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Analysis of lifting operation of a monopile for an offshore wind turbine considering vessel shielding effects☆

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ABSTRACT

This study addresses numerical simulations of the lifting operation of a monopile for an offshore wind turbine with a focus on the lowering process. A numerical model of the coupled system of the monopile and vessel 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 continuous lowering operation are accounted for in this study by developing an external Dynamic Link Library (DLL) that interacts with SIMO program in the time-domain simulations. The DLL is implemented by interpolating fluid kinematics between pre-defined wave points near the vessel. Based on the time-domain simulations, the critical responses, such as the motions of the monopile, the tensions in the lift wire and the contact forces in the gripper device in the disturbed wave fields, are compared with those in incident wave conditions. The results indicate that a great reduction in these extreme responses can be achieved when the shielding effects are considered. The sensitivity study of the responses in different wave directions is performed. The results indicate different behaviours with different wave directions and with short or long

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waves. A comparison of the responses when using a floating vessel and a jack-up vessel is also studied and can be used to support the choice of installation vessel type.

1. Introduction

Various support structures have been proposed for offshore wind turbines (OWTs) at different water depths and soil conditions. With bottom-fixed OWTs, the industry prefers working with four types of foundations: gravity-based, monopile, jacket and tripod [1]. Of these foundations, monopiles are the most commonly used foundations in water depths up to 40 m, and it is estimated that more than 75% of all installations are founded on monopiles [2]. A typical monopile is a long tube with a diameter of 4–6 m. It is driven into the sea bed using a large hydraulic hammer if the soil condition is suitable. The pile diameter is limited by the size of the available driving equipment.

The installation of a monopile generally includes the following steps:

1. Upending the monopile from a horizontal position on the vessel to a vertical position.
2. Lowering the monopile down through the wave zone to the sea bed. The hydrodynamic wave loads induce the motions of the monopile when it passes through the wave zone. The monopile should be precisely landed at the designated point on the sea bed.
3. Driving the monopile into the sea bed with a hydraulic hammer.

This study focuses on the second step, i.e. the process of lowering the monopile.

Lifting operations are the most common means of installing monopiles and of many other offshore structures. Numerical studies have been commonly used to estimate the response characteristics of offshore lifting operations, including the installation of sub-sea templates [3], suction anchors [4], foundations and topsides of platforms, wind turbine components [5] and so on. A few experimental studies have also been conducted to obtain accurate hydrodynamic coefficients, e.g., the hydrodynamic mass and damping of ventilated piles [6], or to tune the critical parameters for numerical models, e.g., the damping or stiffness level of important support structures in the lifting system [7].

In lifting operations with objects (e.g., monopiles) lowered from air into the splash zone and towards the sea bed, the dynamic features of the system change continuously. A process dominated by transient or highly non-linear responses must be analysed differently from a stationary case. There are generally two approaches to simulate such cases [8]:

1. Find the most critical vertical position of the object by simulating a lowering in harmonic waves, and then make steady state simulations in irregular waves at this position.
2. Simulate a repeated lowering with different irregular wave realizations, and study the extreme response observed in each simulation.

It was demonstrated that the second method provides more realistic results [8]. The reason is that an unrealistic build-up of the oscillations that are observed in stationary cases is avoided. Therefore, to provide more accurate estimates of the operations, analyses of the entire lowering process are required.

In lifting operations conducted by floating vessels, hydrodynamic interactions between the structures in waves are of great importance. Studies have been performed to investigate the heavy lifting operations in the oil and gas industry considering shielding effects, such as the lifting of a heavy load from a transport barge using a large capacity semi-submersible crane vessel [9–11]. 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 dimension of the barge compared with that of the crane vessel [11]. Therefore, the hydrodynamic interaction between two floaters close to each other should be taken into consideration when estimating responses.