Experiences with the Poseidon measurement campaign and more

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Experiences with the Poseidon measurement campaign and more

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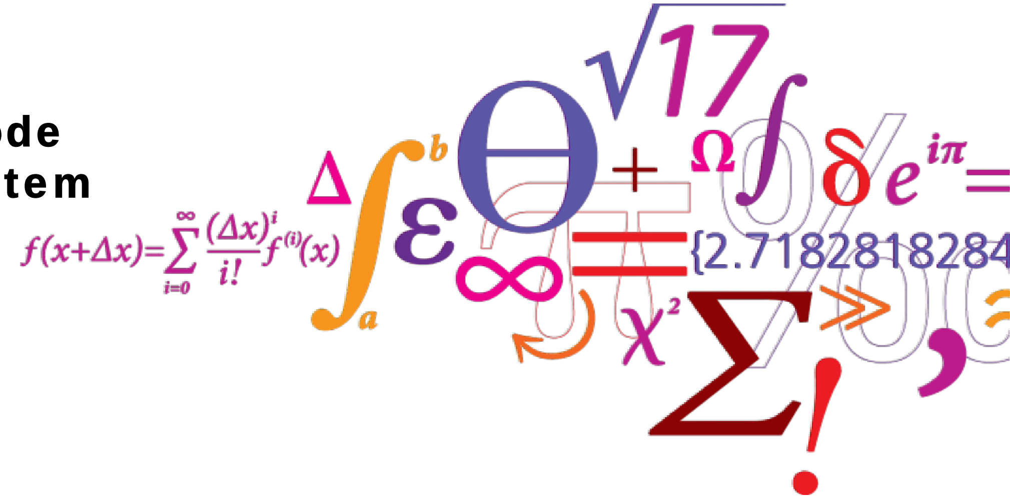
Experts Meeting on Computer Code Validation for Offshore Wind System Modeling
Millennium Harvest House Hotel
Boulder, Colorado
May 15-16, 2012



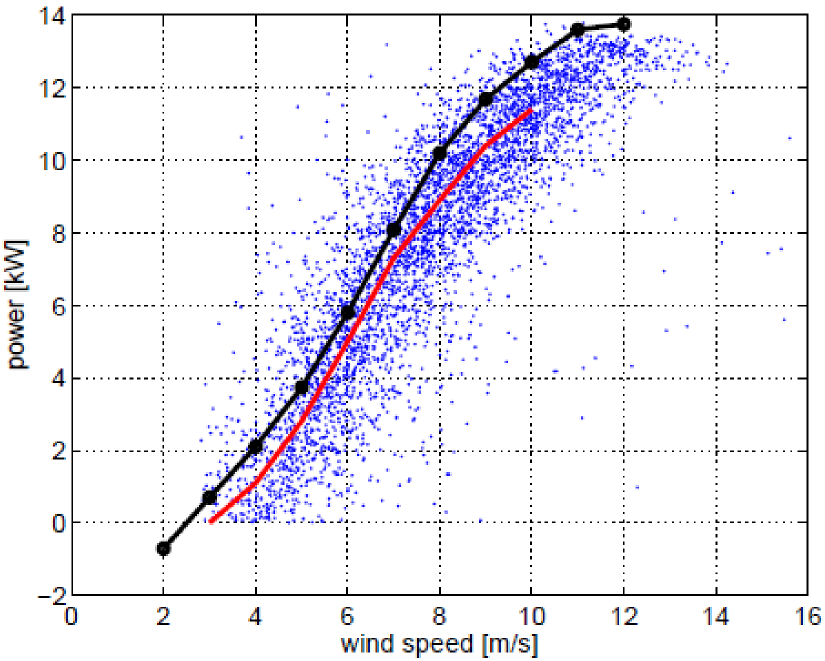
DTU Wind Energy
Department of Wind Energy

Poseidon, by FLOATING POWER PLANT

- Wave energy platform (demo project), 37m wide
- Three Gaia 11kW turbines mounted
- A turret mooring system with three lines are applied

The Gaia 11kW turbine

- 2 Bladed stall regulated wind turbine
- Asynchronous generator
- Down wind configuration
- Passive yaw (stick-slip)
- Teeter mechanism in hub to alleviate loads (non-linear spring)



Overview of measurement campaigns

Year	PSO	Nr.	Test activity	
1998	No	P1	Conceptual design and test in 3D basins of a 2,4 meter (wave front) floating power plant at AAU.	
2000	No	P2	Two empirical wave flume tests phases of different floats designs at DHI.	
2002	No	P3	Test of a 8,4 meter (wave front) model with wind turbines was tested in a 3D basin at DHI.	
2008/ 2009	Yes	*P4.1*	*Off-shore test phase 1.* Off-shore test of a 37 meter (wave front) floating power plant was initiated. The first test was performed without the wind turbines installed.	
2010	Yes	*P4.2*	*Off-shore test phase 2.* Further off-shore test of a 37 meter (wave front) floating power plant. This second test was performed with 3 grid connected wind turbines installed.	
2010	No	P5	Wave flume test of an improved PTO system for the wave energy device.	
			Planned tests	
2011	Yes	*P4.3*	Off-shore test phase 3 Further off-shore test of the 37 meter (wave front) floating power plant. This third and final off-shore test will be performed with 3 grid connected wind turbines (increased measurement program) and further test with a grid connect PTO system from the wave energy device.	
2011	No	P6	3D basin test of key parameters concerning scaling and stability of the platform- stability. The test result will be integrated in the numeric model.	

Show movie

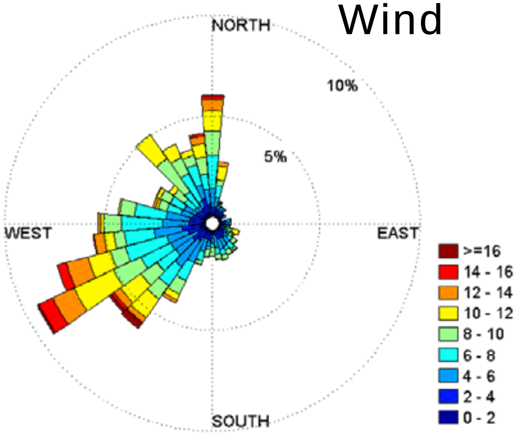
Location of the Poseidon demonstration platform (discussion)

- The wave energy device needs to be scaled according to the specific wave climate (constant ratio of wave and platform length)
- The scale of the demonstration platform fits the waves in the confined Danish water

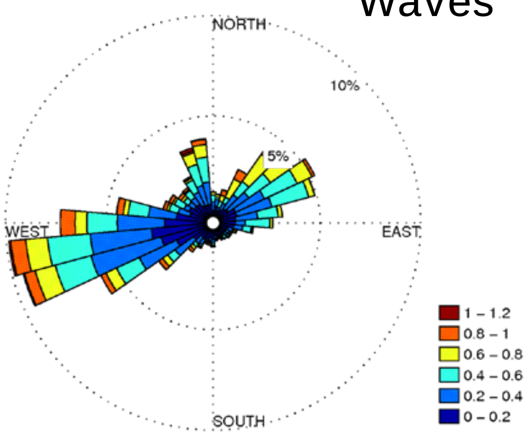
Wind and Wave characteristic

- Site provides cases with:
  - Small waves and high wind
  - Large waves and low wind
  - Large waves and high wind
  - Small waves and low wind
- Allow for analysis of platform motion and turbine loads in all different operational conditions

