Analysis of Lifting Operation of a Monopile Considering Vessel Shielding Effects in Short-crested Waves

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This paper addresses numerical simulations of the lifting operation of an offshore wind turbine monopile foundation, considering both the shielding effects of the vessel and the spreading of the waves. A numerical model of the coupled monopile-vessel system is established. The disturbed wave field near the vessel is investigated and observed to be affected by the diffraction and radiation of the vessel. The shielding effects of the vessel during the lifting operation are accounted for in this study by interpolating the fluid kinematics between predefined wave points near the vessel using MARINTEK SIMO software and an external Dynamic Link Library (DLL). The effects of short-crested waves on the wave field and on the responses of the system are investigated by implementing the directional spreading function in the wave spectrum. On the basis of the time-domain simulations, the critical responses of the lifting system in various conditions are studied. The results indicate that the effects of the wave spreading are considerable in both incident and disturbed waves. The shielding effects are less significant in short-crested waves than in long-crested waves.

INTRODUCTION

Monopiles (MPs) are the most commonly used foundations for offshore wind farms in water depths up to 40 meters. It was estimated that more than 75% of all installations were founded on monopiles by the end of 2013 (EWEA, 2014). Monopiles can be transported to the site by the installation vessel or a feeder vessel. They can be barged to the site or can be capped and wet towed (Kaiser and Snyder, 2013). An offshore crane is often employed to upend the monopile to a vertical position and lower it down through the wave zone to the seabed. During the lifting operation, the monopile and the installation vessel are coupled through the lift wire and a gripper device that limits the horizontal motions of the monopile during the lowering. The monopile is lowered at a position that is very close to the hull of the crane vessel, so the wave forces on the monopile are affected by the presence of the vessel, which is defined as shielding effects. Furthermore, since the lifting operation is commonly performed at relatively low sea states, the waves may spread in different directions and affect the motions of the vessel as well as the wave forces on the monopile. Therefore, it is of great interest to evaluate the effects of the wave spreading as well as the shielding effects of the vessel on the behavior of the lifting system.

Studies have been performed to investigate the heavy lifting operations in the oil and gas industry that consider shielding effects such as the lifting of a heavy load from a transport barge through the use of a large capacity semi-submersible crane vessel (Mukerji, 1988; van den Boom et al., 1988; Baar et al., 1992). The studies found that the hydrodynamic interaction had little effect on the responses of the crane tip but affected the responses of the transport barge and thus greatly affected the lifting operations because of the small dimensions of the barge compared with those of the crane vessel (Baar et al., 1992). The sheltering effects of the columns and caissons of a gravity-based substructure (GBS) on the barge during a float-over installation were studied (Sun et al., 2012). It has been shown that the motions of the barge and the contact forces between the barge and the GBS can be amplified due to the hydrodynamic interactions. Therefore, the hydrodynamic interaction between two floaters close to each other should be taken into consideration when responses are estimated.

The approach to consider the shielding effects in those studies was to calculate the coupled hydrodynamic coefficients in the frequency domain when all the bodies are at their mean positions. This implies that the motions of all bodies in the system must be very small. However, when a continuous lowering operation, in which the positions of the lifted objects change continuously with time, is considered, the method above is not applicable. The main difficulty associated with this process lies in the large motion that the load might experience in waves while being lowered. Bai et al. (2014) introduced a 3D fully nonlinear potential flow model to simulate the wave interaction with fully submerged structures either fixed or subjected to constrained motions in the time domain. The scenario of a cylindrical payload hanging from a rigid cable and subjected to wave actions was studied. However, the approach has been limited to regular waves up to now, and the simulation efficiency has been low. Further application to more complicated operations and to irregular waves with longer duration is questionable.

In the case of lifting a monopile through the use of a floating vessel, due to the small dimensions of the monopile compared with those of the vessel, the hydrodynamic effects of the monopile on the vessel are minor and can be ignored. Li et al. (2014) introduced a method to account for the shielding effects of the installation vessel on a monopile during the entire lowering process. They calculated the wave forces on the monopile using Morison’s equation by interpolating the disturbed wave kinematics at