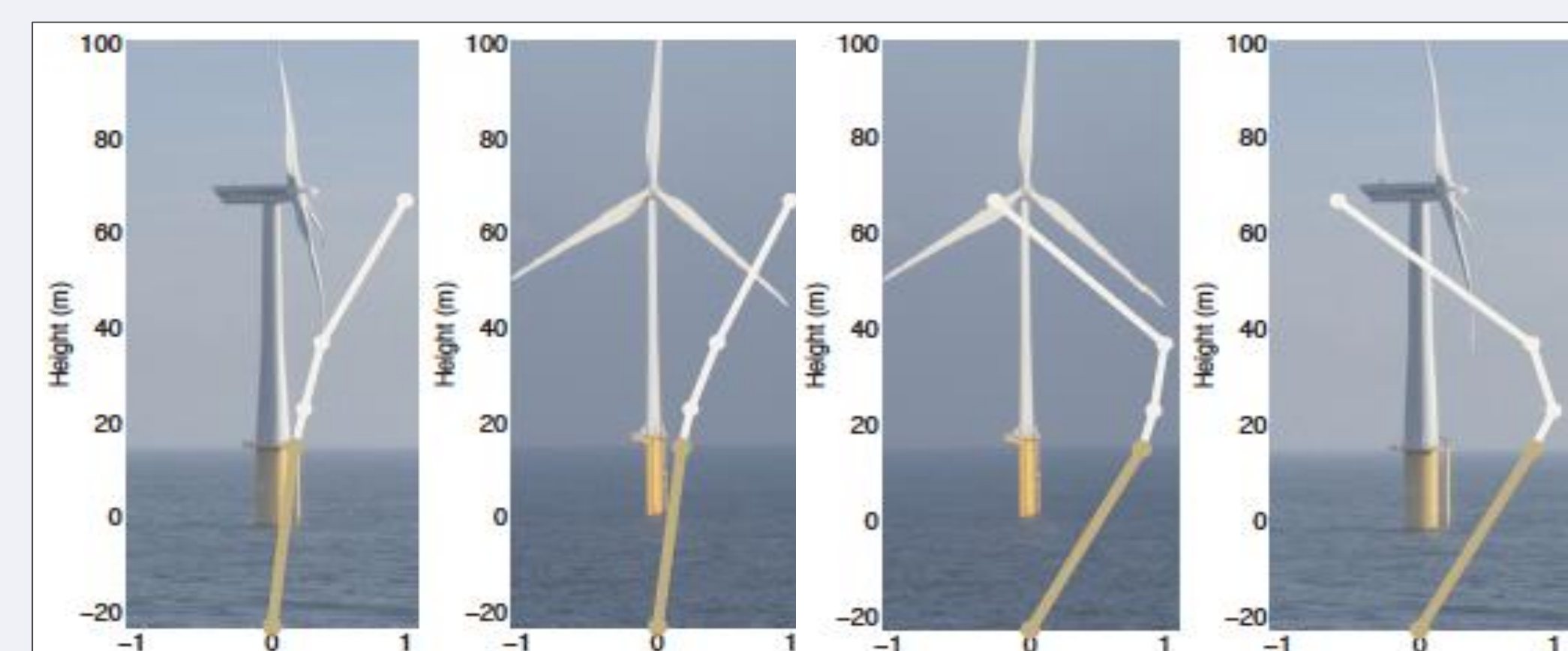


Figure 1: Fundamental tower/foundation modes in parked conditions. From left to right: first fore-aft mode, first side-side mode, second side-side mode, second fore-aft mode

## Foundation optimization

Monopile foundations, currently the most common foundation concept, make up about 20% of the CAPEX of the entire offshore wind turbine structure. **It is not conservative to over-estimate nor to under-estimate the soil stiffness.** Only an accurate estimation is conservative. Underestimating the stiffness in the design phase inevitably results in the use of more steel and thus higher constructions and installation costs.

