Experimental Validation of the Computation Method for Strongly Nonlinear Wave-Body Interactions

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1 Introduction

The project of developing a fundamental CFD model for strongly nonlinear hydrodynamic problems, such as interaction of a floating body and wave in rough seas, violent sloshing inside a tank, et al., has been undertaken in RIAM, Kyushu University for several years. The CFD model, which is recently named as RIAM-CMEN (Computation Method for Extremely Nonlinear hydrodynamic), is a Cartesian grid approach coupled with an interface capturing method. The CIP (Constrained Interpolation Profile) algorithm is adopted as the base finite difference scheme. As the Cartesian grid does not depend on the body boundary and the free surface, the computation of a strongly nonlinear problem, which may require treatment of both complicated free surface deformation and violent body motion, can be more efficient and robust than conventional body fitted approach.

The accuracy of the RIAM-CMEN has been checked by several 2-D test problems such as dam breaking [1], forced oscillation of a floating body [1], sloshing in tanks [2], water entry [3]. 3-D code development and its validations are now in progress [4][5].

Numerical simulation of strongly nonlinear ship-wave interactions, which is one of the goals of RIAM-CMEN, is a very complicated subject because it requires treating the interaction of largely deformed free surface and violently moving body. Although some successful computations have been obtained, more careful validations of the code are required.

In this extended abstract, two experiments for wave-body interactions are reported: a 2-D experiment in a wave channel using a rectangular floating body and a 3-D experiment in a towing tank using a modified Wigley model. These experiments are for validation purpose of RIAM-CMEN for computing strongly nonlinear wave-body interactions. By strongly nonlinear we mean a floating body may perform large amplitude motion in large incident waves and may accompany with water on deck and slamming phenomena. In order to be easily implemented in the numerical computation, simple body geometries are used: a box model for 2-D and a mathematical ship model for 3-D. To investigate the green water loads, a box-type upstructure is placed on the deck of both models. Comprehensive 2-D computations have been carried out and compared to the experiment and some selected results are presented. For 3-D case, only the experiment is described here while the correspondent computation, which is now being conducted, will be presented at the workshop.

2 Numerical Method

The numerical model considers the wave-body interaction as a multi-phase problem that includes water, air and solid body. The fluid is assumed incompressible and viscous. The continuity of fluid mass and the Navier-Stokes equations are used as the governing equations for the fluid. The CIP method is incorporated to the flow solver. To identify different materials, density functions ϕ_m (m=1, 2 and 3 indicates water, air and solid, respectively) are introduced. A fixed Cartesian grid that covers the whole computation domain is used. The free surface is considered as an inner interface that is handled by an interface capturing method. The treatment of solid body is unique in the RIAM-CMEN: the body surface is represented by distributing artificial particles on it and the surface is tracked in the fixed grid by a Lagrangian method. Detailed description of the numerical method can be found in authors' previous papers [1][2][5].

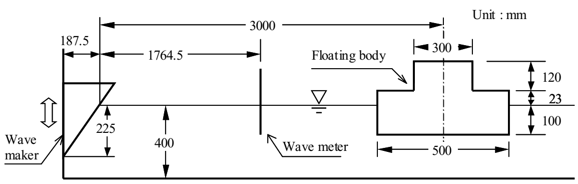


Fig. 1. Schematic view of 2-D NWT

3 2-D Experiment and Computation

The 2-D experiment, as sketched in Fig.1, was performed in a two dimensional wave channel (10m long, 0.3m wide, and 0.4 m deep) at RIAM. The floating body model used for the experiment has the length of 0.5m, the depth of 1.0m and the freeboard of 0.1m. A box type upstructure is installed on the deck. The measurements include position of wave maker, heave and roll of the floating body, and wave elevation in front of the floating body.

Figures 2-5 are comparison of the computation and the experiment for two cases with the sway motion restricted. The only difference is the incident wave periods, being T_w=1.0sec and T_w=0.7sec, respectively. For the case of T_w=1.0sec, as shown in Figs.2 and 3, there is no water on deck phenomena present. The body motions as well as the free surface elevation are very regular. The comparison of heave is not satisfactory and the reason for this should be investigated.

For the case of T_w=0.7sec, as shown in Figs. 4 and 5, nonlinear features appear in both the body motions and the free surface elevation. Main source caused these nonlinearities is considered from the hydrodynamic loads of the shipped water on the deck. These nonlinear features are predicted successfully by the present CFD model.

