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Unified empirical relations for total inline wave forces on pile-supported structures in regular and irregular waves

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ABSTRACT

Wave forces on different pile-supported structures in regular and irregular waves are investigated experimentally. As a new characteristic geometric scale, an effective diameter is proposed to analyze the dimensionless total wave forces. With the effective diameter, unified empirical formulas describing the dimensionless wave forces versus Keulegan-Carpenter (*KC*) number are obtained for different complex pile-supported structures in regular and irregular waves.

1. Introduction

Nowadays, pile-supported structures have been applied in many offshore constructions, especially in wind power industry. The long-term safety of pile-supported structures is still a major concern in coastal engineering. Therefore, the prediction of wave forces on these composite structures plays a key role during the design process of offshore wind farm.

Assuming that the wave force on a slender cylinder could be divided into drag component and inertial component, it could be calculated according to Morison equation when C_d and C_m were known (Morison et al. (1950)). Lots of experimental studies investigated the relationships between these hydrodynamics coefficients and other parameters. Keulegan and Carpenter (1956) suggested using $KC(= U_mT/D)$ to represent the properties of internal solitary waves and cylinders, where U_m was the maximum horizontal velocity of the particle at the surface of still water, T was the wave period and D was the diameter of the pile. Sarpkaya et al. (1976) discussed the effects of the frequency parameter $\beta(= D^2/\nu T)$ on the variations of hydrodynamic coefficients, in which ν was the kinematic viscosity of water. Bearman et al. (1985) proposed that when KC number was small, drag coefficient C_d was inversely proportional to the value of KC number. Significant scatters in the variations of C_d and C_m with KC for inclined cylinders were revealed by Sundar et al. (1998). Vengatesan et al. (2000) and Venugopal et al. (2006) reported that the variations of drag and inertia coefficients with KC number for rectangular cylinders were identical in waves for different β. C_d and C_m were given as some functions of R_e $(= U_mD/\nu)$ for various KC by Boccotti et al. (2013) in a field experimental study. As an important hydrodynamic coefficient, the total force coefficient was also investigated by many researchers through experimental studies. The variations of total force coefficients with KC for a single cylinder were reported by Keulegan and Carpenter (1956), Bearman et al. (1985), Sarpkaya (1986), Davies et al. (1990), Burrows et al. (1997) and Vengatesan et al. (2000). And the total force coefficients were inversely proportional to KC at low KC numbers in most of the early studies.

The types of pile-supported structures for offshore wind turbines could be categorized into monopile, suction pile, pile cap and so on (Ryu et al. (2012)). Zdravkovich (2003) discussed the effects of the interference parameters on the overall drag forces for pile groups. Through both small-scale and large-scale experiments, Bonakdar et al. (2012) and Bonakdar and Oumeraci (2014) reviewed that the interference parameters including the relative spacing between piles and the number of neighbouring piles could noticeably affect the wave forces on each single pile.

The wave forces on complex pile-supported structures could be obtained by calculating the wave forces on each single pile using Morison equation. But the formulas of wave forces on a single pile within pile groups were related with the pile group arrangements, and the effects of different interference parameters were difficult to estimate (Bonakdar and Oumeraci (2015)). The previous experimental work about the variations of total wave forces with KC focused only on the single cylinder. Hence, we need an efficient and robust method to obtain the total wave forces on the whole complex pile-supported structures.

To analyze the variation of the wave forces on complex pile-supported

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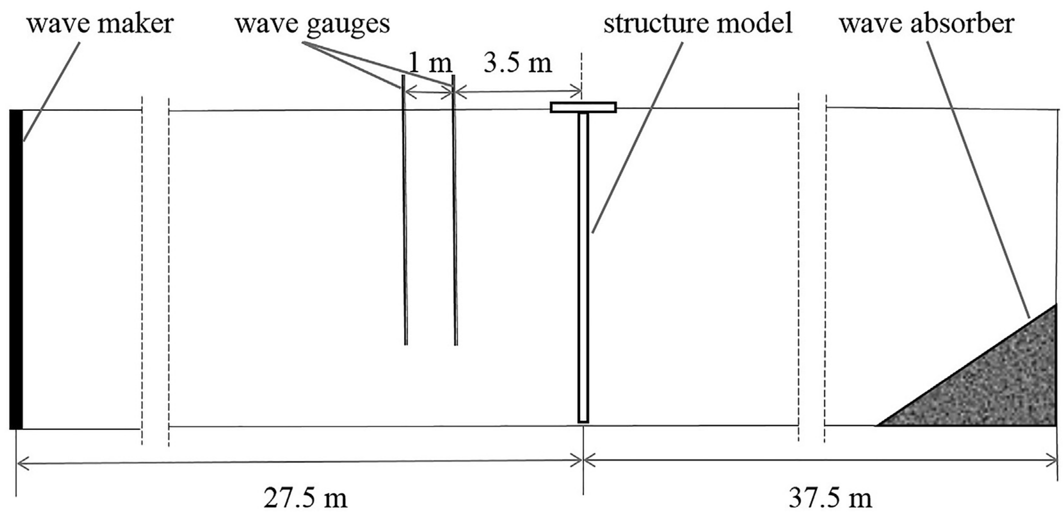

Fig. 1. Layout of the wave flume.