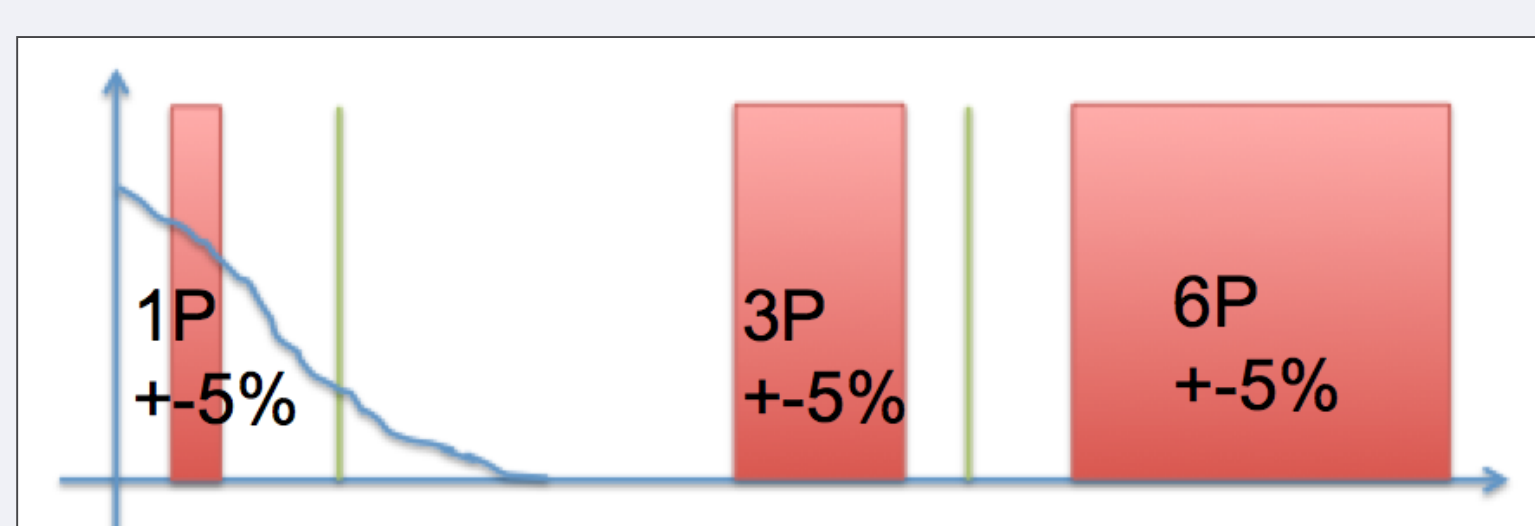
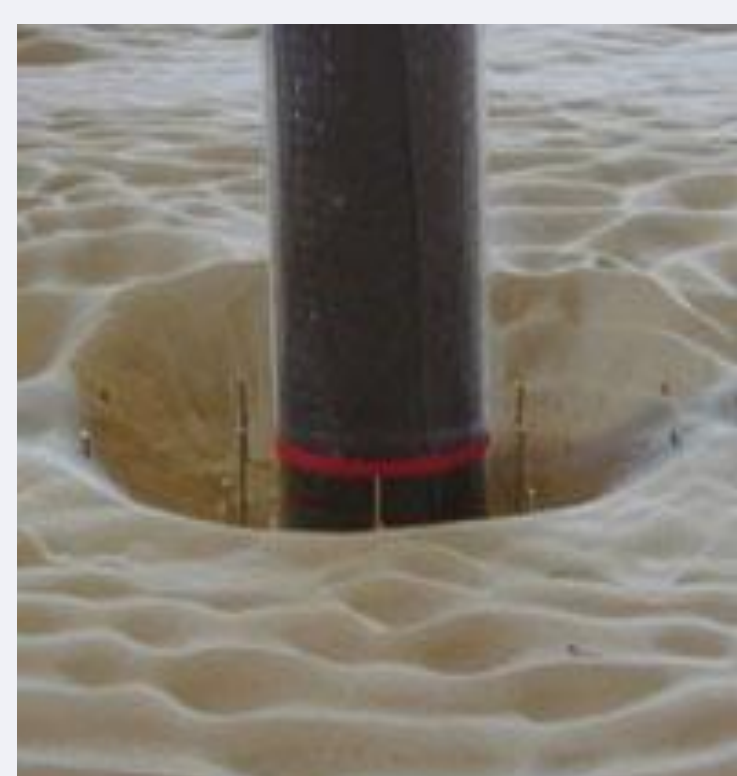


Figure 2: as designed frequencies (green) versus frequency, with wave frequency spectrum (blue) and rotor harmonic frequency bands at rated speed (red zones)

## Scour Monitoring



Scour holes have a significant effect on the resonance frequencies. **With increasing scour depth the resonance frequency will decrease.** This can potentially induce resonant behavior.

Bathymetric surveys are used to monitor the seabed. However, these results do not provide information about the structural integrity. By performing a design verification campaign it is possible to assess the influence of the actual seabed level on the natural frequencies. By analyzing the natural frequencies the risk can be constantly monitored, with greater accuracy and more economically compared with bathymetric surveys.

## Measurements

In 2014 a short-term measurement campaign at the Belwind windfarm has been performed at 4 turbines.

