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Modeling the Influence of Soil-Structure-Interaction on Seismic Response of Jacket Substructure for the DTU 10MW Offshore Wind Turbine

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This paper is intended to study the influence of soil–structure interaction on the seismic response of jacket substructure for the Technical University of Denmark 10-MW reference wind turbine on the west coast of Taiwan. Since Taiwan is located in the circum-Pacific seismic belt, there is significant interest in assessing the behavior of a wind turbine subjected to seismic loading. Based on the flexible volume method, a finite element model was employed to quantify the contribution of foundation damping to overall damping of offshore wind turbines. The results show that foundation damping was estimated to contribute 1.28%–1.50% of critical damping to total offshore wind turbine damping. The soil–structure interaction effects have significant influence on seismic responses.

INTRODUCTION

Wind power is regarded as one of the most promising renewable energy resources, which provides an essential contribution to a clean, robust, and diversified energy portfolio. Advanced technologies and supply chain maturity make offshore wind power an increasingly viable option for renewable energy, as well. Offshore wind power has achieved rapid growth over the past several years. According to WindEurope's technical reports, the European Union (EU) renewable policies aim to achieve at least 27% of the final energy consumption from renewable energy sources by the end of 2030. Therefore, a total of 323 GW of cumulative wind energy projects are planned to be installed in the EU by 2030. That would be more than double the capacity installed at the end of 2016 (160 GW) (European Wind Energy Association, 2017). With the aim of reducing the levelized cost of energy (LCOE), wind turbines with larger rated power capacities have significantly increased to more than 9.5 MW in recent years. However, a number of challenges remain to be resolved. Among the challenges are: 1) the potential resonance problem on larger wind turbines (Von Borstel, 2013), 2) site selection, 3) proper substructure type selection, and others. Although the west coast of Taiwan is rich in offshore wind resources (Chang et al., 2015), the support structures for offshore wind turbines (OWTs) could be subjected to different environmental loads through their design life, such as earthquakes, typhoons, extreme waves, and tsunamis. Consequently, Taiwan's extreme environmental conditions play crucial roles for the installation and structural integrity of OWTs.

Turbines installed in seismically active regions must consider earthquake loads (Prowell et al., 2010). For larger structures in seismically active regions, seismic response becomes a crucial factor for the design of OWT substructures. Additionally, it causes an increased sensitivity to soil stiffness and damping. In practice, onshore wind turbines mounted on Gravity Base Structure (GBS) can sometimes be simplified to fixed base condition. Therefore, the soil–structure interaction (SSI) effects are ignored. In contrast, offshore wind turbines can be described as a high-slenderness, low-stiffness dynamical system. SSI effects have influence on the seismic response of these slender structures. A key factor in estimating seismic response of OWT is proper modeling of the SSI effects (Hussan et al., 2017), which are influenced by different parameters, including wind turbine size, substructure type, and soil properties. In such cases, an inaccurate assessment of the seismic responses can result in either structural failure or uneconomical design.

The overall damping of OWTs plays an important role in the design process as it limits the amplitude of the OWT dynamic response at frequencies near resonance. Damping in an OWT originates from different sources—mainly aerodynamic, structural, hydrodynamic, and foundation damping (Abdollah et al., 2021). During power production condition, aerodynamic damping is a dominant source of damping in the fore-aft direction; however, foundation damping is the most prominent under parked and idle conditions or in the side-to-side direction, and aerodynamic damping is almost negligible (GL WindEnergie, 2005). The International Electrotechnical Commission (IEC) (IEC, 2005) standard indicates that, compared with the other sources of damping for OWTs, the soil damping has a high contribution to overall damping of OWTs.

A few common types of support structures for OWT include monopile, gravity, tripod, and jacket (as shown in Fig. 1). In water depths between 30 m and 60 m, jacket substructures are considered a more cost-effective solution than other types of structures (Seidel, 2007). Jacket substructures have been widely used in the offshore oil and gas industry over the past few decades. Mostafa and El Naggar (2004) described an efficient approach to undertake a parametric study of the SSI on the response of pile groups supporting a jacket substructure for offshore platform subjected to transient loading due to extreme waves and currents. However, the complexity and specialized issues of OWT support structure designs still require new considerations in the assessment procedures.

In the literature, different approaches were presented to address the latter issue. Prowell et al. (2010) built up a full soil-structure system for the National Renewable Energy Laboratory (NREL) 5-MW RWT. In their modeling, linear elastic three-dimensional elements were used to simulate the foundation and soil layers, and the 1994 Northridge Earthquake record was used as excitation at the base of soil layer. The investigation showed SSI had

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