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Theoretical and numerical investigations of wave resonance between two floating bodies in close proximity *

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Abstract: A simple theoretical dynamic model with a linearized damping coefficient is proposed for the gap resonance problem, as often referred to as the piston mode wave motion in a narrow gap formed by floating bodies. The relationship among the resonant response amplitude and frequency, the reflection and transmission coefficients, the gap width, and the damping coefficient is obtained. A quantitative link between the damping coefficient of the theoretical dynamic model (ε) and that devised for the modified potential flow model (u_p) is established, namely, $u_p = 3\pi\varepsilon\omega_n/8$ (where ω_n is the natural frequency). This link clarifies the physical meaning of the damping term introduced into the modified potential flow model. A new explicit approach to determine the damping coefficient for the modified potential model is proposed, without resorting to numerically tuning the damping coefficient by trial and error tests. The effects of the body breadth ratio on the characteristics of the gap resonance are numerically investigated by using both the modified potential flow model and the viscous RNG turbulent model. It is found that the body breadth ratio has a significant nonlinear influence on the resonant wave amplitude and the resonant frequency. With the modified potential flow model with the explicit damping coefficient, reasonable predictions are made in good agreement with the numerical solutions of the viscous fluid model.

Key words: Water wave, narrow gap, fluid resonance, energy dissipation, artificial damping

Introduction

The violent resonant oscillation of the water column in a narrow gap between two closely spaced floating structures may occur as the incident wave frequency is close to the natural frequency of the oscillating fluid mass. This phenomenon is often referred to as the gap resonance. The resonant wave in the narrow gap can bring about extreme local wave loads and large-amplitude motions of the floating structures, and hence affect the normal field operations, such as the side-by-side offloading/uploading operations between the liquefied natural gas (LNG) carriers and the Floating Liquefied Natural Gas (FLNG) platforms, and the ship berthing in front of a wharf.

In the past decades, the gap resonance problem has attracted much attention due to its engineering significance. The influence of the body draft and the gap width on the resonant characteristics was studied through physical experiments[1,2]. In addition, the previous investigations also include semi-analytical solutions and numerical simulations. Semi-analytical solutions[3-6] are mainly based on a potential flow assumption, and are limited to simple geometries. Numerical simulations involve two types of numerical models: the potential flow models and the viscous flow models. The potential flow models[7-11], based on the assumption of irrotational flows of incompressible fluids, are computationally efficient, however, they

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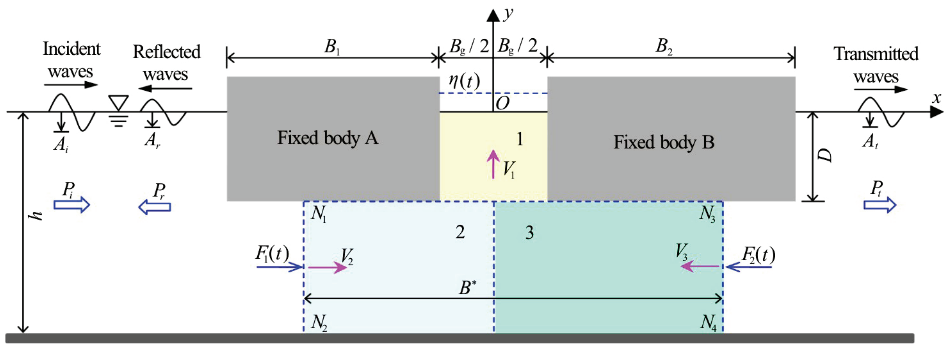

Fig.1 (Color online) Sketch of gap resonance between two stationary floating bodies

might over-predict the resonant response amplitudes significantly due to the neglect of the energy dissipations.

Efforts have been made to modify the potential flow models by introducing a viscous damping mechanism (or a coefficient) while maintaining the computational efficiency. The modified potential flow models[12-16] can predict the resonant response accurately with a damping coefficient being tuned against experimental data. One of the uncertainties associated with the modified potential flow models is the way that the artificial damping coefficient is tuned through trial and error methods. Based on the experience in studying the liquid sloshing dynamics in a tank with a slatted screen, Faltinsen and Timokha[17] reported an empirical formula for estimating the damping coefficient instead of tuning it.

Viscous flow models were also proposed to investigate the fluid resonance in a narrow gap[18-23] in predicting successfully both the resonant frequency and the response amplitude. Moradi et al.[22] studied the effect of the energy dissipations on the resonant amplitudes through viscous model simulations of a gap resonance problem with various gap entrance corner configurations. It was found that the gap edge shape affects both the resonant frequency and the response amplitude. Although viscous fluid models can simulate the gap resonance problem accurately, they require huge computational resources.

However, the underlying physics behind the resonance characteristics in a gap remains unclear. The primary objective of the present work is to explore the relationship among the resonant response amplitude and frequency, the reflection and transmission waves, the body geometry and the damping for the gap resonance problem. Based on the physical understanding, a new approach is proposed to determine the artificial damping coefficient for the modified potential models. Furthermore, to the authors' knowledge, few of previous studies have considered the effects of the body breadth ratio on the resonant characteristics. In this work, both the viscous turbulent model and the modified potential flow model are used to examine the effect of the body breadth ratio.

This paper is organized as follows. After a brief introduction, a simple theoretical dynamic model with a linearized damping coefficient is proposed to describe the fluid resonance in a narrow gap. With the theoretical model, the artificial damping coefficient is quantified for the modified potential model. After that, a viscous turbulent model is used to simulate the gap resonance problem with different body breadths. Numerical results of the modified potential flow model are compared with the available experimental data and the present viscous numerical results. Finally, conclusions are drawn.

1. Fundamental theory

1.1 *A theoretical dynamic model for gap resonance*

A theoretical dynamic model for the motion of the oscillating fluid in the gap is proposed based on the concept of the control volume (CV). The gap resonance problem considered in this study is illustrated in Fig.1, where the wave-induced motions of the fluid trapped between two stationary bodies A and B are of the interest. A two-dimensional Cartesian coordinate system is defined with its origin located at the still water level and the middle section of the narrow gap, and the y-axis pointing vertically upwards. The incident wave propagates along x direction. The parameter h is the water depth from the mean water level to the seabed, B_1 and B_2 are the breadths of the bodies A and B, respectively, B_g is the gap width and D is the draft of the floating bodies A and B.

To analyze the wave induced motion of the fluid trapped in the gap, the energy conservation of the fluid enclosed by a CV is considered. The CV includes three regions, denoted by the regions 1, 2 and 3, as shown in Fig.1. The regions 2 and 3, corresponding to the area surrounded by N_1N_2 - N_2N_4 - N_4N_3 - N_3N_1 , represent the zones