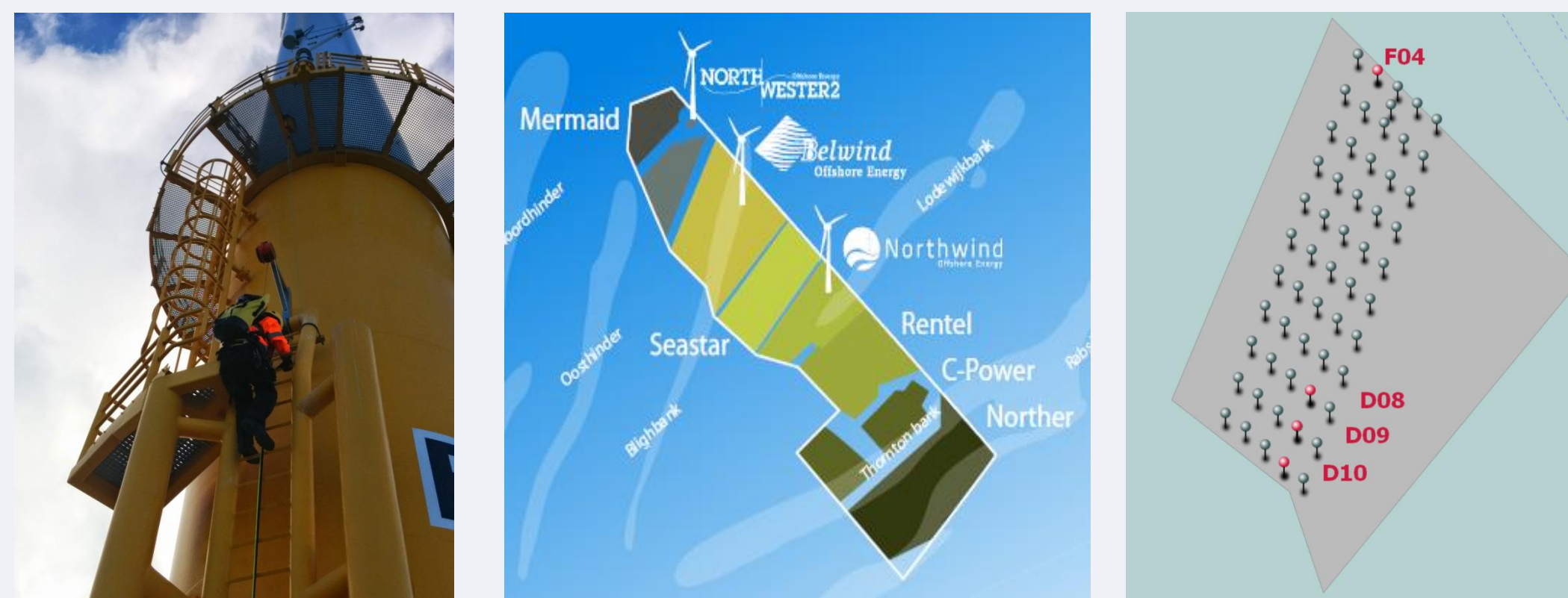


Figure 3: climbing on transition piece with measurement system (left) Belgian offshore wind farms (middle) measured turbines (right)

Biaxial accelerometers have been magnetically mounted on tower just above the transition piece of each turbine. Measurements have been performed during 20 minutes.

