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An experimental and computational investigation on the dynamics of an offshore wind turbine in parked conditions

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Abstract

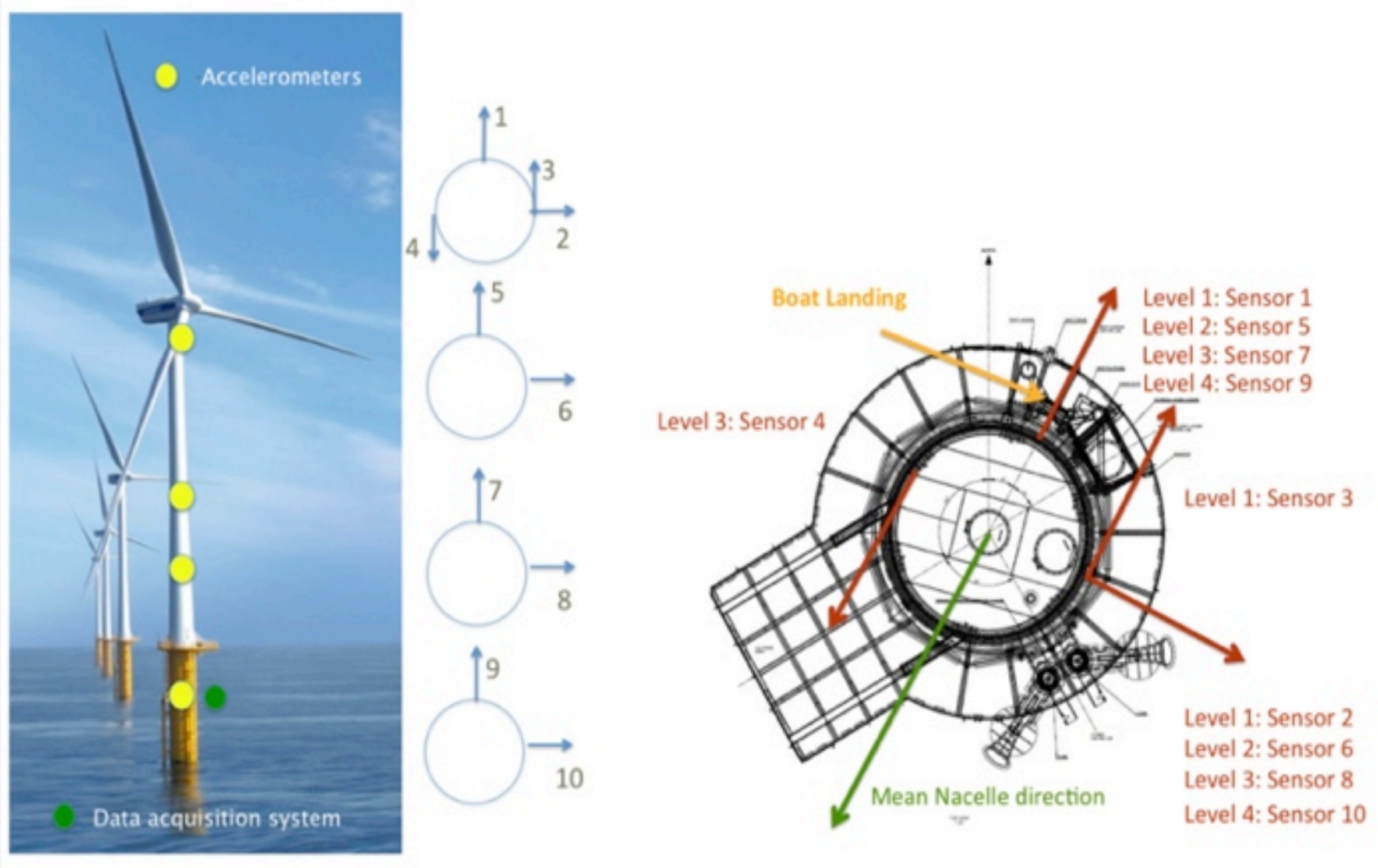
Offshore wind turbines are complex structures and their dynamics can vary significantly due to changes in operating conditions e.g. changing rotor-speed, changing pitch angle or changing ambient conditions e.g. change in wind speed, wave height or wave period. Especially in parked conditions, with reduced aerodynamic damping forces, the response due to wave actions with wave frequencies close to the first structural resonance frequencies can be high.

