2-D Experimental and Numerical Study on Green Water

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ABSTRACT: Firstly an experiment is carried out in 2-D wave tank with floating body placed in regular wave, using PIV and wave height probe. Wave height on deck and the process of wave running up, wave deforming and wave breaking are obtained. Then a 2-D numerical simulation of the green water phenomena of floating body placed in regular wave is performed, based on VOF method, using dynamic boundary condition to make wave, the history of water on deck is obtained under different floating state. The calculation and experiment was compared to validate the feasibility of numerical simulation.

1 INTRODUCTION

Green water has been considered to be an important problem for the safety and operability of ships and offshore structures. The strong impact load and the sloshing pressure of water on deck will damage deck structures when ships voyaging in extreme waves. The related nonlinear wave forces, slamming, green water and structure distortion and local stress evaluation are new problems in current ship structure designs

There is not a numerical method can be applied to describe the whole process of green water effectively at present for a ship in the sea. Model test is still a practical way which can be used to study the mechanism of green water and validate the numerical calculation. Up to now a lot of researches have been performed based on experimental method for the analysis of green water qualitatively and quantitatively. Those works [1-6] include the study of influence of parameters, such as freeboard, bow flare, trim, heave, wave steep, voyage speed and direction etc. on the deck flooding probability, impacting forces and structural response, interaction between ship motions and green water etc.

Many interface tracking or capturing methods, for example, MAC method, VOF method, Level-set method, SPH method and CIP method etc. have being developed and improved in recent decades. Numerical simulation of green water for offshore structures has become an effective way and has being applied by many researchers [7-13].

This paper presents a 2-D experimental and numerical study on green water. Firstly an experiment is carried out in wave flume with floating body placed in regular wave, using PIV and wave height probe. Wave height on deck and the process of wave running up, wave deforming and wave breaking are obtained. Then a 2-D numerical simulation of the green water phenomena of floating body placed in regular wave is performed, based on VOF method, using dynamic boundary condition to make wave. The history of water on deck is obtained under different floating status. The calculation and experiment is compared to validate the feasibility of numerical simulation.

2 MODEL TEST

2.1 *Model and arrangement in the wave flume*

The test was performed in the wave flume of Jiangsu University of Science and Technology. The particulars are 40m long, 0.8m wide and 1.4m high. The water depth is 0.8m. The main parameters of pusher flap type waver maker are ±350mm for the stroke of pusher, 0.2~2.0Hz for frequency. The maximum wave height can reach 400mm.

The model is a rectangle body with round edge. The main dimensions are 1.5m×0.75m×0.25m of the length, breadth and height respectively. The draft is 0.2m (see Figure1). Three cases are chosen for the test of green water when a floating body is in regular wave, namely upright, stern trim 50 and bow trim 50.The model fixed in the wave flume is shown in Figure 2.

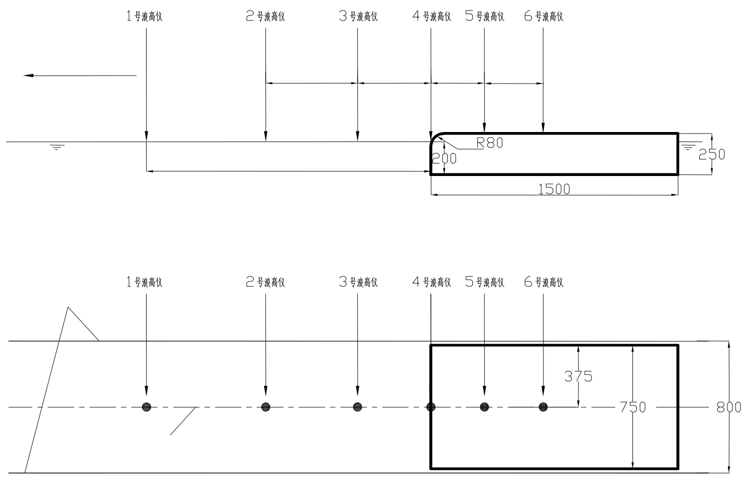


Figure1. The model and the arrangement of test

(a) upright

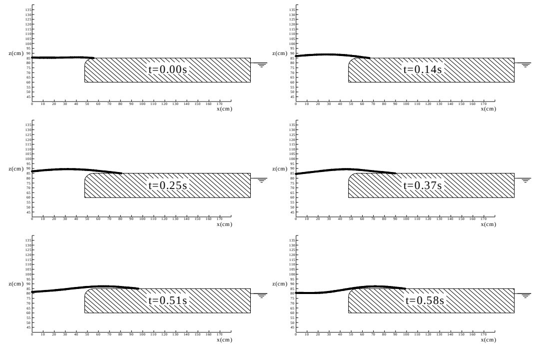
(c)   bow trim

(b) stern trim

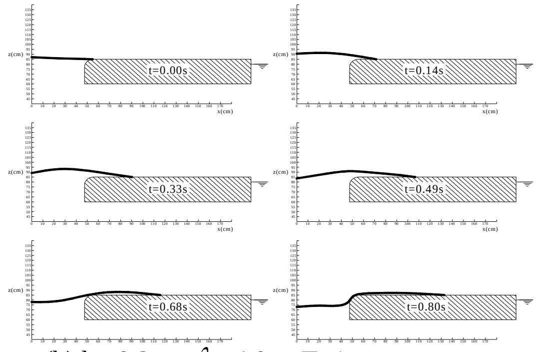
Figure2. The model fixed in the wave flume