Wind



Waves



the

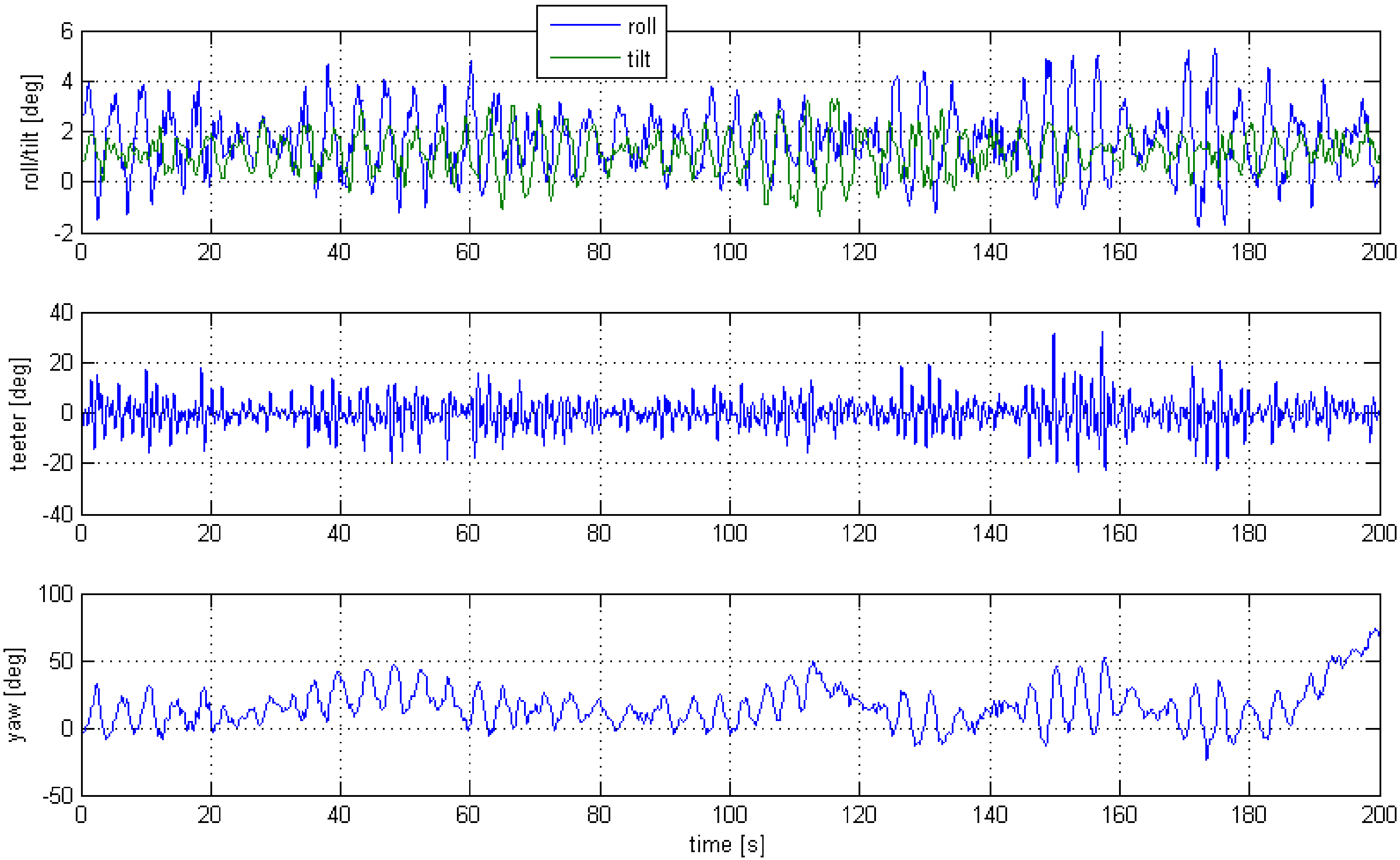
Experimental setup

- Sea state as 20 min statistics (5 min)
  - Wave height, period and direction
  - Current speed and direction
- Wind characteristic (35 Hz)
  - Wind speed and direction at hub height (12m)
- Platform motion
  - Inclinometers measuring platform DC pitch and roll (35 Hz)
  - One 3-axis accelerometers at each of the three turbine foundations (35 Hz)
  - Platform direction (1 min)
- Turbine loads (35 Hz)
  - Tower bottom and top bending in two directions
  - Shaft rotating bending and driving torque
  - Blade root bending in two directions
  - Yaw, rotor and teeter position
  - Rotor speed

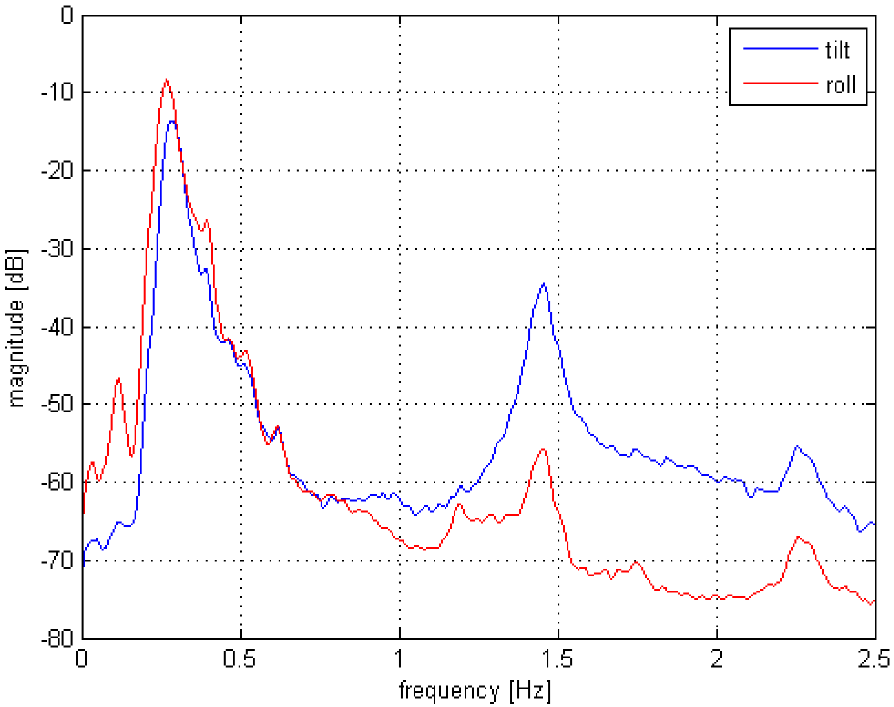
Result of second measurement campaign with turbines

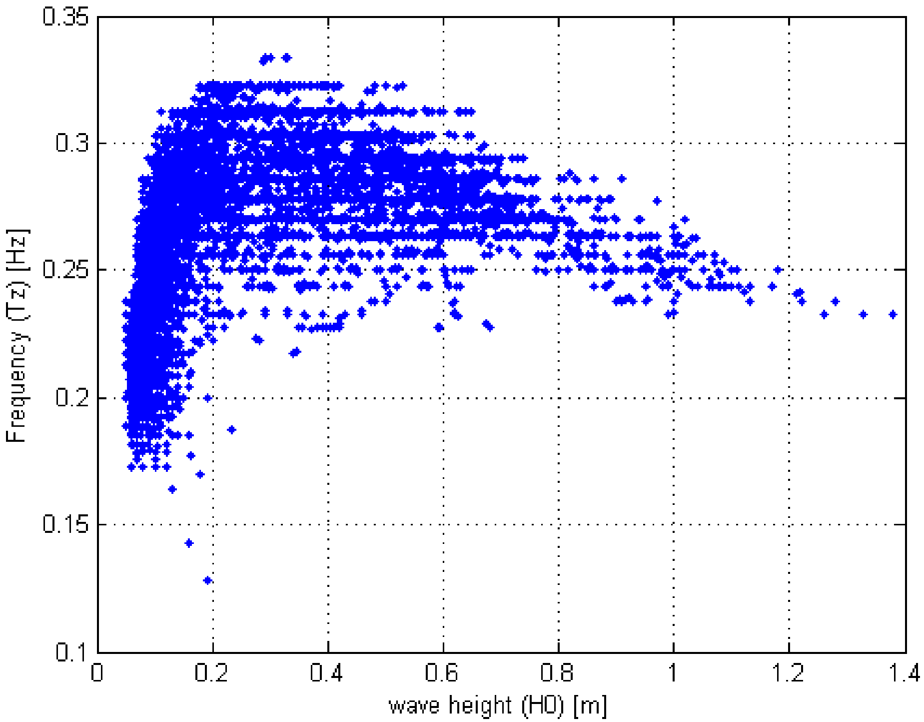
- Four months of continues operation
- Accounting for periods with signal outage and special test campaigns a total of 6799 10 minutes time series are available for analysis

Tilt and roll motion of platform



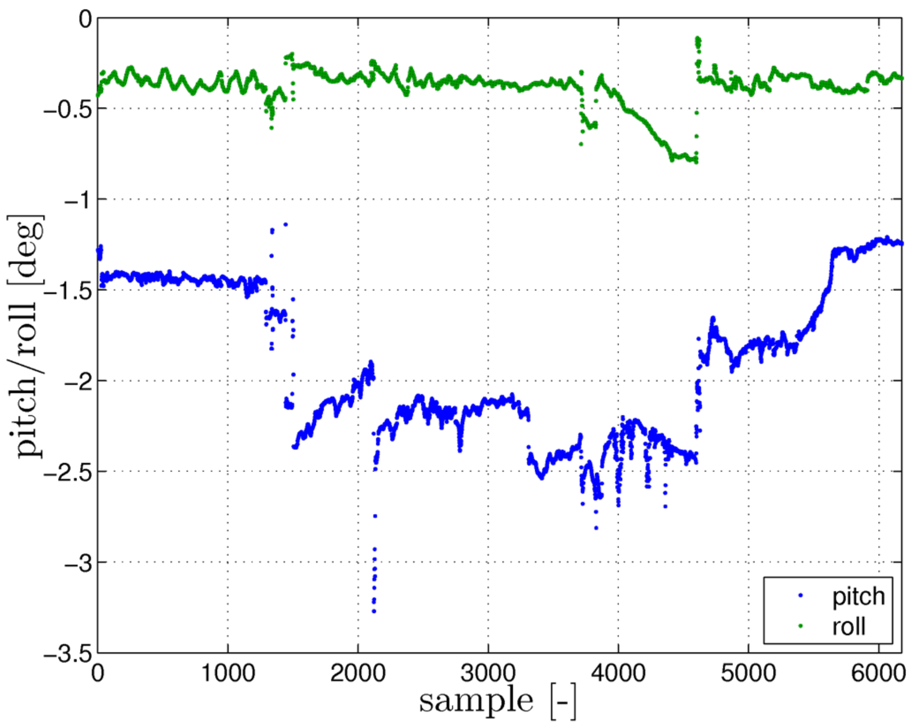
Power spectrum – no turbines





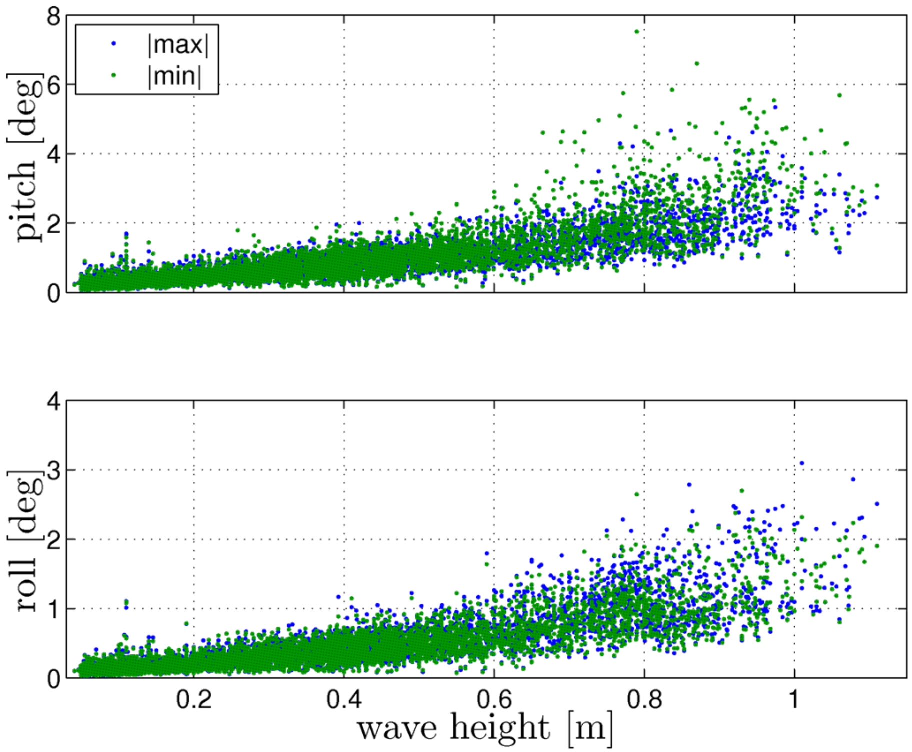
Frequencies from DHI:
Tilt: 0.146 Hz
Roll: 0.203 Hz