This paper presents numerical simulations using the HAWC2 code to study an offshore wind turbine in parked conditions. The damping value of the first fore-aft (FA) mode has been tuned based on measurements obtained from a long-term ambient monitoring campaign on the same wind turbine.

The results from the simulations will be compared with the processed data obtained from the real measurements. The accuracy of the model will be discussed in terms of resonance frequencies, mode shapes, damping values and acceleration levels and the limitations of the simulations in modeling of an offshore wind turbine will be addressed.

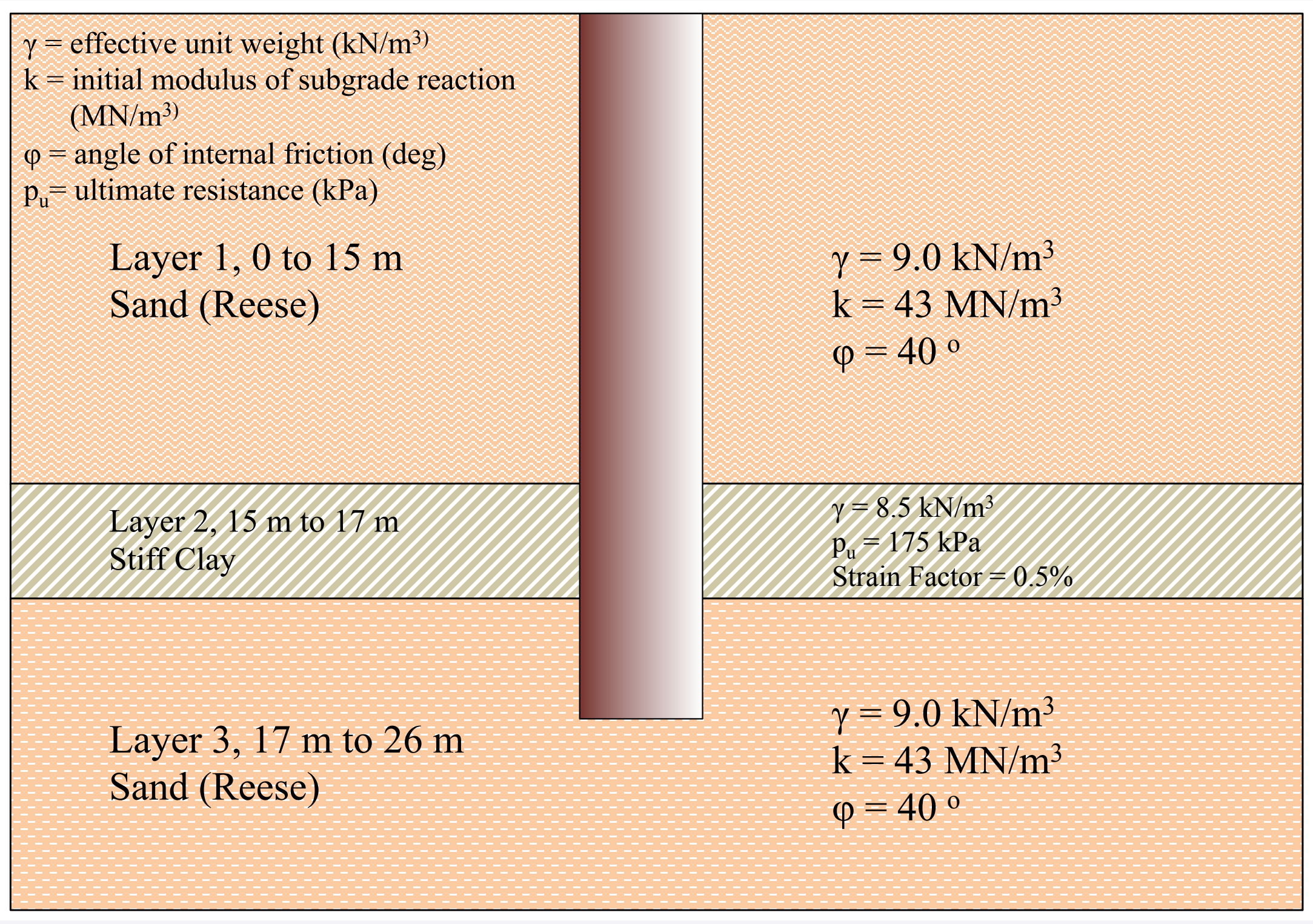
Offshore measurements

The measurement campaigns have been performed at the Belwind wind farm, which consists of 55 Vestas V90 3MW wind turbines. The wind farm is located in the North Sea on the Bligh Bank, 46 km off the Belgian coast.



Offshore V90 wind turbine (left) Measurement locations on BBCO1 (right).

The chosen levels are 69 m, 41 m, 27 m and 19 m above LAT, respectively level 1 to 4.

