Floater flexibility and efficient FEM stress calculation

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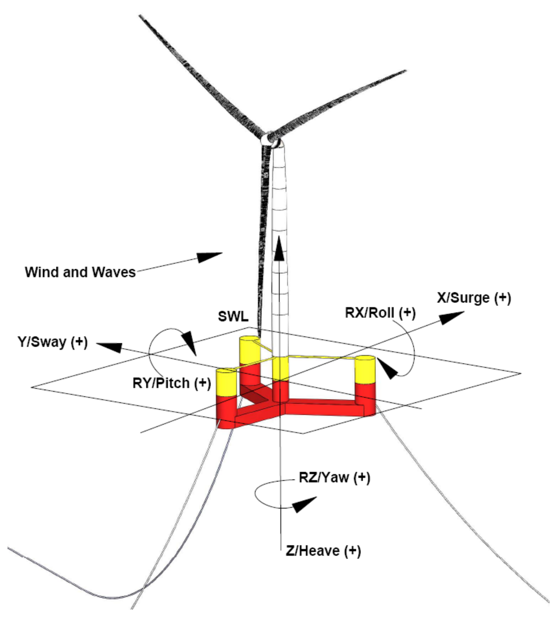
Introduction

Design tools for floating wind turbines must be able to quantify the effects of floater flexibility. The implementation of Borg et al (2016) in HAWC2 is here validated against experiments from the FloatStep project.

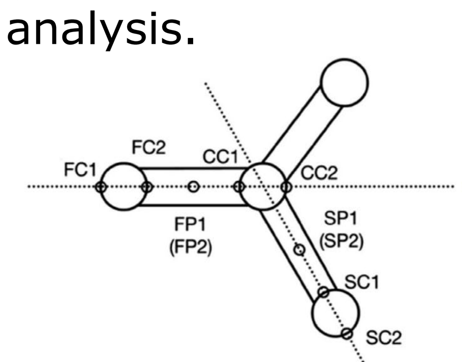
Next, the detailed stresses in the floater require Finite Element Modelling (FEM). Since the deformations are generally small, linear analysis is sufficient and superposition can be utilized. Thus following modest pre-computation, stress time series for any random realization can be achieved efficiently through influence functions and FFT. A proof of concept is provided here.

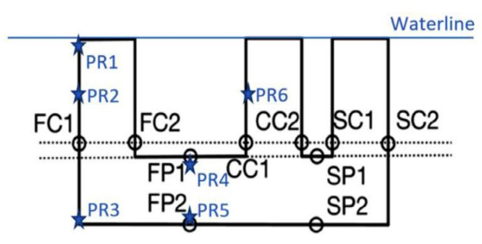
15 MW turbine in operation



We select the IEA Wind 15 MW reference wind turbine (Gaertner et al 2020) on the UMaine semisub floater (Allen et al 2020) as a reference case. The selected case is for turbine operation with power production in a sea state of Hs= 4.52 m and Tp = 9.45 s.

We pick a point at the front pontoon (FP1) and the centre column (CC1) for analysis.





Conclusions

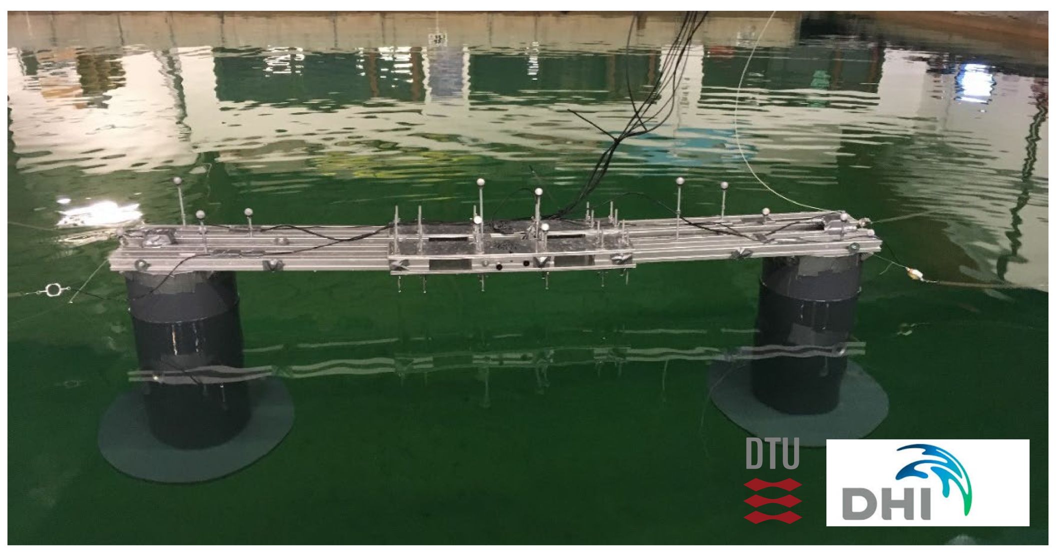
HAWC2 validated for flexible floater calculations.