Mean Platform pitch and roll



- 10 minutes mean pitch and roll
- Very constant in roll
- Stepwise behavior of pitch => can be reduced by changed ballast control strategy

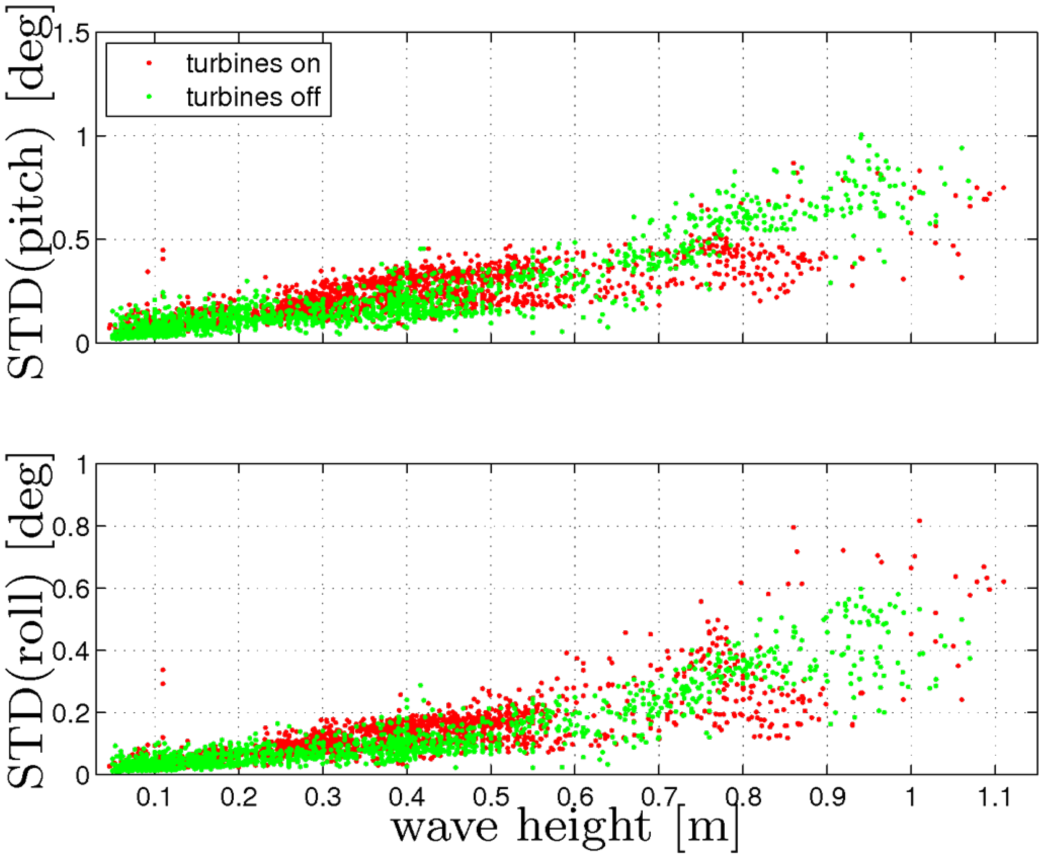
Platform pitch and roll amplitudes



- Absolute value of min and max excursion around mean position for each 10 minutes time series
- Pitch in general below 4deg, but up to 8deg are seen
- Roll is approx. 2 times lower than pitch

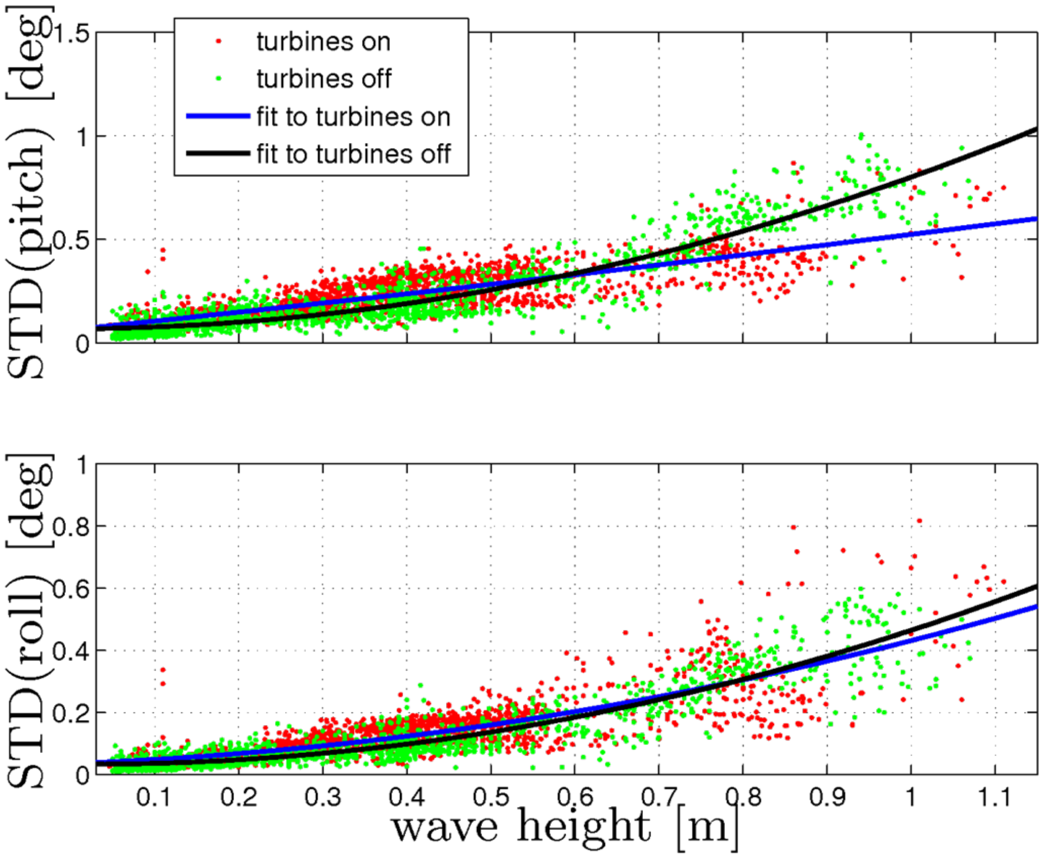
Effect of wind turbines on platform motion

- Collect periods with no turbines running and periods where at least two turbines are running



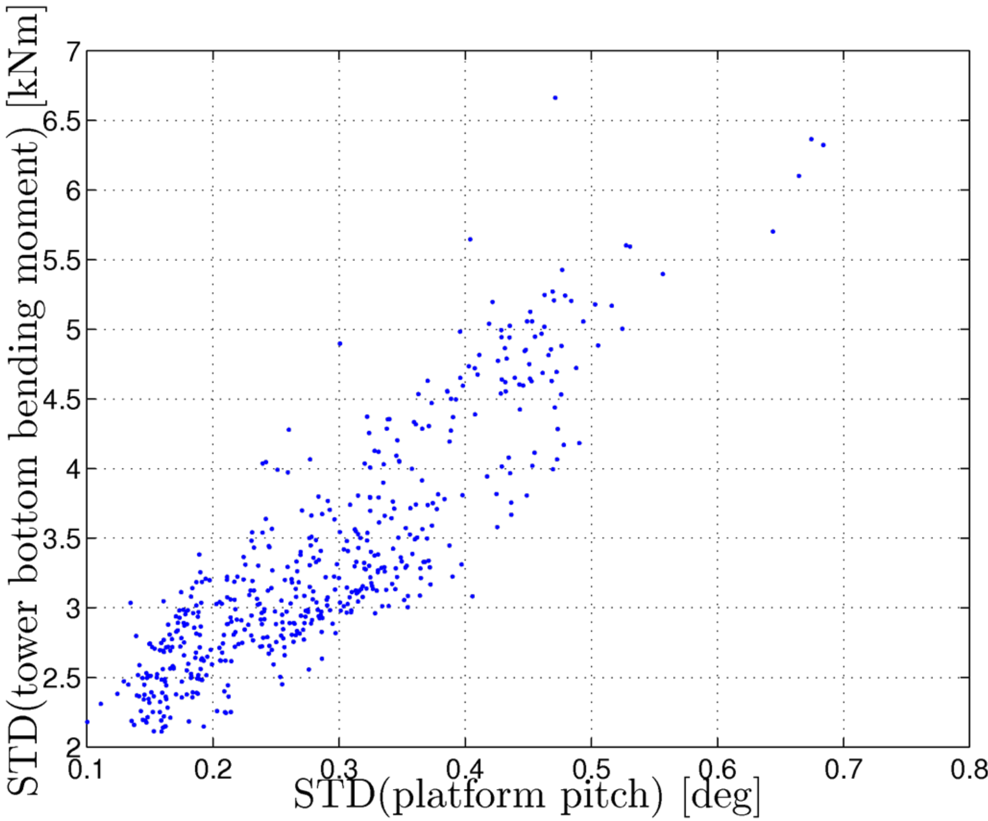
Effect of wind turbines on platform motion