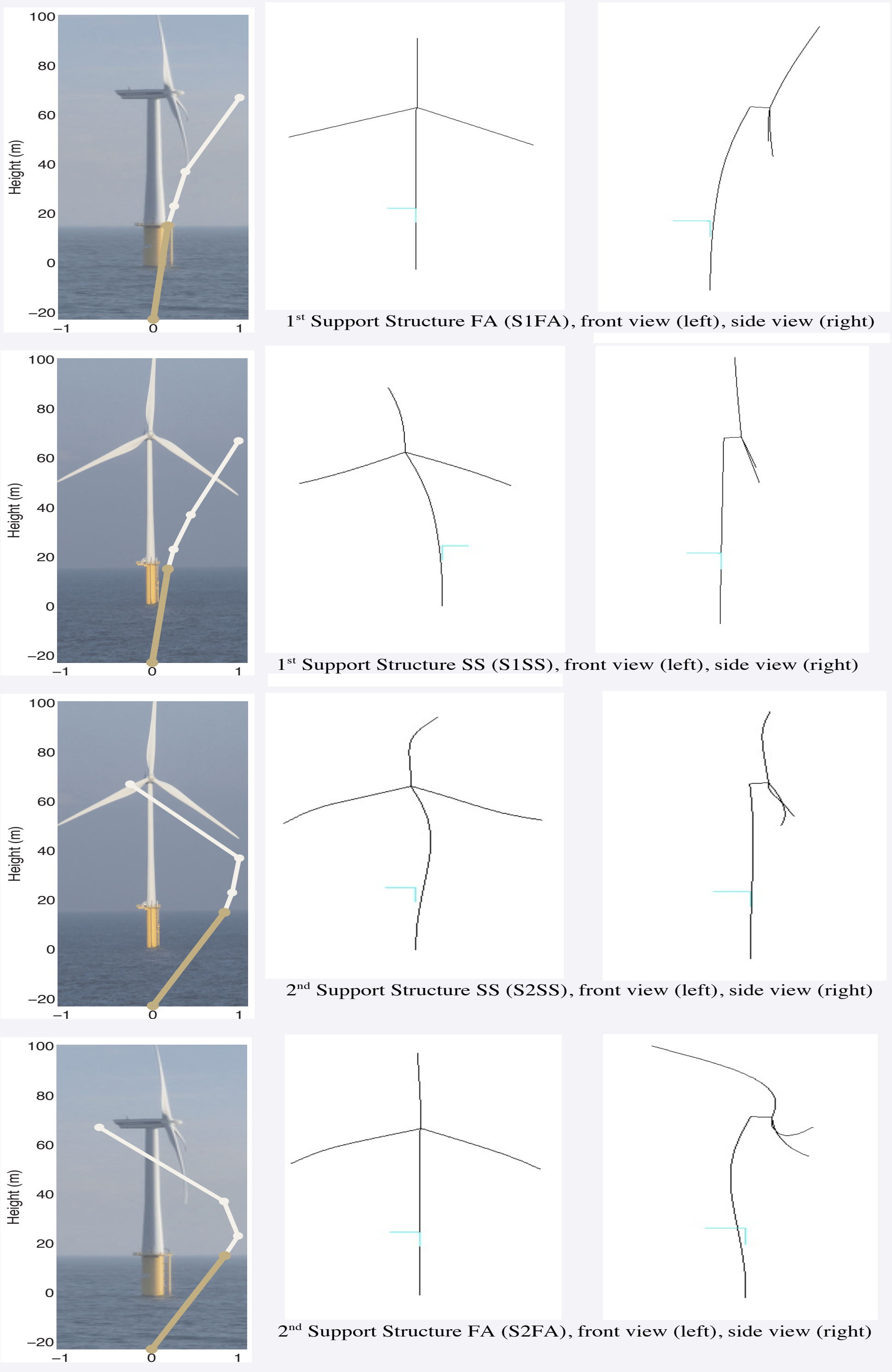


Different soil profiles for the monopile support at wind turbine location.

The numerical simulations have been carried out using HAWC2 aeroelastic code developed at DTU.
The detailed specifications of the blade aerodynamic properties; monopile foundation, tower, nacelle and drivetrain structural properties are provided as an input file for the HAWC2 code.

Natural frequencies and mode shapes

The natural frequencies of the structure were identified using automated operational modal analysis applied to the measurement data and the simulated time data.



1st Support Structure FA (S1FA), front view (left), side view (right)

1st Support Structure SS (S1SS), front view (left), side view (right)

2nd Support Structure SS (S2SS), front view (left), side view (right)

2nd Support Structure FA (S2FA), front view (left), side view (right)

Mode shapes of the support structure for the first and second FA and SS modes obtained from measurements (left) and HAWC2 eigenvalue analysis (right).

Experimental and computational natural frequency comparison for 10 lowest frequencies.