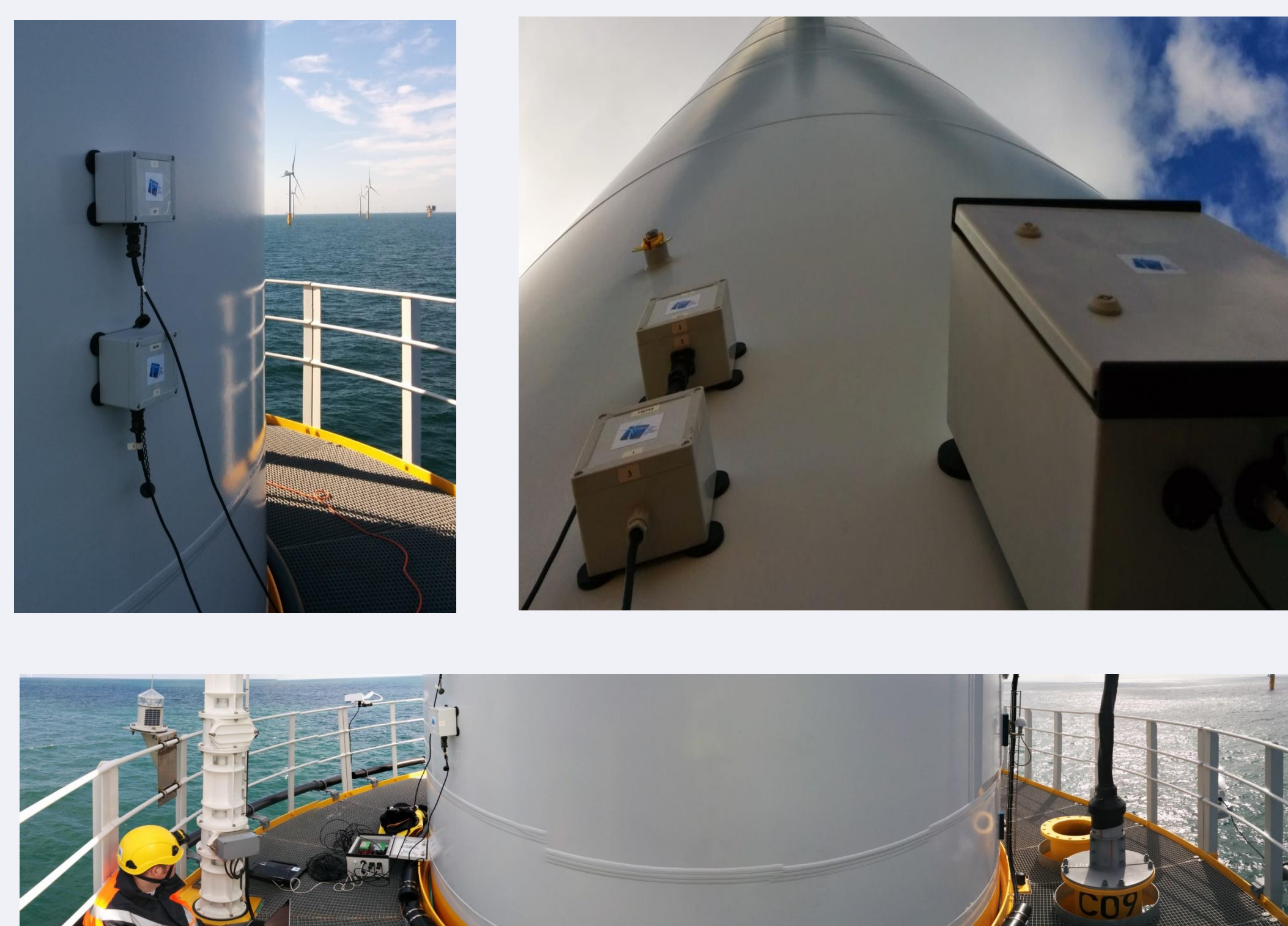


Figure 4: magnetically mounted accelerometers and data acquisition system (top) panorama picture during measurements (bottom)

## Operational Modal Analysis

The vibration data has been processed using state-of-the-art operational modal analysis techniques. This approach allowed to identify the resonance frequencies of the first 2 bending modes in both the fore-aft and side-side direction with great accuracy.