2.2 *Test results*

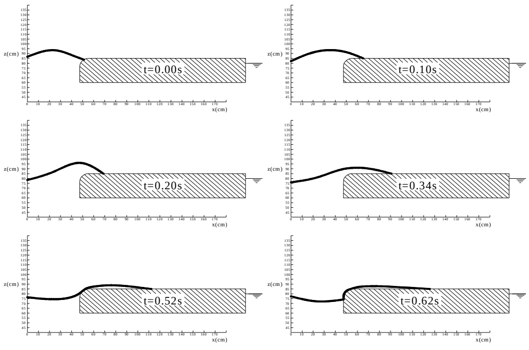
The test results are shown in Figure 3-5



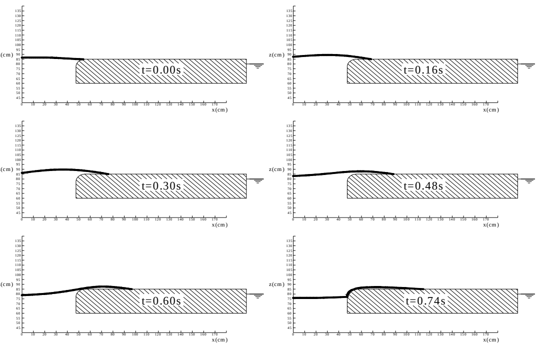
(a) h=0.1m, λ =4.0m, T=1.6s



(b) h= 0.2m, λ =4.0m, T=1.

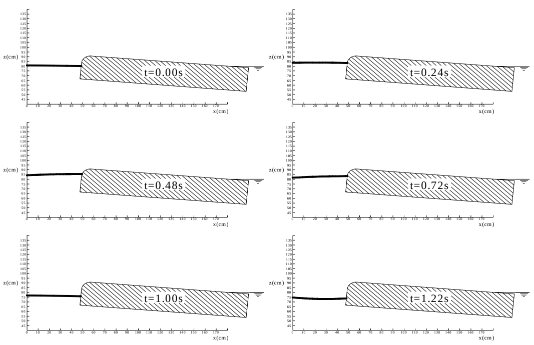


(c) h=0.16m, λ =2.0m, T=1.131s

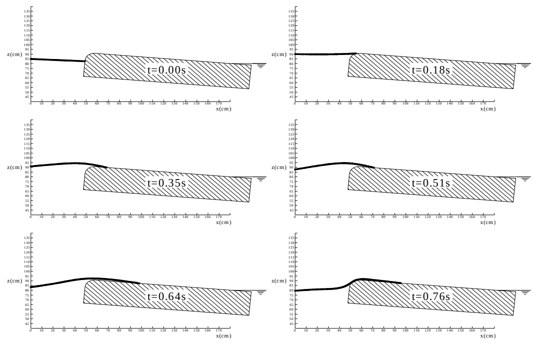


(d) h= 0.16m, λ =4.0m, T=1.6s

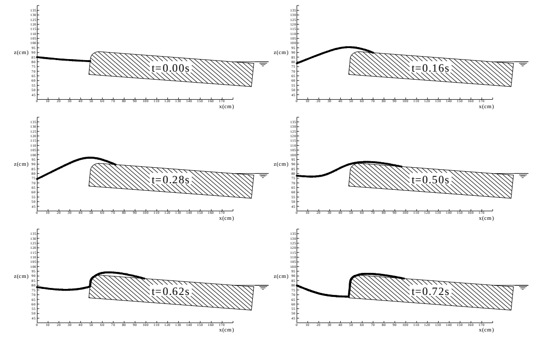
Figure3. Wave profile when model is upright