Description	Long-term measurements Mean Freq±Std Freq (Hz)	Overspeed stop test Freq (Hz)	HAWC2 (Eigenvalue analysis) Freq (Hz)	HAWC2 (Time domain) Freq (Hz)
1st Support Structure FA (S1FA)	0.3614±0.0039	0.3529	0.3744	0.3658
1st Support Structure SS (S1SS)	0.3656±0.0045	0.3634	0.3794	0.3706
1st Blade Asymmetric Flapwise Pitch (B1AFP)	—	0.6672	0.8279	—
1st Blade Asymmetric Flapwise Yaw (B1AFY)	—	0.7531	0.8499	—
1st Drivetrain Torsion (DTT1)	—	1.0714	1.0283	—
1st Blade Collective Flap (B1CF)	—	1.1523	1.1443	—
1st Blade Asymmetric Edgewise Pitch (B1AEP)	1.2007±0.0055	1.2000	1.1450	1.0979
1st Blade Asymmetric Edgewise Yaw (B1AEY)	—	1.3573	1.4446	1.3342
2nd Support Structure SS (S2SS)	1.4489±0.0178	1.4664	1.6622	1.4277
2nd Support Structure FA (S2FA)	1.5600±0.0162	1.5704	1.7558	1.5038

Tuning the damping

The overall damping of the first FA mode of the model has been tuned to be in agreement with the measurements obtained during ambient excitations, respectively 1.6%. This damping value was obtained during low wind speeds while the wind turbine was in parked conditions and the mass tuned damper was switched on.
The overall measured system damping (D_{tot}) of an offshore wind turbine can be approximated as a linear combination of following damping sources:

