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Experimental study of unidirectional irregular wave slamming on the three-dimensional structure in the splash zone

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A B S T R A C T

The experimental investigation of unidirectional random wave slamming on the three-dimensional structure in the splash zone is presented. The experiment is conducted in the marine environment channel in the State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology. The test wave is unidirectional irregular wave. The experiments are carried out with perpendicular random waves ($\beta = 0^\circ$) and oblique random waves ($\beta = 15^\circ, 30^\circ, 45^\circ$), the significant wave heights $H_{1/3}$ ranging from 7.5 to 20 cm with 2.5 cm increment, the peak wave periods T_p ranging from 0.75 to 2.0 s with 0.25 s increment, and the clearance of the model with respect to the significant wave height $s/H_{1/3}$ ranging from 0.0 to 0.5 with 0.1 increment. The statistical analysis results of different test cases are presented. The statistical distribution characteristics of the perpendicular irregular wave impact pressures are compared with that of the oblique irregular wave on the underside of the structure. The effect of the wave direction β on the wave impact forces on the underside of the structure is determined. The relation between the impact forces and the parameters such as the significant wave height, the relative structure width and the relative clearance of the structure is also discussed.

1. Introduction

With the rapid development of ocean exploitation, more and more open structures, such as artificial islands, detached wharves, offshore platforms and sea terminals are built up in the deep water of open sea. And the extreme slamming loads due to the big waves threaten the safety of those marine structures.

The mechanics of wave slamming is very complicated and the present study on wave slamming is limited to two-dimensional problems. Wang (1970) studied the wave-induced pressures on the underside of a horizontal flat plate mounted on a pier deck under a dispersive wave system. Based on the assumption of irrotational flow and an incompressible fluid, Kaplan (1992) and Kaplan et al. (1995) extended the solution of small horizontal cylinders to the larger plate. Laboratory experiments were carried out to estimate the wave-impacting pressures by Goda (1967), Elghamry (1971), Guo and Cai (1980), Wang et al. (1998), Ren and Wang (2002) and Zhou and Chen (2004). Wang and Ren (1997) and Ren and Wang (1999, 2004) developed numerical models based on the improved VOF method to simulate the wave-impacting pressures.

However, the studies mentioned above assume that waves act on two-dimensional structure perpendicularly. There are little work on the study of three-dimensional wave slamming problems.

The objectives of this paper are to investigate the characteristics of unidirectional irregular wave impact on the three-dimensional structure and the corresponding spatial and temporal distribution of impact forces. The experiment is conducted in the marine environment channel in the State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology. The statistical distribution characteristics of the perpendicular wave impact pressures are compared with that of the oblique wave on the underside of the structure. The effect of the wave direction β on the wave impact force on the underside of the structure is determined. And the relation between the impact force and the parameters such as the significant wave height, the relative structure width and the relative clearance of the structure is also discussed.

2. Experimental setup

The experiment is conducted in the marine environment channel in the State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology. The wave channel is 50 m in length, 3.0 m in width and 1.0 m in height. It is equipped

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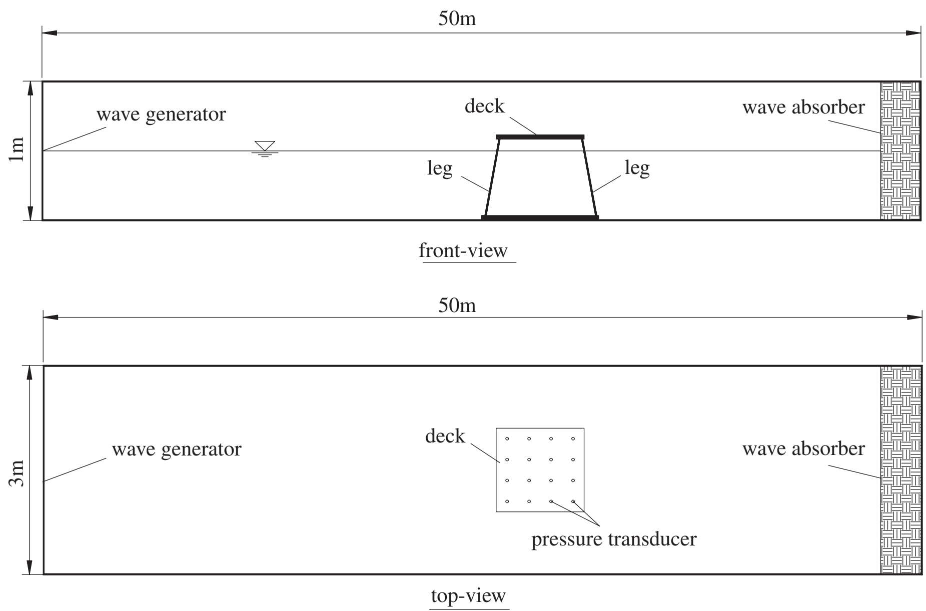

Fig. 1. Sketch of the experimental setup.

