Analysis of second order effects on a floating concrete structure for FOWT's

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Dynamic co-rotational FE analysis for FOWT's

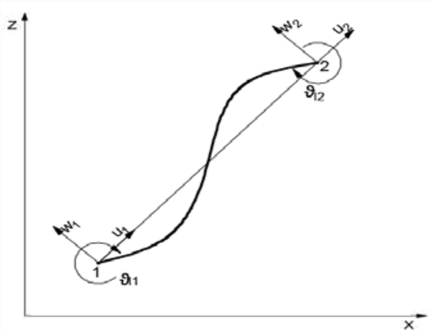
With the aim of improving the tools for the **analysis of floating spar type structures for offshore wind turbines**, a model which includes the **nonlinear FEA for large displacements based on a co-rotational formulation** is under development at the UPC-BarcelonaTech. The model is able to take into account the wind loads, hydrodynamic loads, the elasticity of the full structure and the mooring response. All forces integrated in the time domain. In its present stage, the model is working in 2D.

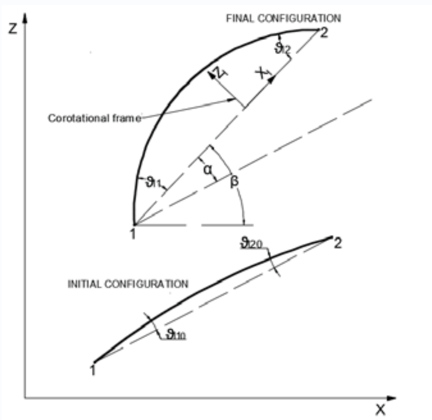
Formulation

A nonlinear dynamic finite element numerical model has been developed to analyze the structural behavior of the spar type structure using beam elements in 2D for its discretization. The model assumes small strains but considers large displacements. The FE are implemented with cubic shape functions in combination with the elasticity theory and the Euler beams theory. To deal with the **large displacements**, a **co-rotational formulation** is considered [1] [2].

$$\vec{X}_e = [u_1 \quad w_1 \quad \vartheta_1 \quad u_2 \quad w_2 \quad \vartheta_2]^T$$

$$\vec{x}_e = [0 \quad 0 \quad \vartheta_{l1} \quad u_l \quad 0 \quad \vartheta_{l2}]^T$$





Loads

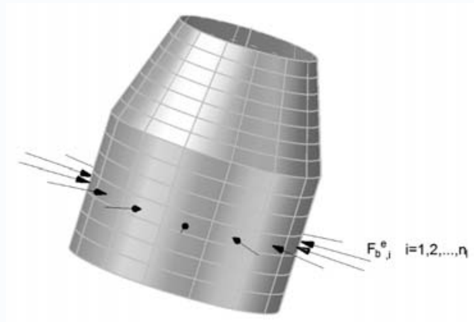
The external forces considered in the model include the effects of the environmental loads (buoyancy and waves), the mooring system, the wind turbine and the self-weight.

The equivalent **buoyancy forces** acting over the structure are computed by the **3D integration of the pressures over the structure**. A 3D mesh of the external face of the structure is used to obtain at each time step the global position of the mesh elements centroids to finally compute the hydrostatic pressures to compute the resultant force at each element.

The **drag forces** and the **wave loads** are computed with the **Morison's equation**, which was validated during the test campaign of the WindCrete scaled model in the AFOSP project [3]. The water particle kinematics are computed wit the **Stokes 5th order** non-linear wave theory.

The **mooring system** loads are computed in a **quasi static** way, combining it with the dynamic time-domain analysis of the structure.

The loads exerted by the **wind turbine** at the yaw bearing are computed with **FAST** software from NREL



Numerical studies

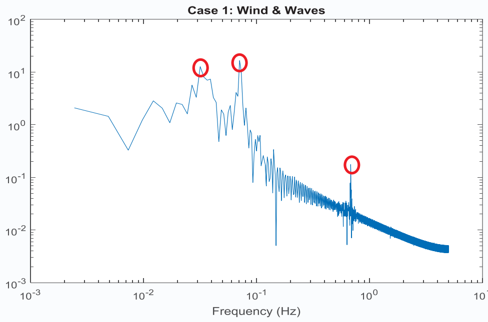
A **sensitivity study** of the 2nd order effects to the **Young modulus (E)** of the structural material has been performed. Three different assumptions for E, are considered:

- Case 1: Standard concrete structure (E_c=3.7E4 MPa)
- Case 2: Rigid body assumption (E=3.7E6 MPa
- Case 3: Flexible structure (E=3.7E3 MPa)

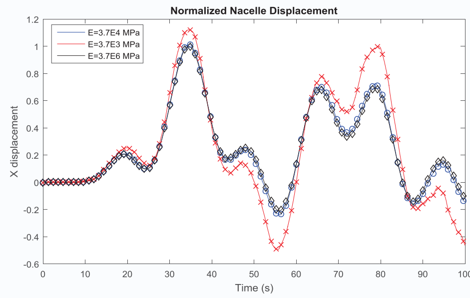
The selected structure for the study is the **WindCrete** concept [4], a full concrete monolithic SPAR structure for FOWTs, subjected to aligned wind and waves.

Results

The FFT of the nacelle global X motion detects the peaks corresponding to heave motion (30s), the first structural frequency (0.7Hz) and the wave period (14s).



Due to the significant differences in the inertial terms, the computation of the internal forces for the structural assessment seems to be reasonable to be based in a dynamic FE analysis considering the 2nd order displacements, especially for the fatigue limit state.



Acknowledgements

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