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Numerical Investigation on Wave Loads of the High-Rise Pile Cap Foundation of Offshore Wind Turbines in East China Sea

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ABSTRACT

High-rise pile cap foundation of offshore wind turbine is used in Donghai Bridge windfarm, East China Sea. The wave load characteristic of this new type of fixed structure has been paid close attention in engineering. In this investigation, based on Navier-Stokes equation, a fully nonlinear numerical wave tank was established for this high-rise pile cap foundation, and the wave loads and moments were obtained by integrating pressure over the surface of the structures. The effects of interaction between the cap and the piles are discussed in detail. In case of extreme wave height, the results indicate that the wave load on the piles with the cap increases by about 30 percent of those without it, and the maximum wave load is nearly doubled. The horizontal wave load on the cap with the piles increases by about 15 percent, while the vertical wave load decreases slightly. In addition, simply using Morison equation will seriously underestimate the wave loads of the piles.

KEY WORDS: offshore wind turbine; high-rise pile cap foundation; Donghai Bridge windfarm; wave loads; CFD.

INTRODUCTION

A new type of fixed structure supporting offshore wind turbines is used in Donghai Bridge windfarm, East China Sea. It is a high-rise pile cap foundation, which consists of a circular platform of 14 m diameter and eight supporting piles of 1.7 m diameter. A high vertical tower is mounted to the platform with a 3.4 MW wind turbine fixed at its top end. This foundation has many advantages over other conventional supporting systems, such as high stiffness, controllable risk for construction, economical cost, anti-collision, etc. (Chen & Zhou, et. al., 2016). However, it serves at present as an in-situ test model for the new type of structure to support offshore wind turbines (Lin YF, 2007).

However, the wave load characteristics are still not very clear. Because of complexity of this structures, traditional methods (such as Morison equation, diffraction theory), are unable to estimate the wave loads accurately. Moreover, the ratio of the cap diameter to the wave length is about 0.2, and there is no specific approach to calculate wave loads for the structures of this scale in nonlinear wave conditions. What is more, the cap just pierces the still water surface so that it is sometimes exposed to air and sometimes submerged in case of large amplitude waves. Most standard engineering tools of today are not capable of accurately modelling these contributions, and the design load values are therefore often based on model test experience. CFD computation of wave impacts on these type of structure has been rarely undertaken. However, similar work of wave-in-deck loading have been achieved. Bredmose et al (2011) presented a numerical simulation of wave impacts on a monopile, and then showed a subsequent vertical impact on the inspection platform. Schellin et al (2011) demonstrated that a modern CFD technique was able to predict the loads on a typical jack-up platform, and the wave-in-deck load acting on the hull in freak wave is particularly taken into account.

In our investigation, the high-rise pile cap structure has eight intensive piles so that wave loads of both the piles and the cap would be seriously affected by wave-in-deck impact. The interaction of the piles and the cap will be analyzed by CFD computation. The results of the present paper are of significant implication for widely use of the high-rise pile cap structure in other windfarms.

TEST CASE AND WAVE CLIMATE

The offshore wind farms in the East China Sea are typically shallow conditions. A depth of 11m is chosen for the present study according to the actual situation. In the present study, we choose wave parameters of significant wave height $H_{1\%}$ in 50 years. This significant wave height $H_{1\%}$ is defined as the average height of the highest one-hundredth waves in the indicated time periods. The wave length is 75 m, the wave height is 5.8 m and the period is 7.8 s, which is close to the limit of wave breaking. This nonlinear wave is achieved by stream function theory (Dean, 1965; Fenton, 1988) and twenty-order truncation is used in this case. These are exactly the in-situ hydrodynamic environments of the windfarm.

The computational domain is shown in Fig. 1. The structure supporting offshore wind turbines consists of a circular platform of 14 m diameter, a tower of 4.5 m diameter and eight inclined supporting piles of 1.7 m diameter. The large circular platform is the surface piercing cap consisting of two parts. The lower part is a cylinder of 3 m height, and the