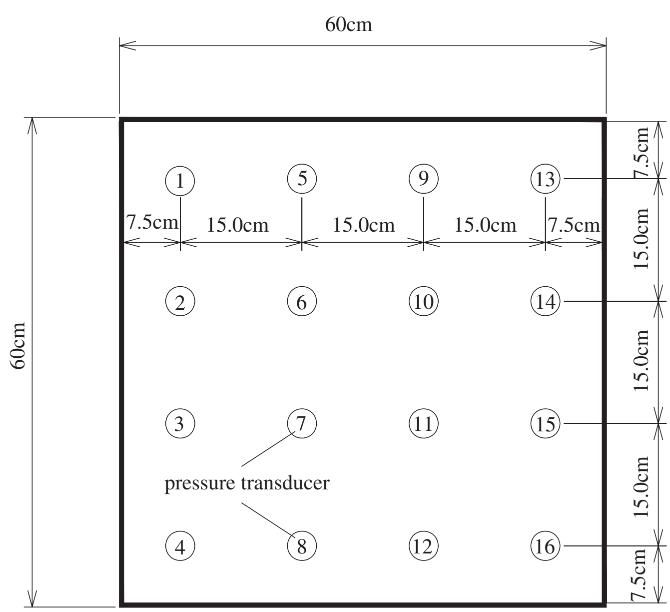

Fig. 2. Sketch of the pressure transducers on the subface of the model.

with a wave generator driven by an servo-electro-hydraulic system, with a related computer control and a data acquisition system. At the far end of the tank, a wave energy dissipation device is set to attenuate the reflected waves. The structure model is centrally installed in the mid-back part of the tank, as shown in Fig. 1.

In the experiment a platform structure model is designed as the experimental model. The deck of the platform is made of organic glass with 60 cm long, 60 cm wide and 2 cm thick. The supporting legs of the platform are made of steel pipe with the diameter of 2 cm. The slope of the legs is 10:1. The clearance of the underside of the model deck above the water can be adjusted by adjusting the height of the supporting legs, which are designed adjustable. The distance between the edge of the deck and the side wall of the tank is from 1.0 to 1.2 m. The effect of the side walls of the flume on the oncoming waves can be neglected. Sixteen pressure transducers are fixed on the underside of the deck, and are marked as 1–16 as shown in Fig. 2. The wave impact pressures on the underside of the deck are measured using a SG-2000 multi-point pressure-measuring system, which was made by the Institute Water Transportation of Tianjin. The natural resonant oscillating frequency of the pressure transducers is 500 Hz. The data-sampling interval is 0.004 s.

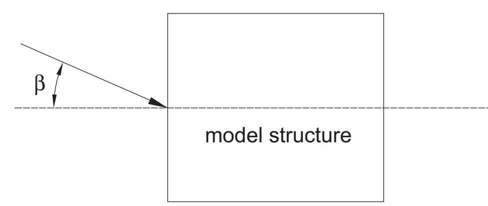

Fig. 3. The definition of wave direction β.

3. Case studies

In the experiment, the modified JONSWAP spectrum with $\gamma = 3.3$ (Goda, 1999) is chosen as the target spectrum, and written as

$$S(f) = \beta_j H_{1/3}^2 T_p^{-4} f^{-5} \exp\left[-\frac{5}{4}(T_p f)^{-4}\right] \gamma^{\exp[-(f/f_p-1)^2/2\sigma]} \tag{1}$$

$$\beta_j = \frac{0.06238(1.094 - 0.01915 \ln \gamma)}{0.23 + 0.0336\gamma - 0.185(1.9+\gamma)^{-1}} \tag{2}$$

$$\sigma = \begin{cases} 0.07, & f \leqslant f_p \\ 0.09, & f > f_p \end{cases} \tag{3}$$

where f_p denotes the peak frequency, γ is the peak enhancement factor, σ is defined as the shape parameter. The incident wave is