4 3-D Experiment

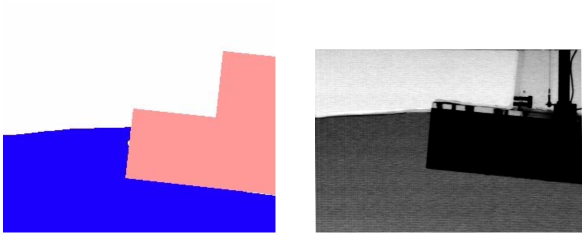
The 3-D experiment is conducted in the towing tank of RIAM. A modified Wigley model that can be expressed by Eq. (1) is used for the experiment.

$$\eta=\left(1-\zeta^2\right)\left(1-\xi^2\right)\left(1+a_2\xi^2+a_4\xi^4\right)+\alpha\zeta^2\left(1-\zeta^8\right)\left(1-\xi^2\right)^4 \tag{1}$$

In Eq. (1), $\xi=2x/L$, $\eta=2y/B$ and $\zeta=z/d$ are defined and the parameters are chosen as $\alpha=1.0$, $a_2=0.6$, $a_4=1.0$, L =2.5m, B =0.5m, and d =0.175m. The free board is f =0.045m.

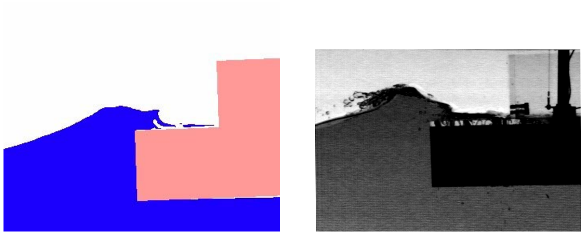
As shown in Fig. 6, a vertical wall is installed on the foredeck to block out the inflow of green water. The free surface variation are recorded by a high speed video camera and 6 pressure gauges are installed on the horizontal deck and the vertical wall, which are indicated in Fig. 6, to measure the pressures induced by the green water. Large-amplitude regular waves of different wavelengths are generated as the incident waves. Experiments are conducted for motion restricted and motion free cases. For both cases, several forward speeds are tested.

In Fig. 7, experimental photos are shown for a motion restricted case of $\lambda/L=1.0$, $H/\lambda=1/20$ and $Fn=0.2$. In the figure, T_e stands for the encounter period. These images are taken from a video record by the high speed camera. Both the recorded free surface variation and the measured pressures will be compared to the computation.



(a) computation (b) experiment

Fig. 2. Snapshot comparison at t/T=17.3 for T_w=1.0sec.



(a) computation (b) experiment

Fig. 4. Snapshot comparison at t/T=17.3 for T_w=0.7sec.

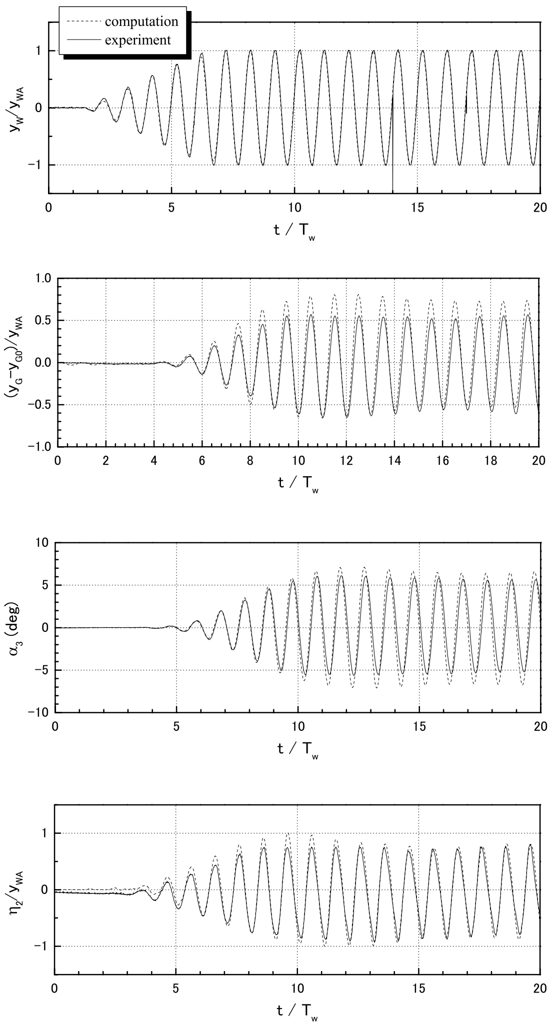


Fig. 3. Comparison of time histories for T_w=1.0sec. From top: position of wave maker, heave and roll of floating body, and wave elevation in front of the floating body.