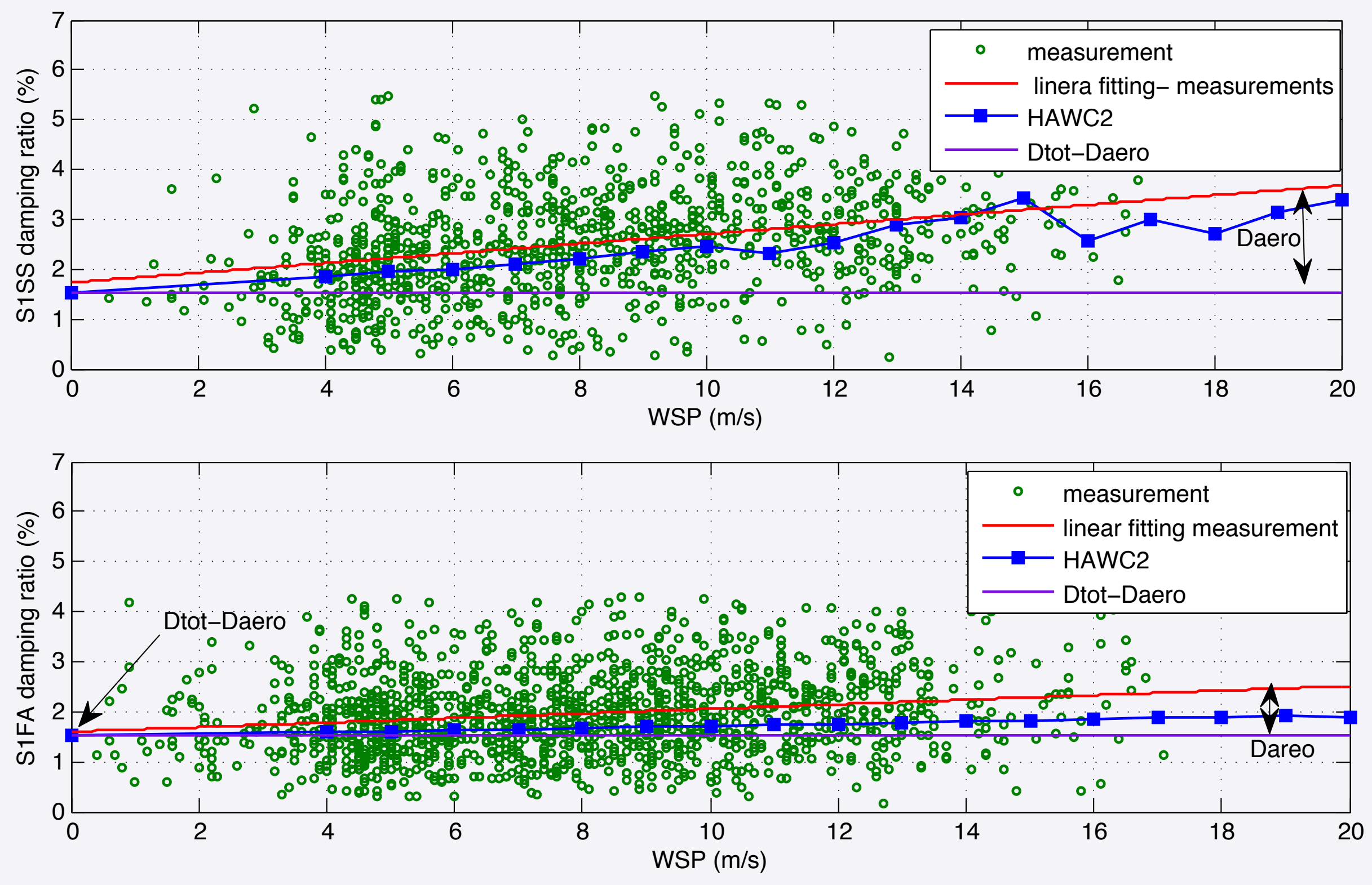
$$D_{tot} = D_{struc} + D_{soil} + D_{aero} + D_{hydro} + D_{mass.damp}$$

D_{struc} = structural damping = 1.09%
D_{soil} = soil damping due to inner soil friction = 0.39%
D_{aero} = aerodynamic damping = 0.05%
$D_{mass.damp}$ = tower tuned mass damper (TMD), included in structural damping
$D_{hydro} = D_{radiation} + D_{vis}$, hydrodynamic damping which consists of two terms = 0.06%,
$D_{radiation}$ = damping from wave creation due to structure vibration;
D_{vis} = viscous damping due to hydrodynamic drag

