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# Operability Analysis of Monopile Lowering Operation Using Different Numerical Approaches

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**Offshore installation operations require careful planning in the design phase to minimize associated risks. This study addresses numerical modeling and time-domain simulations of the lowering operation during installation of a monopile (MP) for offshore wind turbine (OWT) using a heavy lift vessel (HLV). The purpose is to apply different numerical approaches to obtain the allowable sea states and to assess the operability. Four critical factors regarding the numerical modeling approaches for the coupled HLV–MP lowering process are studied. Those factors include wave short-crestedness, shielding effects from the HLV, radiation damping from the MP, and the nonstationarity of the process. The influence of each factor on the allowable sea states and operability is assessed. A large number of time-domain simulations are performed, considering random waves, to derive the allowable sea states. The results indicate that, although the radiation damping from the MP is secondary, it is essential to consider the other features. The study can be used as a reference for the numerical modeling of relevant offshore operations.**

## INTRODUCTION

Installation of offshore wind turbine (OWT) components is more challenging than that of land-based wind turbines. It was estimated that the installation and assembly of OWTs make up 20% of the capital costs compared with approximately 6% for land-based wind turbines (Moné et al., 2015). Because of the low profit margin of the offshore wind industry, it is essential to reduce the installation costs by improving the methodology during the design and planning phases.

Because of their structural simplicity and low manufacturing expenses, monopiles (MPs) are the most preferable bottom-fixed foundations for OWTs in shallow water (EWEA, 2014). The installation of an MP consists of several steps. After arriving at the offshore site, an MP is upended to a vertical position, then lowered through the wave zone so that it stands vertically on the seabed. A hydraulic hammer is used to drive it into the seabed to a predetermined depth. Although MPs are easy to install compared to other foundations, the installations have been carried out with various levels of success because the challenges have not been taken seriously enough (Thomsen, 2011). Therefore, it is of great importance to evaluate and improve the allowable sea states by considering each activity during the operation. More importantly, the allowable sea states for a single operation would affect the installation efficiency of the entire wind farm. For this reason, accurate numerical models are required.

There are generally two types of vessels for installation of MPs: the jack-ups and the floating crane vessels. A jack-up vessel provides a stable working platform for the lifting and piling operations. However, the installation and retrieval of the legs of the jack-ups are time-consuming and weather-sensitive. Compared to jack-ups, floating vessels have more flexibility for offshore operations and are effective in mass installations of wind farms because of fast transit between foundations. Floating vessels have been used to install MPs for several large offshore wind farms, e.g., Sheringham Shoal and Greater Gabbard wind farms. Hence, the potential of reducing installation costs by using floating installation vessels is huge.

Very few studies on the installation of MPs have been published. Sarkar and Gudmestad (2013) suggested a method to install MPs by isolating the installation operations from the motion of the floating vessel using a preinstalled submerged support structure. The responses of a coupled vessel–MP system during the lowering process of the MP were studied by Li et al. (2013), where sensitivity studies regarding the mechanical couplings and the vessel type were performed. Furthermore, they introduced a method to account for the shielding effects from the floating installation vessel during the entire lowering operation of the MP (Li et al., 2014). It was concluded that shielding effects can greatly reduce responses in short waves. This method was further studied to compare the performance of two lifting systems, i.e., the lifting of an MP and a jacket wind turbine foundation (Li et al., 2015a). Moreover, the importance of radiation damping of the MP during the nonstationary lowering operation was examined by Li et al. (2015c). A new approach was proposed to implement the radiation damping effects into the time-domain simulation of the nonstationary lowering process.

The previous work aimed at developing more accurate numerical methods to simulate the lifting operation of the MP, with special focus on the nonstationary process. In those studies, some simplifications were made in the numerical model, e.g., the hydrodynamic forces on the vessel were simplified by only considering the first-order wave excitation forces in Li et al. (2013, 2014, 2015c), and the hydrodynamic interaction between the floating installation vessel and the MP was not included when studying

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