- Collect periods with no turbines running and periods where at least two turbines are running
- Fit trend line to data points
- Increased pitch activity for small waves
- Decreased pitch activity for large waves
- Increased roll activity for small waves
- No effect at large waves

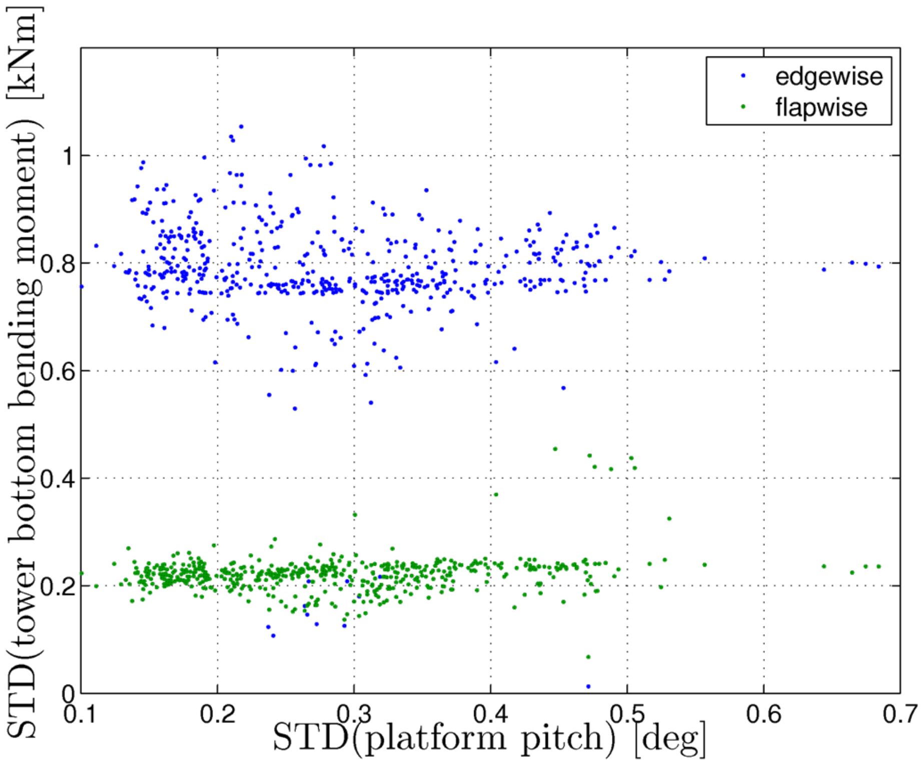


Turbine tower fatigue

- Use standard deviation as fatigue indicator
- Standard deviation of tower bottom bending versus standard deviation of platform pitch
- Wind speeds between 9 and 10 m/s => constant aerodynamic loading
- Linear increased tower “fatigue” with increased platform motion



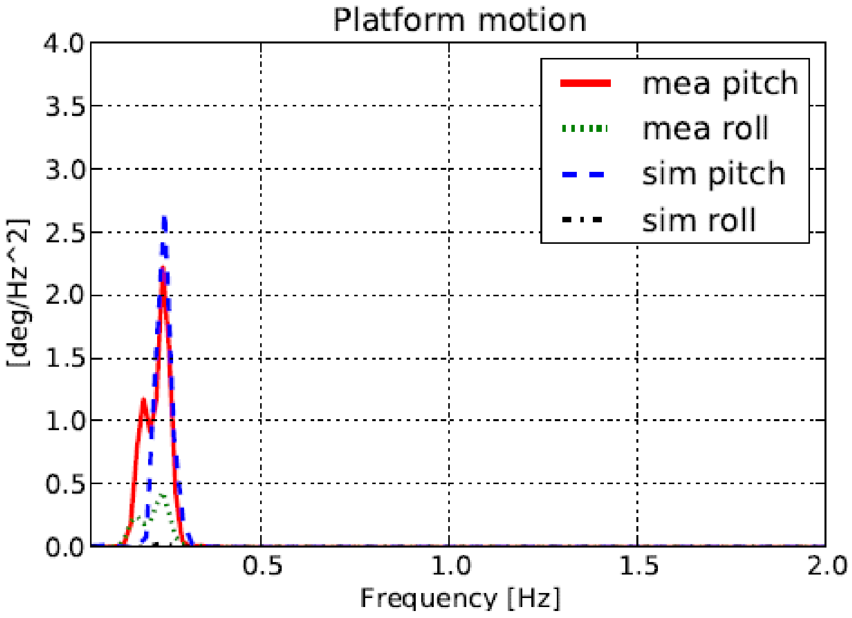
Turbine blade fatigue

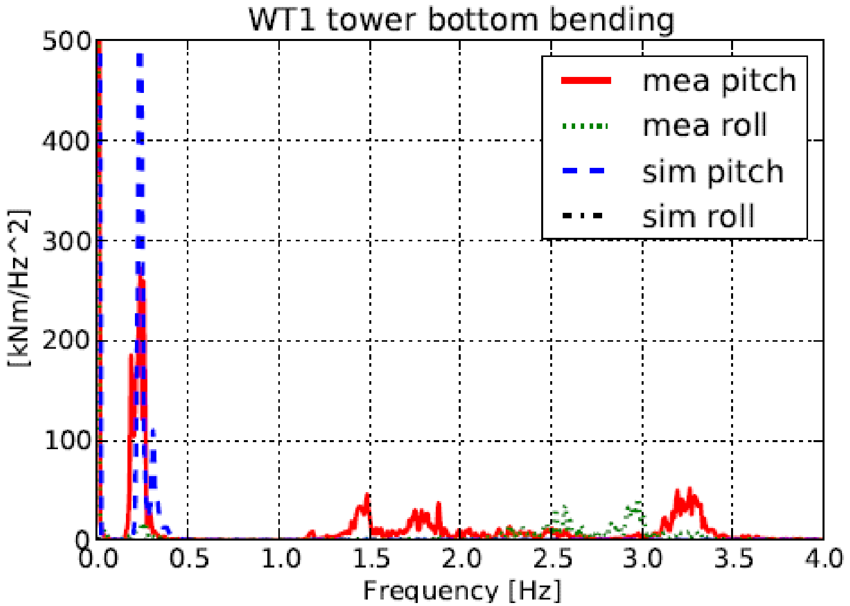


- Standard deviation of blade root bending versus standard deviation of platform pitch
- Wind speeds between 9 and 10 m/s => constant aerodynamic loading
- Blade loads not affected by platform motion

Comparison at stand still with simulations performed with coupled HAWC2-WAMSIM approach

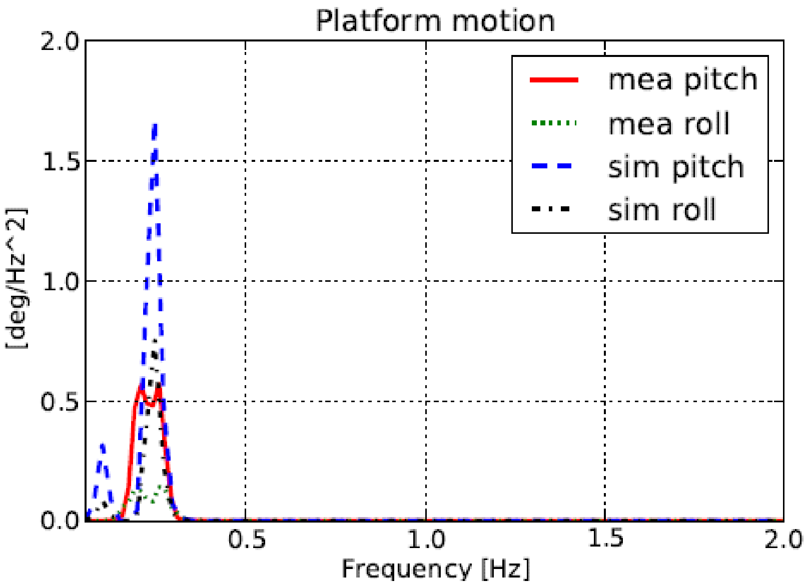
-Floaters not active, turbines at standstill
-Hs=0.66m, Tp=3.5s, V=2.5m/s
-Incoming wave direction 0deg.
-A good agreement is seen, but high frequencies only present in measurements

