Validation of INNWIND.EU Scaled Model Tests of a Semisubmersible Floating Wind Turbine

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WINDFORS
Windenergie
Forschungscluster

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Motivation and Background

INNWIND.EU Test Campaign

[Florian Amann, SWE]

Test Campaign:

- 4 weeks in September – November 2014
- combined wind-wave tank LHEEA at École Centrale de Nantes (F)
- **1/60 Froude-scaled** Innwind 10 MW wind turbine (built by POLIMI)
- low-Reynolds Froude-scaled blades
- **semi-submersible** floater based on „OC4-DeepCwind“ (built by USTUTT)
- additional ballast below the floater to achieve scaled CM
- several measuring sensors
- **goals**:
  - increasing experience w/ model tests
  - reducing uncertainty in results
  - deliver another semi-sub datatset

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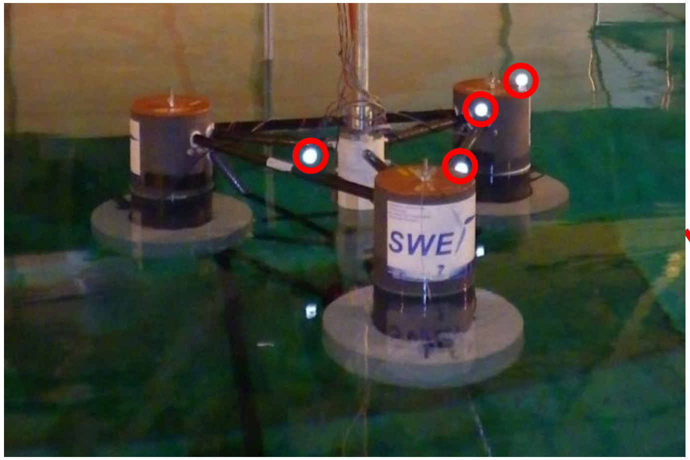
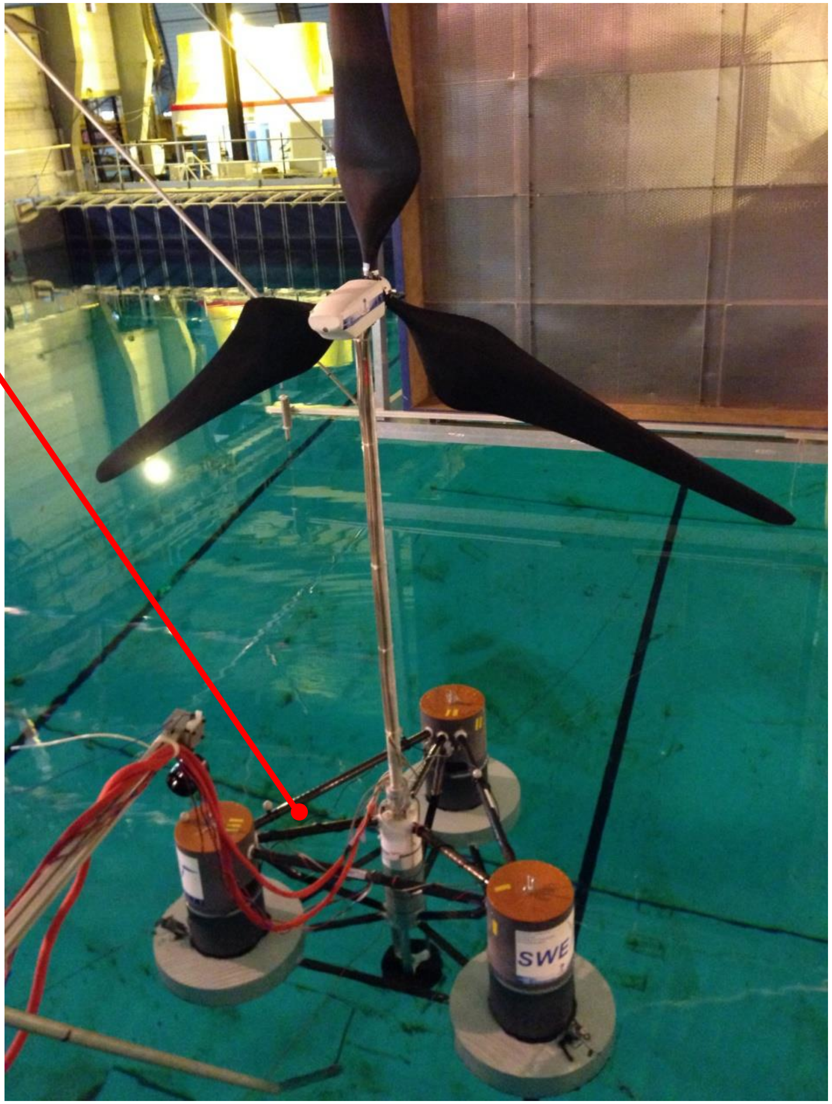
Sensors: Global Floater Motion



[Florian Amann, SWE]

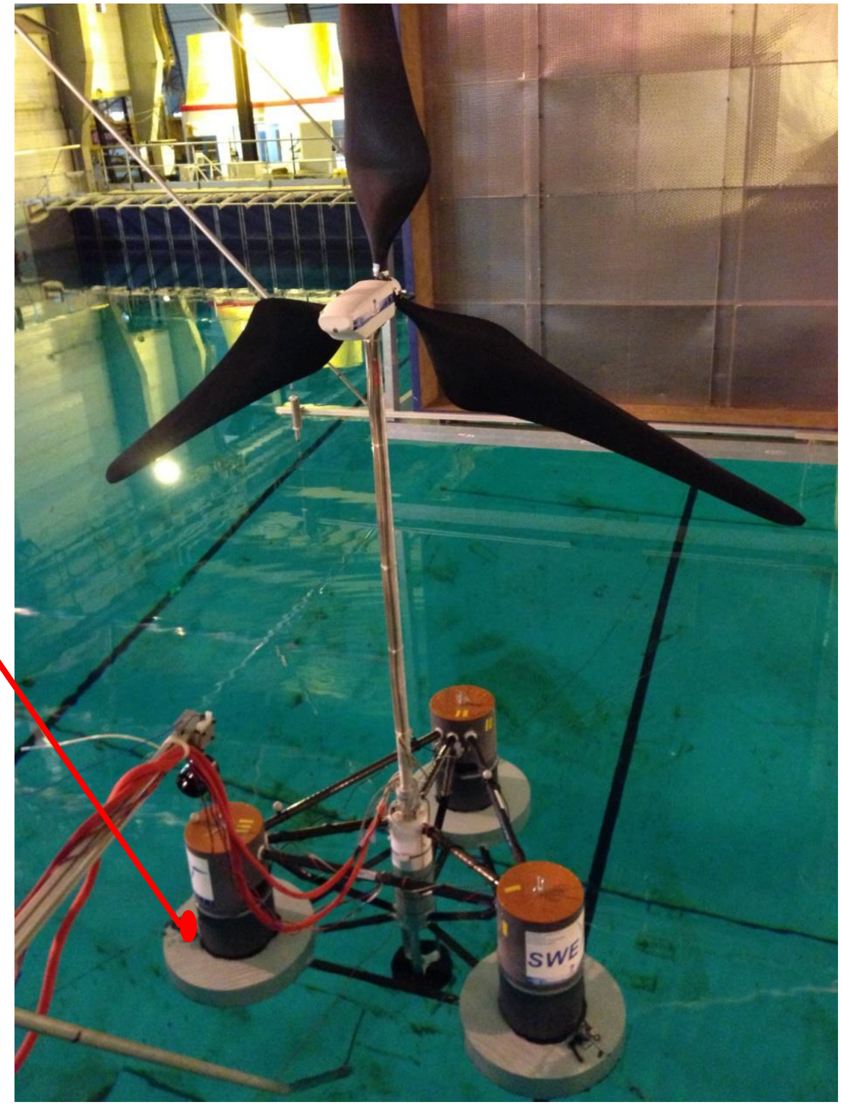
- optical motion tracking system and inertial measuring unit (backup)
  - floater surge, sway, heave, roll, pitch, yaw
  - accuracy: 1,2 mm / ~0,08 deg



[Florian Amann, SWE]

