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Hydrodynamic Resonance of Three Identical Rectangular Boxes with Narrow Gaps by a CIP Method

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The research on interactions between water waves and floating structures with narrow gaps plays an important role in revealing the mechanism of hydrodynamic resonance in very large floating structures and side-by-side offloading ships. To investigate free-surface oscillations in two narrow gaps between three identical fixed rectangular boxes, a two-dimensional viscous flow numerical wave tank based on a constrained interpolation profile method is established. A tangent of hyperbola for interface capturing method is employed to capture the free surface, whereas a virtual particle method is used to treat the floating body surface. An internal wave maker is used for generating the incident waves. The computational results of wave height in narrow gaps are found in good coincidence with available experimental data, especially for the resonant frequencies. At the fundamental frequencies, the resonant wave heights both in both gaps are more than four times that of the incident wave height, whereas at the second resonant frequencies, they are about three times that of the incident wave height. In addition, the wave forces on the floating bodies are calculated. The fundamental frequencies of wave forces on the upstream body and downstream body are generally consistent with the fluid resonance frequencies in narrow gaps, whereas the frequency response of wave forces on the middle body happens at the second resonant frequency in the gap between the upstream body and the middle one.

INTRODUCTION

For an effective utilization of ocean space, very large floating structures (VLFS) are a good and potential solution, and they have triggered extensive investigations in last two decades, such as offshore airports, floating bridges, floating piers, disaster footholds, and so forth (Ohmatsu, 2005; Suzuki, 2005; Wang and Tay, 2011). In general, VLFS are composed of a number of modules that introduce narrow gaps between multimodules arranged side by side (Iwata et al., 2007). Besides, side-by-side offloading, such as a floating liquefied natural gas (FLNG) facility to an LNG carrier, drilling vessels, or offshore wind turbines, also forms a very narrow gap in offshore operations. The characteristic scales of the gaps are very small in comparison with the typical dimensions of those floating modules. The fluid resonance in the narrow gaps tuned by the incident wave induces large-amplitude wave run-up in the gaps and leads to a significant increase of wave forces on the adjacent modules, which can pose a serious threat to engineering safety. Therefore, it is of practical importance to investigate the resonance influence because of these gaps.

A great many researchers have devoted their efforts to the mechanisms of resonance and its impact on structure safety. Newman (1974) analytically studied the interaction of free surface upon a pair of vertical flat plates in a fluid of infinite depth and discovered that the reflection and transmission coefficients undergo rapid changes in the vicinity of the resonant wave number. Miao et al. (2000, 2001) investigated the effect of gaps on wave forces on twin fixed caissons by the boundary integral method and potential flow model, and they found that the resonant wave forces on each caisson increased to 10 times that of the isolated. Gap resonance problems share some features with moonpool resonances, for which Molin (2001) derived an analytical formula to estimate the natural frequencies and associated modal shapes of the resonant modes based on linear potential flow theory. More potential flow models in frequency domain or time domain were established for the gap resonance problem, such as Zhu et al. (2005) and He et al. (2006). Sun et al. (2010) made a comprehensive study of the frequencies, mode shapes, and response amplitudes of the gap resonances in between two fixed boxes. Zhao, Pan, et al. (2018) investigated both the transient and steady-state resonant responses of the fluid in narrow gaps using different types of incident waves with the addition of calibrated damping within the scope of potential flow theory.

As well, physical experiments on resonance problems were carried out by scholars and experts. Saitoh et al. (2006) derived a theoretical nature frequency of fluid in the narrow gap between twin boxes and experimentally demonstrated the appearance condition of resonant phenomena. Subsequently, Iwata et al. (2007) extended the method to the case of three rectangular modules with two gaps and had the experimental confirmation of occurrence as well. Zhao et al. (2016) conducted scale model tests for twin fixed vessel in a side-by-side configuration and made clear the difference of fluid resonance between three dimensions and two dimensions. Zhao et al. (2017) investigated the first and higher harmonic components of the resonant fluid response in the gap between two identical fixed rectangular boxes in a wave basin

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