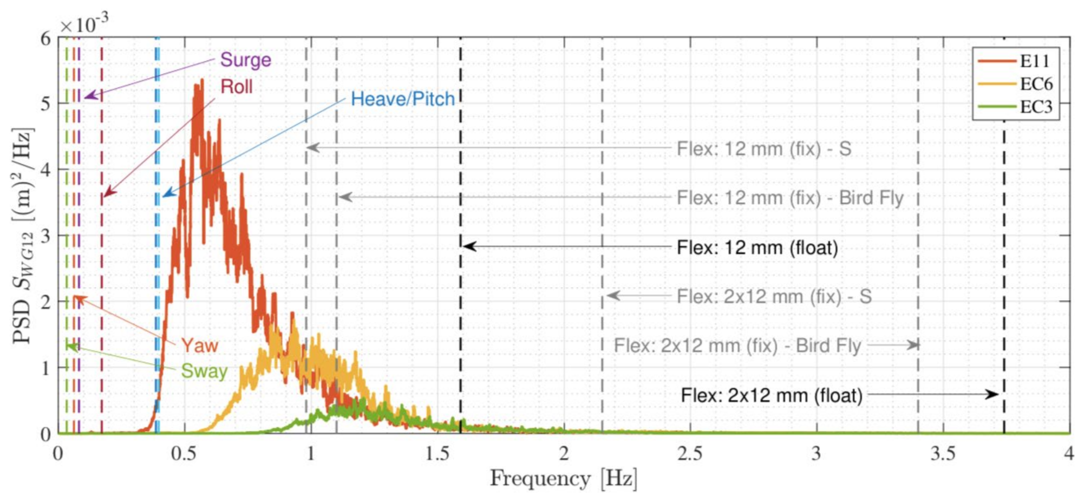
Proof of concept for rapid FEM stress calculation based on transfer functions and influence functions. Present results obtained 10 x faster than real time on a standard laptop after pre-computations.

Ongoing work: Check of residual loads to ensure total force balance.

Experiment with a flexible floating structure

Model tests were conducted at DHI Denmark in the FloatStep project. Two cylinders with heave plates are connected by a beam with a flexible hinge (Hansen et al 2024).





Natural frequencies and tested sea states. Note the two pssible elastic natural frequencies