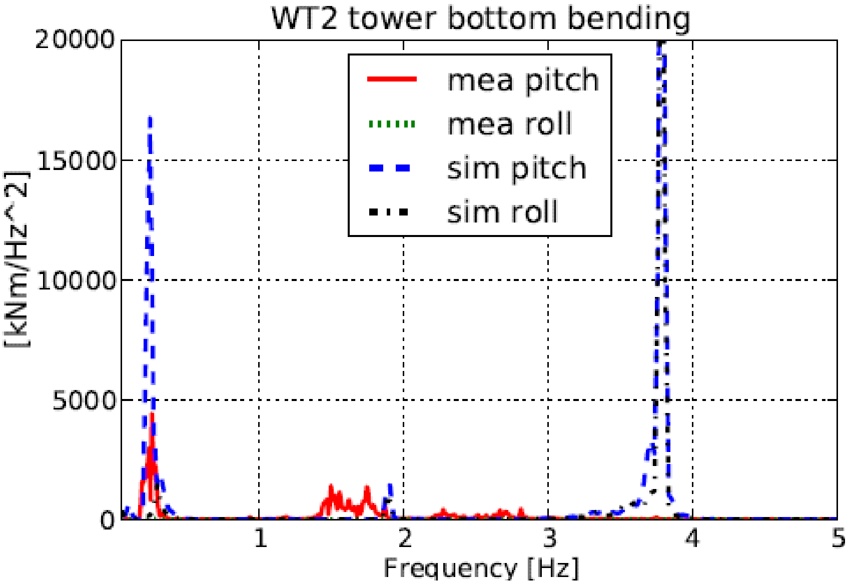




Comparison during wind turbine operation

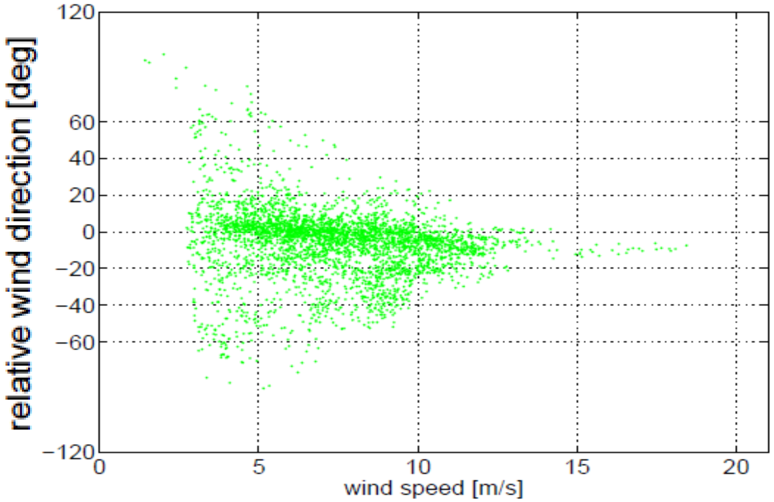
-Floaters not active, turbines are operating
-Hs=0.51m, Tp=3.44s, V=6.4m/s, Vdir=12deg, tint=9%
-Incoming wave direction 0deg.
-Agreement is not very good, but high frequencies only present in measurements, however 4P signal only present in simulations.

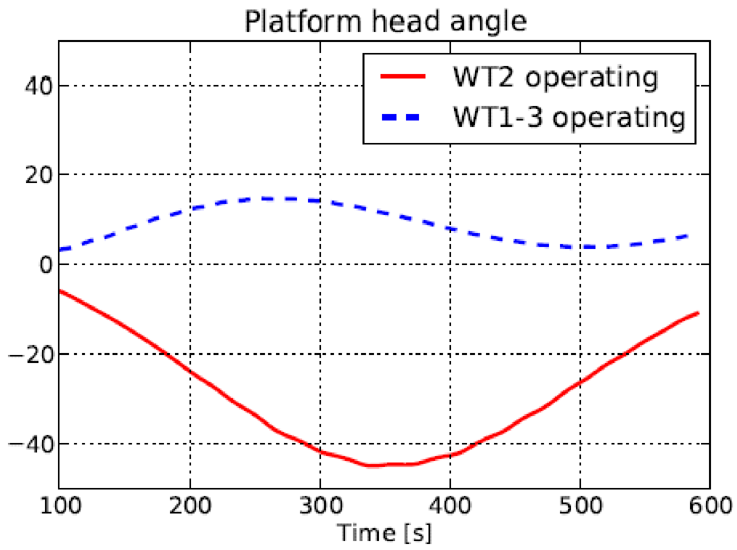


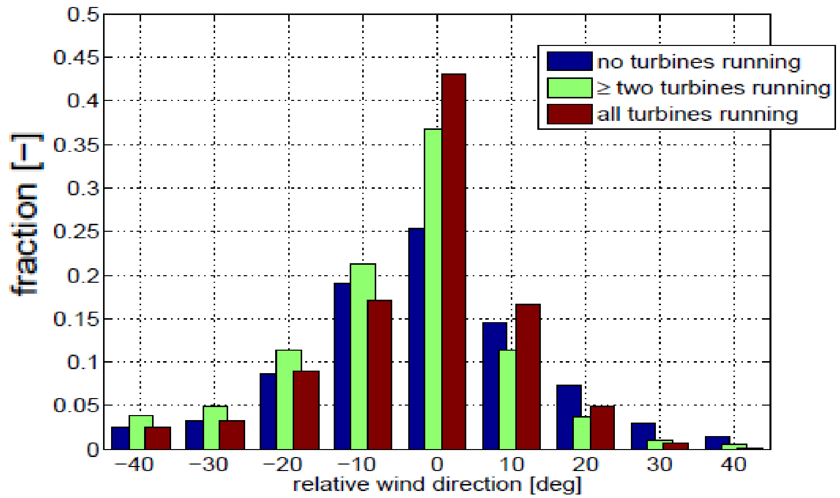


Platform alignment to wind and waves

- Yaw errors have been mapped
- Operating turbine increases wind alignment
- In only one front turbine is present, large misalignment occurs.
- A halfwake situation occurs at 24deg.







Model test of a flexible monopile.

New tests at DHI with a rigid and a flexible structure

DTU:
Henrik Bredmose
Torben J. Larsen
Signe Schløer
Bo Terp Paulsen

DHI:
Flemming Schlütter
Jacob T. Sørensen
Anders W. Nielsen

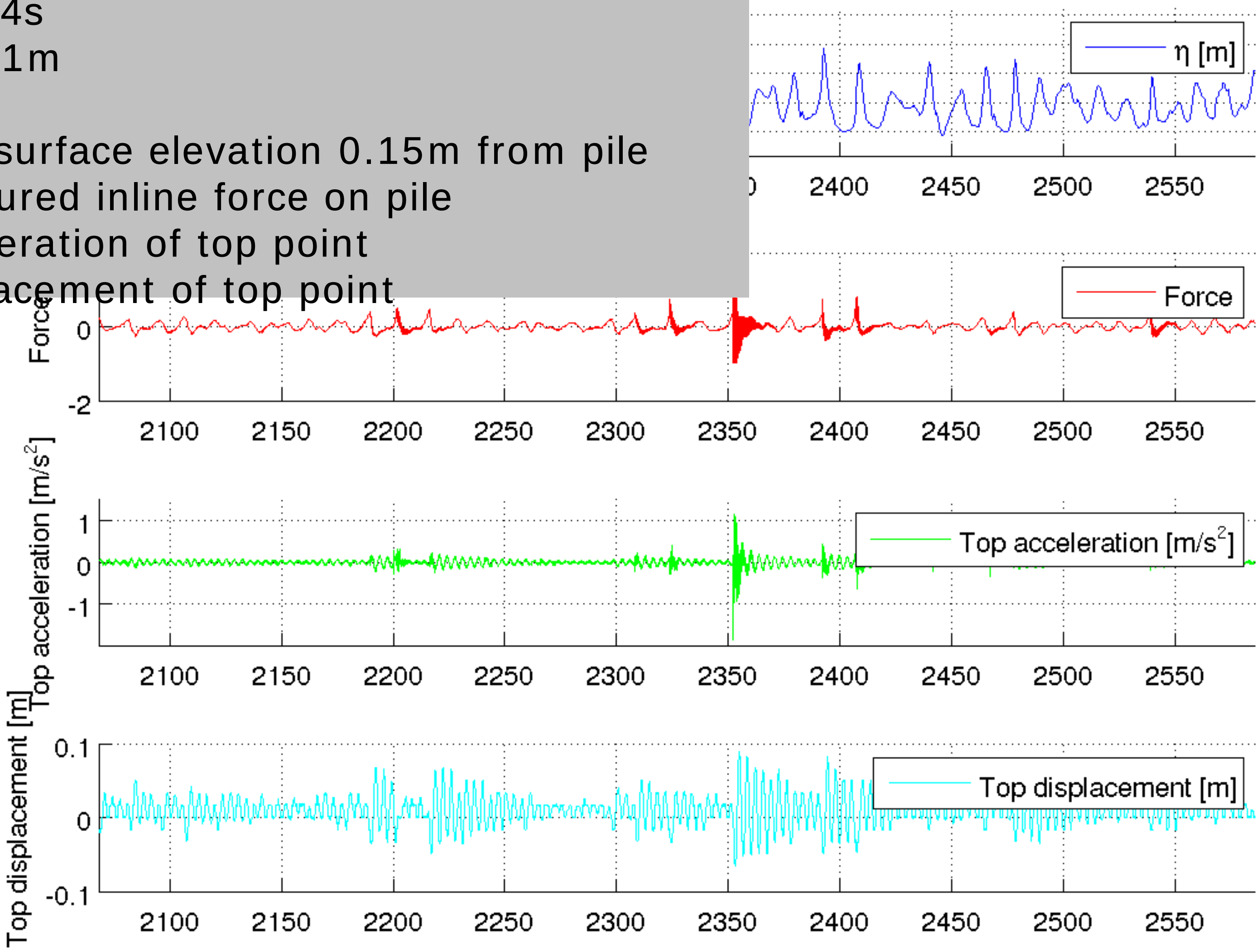
Zang & Taylor (2010)
Experiments at DHI with focused wave groups