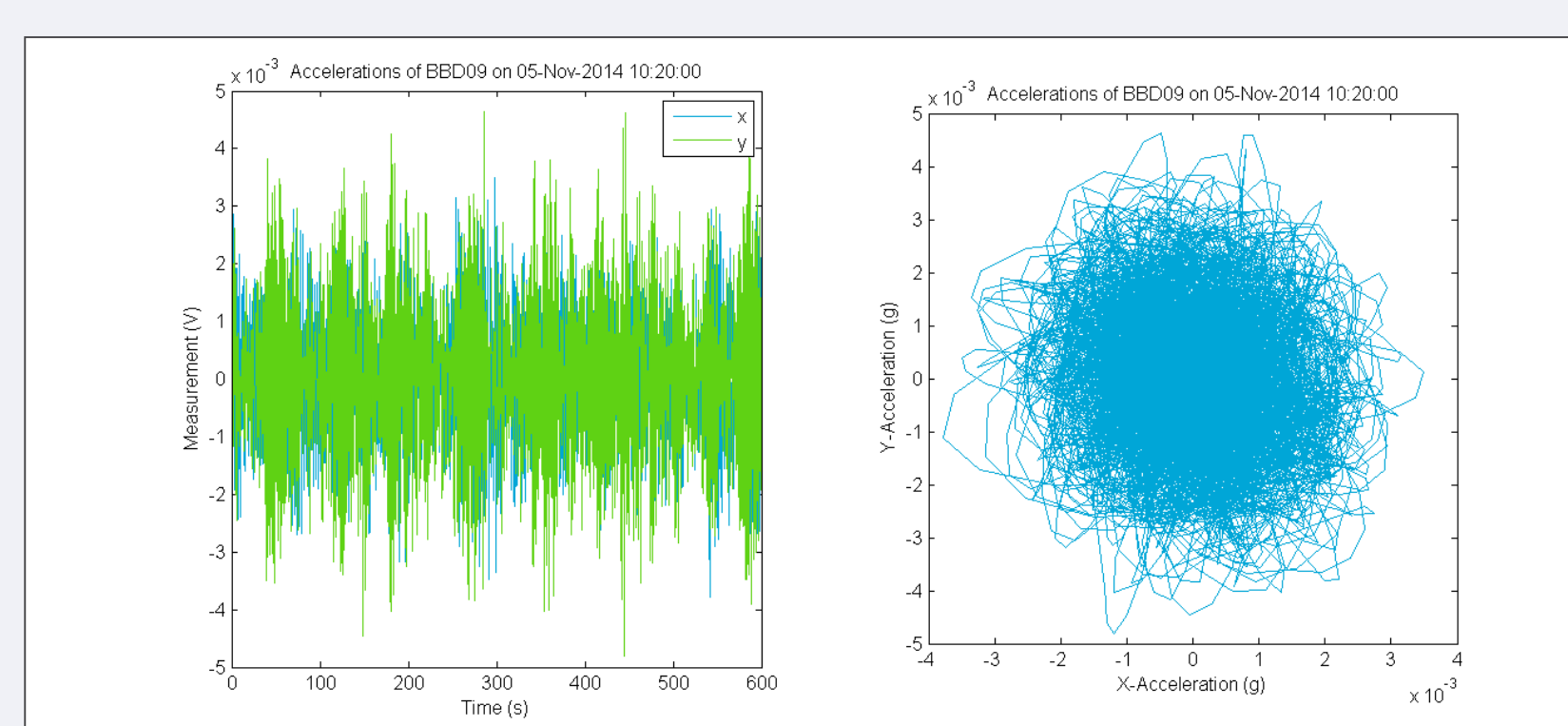


Figure 5: Example measured vibrations in fore-aft and side-side direction (left) topview of motion (right)

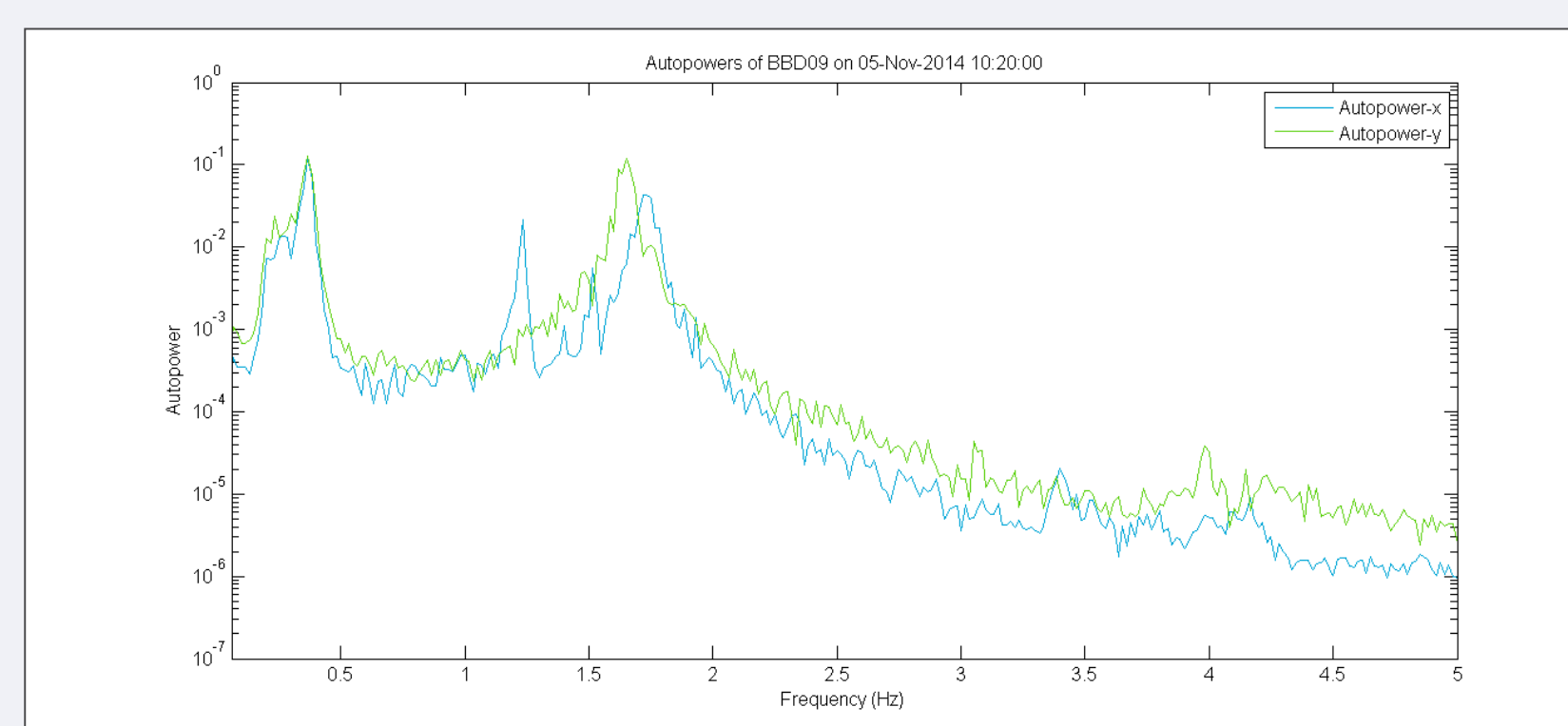


Figure 6: Example of auto-power spectra of the measured vibrations in fore-aft (blue) and side-side (green) direction