SWE Sensors: Mooring Lines

[Florian Amann, SWE]



[Florian Amann, SWE]

- beam cell with lugs
  - vertical fairlead tensions

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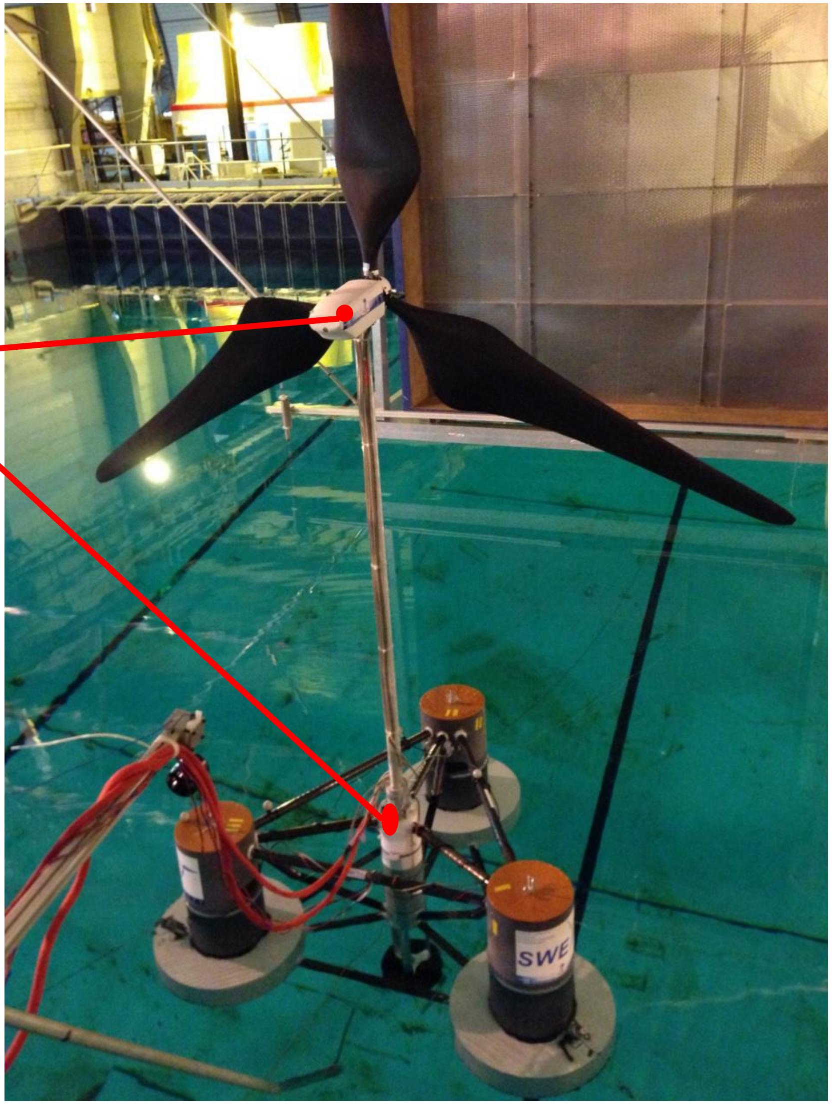
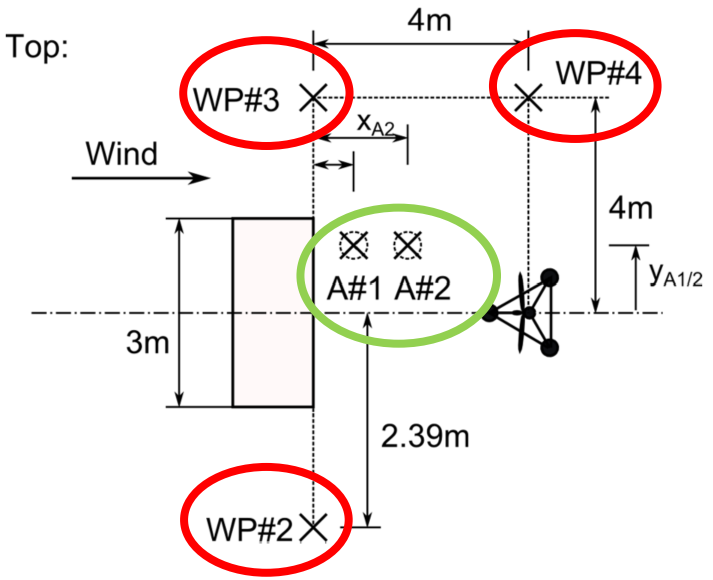
Sensors: Wind Turbine

- multiple more sensors
  - blade pitch angle
  - rotor speed
  - power
  - shaft bending moment
  - generator torque
  - rotor azimuth angle
  - tower base fore-aft/side-side bending moment

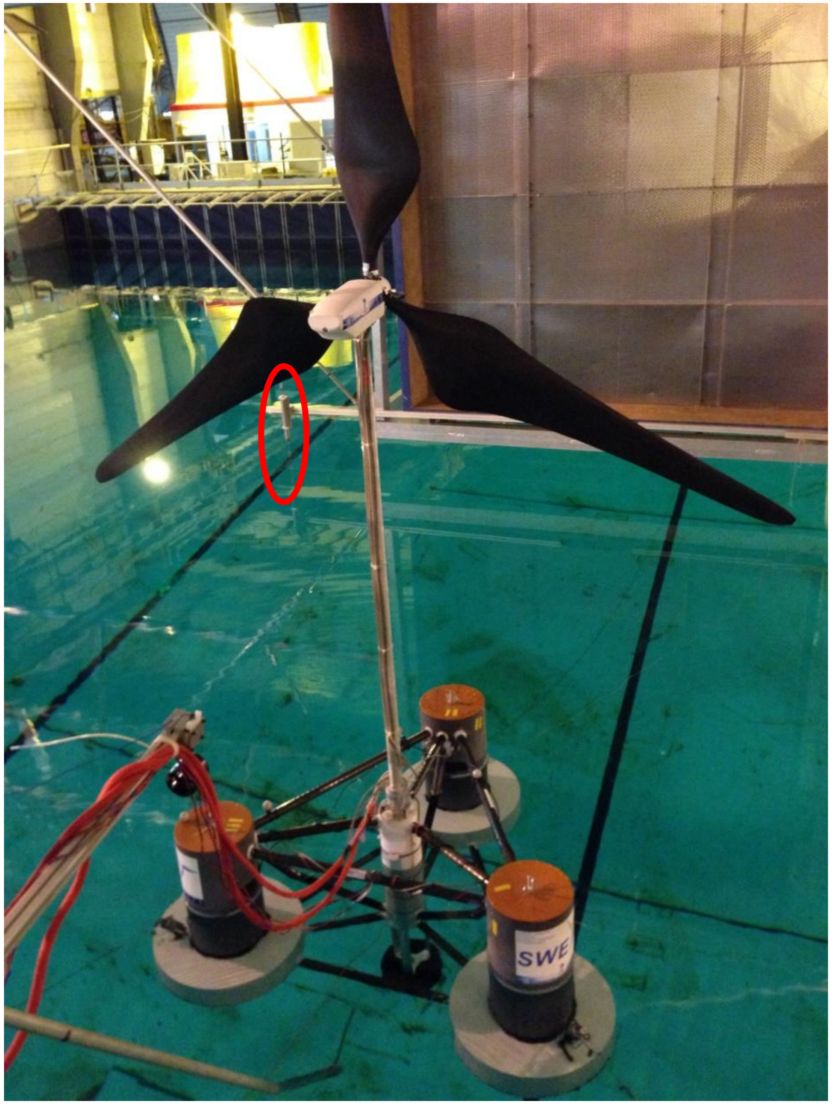


[Florian Amann, SWE]

SWE Sensors: Environmental Conditions



- two anemometers and three wave gauges
  - wave height, wind speed
  - signal noise reduction using a Butterworth low-pass filter



[Florian Amann, SWE]