Results and brief analysis

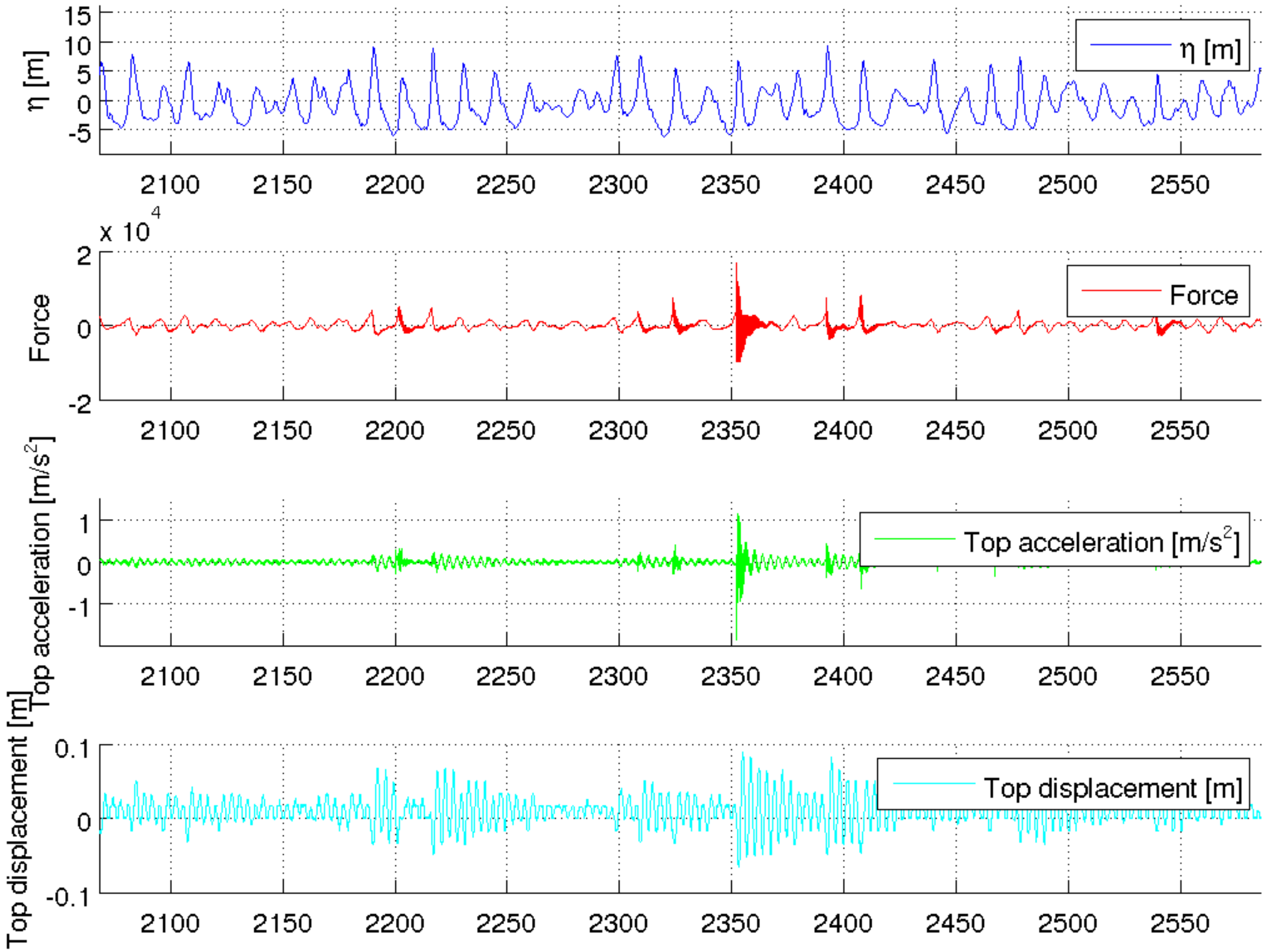
Irregular JONSWAP waves, unidirectional

Tp=14s
Hs=11m

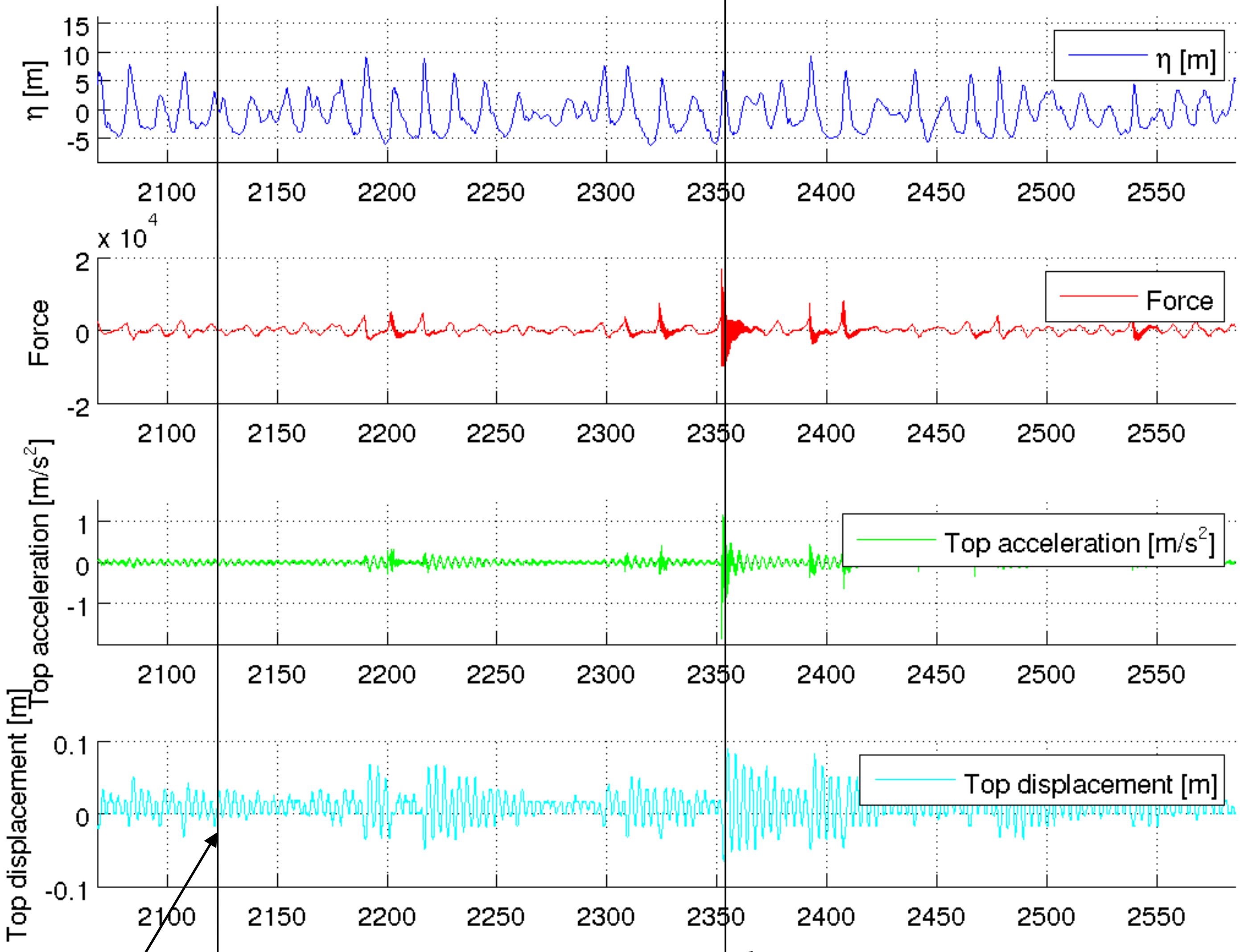
Free surface elevation 0.15m from pile
Measured inline force on pile
Acceleration of top point
Displacement of top point



Results and brief analysis



Results and brief analysis

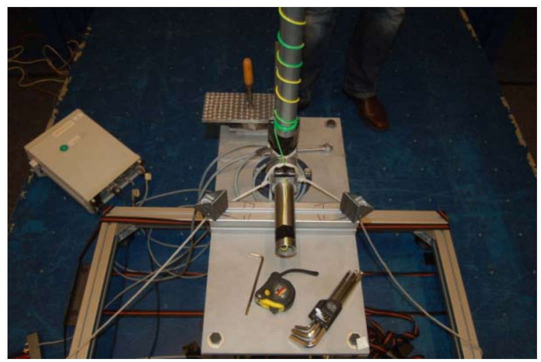


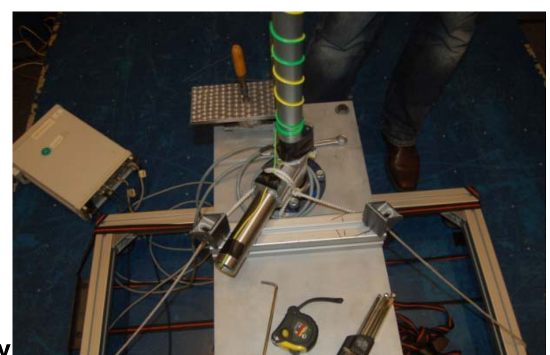
'continuous' forcing of 1st natural mode from wave-nonlinearity

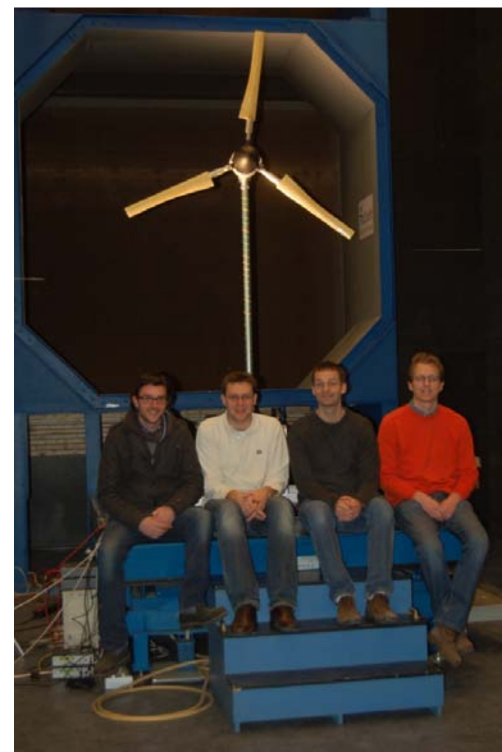
Impulsive load from breaking (presumably the force load ce