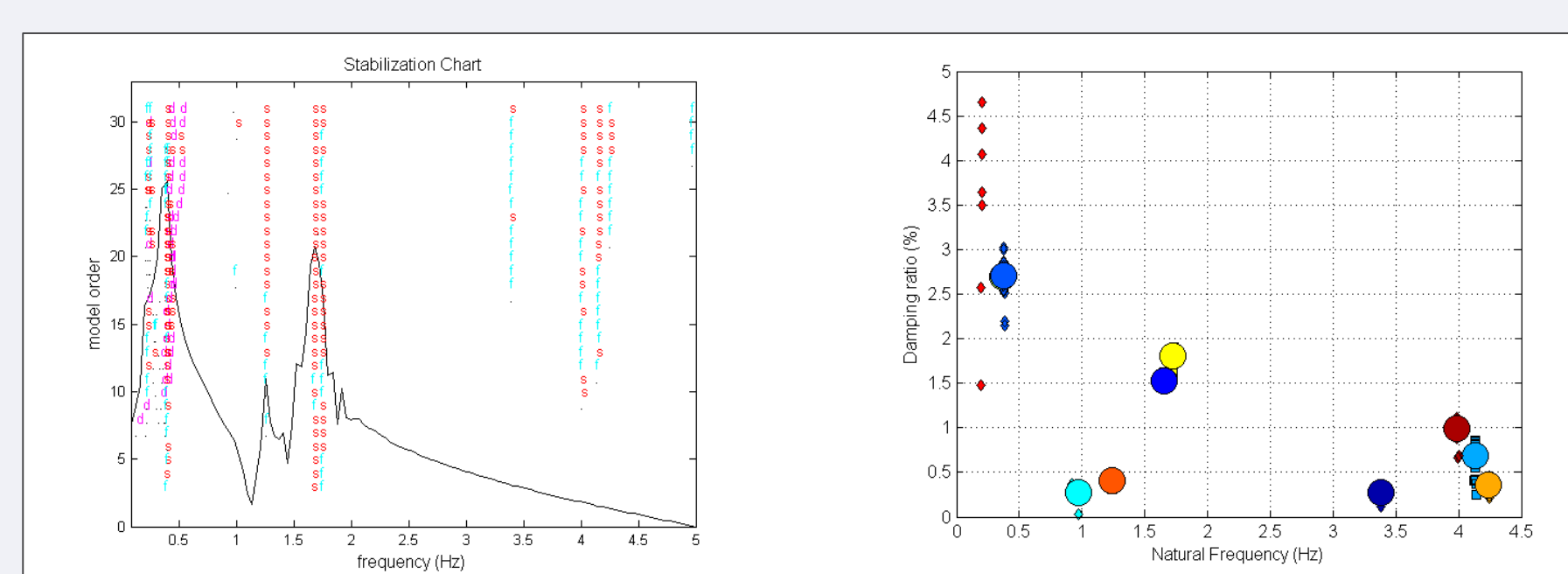


Figure 7: automated operational modal analysis: stabilization diagram (left) frequency damping cluster plot (right)

## Results

When performing a design verification campaign one needs to take into account that the resonance frequencies can shift significantly due to changing operational and environmental conditions. The results have to be corrected for these influences.