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Simulation Model

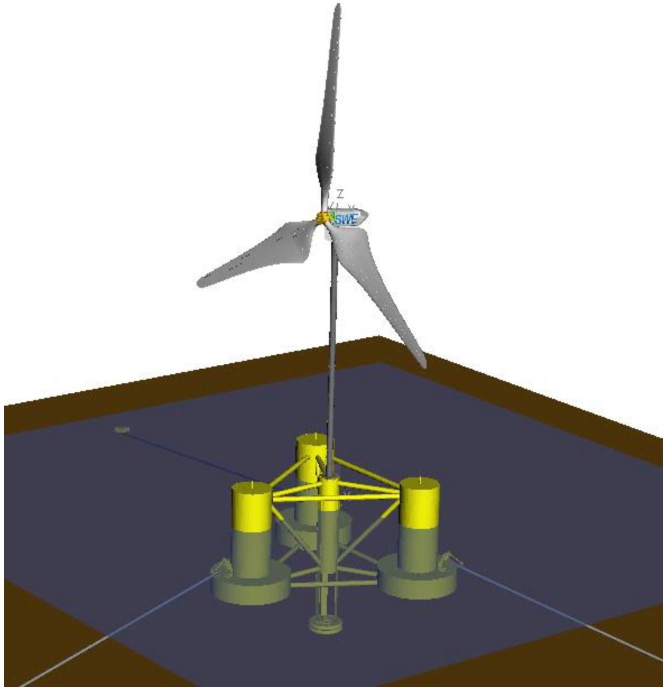
Aerodynamics
AeroDyn v13.00

Structural Dynamics
Simpack 9.9.1

SIMPACK

Hydrodynamics
HydroDyn v2.02.a-gjh

Mooring Dynamics
MAP++ v1.10.0.rc



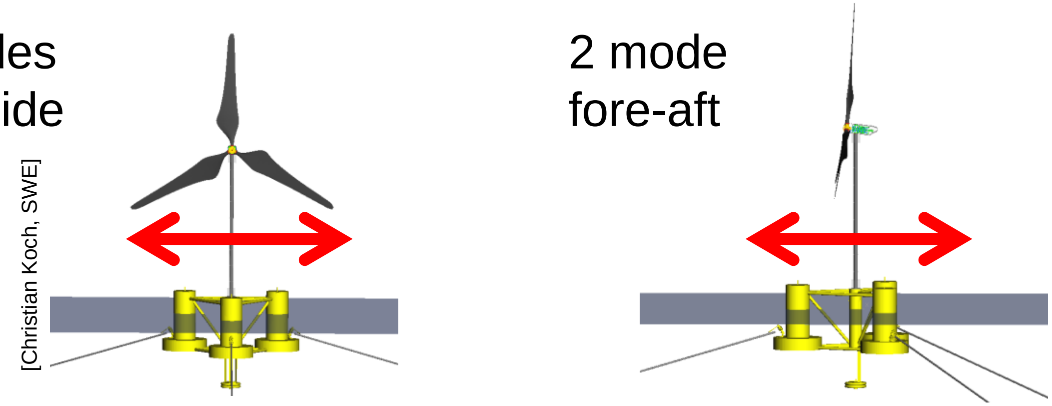
[Friedemann Borisade, SWE]

SWE Structural Dynamics

- blades approximated as rigid bodies
- tower modelled as flexible bodies using Timoshenko beams

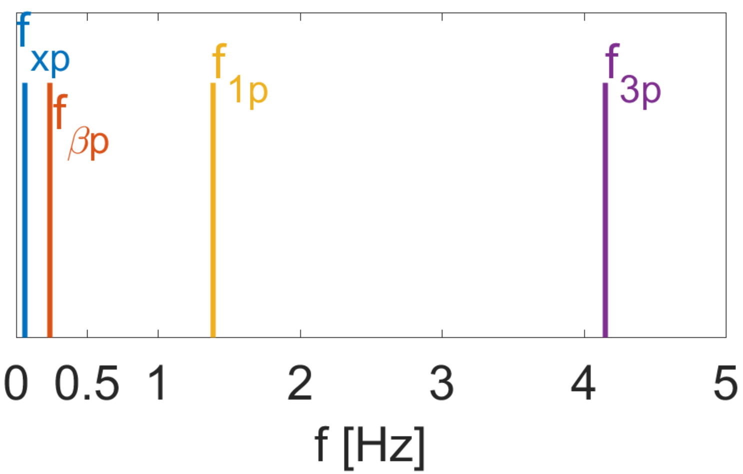
2 modes side-side

2 mode fore-aft



Range of 0- 20Hz

- natural frequencies:

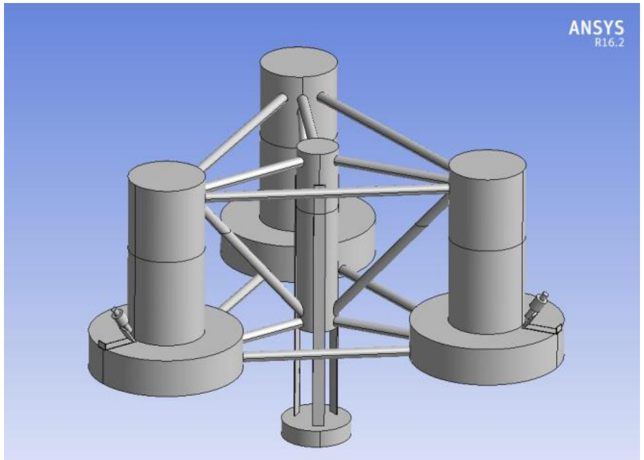


➢ good agreement between model test and simulation

SWE Hydrodynamics

- frequency domain:
  - recalculation of the floater hydrodynamics due to changed hull shape using the panel code software ANSYS AQWA

added mass



[Christian Koch, SWE]

damping terms

first order wave loads

- time Domain (HydroDyn):
  - consideration of member-based Morison elements and second order terms

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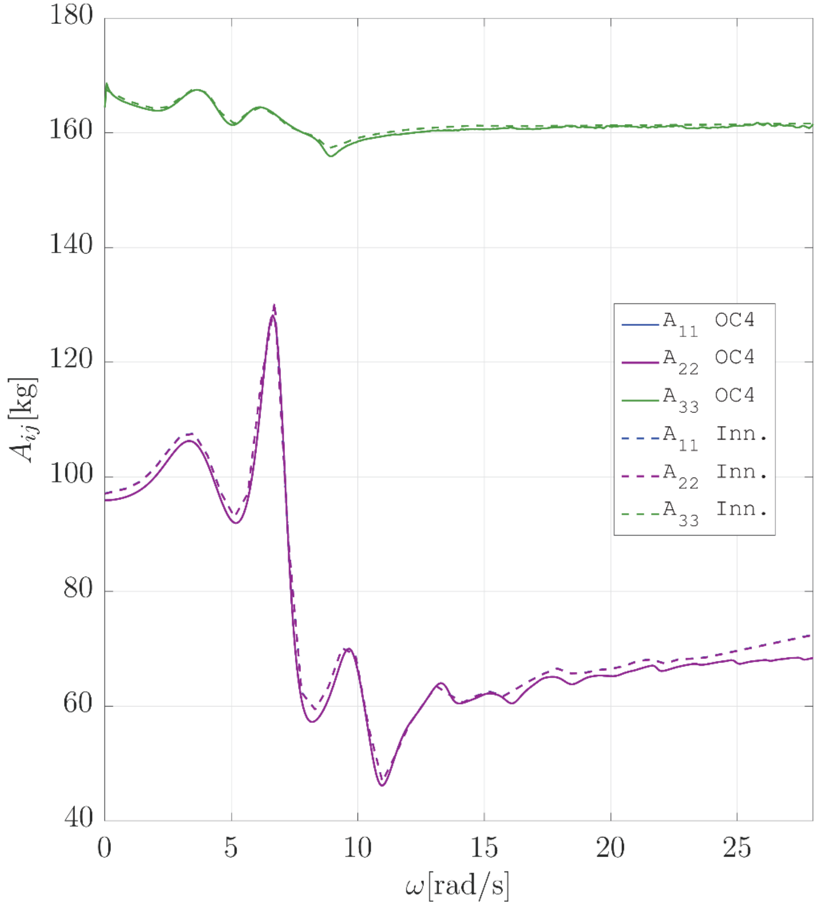
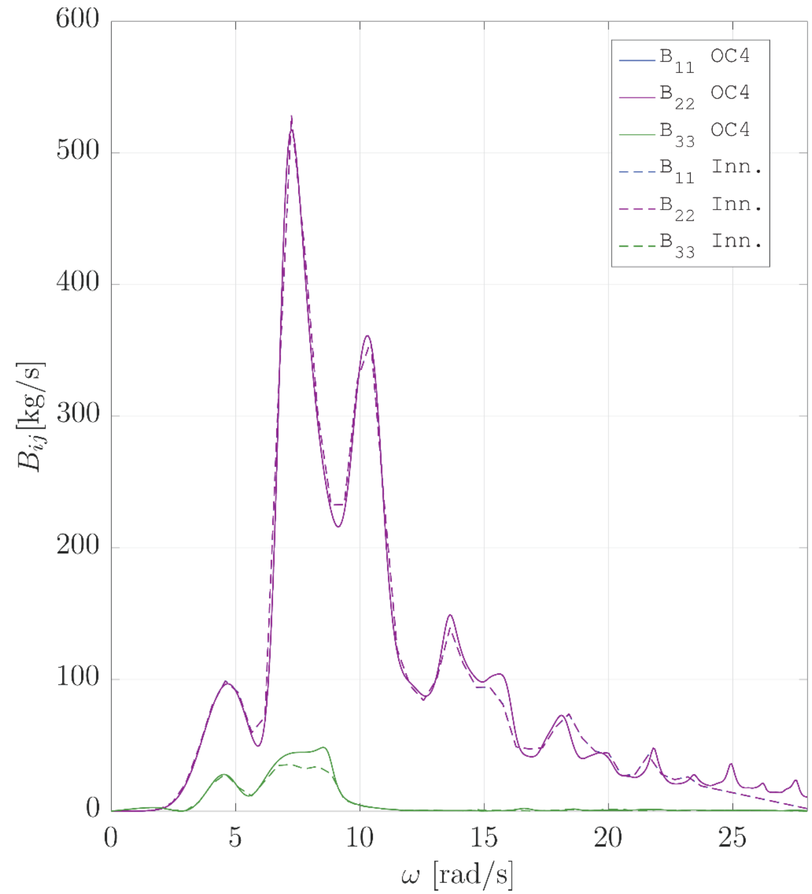
Added Mass and Damping Coefficients