Model test of a 3bladed, downwind, passive yaw turbine in the Delft Open-jet wind tunnel

- Part of an EU-funded Marie-Curie project WINDFLOWER (3E, DTU-WIN, TUDelft)
- Goal is a robust, servicefree medium sized wind turbine for 3rd world countries (100kW range)
- Wind tunnel tests at the TU Delft Open Jet Facility (OJF):
- Comparing different degrees of blade flexibility, different cone angles
- Free yawing, downwind turbine
- Comparison HAWC2 simulations with wind tunnel tests







Overview of the OJF test setup

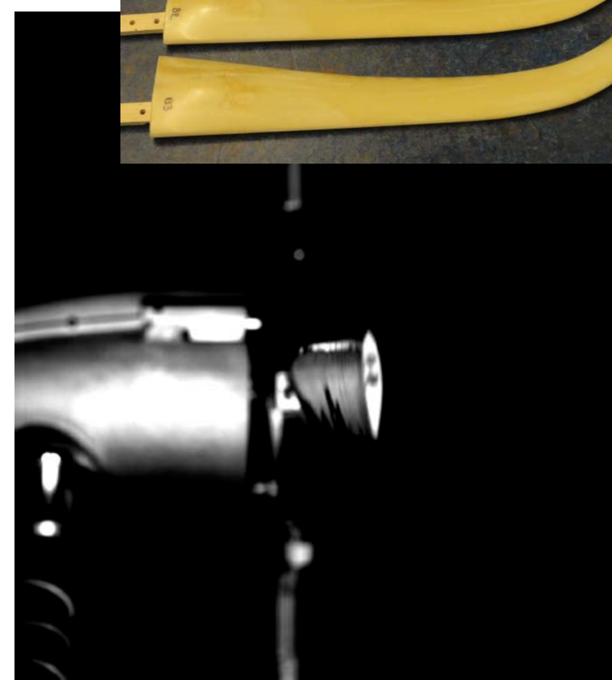
- OJF properties:
  - Nozzle exit section 2x2m
  - Wind speeds: 3 – 25 m/s
- The wind turbine:
  - Free yawing (tower base), control with wire
  - Blades made from injected PVC foam, internal glass fiber stiffener
  - No active RPM control
- Measurements:
  - Rotor speed
  - Tower base strain FA, SS
  - Blade strain (flapwise)
  - Yaw angle
  - Tip deflection (HS camera)
  - Electrical power, load side

Rotor design considerations

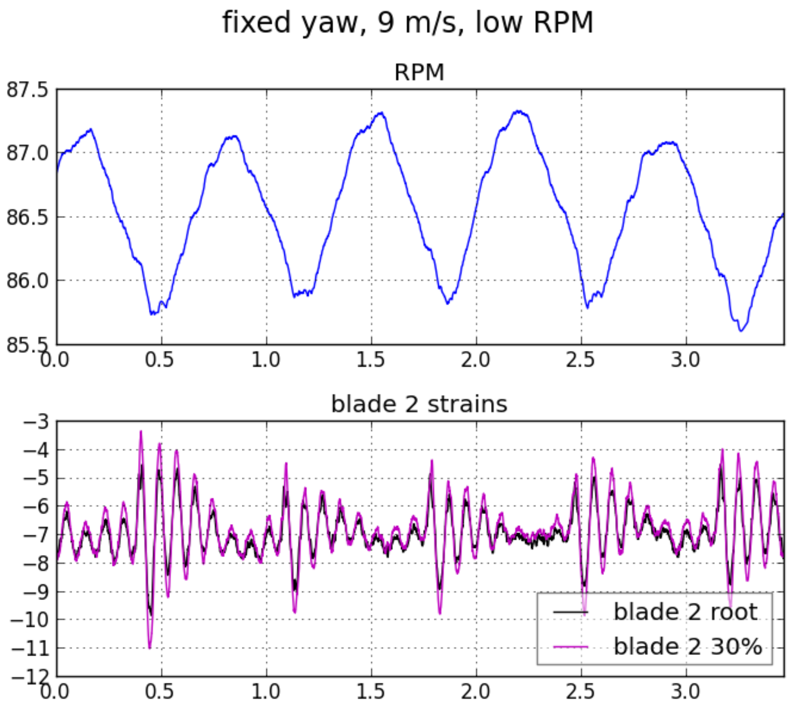
- Full scale starting point (only existing on paper)
  - 100kW
  - 24m rotor diameter
  - Optimal tip speed ratio (TSR): ~ 6
  - Typical Reynolds numbers at optimal TSR:
    - 0.50e6 - 1.30e6
- Scaled down model:
  - Rotor diameter < 1.8m (wind tunnel size restriction)
  - Maintain TSR, consequently optimal RPM's / wind speeds are:
    - 300 RPM @ 4 m/s, 750 RPM @ 10 m/s
  - Typical Reynolds number similarity is not maintained:
    - 0.10e6 – 0.15e6
  - Selected airfoil profiles for which 2D wind tunnel data exists at given Reynolds numbers: NREL S822 and S823
  - Maximize blade tip deflection (see next slides)

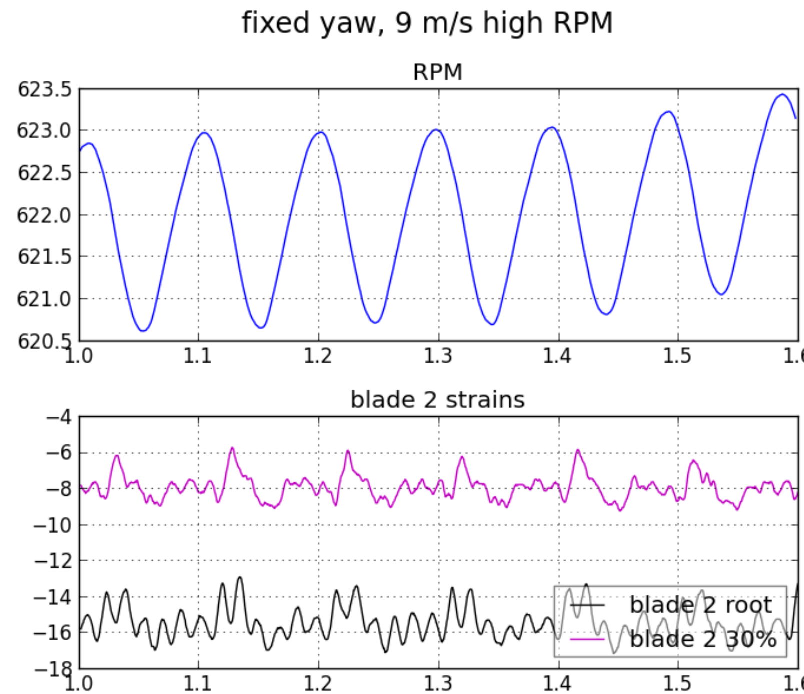
More details on the rotor

- 4 sets of blades:
  - PVC foam injection into negative mold
  - Stiff, less stiff, flexible, swept+flexible
  - Stiff and less stiff have glass fiber sandwich inner beam and PVC foam around
  - Stiff and less stiff fitted with strain gauges
  - Flexible: pure foam
- The stiff blades where additionally tested for a coning angle of 10 degrees
- Verify blade pitch angle, estimate tip deflection with a high speed camera.
- Operational inflow conditions:
  - Fixed yaw at zero yaw error
  - Free yawing
  - Impose yaw error and release



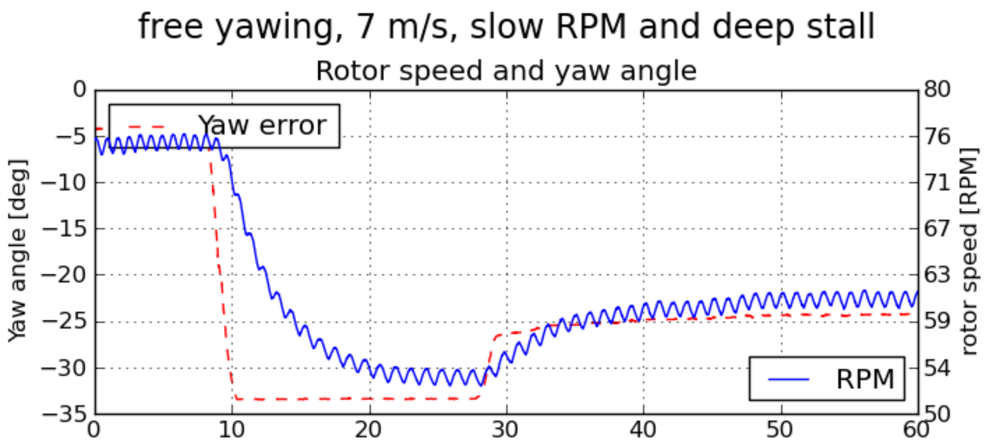
Early results: tower shadow passage introduced blade vibrations



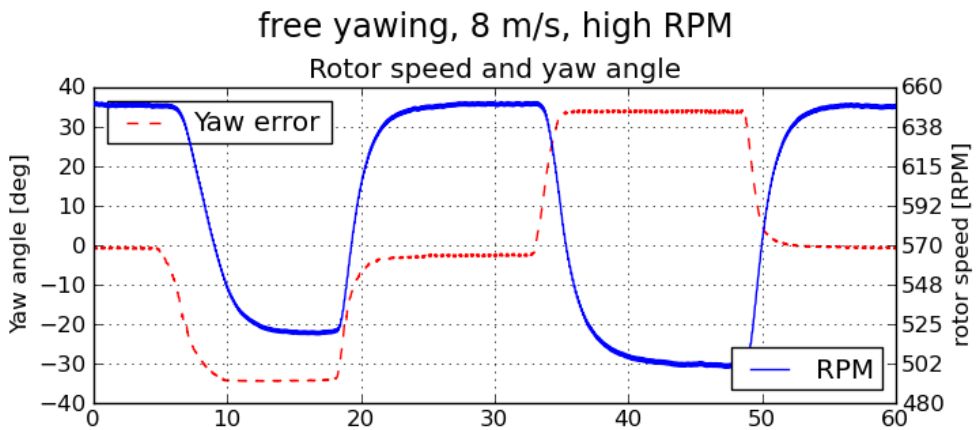


The damping is clearly higher for the high rpm operation.
Centrifugal forces affect the strain level

Early results: free yaw stability



At low rpm (in stall), a large yaw misalignment is seen.