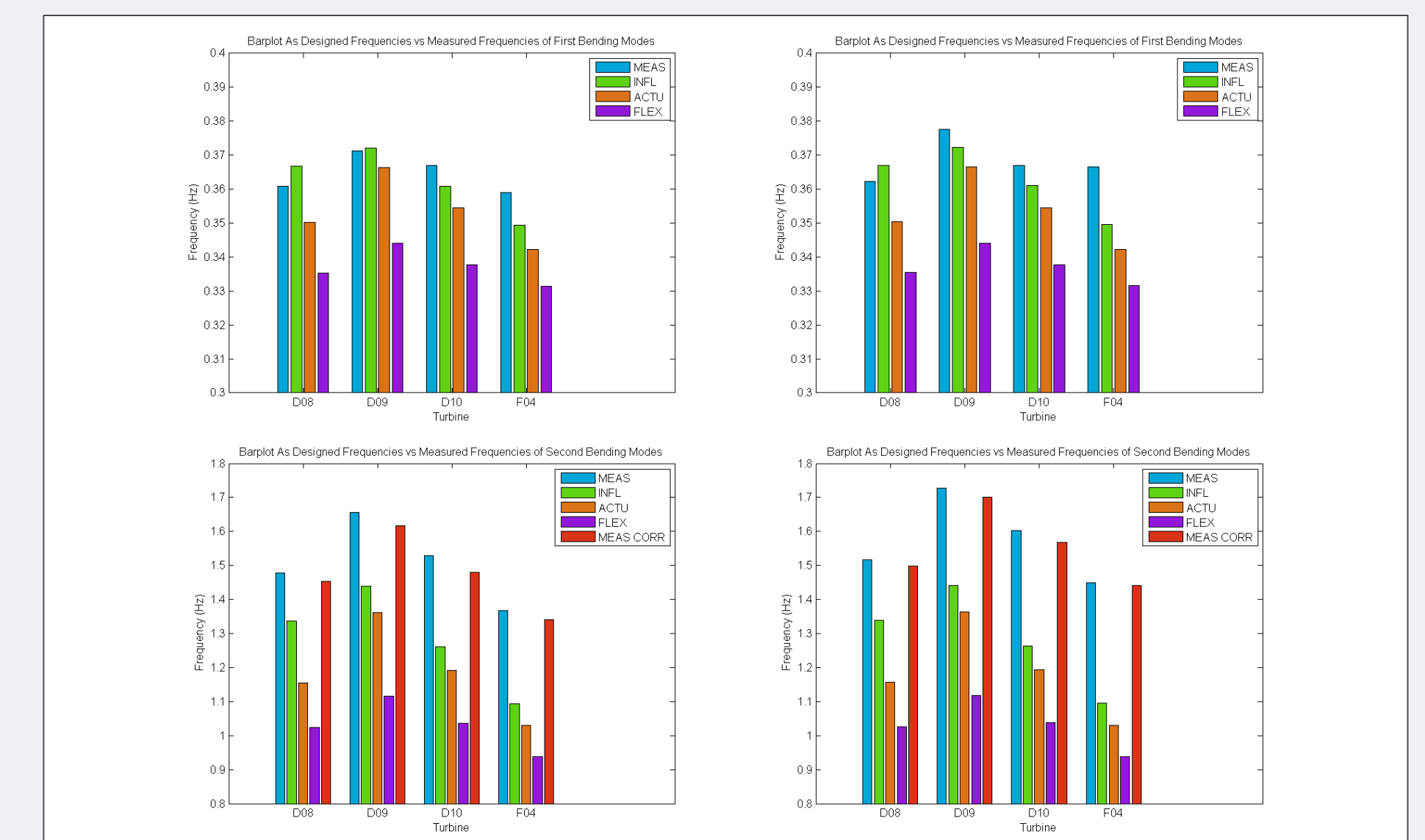


Figure 8: Measured frequencies and corrected frequencies versus designed frequencies for the first fore-aft mode, first side-side mode, second fore-aft mode, second side-side mode

The resonance frequencies of the higher modes differ significantly from the designed resonance frequencies. This can result in higher vibration levels, due to an increased interaction with rotor harmonic frequencies.

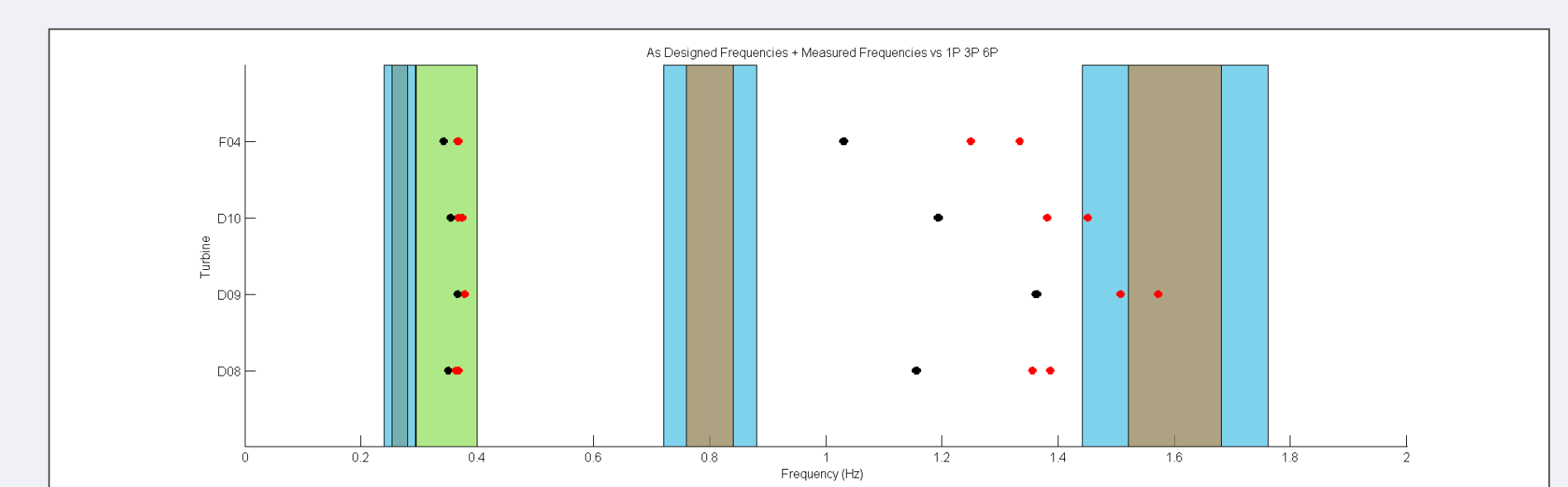


Figure 9: Measured frequencies, corrected frequencies and as designed frequencies versus rotor harmonic frequencies

Finally, a detailed analysis of the obtained resonance frequencies is performed versus e.g. water depth, monopile length and monopile fixity.