- added mass



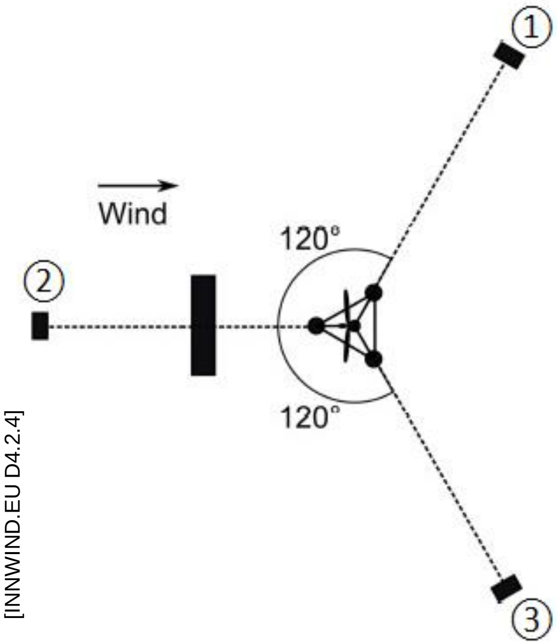
- damping



➢ only slight changes between original OC4 and INNWIND.EU

SWE Mooring Dynamics

- quasi-static mooring line model MAP++



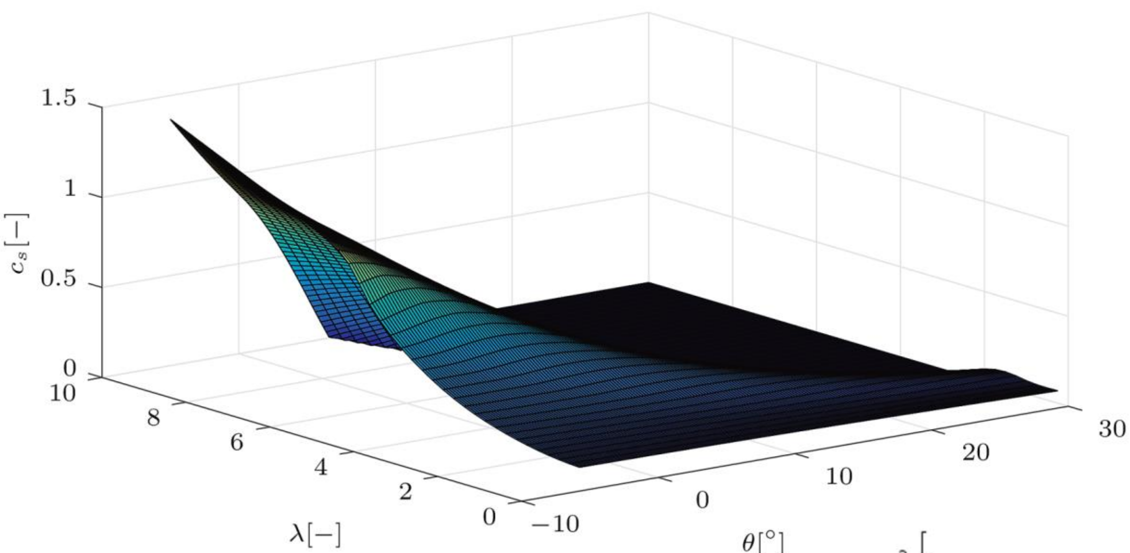
[INNWIND.EU D4.2.4]

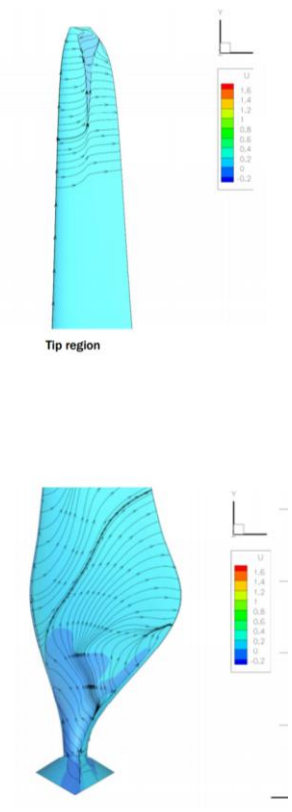
	Fairlead 1			
	Measurement [N]	Sim. [N]	Deviation [%]	Deviation [N]
Displacement 1	9,333	9,845	5,488	0,512
Displacement 2	8,492	8,904	4,849	0,412
Displacement 3	8,246	8,565	3,866	0,319
Displacement 4	8,155	8,434	3,428	0,280
			+4,408	**+0,381**

- high sensitivity to axial mooring line stiffness
- high sensitivity to changes; especially regarding to anchor position
- shifting of the radial anchor distance of 0,35 % leads to a mean overall mooring line tension change of nearly 7 %
  - ➢ MAP++ shows reasonable results

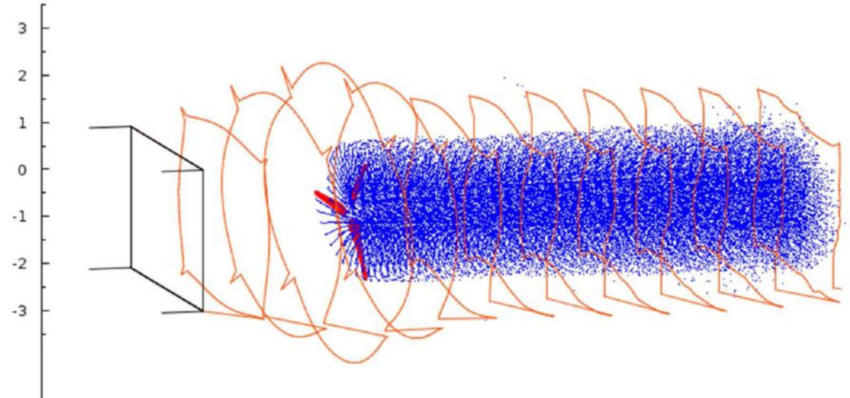
SWE Aerodynamics

- blade element momentum theory with Prandtl hub- and tip loss model
- no dynamic stall model