At high rpm the yaw misalignment is ~1deg. The decay is fast without overshoot.

Discussion

- Model tests in windtunnels, wave basin and open air/water are essential. Can supplement the knowdledge at early stage, but not replace the final full scale measurements.
- General performance of sub components (eg. Airfoils) and stability related matters can be clarified with known environmental conditions.
- Even though the wind and wave input are well defined, it does not necessarily represent ambient complexs loading. Especially atmospheric turbulence is allways missing.
- It is not possible to downscale a turbine with all correct properties. Reynolds numbers too low, structure easily becomes too stiff, centrifugal forces much more dominent. Choices have to be done.
- Since the data for the model does not really reflect a fully correct scaling of all parameters it might be easier to distribute data.
- From a simulation and measurement point of view it requires just as much work as for a full scale comparison…
- As with all other comparisons, start out simple and gradually increase the loading complexity.

Example of a consequence study:
- Influence of non-linear waves impact

Comparisons of wave kinematics models for an offshore wind turbine mounted on a jacket substructure

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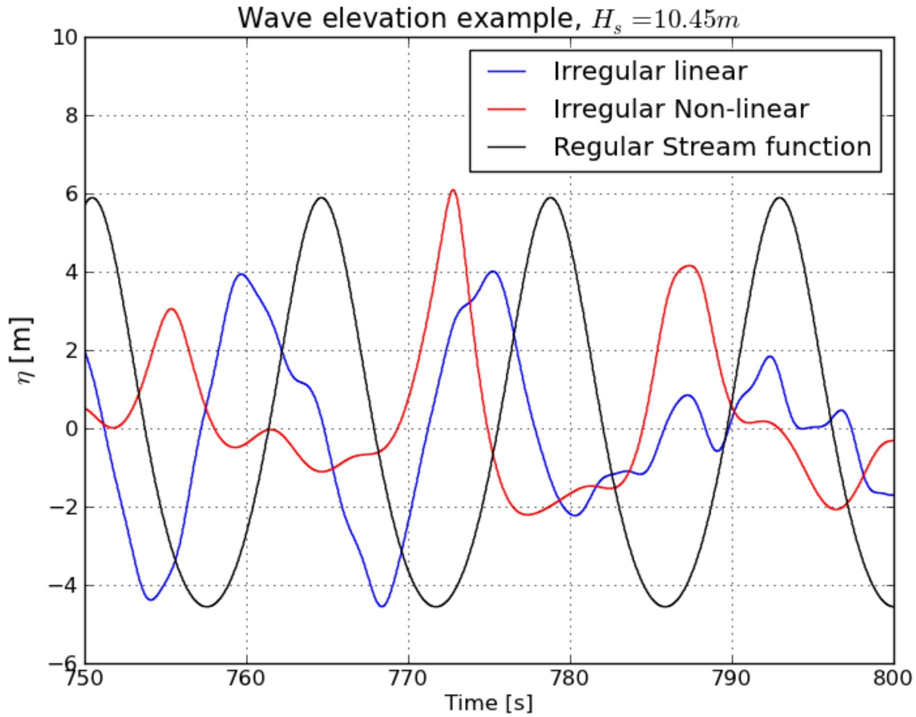
EWEA Offshore 2011
Amsterdam, The Netherlands
29th November - 1st December 2011

Abstract

The purpose of this study is to investigate the dynamic influence of wave loads for wind turbines placed at intermediate water depths (40-60m) using a jacket substructure. We analyze whether nonlinear wave loading may lead to "ringing", which is a transient excitation of structural modes with much larger amplitudes than seen for linear wave kinematic models. Full interaction between dynamics of the wind turbine and the substructure is included in the study performed for a standstill situation using the fully flexible aeroelastic code HAWC2. Wave loads are modeled using classic methods like Airy and stream function theory, but also a new and more advanced fully nonlinear irregular model has been applied. This nonlinear wave model solves the 3D Laplace equation for the velocity potential with nonlinear boundary conditions at the free surface and an impermeability condition on the sea bed on a variable depth, representing state-of-the-art within nonlinear irrotational wave modeling. The results show a significant increase in dynamic load contribution by the nonlinear waves.

Wave load methods

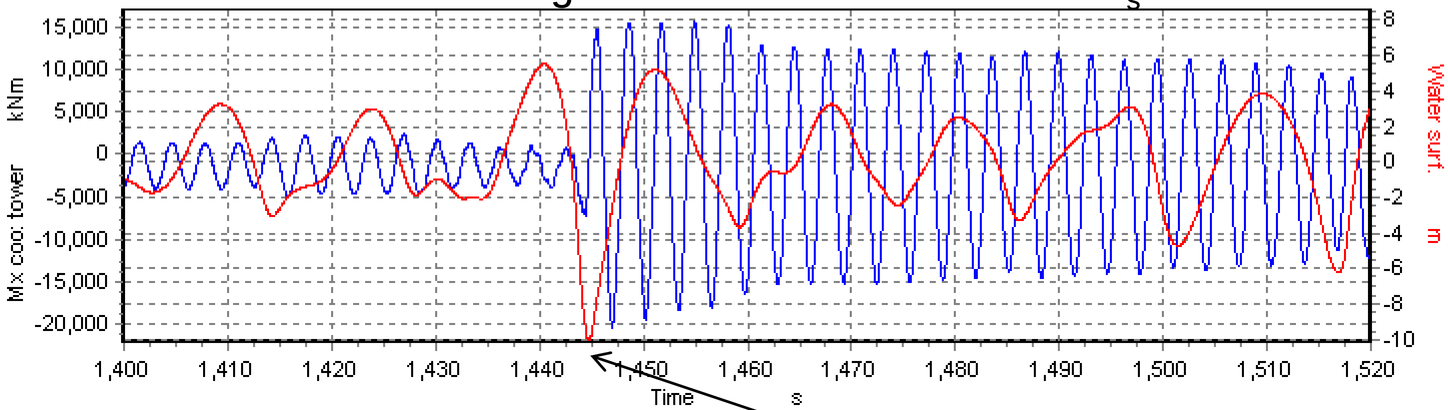
- Classic linear irregular Airy theory with wheeler stretchning
- Stream function theory – regular waves
- Full non-linear solution of the 3D Laplace equation for the velocity potential with nonlinear boundary conditions at the free surface and an impermeability condition on a variable depth [1]



[1] Engsig-Karup, A.P., Bingham, H.B., Lindberg, O. An efficient flexible-order model for 3D nonlinear water waves. Journal of computational physics 228 (2009) 2100-2118

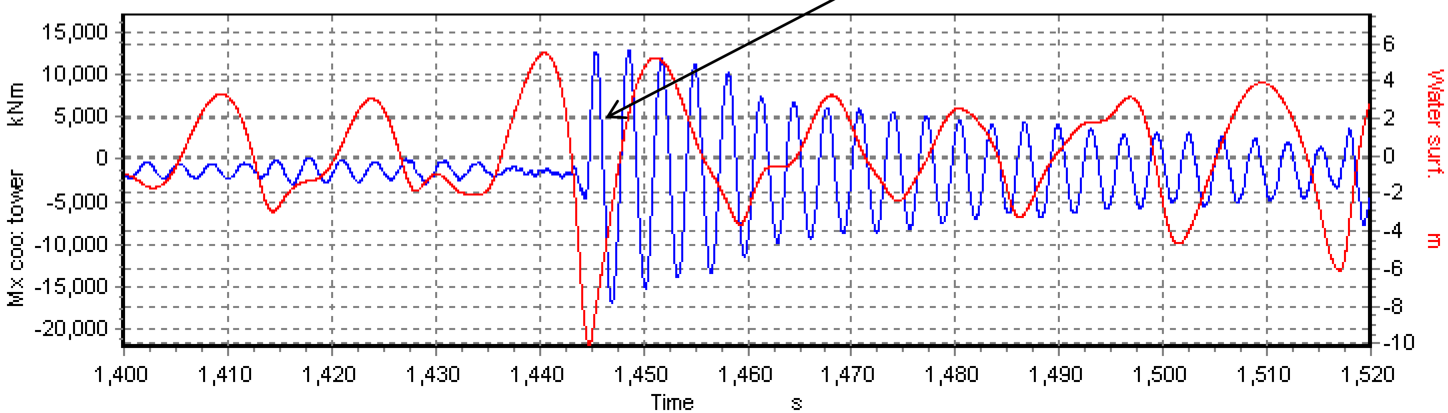
Time series – an example

Tower bottom bending and wave elevation for H_s=9m



2% log. decr.

The single large waves may cause ringing



10% log. decr.