

Numerical Simulation of Hydrodynamic Resonance in a Narrow Gap between Twin Bodies Subject to Water Waves

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ABSTRACT

A numerical wave flume is developed to simulate the hydrodynamic resonance in a narrow gap formed between twin bodies of identical dimensions. The numerical wave flume is based on the Navier-Stokes equations and CLEAR-Volume of Fluid method in the frame of Finite Element Method. Comparisons of the present numerical results and the experimental data available in literature show that the present numerical wave flume works well in predicting the well-known hydrodynamic resonance in narrow gaps. It is found that the amplitudes of the free surface oscillations in the narrow gap are not as large as those predicted by the potential theory and are rather limited. The influence of non-dimensional incident wave frequency on the resonance is examined using the numerical wave flume.

KEY WORDS: Very large floating structure (VLFS), narrow gap, fluid resonance, numerical wave flume (NWF), finite element method (FEM), volume of fluid method (VOF)

INTRODUCTION

Very Large Floating Structures (VLFS) are favorite options as floating airports, storage units and manufacturing facilities. A VLFS is generally composed of a number of box-shaped modules connected by flexible conjunctions. Gaps exist between these separated units. The characteristic dimensions of the gaps are usually very small in comparison with dimensions of individual modules. When a VLFS is subject to water waves the fluid resonance in the narrow gaps may take place, which is characterized by large amplitude of wave motion in the gaps and sharp peak responses of wave forces on the modules at resonance frequency. The resonant phenomena have received some attentions recently since the gap influence can not be neglected for the very large floating structures. Saitoh et al. (2006) conducted physical model tests on the fluid resonance in a narrow gap between two identical side by side floating boxes. It was found that the wave height in the gap reached as high as five times of the incident wave height when the resonance took place. Iwata et al. (2007) further investigated hydrodynamic resonance of three bodies with two gaps by model tests. Experimental results and theoretical analysis results showed that the condition for fluid resonance narrow gaps can be approximated by

$kl \tanh(kh) = 1$, where k is the incident wave number, l is a geometrical condition and h is the water depth. Miao et al. (2000 and 2001) studied the influence of gaps on wave forces on two floating caissons employing the boundary integral method. It was found that the resonant wave forces on each caisson attained as large as ten times of the forces on an isolated caisson. By means of theoretical analysis, Miao et al. (2000 and 2001) demonstrated that resonance takes place at the non-dimensional resonant wave number of around $kl = n\pi$ ($n=1, 2, 3, \dots$), where k is the wave number and l is the length of caisson. Zhu et al. (2005) investigated the wave forces and hydrodynamic interactions of two box-shaped floating structures using a three-dimensional potential flow model. Li et al. (2005a, 2005b and 2006) and Teng et al. (2006) employed a novel scaled boundary finite element method to study the problem of fluid resonance in the narrow gap of twin bodies subject to wave actions. He et al. (2006) examined the wave forces, reflection coefficient and transmission coefficient for three fixed floating boxes with two gaps based on the above numerical model. These published numerical studies gave many insights into the problem of fluid resonance in narrow gaps of very large floating structures and multi-body interactions.

The numerical models developed so far on hydrodynamic resonance in narrow gaps are based on the potential flow theory. It is speculated that the potential flow models over-predict the wave amplitudes in the narrow gap due to negligence of fluid viscosity and energy dissipation. The main purpose of the current work is therefore to develop a numerical model to simulate the fluid resonance in the narrow gap of twin bodies. The numerical model solves Navier-Stokes equations using a three-step Taylor Galerkin finite element method. The free surface is captured using a Volume of Fluid (VOF) method. The numerical results of free surface oscillations in the gap are compared with the experimental data in literature.

NUMERICAL WAVE FLUME

In order to simulate the fluid resonance in the narrow gap between twin bodies, a numerical wave flume is developed firstly. Considering the importance of viscous dissipation of fluid flow, large amplitude of wave motion in the narrow gaps and significant wave reflection due to the presence of floating structures, the wave flume to be developed should be composed of the following necessary components: a reliable numerical solver of Navier-Stokes equations, an accurate free surface capture technique, an efficient wave absorbing method and an appropriate approach to generate desirable waves. A definition sketch of the numerical wave flume developed in this study is shown in Fig. 1.