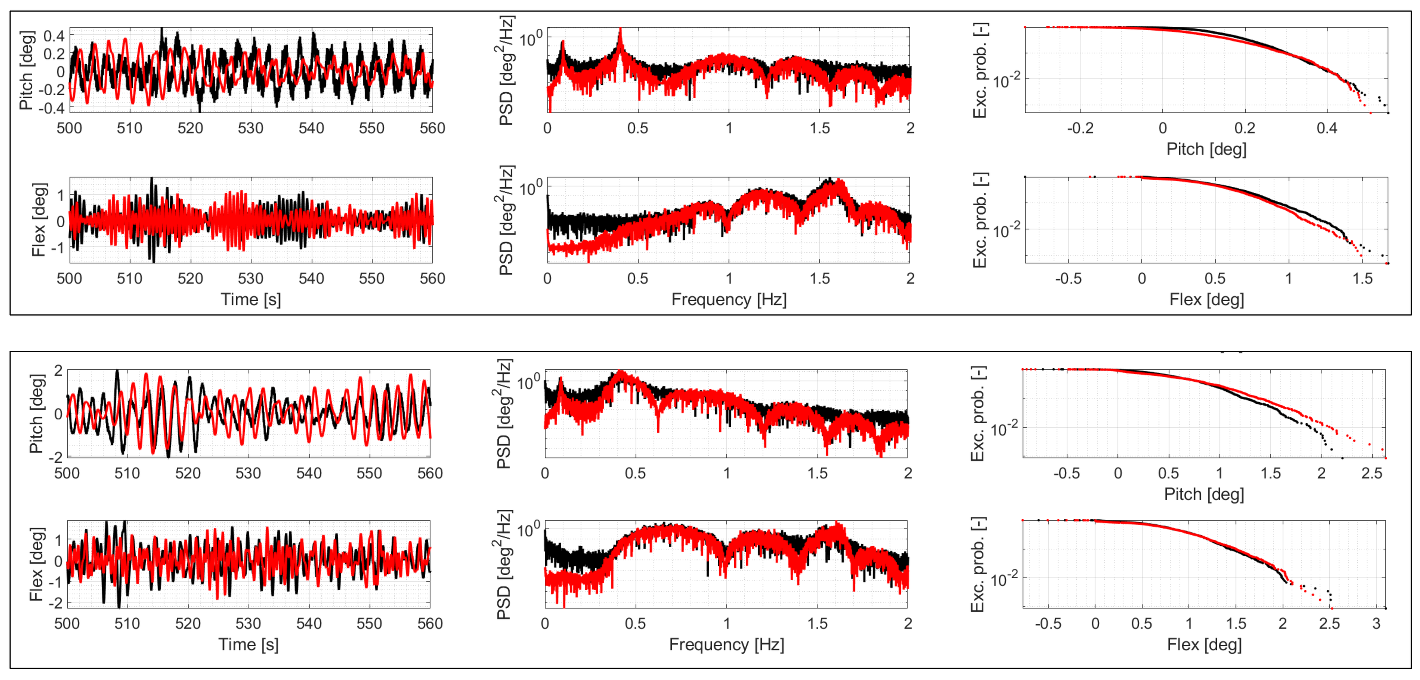
HAWC2 validation

The model was set up in HAWC2.

Rigid floater motion: Wamit 1st-order and 2nd-order QTF.

Flexible mode: Wamit 1st order.

Morison relative drag plus calibrated damping included.



Response in pitch and flexible mode for sea state EC3 (top) and EC11 (bottom). Good match in picth requency (0.4 Hz), wave range and flexible frequency (1.6 Hz).

Stress as a linear response to waves, motion and sectional loads

The stress field σ in a linear-elastic structure satisfies

$$\rho \ddot{u} - \partial^T \sigma = \mathbf{f} \qquad \sigma = \begin{bmatrix} \sigma_{xx} & \sigma_{yy} & \sigma_{zz} & \tau_{xy} & \tau_{xz} & \tau_{yz} \end{bmatrix}^T$$

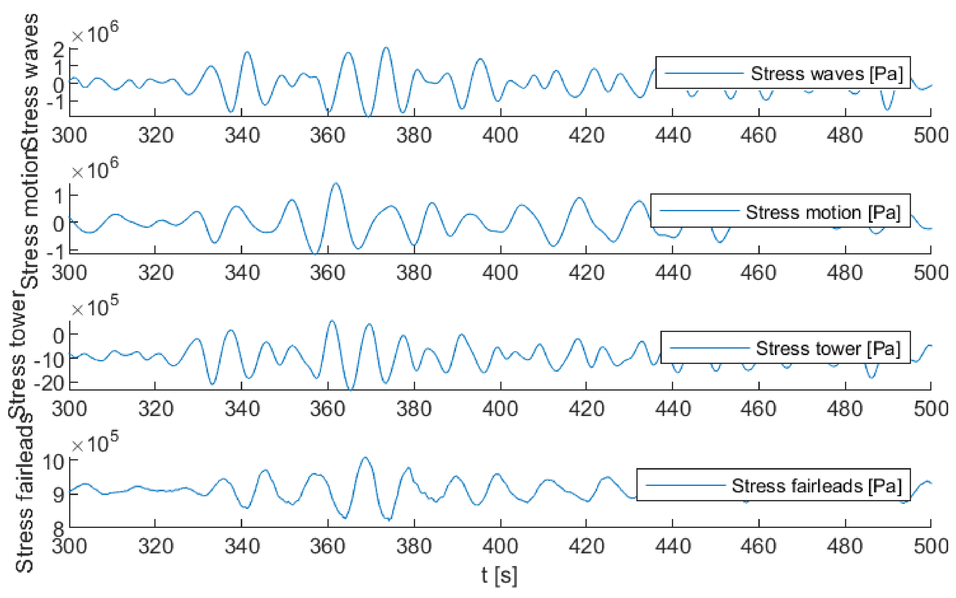
where u is the deformation field and **f** the local forces. Within linear radiation-diffraction theory, the hydrodynamic pressure can be written