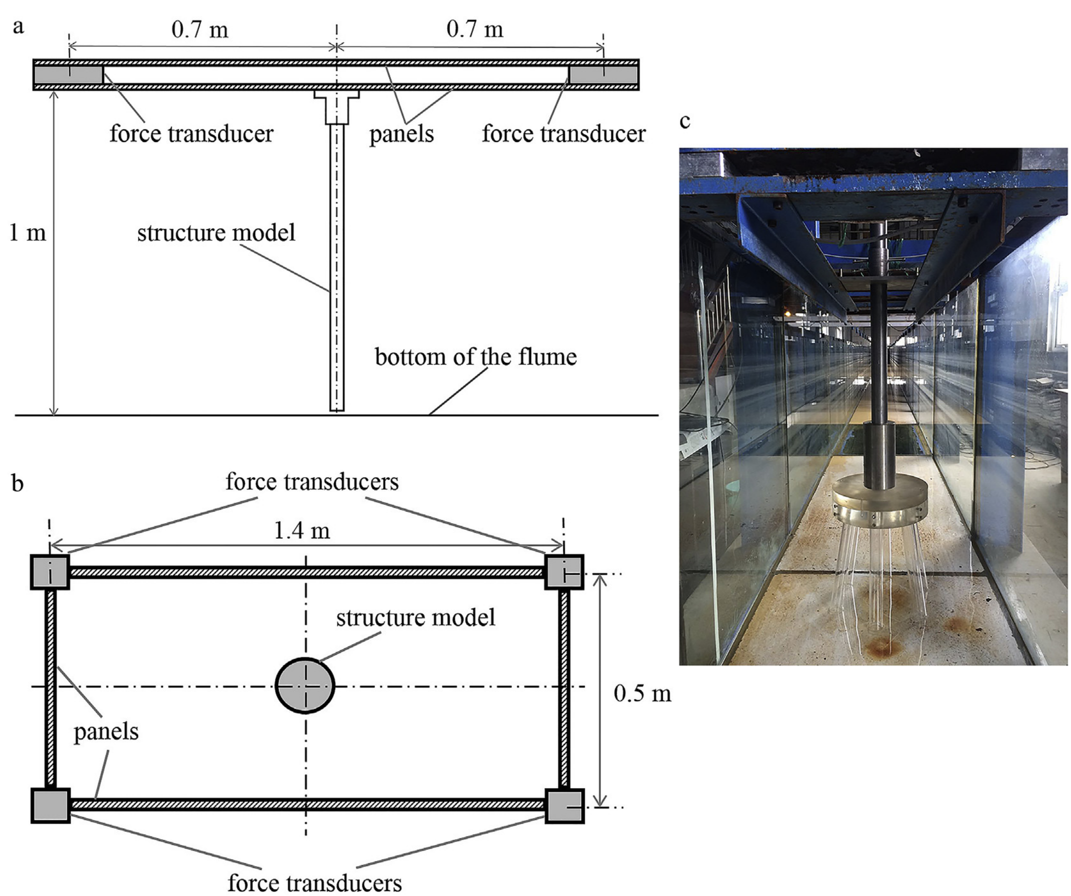

Fig. 2. Sketches of the structure model: (a) front view; (b) top view; (c) photograph.

structures, a series of experiments have been conducted. Based on the experimental results, an effective diameter is proposed to represent the characteristic geometric scale of different centrosymmetric pile-supported structures. Finally, the unified empirical formulas of the total inline wave forces and the zeroth moments of total inline wave force spectrums are obtained. These empirical equations are consistent with the results of monopiles in experiments and calculations based on Morison equation.

2. Experimental scheme and conditions

2.1. Measurement technique and structure models

The experiments were conducted in the wave flume of School of NAOCE at Shanghai Jiao Tong University. The dimensions of this wave flume were 0.8 m wide, 1.2 m deep and 65 m long. The wave maker was located in the left of the wave flume, and the structure model was fixed at a distance of 27.5 m from the wave maker. A wave absorber packed with