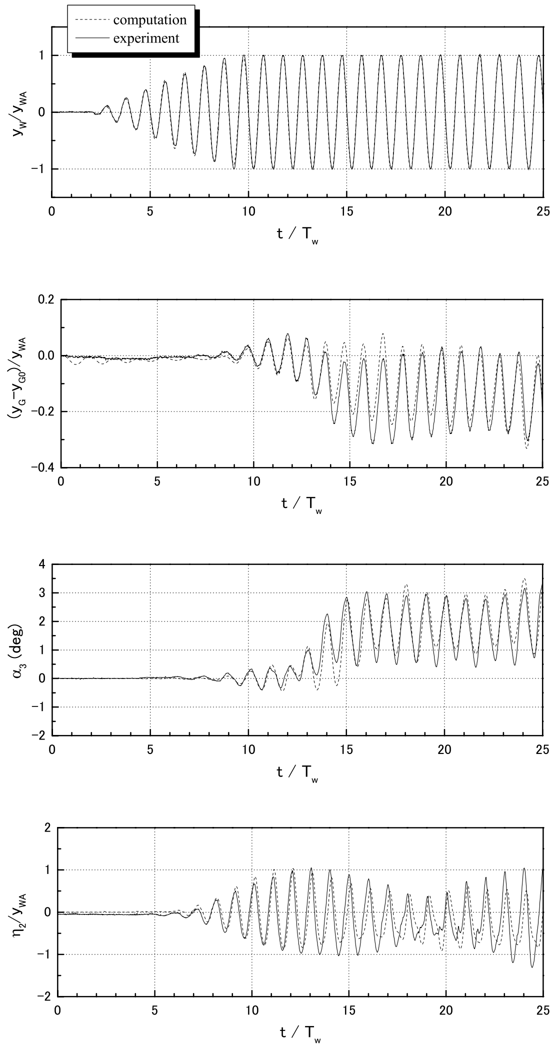


Fig. 5. Comparison of time histories for T_w=0.7sec. From top: position of wave maker, heave and roll of floating body, and wave elevation in front of the floating body.

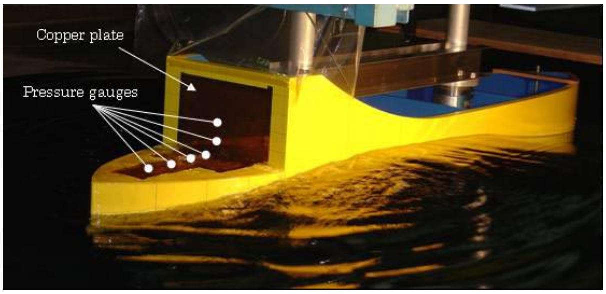


Fig. 6. Modified Wigley model for 3-D experiment

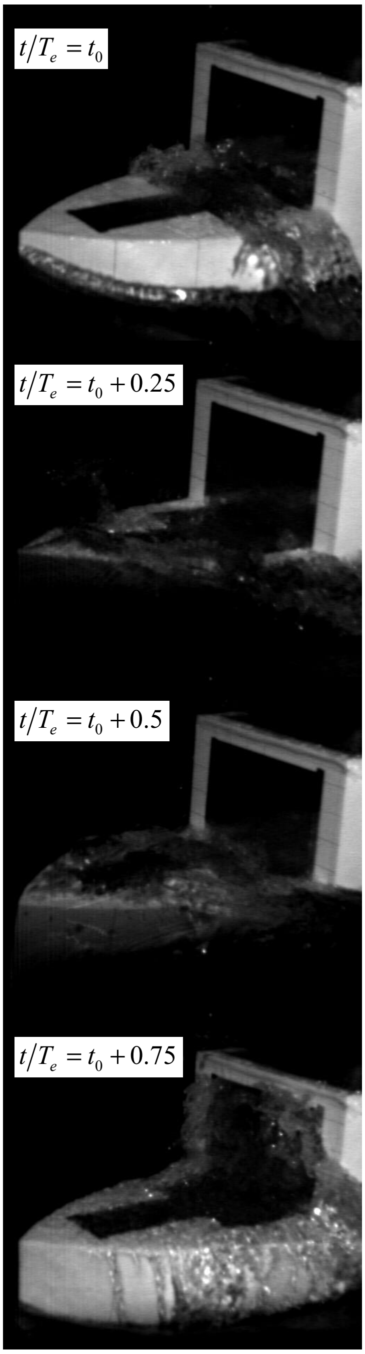


Fig. 7. Experimental photos for motion fixed case of $\lambda/L = 1.0$, $H/\lambda = 1/20$, $Fn = 0.2$

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'Experimental validation of the computation method for strongly nonlinear wave-body interactions'

Discusser - H.B. Bingham:

How many grid points did you use for the 3-D results shown here, and how much CPU time was required?

Reply:

The number of grid points is about 1 million for the 3-D ship-wave interaction computation. For simulation of 8 wave periods, the CPU time is about 160 hours by using a single CPU workstation.