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Nonlinear Wave Loads on High-rise Pile Cap Structures in the Donghai Bridge Wind Farm

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A new type of bottom-fixed structure, the so-called high-rise pile cap foundation, has been proposed and used to support offshore wind turbines in the Donghai Bridge Wind Farm, China. Engineers are unaware of the wave load mechanisms for this new structure. Using the Navier–Stokes equations and volume of fluid technique, a fully nonlinear numerical wave tank is established to investigate free surface wave loads and moments for the new structure. The interaction between the cap and piles are discussed in detail. In the case of fully nonlinear waves, the maximum horizontal wave load on all the piles with the cap can increase by 30% compared with those without the cap, and the maximum horizontal wave load on a single pile is nearly doubled. The horizontal wave load on the cap with the piles can increase by about 15%, while the vertical wave load decreases slightly. The conventional Morison formula and diffraction theory generally underestimate the wave loads on the piles and the cap as well.

INTRODUCTION

In 2010, China built the first large-scale offshore wind farm in Asia, the Donghai Bridge Wind Farm in the East China Sea. Unlike the monopole foundations widely used in the North Sea, the foundation for wind turbines in the Donghai Bridge Wind Farm is a high-rise pile cap structure. It was proposed for the following reasons. First, the hydrogeological conditions in the East China Sea are quite different from those in the North Sea. Multilayer soft clay with a total thickness of more than 25 m covers the seabed. For the safety and stability of offshore wind turbine structures on this soft clay, the sea bed near a large-diameter monopile or tripod foundation for large installation capacity should be protected by a wide range of surface hardening. But this will greatly impact marine ecosystems, which contrasts with environmental protection requirements (Chen et al., 2016). Second, severe typhoons frequently hit this area; thus more stringent requirements on the structure's strength and stability need to be met. Third, there is a busy fairway across the wind farm, making the cap necessary for preventing collisions between the foundation and ships.

The high-rise pile cap structure consists of a cap platform and eight piles. Two photos of this structure under construction and a sketch model can be seen in Fig. 1. The cap platform is the reinforced concrete structure with a 3-meter-high cylinder and an upper 1.5-meter-high frustum. The diameters of the cylinder and the top of frustum are 14 m and 11 m, respectively. The cap bottom is a flat plate with girders on the inside. Eight inclined supporting piles below the cap are evenly distributed around the cap bottom, each with a diameter of 1.7 m and a 5.5:1 slope ratio. Other detailed information about this structure can be found in Lin et al. (2007), Lu (2010), and Chang et al. (2014). This new foundation has many advantages over other conventional supporting systems, such as high stiffness, manageable risk, economical cost, anticollision, environmental hospitality, etc. (Chen et al., 2016). As a result, it has served as an in-situ test model to support offshore wind turbines (Lin et al., 2007).

Although it symbolizes a benchmark project in China, or even in Asia, it still needs more verification of extreme events. One of the fundamental issues is the extreme wave loads on the high-rise pile cap foundation. Because of the complexity of the structures and the strong nonlinearity of extreme waves, traditional methods, such as the Morison equation and the diffraction theory, are unable to estimate the wave loads accurately. Moreover, the cap just pierces the still water surface so that it is sometimes exposed to air and sometimes submerged, especially in the case

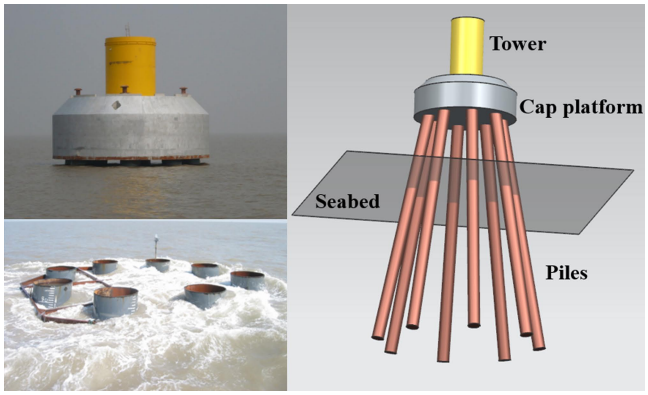

Fig. 1 Photos of a high-rise pile cap structure under construction in the Donghai Bridge Wind Farm (left) and the foundation sketch model (right)

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KEY WORDS: Offshore wind turbine, high-rise pile cap foundation, wave loads, impact effect, Donghai Bridge Wind Farm.