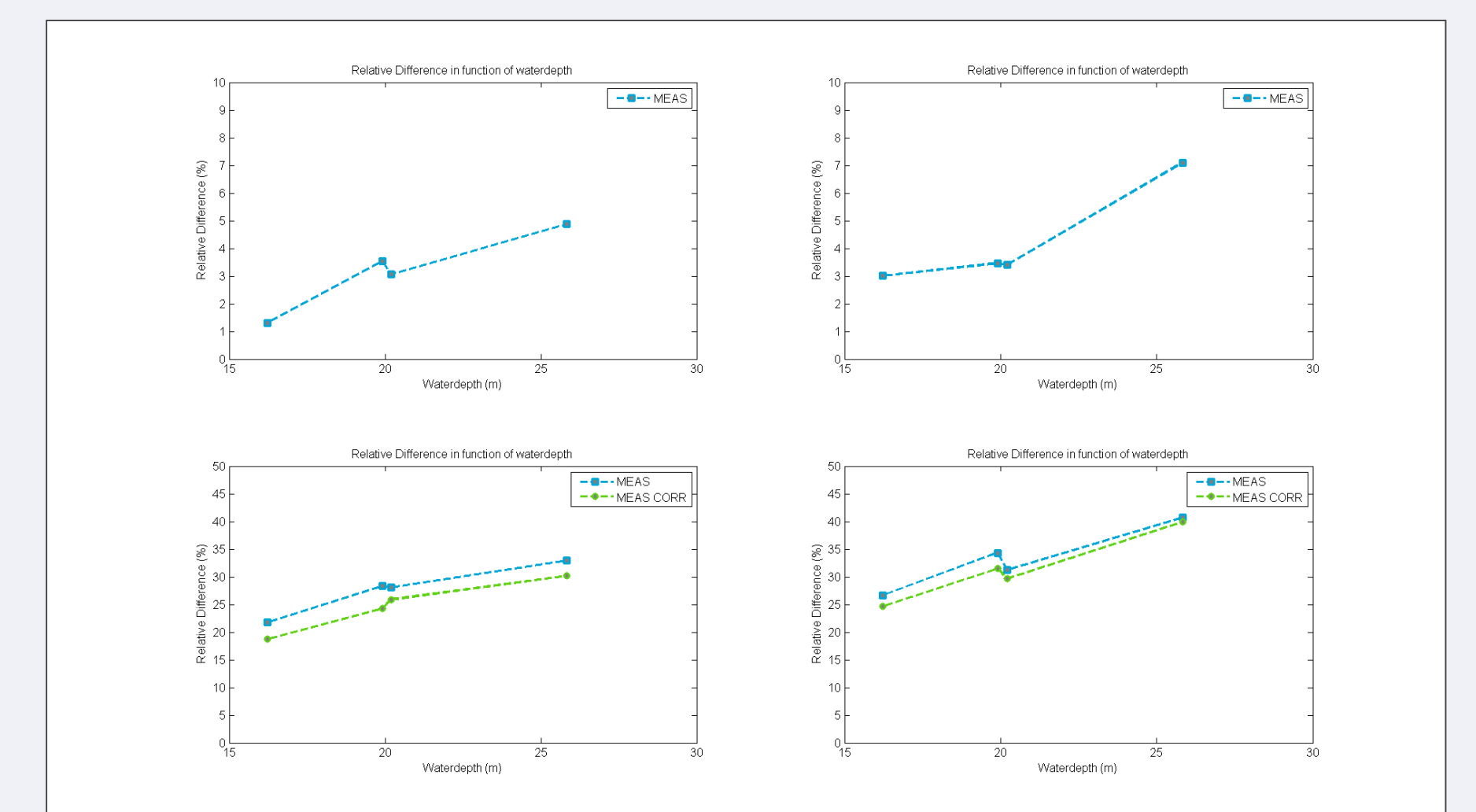


Figure 10: Relative difference between measured frequencies and as designed values versus water depth

## Conclusions

Results indicate a general underestimation of the soil stiffness. The first resonance frequency is between 5% and 10% greater than designed. The second resonance frequency is between 15% and 40% greater than designed. It was found that the relative difference with as designed values increased with water depth and was independent of the monopile length. Moreover it was found that the second bending mode frequencies coincided with the 6P rotor harmonic frequencies. This can result in higher loads and therefore reduced life-time or increased O&M costs.

## Acknowledgements

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