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

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Abstract

The irruption of the floating wind energy in the offshore engineering is changing the paradigm of the structural analysis for those new structures, which are significantly smaller and more slender than those previously existing from the O&G industry and in which the most important load is applied around 100m above the mean sea level. Those characteristics require the structural analysis to include the dynamic effects over the deformation of the structure, integrating the instantaneous deformation of the structure into the nonlinear dynamic finite element analysis (FEA) computation.
A numerical model which couples the hydrodynamic and aerodynamic effects in a time domain structural analysis, has been developed at the UPC. The code integrates the forces exerted by the waves and currents as well as the aerodynamic loads, including the wind turbine, and the mooring system. For the hydrodynamic loads, Morison's equation in combination with the Stoke's 5th order nonlinear wave theory are used to compute the resulting forces. The mooring system is treated in a quasi-static way and the aerodynamic loads are computed with FAST. The structure is discretized with one-dimensional beam elements, in which the formulation considers small strains as well as large motions.
The model computes a dynamic time domain nonlinear FEA for FOWT's, integrating all the effects of the external forces and the structural stiffness to obtain the displacements at each point of the structure at each time step. With this approach, the dynamic interaction between the wind turbine and the structure, as well as the effects on the internal forces are implicitly considered in the formulation. A comparison of the structure motions and internal forces for a concrete spar concept is presented assuming a nonlinear rigid body approach and a nonlinear dynamic time-domain FEA.

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1. Introduction

The dynamic analysis of floating offshore platforms is a complex problem because most actions are dynamic and interact with a flexible structure. Currently, most of the analysis of these structures are performed by means of codes which assume a rigid body for the floater and a flexible tower, with its dynamic properties, interacting in the time domain. The rigid body approach is commonly accepted for the major part of the offshore structures, in which their dimensions and proportions are large enough to neglect both structural dynamic and second order effects, the latter produced by the deformation of the structure. In addition, the most commonly used commercial softwares compute the overall motions of the floating structures as rigid bodies and afterwards, the computed loads and accelerations are integrated in a linear or nonlinear static FEA. This methodology permits to consider the effects of the structural deformations for the internal forces computation, but it does not consider the effects of those deformations in the computation of the overall motions of the floating system, which can lead to different internal forces. This effect may be relevant in FLS analysis, but also for the ULS, depending on the structure flexibility.

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.

This paper presents the description of the main features of the model and some detail of its implementation, particularly the co-rotational formulation, the dynamic integration scheme, the wind and hydrodynamic loads and the moorings. A validation example for the dynamic model with the co-rotational formulation is included. Then, the model is used in a parametric analysis for a set of prescribed wind and waves loads and varying the material Young's modulus to compare the effects on the dynamic behavior of the concrete spar concept. Results include the comparison of the maximum horizontal displacements at the nacelle, the maximum average inclination of the overall structure and the maximum bending moment at the base of the tower. Finally, some conclusions of this preliminary application of this model are presented.

2. The Windcrete concept

The monolithic concrete spar, he so-called Windcrete [1] , is a prototype floating platform for wind turbines developed in AFOSP (Alternative Floating Platform Designs for Offshore Wind Turbines using Low Cost Materials) within a KIC-InnoEnergy innovation project [2]

The spar prototype is designed as a monolithic concrete structure from the top of the tower to the bottom of the buoy, thus joints are avoided to ensure water-tightness and a good fatigue behavior. The structure, for a 5 MW wind turbine, is composed of three parts: first, the buoy, composed of a cylinder with a diameter of 13 m and a height of 120 m; second, the transition segment, which is a cone of 10 m high, these two parts are the submerged ones, therefore the total draft of the structure is 130 m. The third part is the emerged tower that reaches 87.6 m above the SWL. A sketch of the concept and its hydrodynamic characteristics are shown in Figure 1 and Tables 1 and 2. The moorings system is connected to the platform at the fairleads located 60 m above the bottom with a draft of 70 m, near the Centre of Gravity (COG) to reduce the coupling motions between the surge and pitch.

In this study, the Windcrete is considered to be placed in a 250 m depth sea location. The mooring system is configured to provide enough restoring force to maintain the platform motion in a relative offset and to prevail over the wave

Property	*Value*
Displaced Volume [m^3]	1.69E+4
Draft [m]	130.0
Concrete mass [kg]	8.71E+6
Ballast mass [kg]	7.89E+6
Wind turbine mass [kg]	3.50E+5
CM [m]	53.34
CB [m]	63.97
Metacentric height [m]	10.57

Table 1: WindCrete main dimensions

Property	*Value*
Draft to fairlead [m]	60.0
Mass per unit length [kg/m]	150.3
Mooring depth [m]	195
Radius to anchor [m]	660
Line length[m]	732.9
Total depth [m]	265

Table 2: Mooring system properties