- expanding jet flow

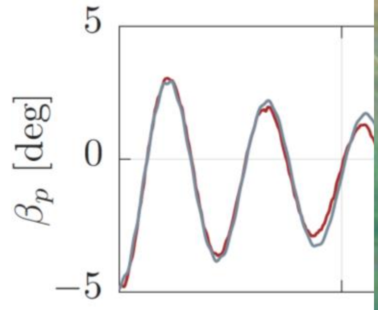


[INNWIND.EU D4.2.4]

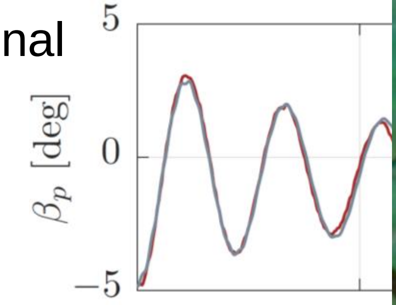
Pitch Free Decay Tests

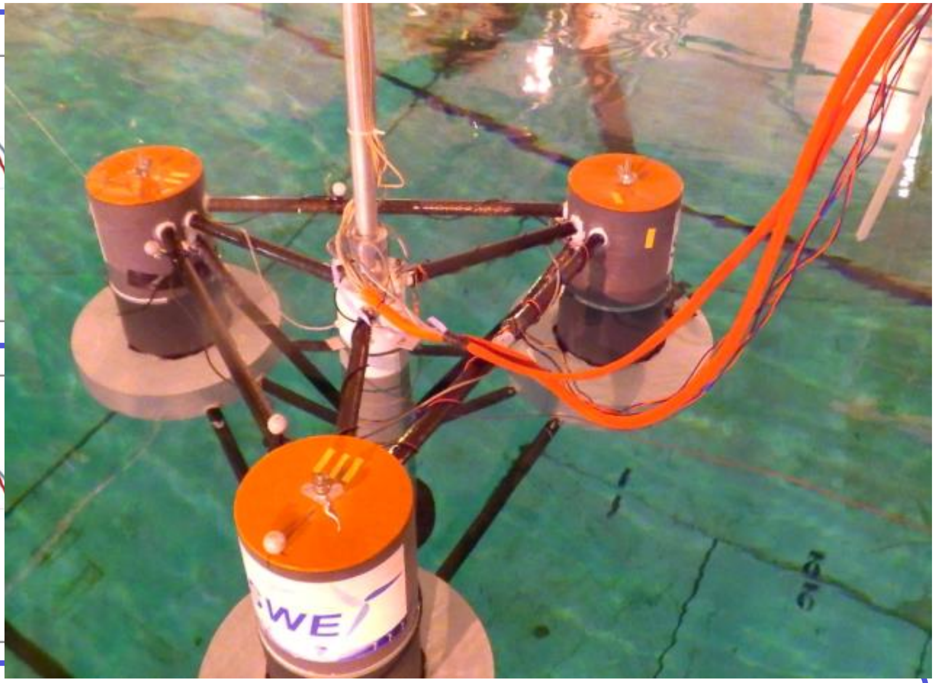
— measurement
— simulation

- clean

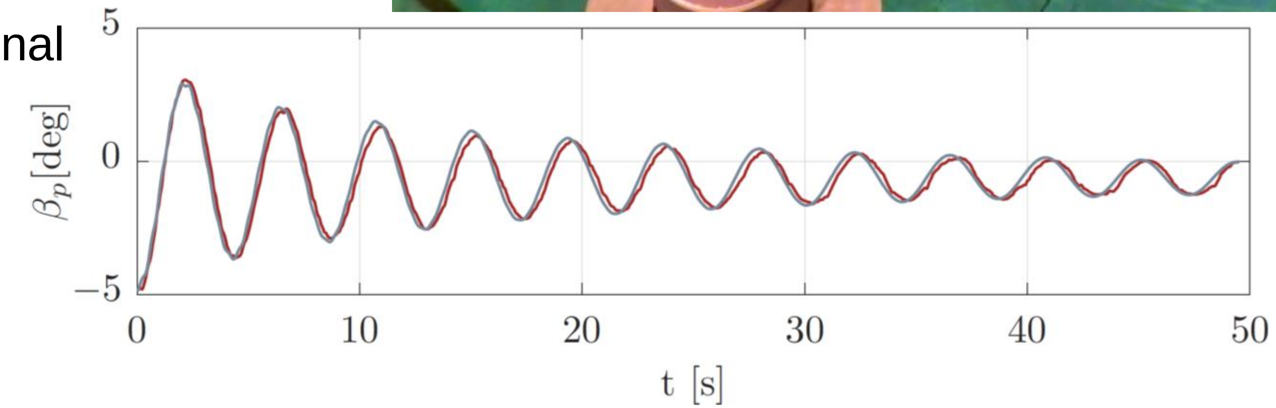


- w additional damping



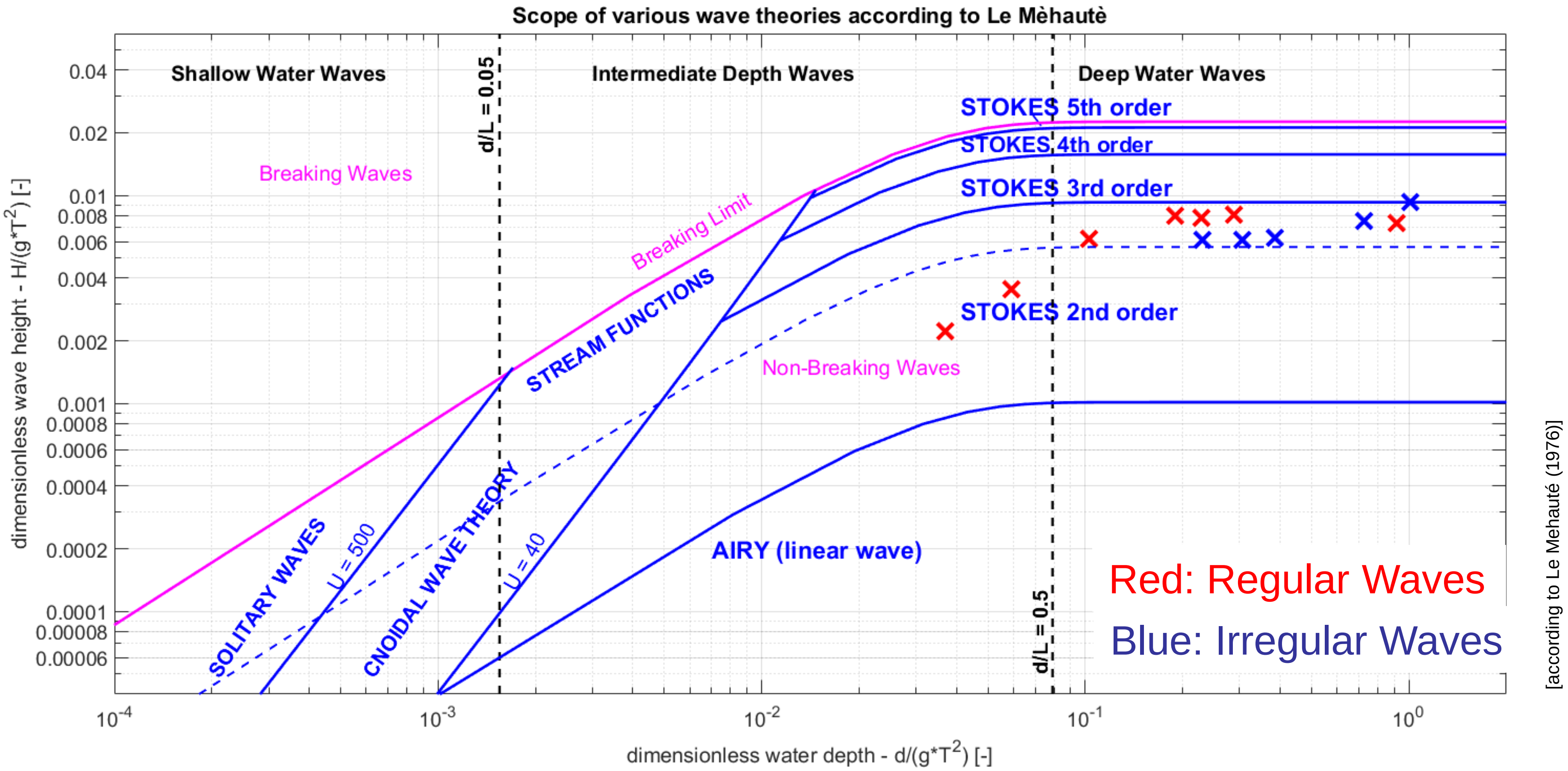


- w additional damping and stiffness



