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Accounting for Hydroelasticity in the Analysis of Offshore Wind Turbine Spar-Type Platforms

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In this paper, linear frequency-domain hydroelastic analysis is performed to investigate the behavior of the spar-type supporting platform of a floating offshore wind turbine, considering the platform's flexibility. A "dry" mode superposition approach is used, wherein the flexible mode shapes are determined through the application of a finite element method (FEM)-based structural model. The diffraction/radiation problem is solved by using the boundary integral equation method. Focus is given to the flexible modes' generalized hydrodynamic forcing and responses, the spar's hydroelastic response, and the coupling effects between the flexible and the rigid-body modes. For irregular waves, the effect of the peak period on the response spectra and the hydroelastic response is analyzed.

INTRODUCTION

Floating offshore wind turbines (FOWTs) had shown great progress in the past decade, facilitating access to deeper waters, where stronger winds exist. In 2017, the first floating offshore wind farm started operation (Pineda, 2018). Currently, extensive investments in building floating offshore wind farms at deeper offshore sites are being made. To make offshore wind more competitive, offshore wind turbines grew in size. The trend shows a continuous increase in the size of wind turbines (Wind Europe, 2017; Pineda, 2018), which, in turn, requires the utilization of proper, large floating supporting platforms for them. For designing cost-efficient large supporting platforms for FOWTs, slender, load-carrying structural elements should be engineered to decrease the material used. This fact leads to FOWTs that are characterized by substantial structural deformations (i.e., great flexibility) resulting not only from the tower but also from the supporting platform. In these cases, the elastic responses of the supporting platform may become important, and the platform's flexibility may affect the dynamic response of the whole floating system. Therefore, the application of an appropriate hydroelastic analysis, accounting for a wave-flexible platform interaction, is very vital in the reliable and realistic design and structural integrity assessment of this type of structure.

The potential flow theory is normally used to estimate the hydrodynamic forcing and global responses of FOWTs, assuming a rigid-body platform. However, recently, several studies have looked at the possibility of including the platform's flexibility while still using large-volume hydrodynamics in global analyses of FOWTs (e.g., Hegseth et al., 2018). A sectional approach to the distribution of hydrodynamic loads from the linear potential theory over a beam model of the floater may be used (Svendsen, 2016), and a similar method has been proposed by Luan et al. (2017) wherein sectional loads were derived and compared to the results from a frequency-domain model. On the other hand, Finn (2014) accounted for hydroelasticity in the case of a semi-submersible wind turbine platform, while Kang et al. (2017) performed a time-domain hydroelastic analysis of a multi-unit FOWT.

In the case of spar-type supporting platforms, representing the first commercially deployed floater for FOWTs, Borg et al. (2016) proposed a method, based on the mode superposition approach, for including the platform's flexibility in aero-hydro-servo-elastic simulations. The structural deformations of the spar were described by introducing only one generalized mode (first in-plane bending mode with shape calculated using a finite element (FE) structural model), in addition to the six rigid-body modes of the platform. Finally, it is noted that hydroelastic analysis of a slender vertical column based on the mode superposition approach has been implemented by Newman (1994), who used orthogonal polynomials (modal functions) to analytically express the flexible mode shapes.

In the present paper, linear hydroelastic analysis is performed to investigate the behavior of the supporting platform of a spar-type FOWT, considering its flexibility. The numerical analysis is implemented in the frequency domain, and it is based on a "dry" mode superposition approach. In this approach, the generalized (flexible) modes concept is used to describe the structural deformations of the platform in addition to the six rigid-body modes, while the required flexible mode shapes are determined in vacuum through the application of a finite element method (FEM)-based structural model to solve the corresponding "dry" eigenvalue problem. The diffraction/radiation problem is solved by using the conventional boundary integral equation method. Both regular and irregular waves are considered. To provide additional information on the significance of the flexibility of the platform of a spar-type FOWT, focus is given to the generalized hydrodynamic forcing and responses of the flexible modes, the hydroelastic response

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