➔ D_{tot}= 1.59% for the FA mode

Damping of first FA and SS modes vs. WSP

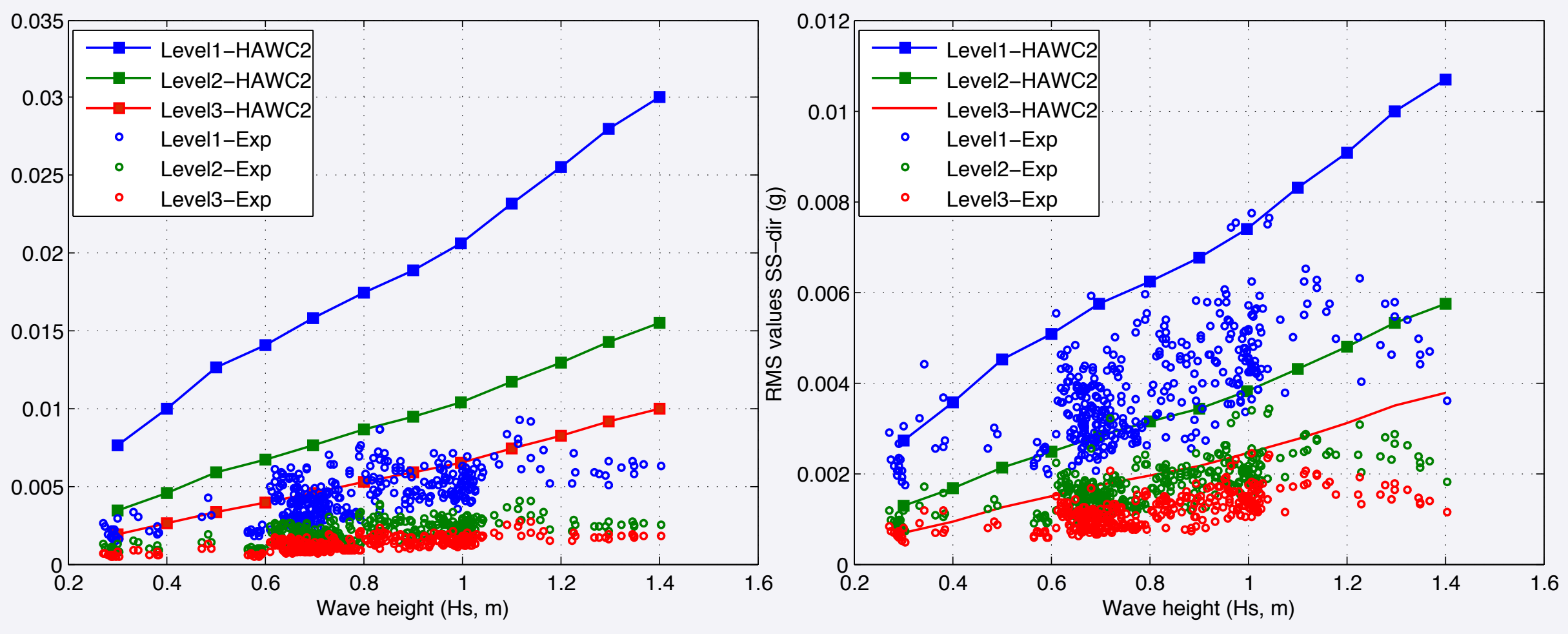
- The damping contribution that is mostly affected by ambient conditions is the aerodynamic damping.
- The wind turbine is in parked condition and the blades are pitched to 80.5 deg.
- The simulations have been performed at different wind speeds (from 4 m/s up to 20 m/s) while the wind-wave misalignment is 20 deg.