➢ good agreement of the hydrodynamic properties

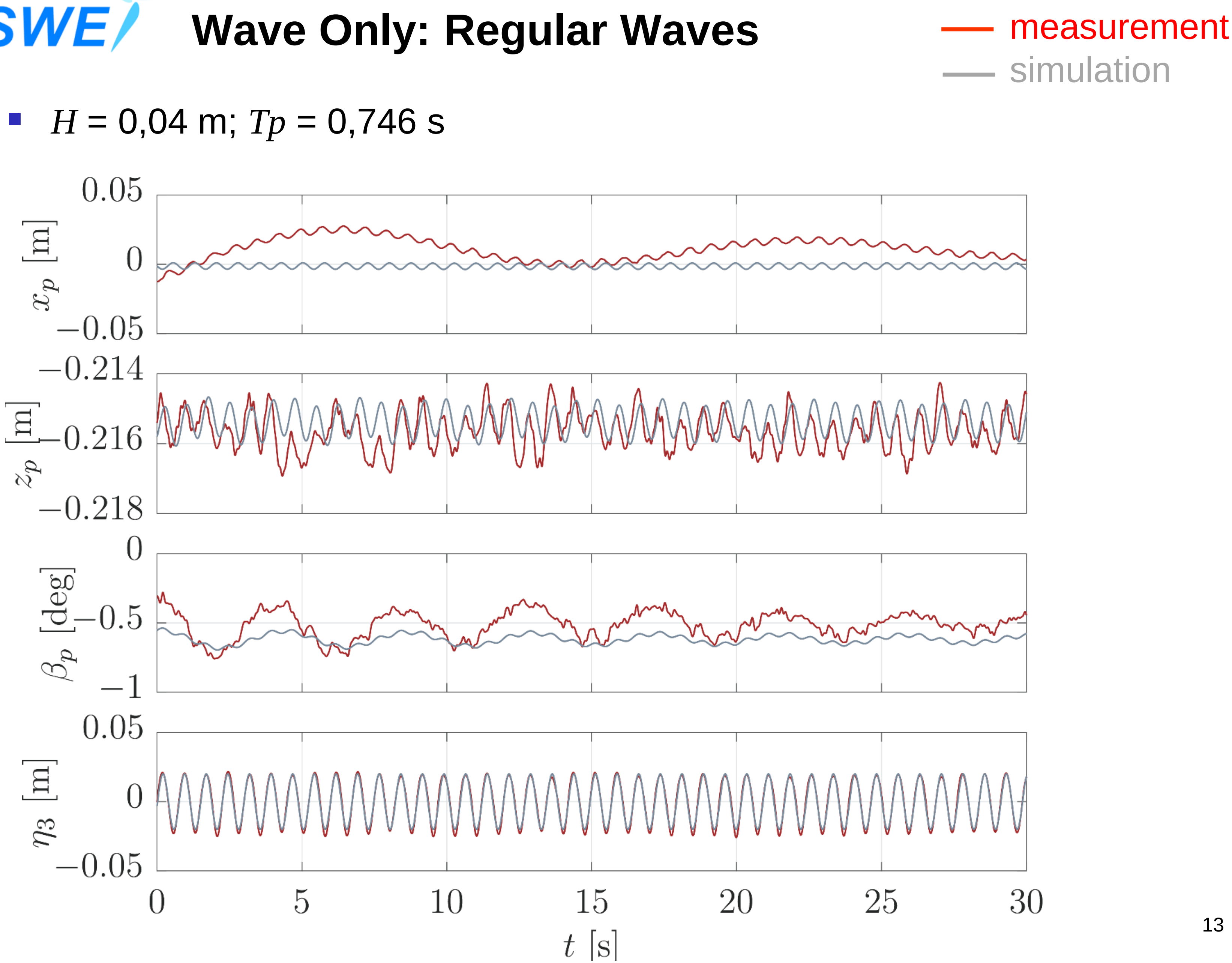
SWE Wave Only Load Cases



- higher wave theories should be considered

SWE Wave Only: Regular Waves

- H = 0,04 m; Tp = 0,746 s



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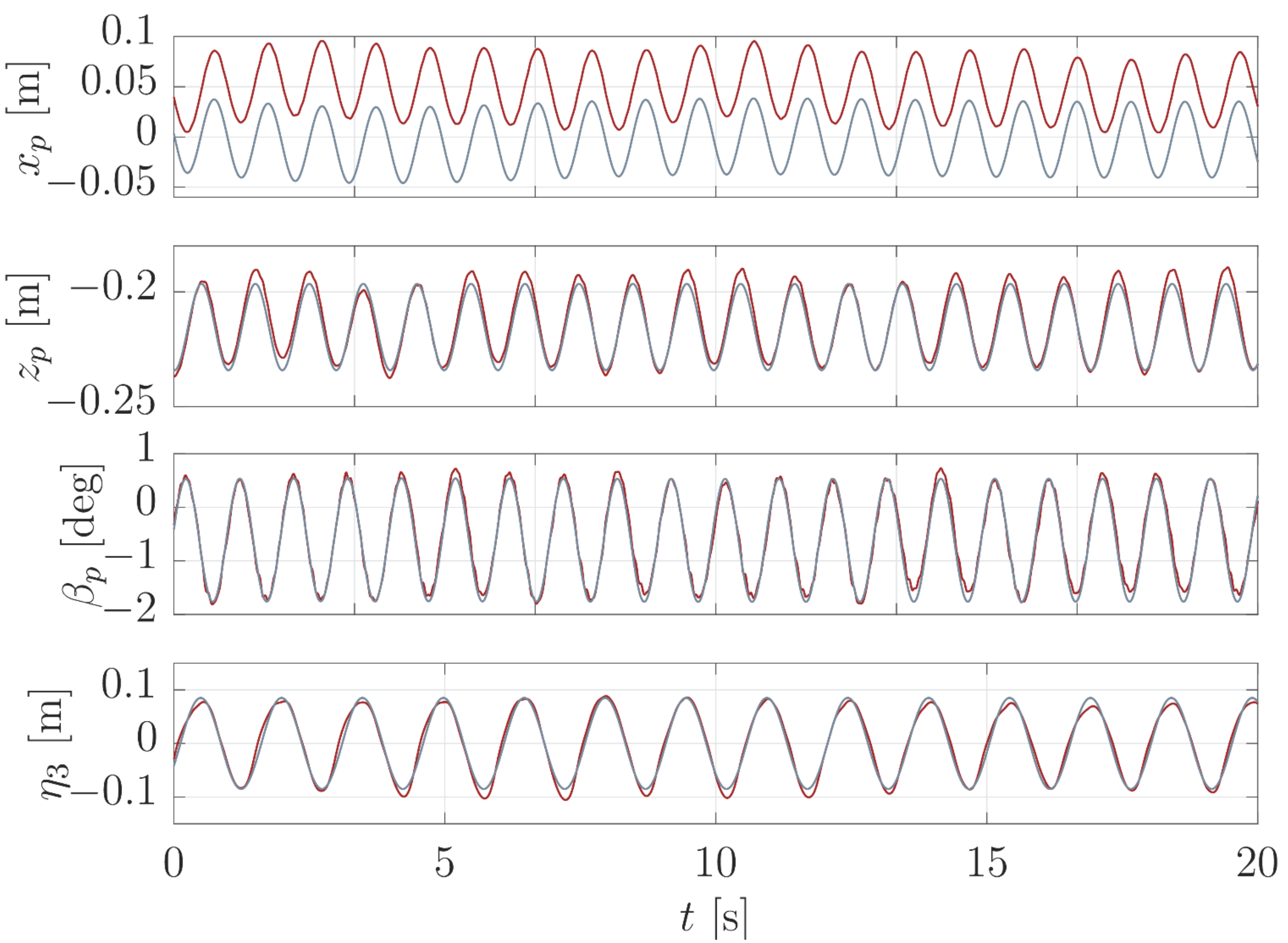
Wave Only: Regular Waves