$$p(t) = -\rho g z - \rho \sum_{j=1}^{N_{freq}} i\omega_j \{\phi_{(0+7)jR}, \phi_{(0+7)jI}\} e^{ij\omega t} \hat{\eta}_j - \rho \sum_{l=1}^{6} \sum_{j=1}^{N_{freq}} i\omega_j \{\phi_{\xi ljR}, \phi_{\xi ljI}\} e^{ij\omega t} \hat{\xi}_{jl}$$

Other forces result from tower, mooring and inertia such that the total stress is contributed from

$$\sigma(t) = \sigma_{eq} + \sum_{j=1}^{6} F_{Tj}(t)\{\sigma_{Tj}\} + \sum_{j=1}^{3N_M} F_{Mj}(t)\{\sigma_{Mj}\} + \sum_{j=1}^{N_{freq}} \{\sigma_{XjR}, \sigma_{XjI}\} e^{ij\omega t} \hat{\eta}_j + \sum_{l=1}^{6} \sum_{j=1}^{N_{freq}} \{\sigma_{\xi ljR}, \sigma_{\xi ljI}\} e^{ij\omega t} \hat{\xi}_{jl}$$

These operators can be pre-computed and driven by results of global response calculation from e.g. SIMA.



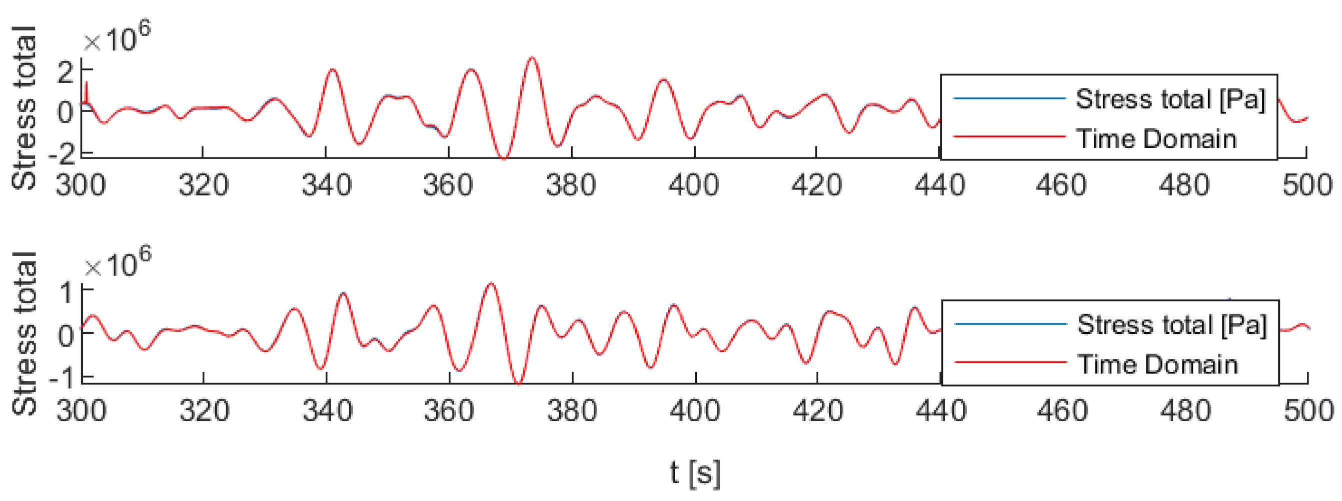
Stress contribution from waves (top), inertia + motion-induced pressure (second), tower interface loads (third) and mooring (bottom) for σ_{yy} in front pontoon (FP1).

Comparison to direct Finite Element Analysis

A global response calculation was made in SIMA with subsequent FEM analysis in each time step (Gao et al 2023).

The new method (blue) are compared to these results (red).

A good match is shown for σ_{yy} in FP1 (top) and σ_{xx} in CC1 (bottom).



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