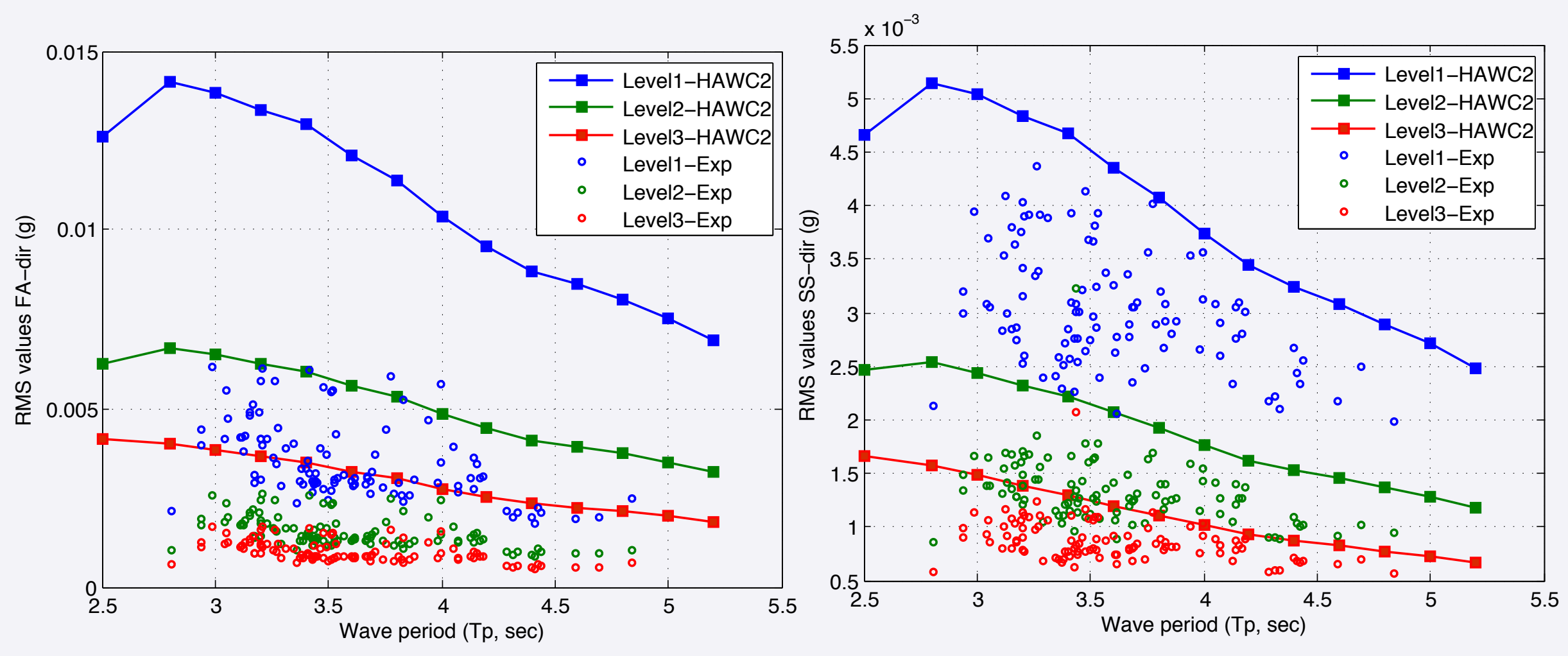
Damping values for the first FA (up) and SS (down) modes as a function of wind speed for a parked wind turbine.

Comparison of acceleration levels

The acceleration levels measured form the measurements are compared with the simulations. The influence of wave period and wave height have been analysed.



The RMS values of accelerations at different levels in FA (left) and SS (right) directions as a function of wave height.



The RMS values of accelerations at different levels in FA (left) and SS (right) directions as a function of wave period.

Conclusions

The resonance frequencies, modes shapes and the evolution of damping values versus windspeed of the simulations are in good agreement with the measurements. However at first glance the simulations seem to overestimate the vibration levels. This can have important consequences on the correct calculation of the fatigue life of an offshore wind turbine. A further detailed investigation is required to better understand the underlying cause of this difference.

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