— measurement
— simulation

- H = 0,17 m; Tp = 1,493 s

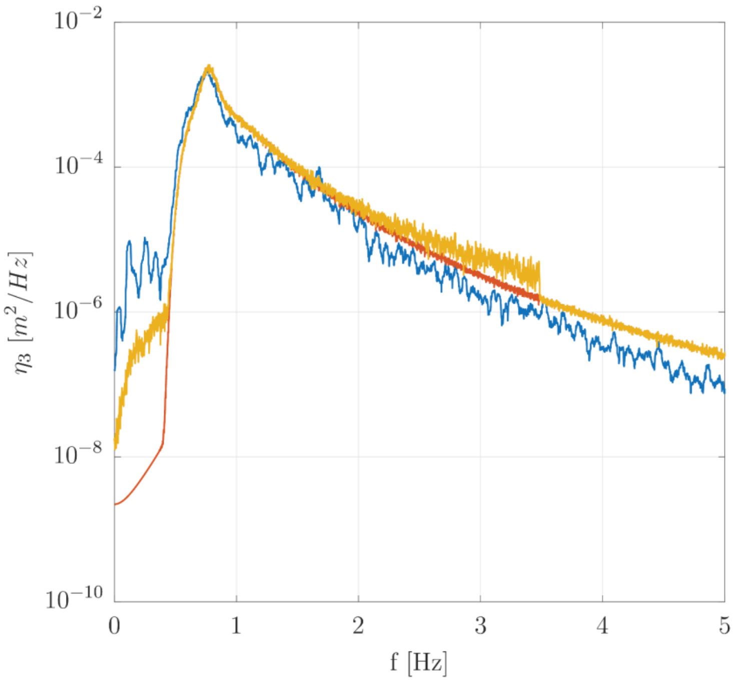


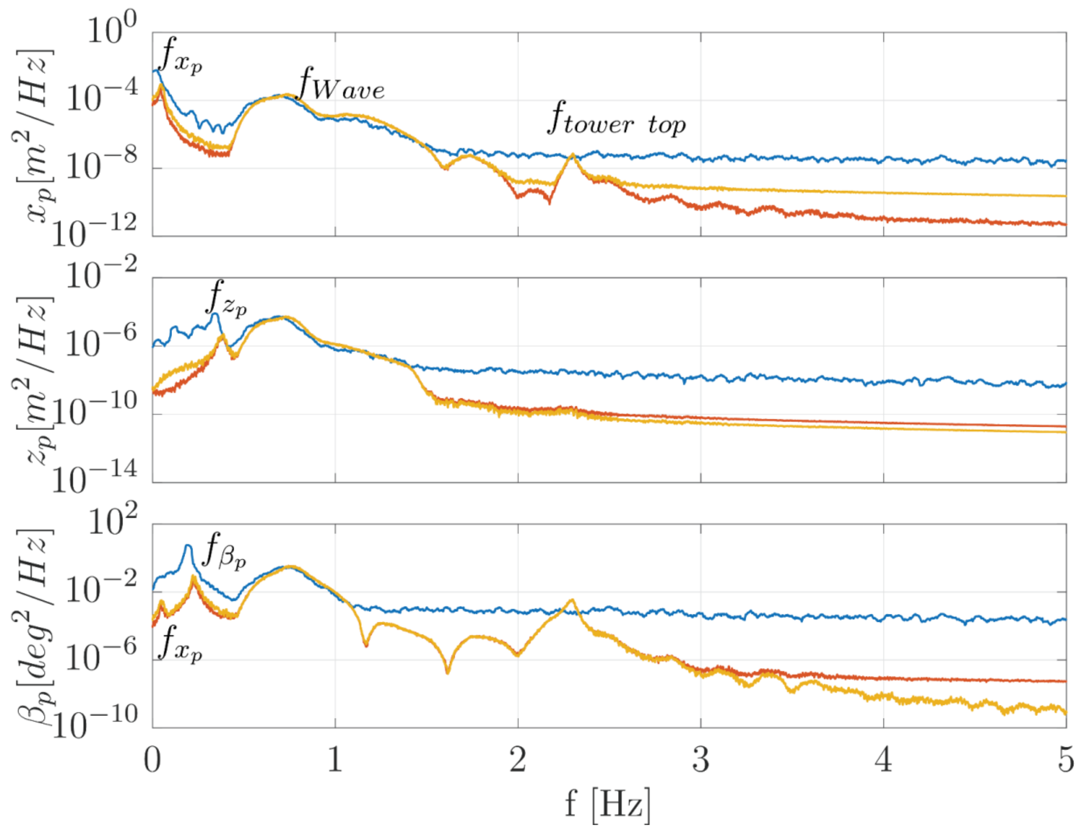
➢ better agreements for larger waves

SWE Wave Only: Irregular Waves

- H = 0,1 m; Tp = 1,291 s; γ = 2,87

measurement
simulation 1st
simulation 2nd





SWE Wind Only

- uncertainties in the wind generation system
- wind speed variations

- surge displacement:

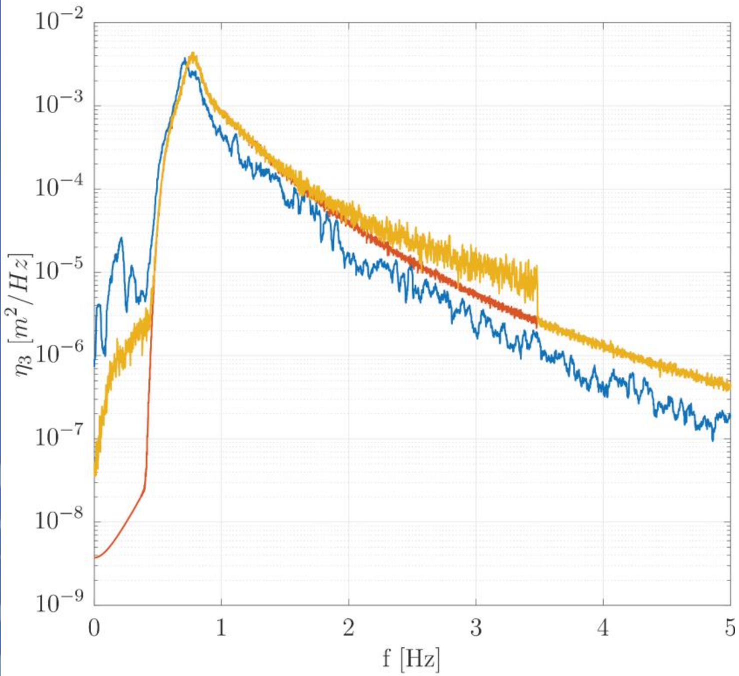
v [m/s]	Exp [m]	Sim [m]	Δ_{abs} [m]	Δ_{rel} [%]
1,50	0,198	0,226	0,03	12,25
1,40	0,198	0,206	0,01	3,69
2,63	0,054	0,090	0,04	40,23
2,58	0,054	0,054	0,00	0,36

