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Experimental and numerical study on wave response at the gap between two barges of different draughts

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ABSTRACT

This study considers two barges of different draughts in incident waves. Physical experiments are carried out in a wave flume to investigate the wave response at the gap between two barges. New experimental data are used to calibrate the artificial viscous coefficient of a typical time-domain potential-flow solver. Through a comparison between the experimental and numerical results, the artificial viscous coefficient that indicates dissipation effects at the gap is identified. It is found that the artificial viscous coefficient is determined not only by the relative barge draughts but also by the propagating direction of incident waves. Hydrodynamic characteristics of two barges with different draughts are further investigated. The wave frequency corresponding to the largest wave amplitude at the gap is found to decrease, as either barge draught grows. The maximum wave heights at the gap for different combination of barge draughts are analyzed. Corresponding physical explanation for the chart is given in detail.

1. Introduction

In the field of ocean engineering, it is common that multiple floating structures are arranged side by side. For example, a liquefied natural gas floating production storage and offloading unit (LNG-FSPO) and a LNG carrier are arranged side-by-side with a narrow gap between them when LNG production is transporting from the LNG-FSPO to the LNG carrier. Another typical example is the pontoon-type 'very large floating structure (VLFS)' comprised of floating units. Under certain wave conditions, the free surface in the narrow gap between two adjacent floating units can oscillate violently, leading to a significant increase of the hydrodynamic forces acting on the structures and green water over the deck.

Numerical studies on the narrow gap problem have been carried out extensively. The simplest numerical model for the narrow gap problem is based on the linear potential-flow theory. For example, Molin [6] performed a 2D quasi-analytical approximation to study natural frequencies associated free surface waves between two identical barges with infinite length. Miao et al. [7] used a 2D frequency-domain numerical method to investigate the influence of the small gap between twin barges on the wave forces. Zhang and Bandyk [8] studied the moonpool resonance of two heaving rectangular bodies in a two-layer fluid using an analytical method. Based on the frequency-domain numerical method, Sun et al [9] investigated the wave interaction between a FLNG vessel and a tanker in a side-by-side arrangement with a very close gap between them. However, it has been well recognized that the linear potential-flow theory normally overestimates the maximum wave amplitude (e.g. Lu et al. [10]). Various approximations were further proposed to hold the unrealistically large fluid motion back to a realistic level. Buchner et al. [11] placed a lid condition on the gap free surface between two ships to suppress the excessive wave amplitude. Newman [12] further applied a flexible lid condition based on Chebychev base functions to represent the wave motion in the gap. Chen [13] introduced a dissipation term to the free-surface boundary condition to account for the energy dissipation in the ideal fluid. Liu and Li [14] also used damping terms on the free-surface boundary conditions in a linear semi-analytical solution to approximate the energy dissipation in the gap between twin fixed barges.

A straightforward way to mitigate the discrepancy between linear potential-flow and experimental results is to involve the nonlinear free-surface boundary conditions and viscous effects. For example, Yan et al. [15] developed a quasi-arbitrary Lagrangian-Eulerian finite element method (QALE-FEM) based on the nonlinear potential-flow theory, and studied the fluid motion at the gap between two structures in close proximity. Kristiansen and Faltinsen [16] considered the ship motion near a bottom-mounted terminal and exposed to regular waves, with an inviscid vortex tracking method integrated with the boundary element method (BEM) to model the flow separation in the gap. Wang et al. [17]

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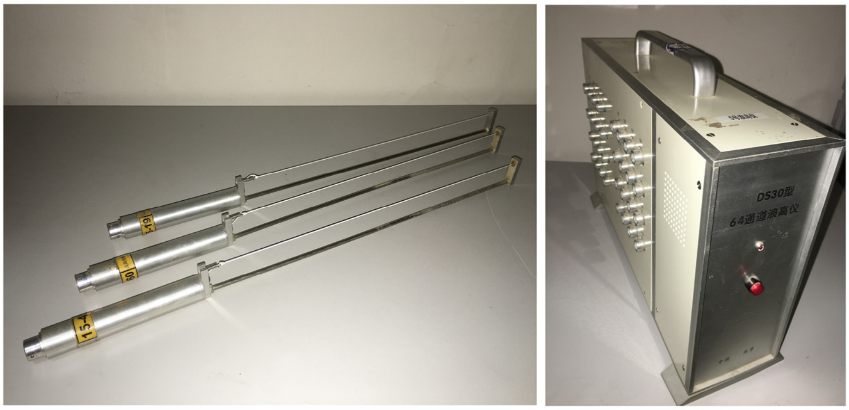
(a) Wave flume (b) Physical models



(c) Wave gauges (d) Data collector

Fig. 1. Facilities of model experiments: (a) wave flume; (b) physical models; and (c) wave gauges; and (d) data collector.

carried out the nonlinear analysis of the liquid confined between twin rectangular, wedge-shaped and semi-elliptic cylinders. Effects of the body surface flare at the water line on the gap wave response were discussed. Ning et al [18] developed a nonlinear potential-flow numerical wave flume to investigate the hydrodynamic difference of rectangular-box systems with and without narrow gaps. The numerical model was further used in Ning et al. [19] to investigate the wave response at narrow gaps of multiple barges, and in Ning et al. [20] to analyze the interaction between the solitary wave and twin barges with a narrow gap. Li and Zhang [21] simulated the wave response at the gap of two heaving barges, and studied the transition between the piston and sloshing modes of the gap. For 3D cases, Feng and Bai [22] investigated the three-dimensional effects of the gap wave response between two identical barges, based on the time-domain potential-flow model.

Some viscous-flow numerical models were also used to simulate the narrow gap wave motion between two floating structures. Lu et al [23] employed the viscous numerical wave flume to study the fluid response at narrow gaps between three identical rectangular cylinders. The vortex structures in the gaps were observed. Lu et al. [10] further demonstrated that the potential-flow model with a proper damping coefficient could work as well as the viscous fluid model for the narrow gap problem. Moradi et al. [24] investigated the wave response in the narrow gap between two identical barges using the OpenFOAM open source CFD codes, where the influence of the inlet configuration of the gap was highlighted. Although viscous flow model can predict the energy dissipation due to vortex flow, simulating large scale floating structures using viscous model is challenging because predicting vortex flow accurately requires unaffordable computer time.

It should be noted that, most numerical methods inevitably include artificial parameters or empirical constants, no matter in the turbulence model of a viscous-flow solver or in the artificial term of a potential-flow solver. Thus, experimental results are significant for calibration of these parameters and validation of the numerical approaches. Typical experimental studies are as follows. Saitoh et al. [1] measured the wave height at the gaps formed by two or three identical barges, whose experimental data were mostly often used for the numerical validation. Zhao et al. [5] considered the gap wave response driven by focused transient wave groups, where the first and higher harmonic components of the fluid response in the gap between two fixed identical barges were experimentally investigated. Besides, experiments on a narrow gap formed by complex-geometry hulls can be found in some literature. For example, Zhao et al. [2] conducted laboratory tests of side-by-side operations between a FLNG and a LNG carrier, and found evident effects of the gap wave response on wave forces. Watai et al. [3] conducted the experiment of a multi-body system comprised of a fixed barge and a movable prismatic geosim in regular head waves. Peric and Swan [4] investigated the gap wave response between a ship-shaped vessel and a large rectangular box, in which effects of the ship motion were discussed.

Due to simplicity of the geometry, the two-barge model is normally chosen for the first-step benchmark test, before the numerical method is applied to a more general narrow gap problem. At present, numerical approaches can only be validated through comparison with