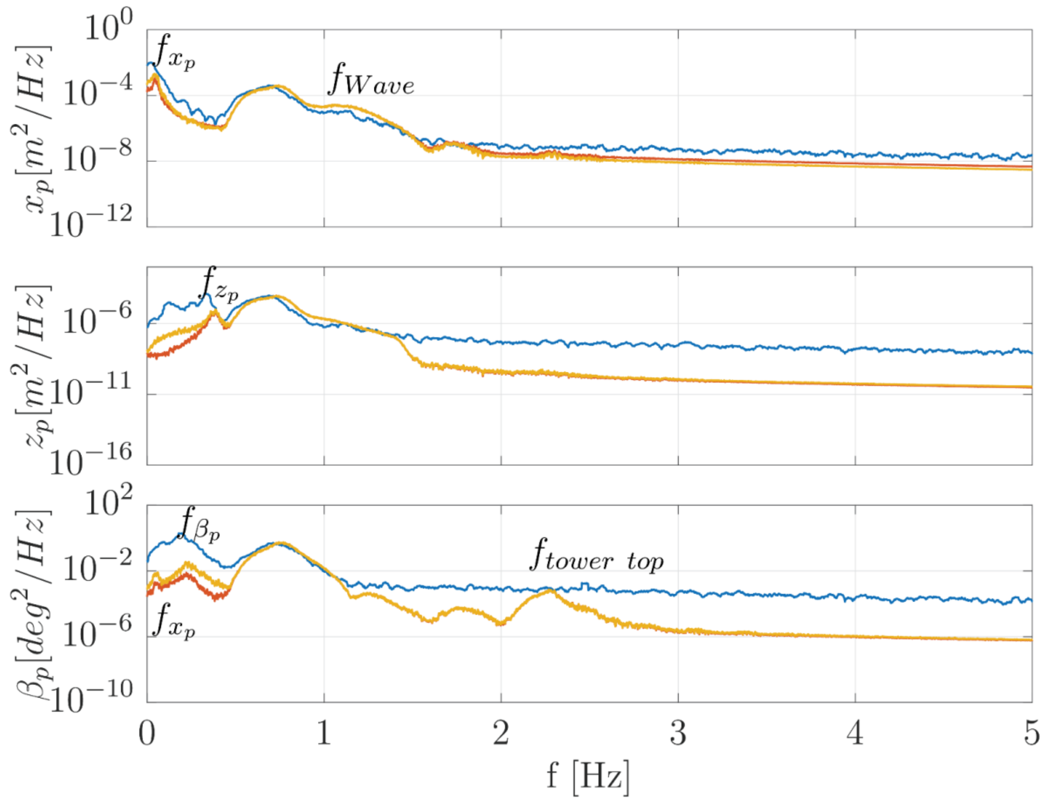
- variations of blade pitch angle conducted
  - ➢ reduction of wind speed leads to better results

[Henrik Bredmose, DTU]

SWE Wind and Waves: Irregular Wave

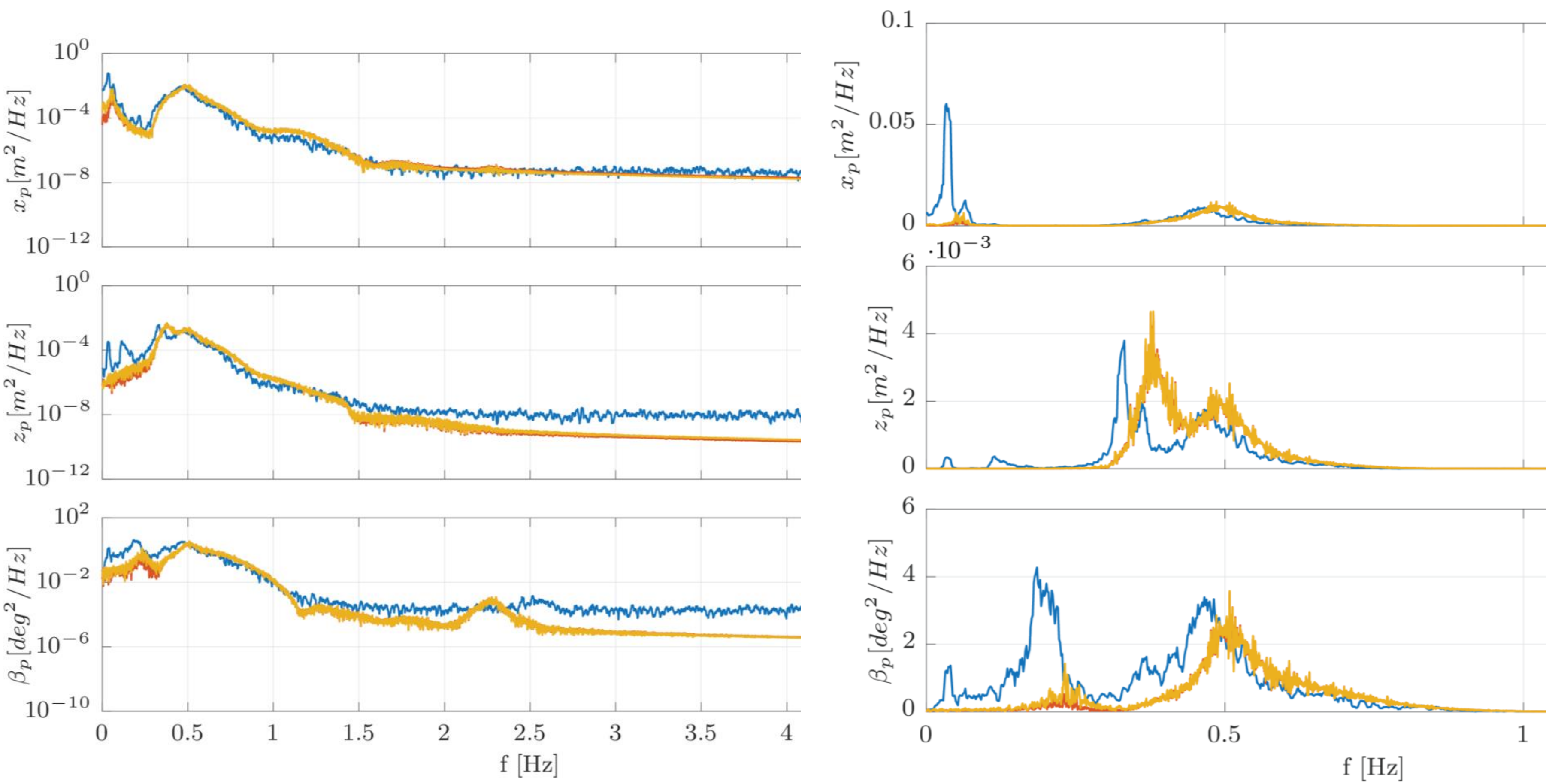
- v = 2,63 m/s; H = 0,13 m; Tp = 1,29 s; γ = 2,87





Extreme Load Case: Wind and Irregular Waves

- v = 4 m/s; H = 0,23 m; Tp = 2 s; γ = 2,87



- good agreement, missing second order loads in simulation

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Summary

- good agreements
- but: For smaller wave heights the agreements decreases (measuring accuracy, wall friction- and water wave reflections in the tank)
- MAP++ is showing reasonable results
- higher order wave theories are required for simulation (slow drift)
- wind speed and expanding jet flow

- ➢ successful validation of the simulation model and approach
- ➢ many load cases available that may be used for validation studies

SWE Outlook

- comparison of the results of different simulation codes (D4.25)
- direct calculation of the QTF matrices in a panel code software
- conduct model tests with variable blade pitch controller
- conduct model tests with turbulent wind fields

➢ Triple Spar Project

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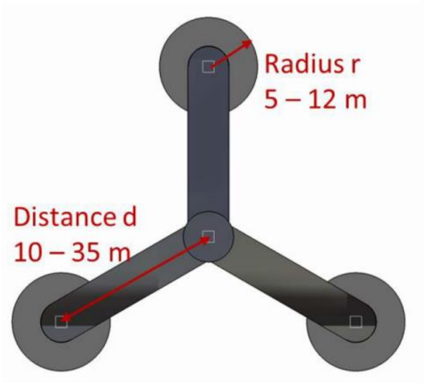
Triple Spar Project (1/2)

- April 2016 @ DHI, Denmark
- Participants: CENER, DTU, USTUTT
- Model: DTU 10 MW reference wind turbine mounted to SWE Triple Spar

[Henrik Bredmose, DTU]

SWE Triple Spar Project (2/2)

- **community-based public development** including specification report and FAST v8:
  „F. Lemmer et al., *Definition of the SWE-TripleSpar Floating Platform for the DTU 10MW Reference Wind Turbine*, to be published soon online"
- specified properties:
  - modified tower properties
  - floater structural properties
  - floater hydrostatic and hydrodynamic properties
  - mooring system
  - control system



[SWE]

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Thank you for your attention!

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