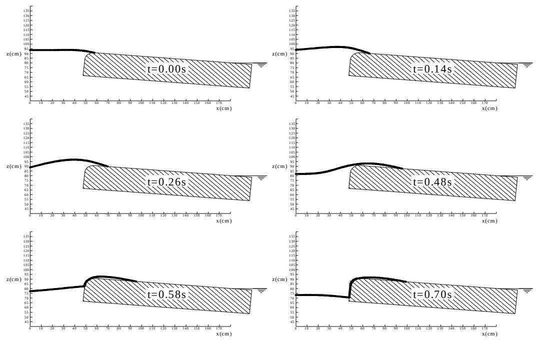
(a) h=0.1m, λ =4.0m, T=1.6s



(b) h= 0.2m, λ =4.0m, T=1.6s

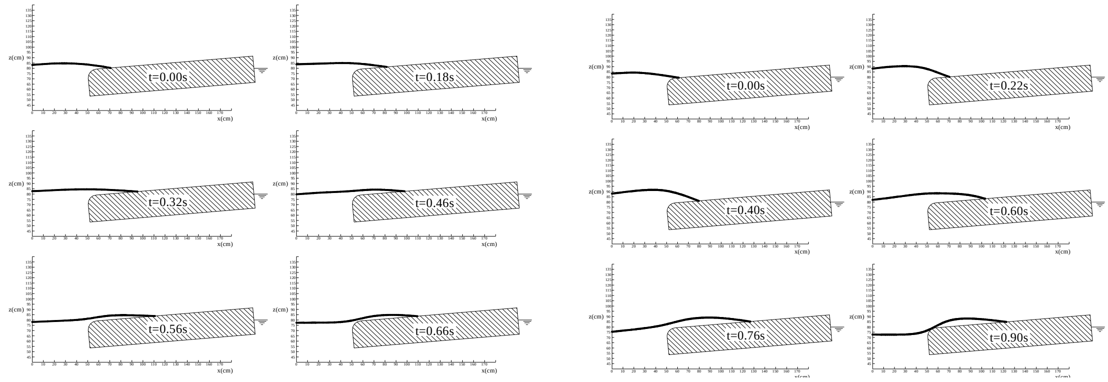


(c) h=0.16m, λ =2.0m, T=1.131s



(d) h= 0.16m, λ =4.0m, T=1.6s

Figure4. Wave profile when model is stern trim



(a) h=0.1m, λ =4.0m, T=1.6s (b) h= 0.2m, λ =4.0m, T=1.6s

Figure5. Wave profile when model is bow trim

3 NUMERICAL SIMULATION

3.1 *Governing equations*

The fluid domain is composed of two-phase fluid, namely, one is liquid and another is air. The effect of air cushion, as well as the cavitations and other phase change during the deck flooding process is neglected. The continuity equation and the transport of fluid momentum equations expressed are

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \left(\rho \mathbf{v}\right) = 0 \tag{1}$$

$$\frac{d\boldsymbol{v}}{dt} = \boldsymbol{F_b} - \frac{1}{\rho}\nabla p + \frac{\mu}{\rho}\nabla^2 \boldsymbol{v} \tag{2}$$

where $\mathbf{V}$ is the velocity of fluid field, ρ, p and μ are respectively the fluid density, the scalar pressure, and the coefficient of dynamic viscosity. $\mathbf{F}_b$ is a body force. Meanwhile the non-slip conditions of the viscous flow over the solid boundary and the velocity and the pressure boundary conditions on the free surface have to be satisfied.

3.2 *Free surface representation*

Non-linear kinematic free surface conditions were adopted in the analysis of green water. The profile of liquid surface was reconstructed in each time step by a scalar function of the volume of fluid, $F(x, y, z, t)$, on the basis of the VOF method. The average value of F in a cell of the computing mesh is equal to the fractional volume of the cell occupied by liquid. Therefore the meaning of F is as follows:

$$F(x, y, z, t) = \begin{cases} 1, & \text{the cell is in the liquid} \\ 0\sim1, & \text{the cell is intersected by free surface} \\ 0, & \text{the cell is in the void} \end{cases} \tag{3}$$

As a Lagrangian invariant, F should satisfy the scalar advection equation

$$\frac{dF}{dt} = \frac{\partial F}{\partial t} + (\vec{V} \cdot \nabla)F = 0 \tag{4}$$

Solving F -fluxes together with the equations of mass and moment conservation needs special attention to preserve a sharp interface between liquid and void phases.

3.3 *Numerical wave tank*

Here, a flap type wave maker is adopted for numerical wave tank. Assuming that the origin is a balance point of wave maker, the piston is Xo and the circular frequency is ω, then the speed of wave maker is

$$U(t) = \frac{X_0 \omega}{2} \cos \omega t \qquad 5$$

By potential flow theory the wave profile can be described by following formula

$$\eta(x) = \frac{i\omega}{g}\left(C_0 e^{ik_0 x} + \sum_{m=1}^{\infty} C_m e^{-k_m x} \right) \qquad 6$$

The wave amplitude is

$$A = \left| \frac{i\omega}{g} C_0 \right| \qquad 7$$

The coefficients included in above are

$$C_0 = -\frac{\omega S}{N_0 k_0}\left[\frac{\tanh k_0 d}{k_0} + \frac{1}{d k_0^2 \cos k_0 d} - \frac{1}{d k_0^2} \right] \qquad 8a$$

$$C_m = -\frac{i\omega S}{N_m k_m}\left[\frac{\tanh k_m d}{k_m} - \frac{1}{d k_m^2 \cos k_m d} + \frac{1}{d k_m^2} \right] \qquad 8b$$

where

$$N_0 = \frac{1}{\cosh^2 k_0 d}\left(\frac{d}{2} + \frac{\sinh 2k_0 d}{4k_0} \right) \qquad 9a$$

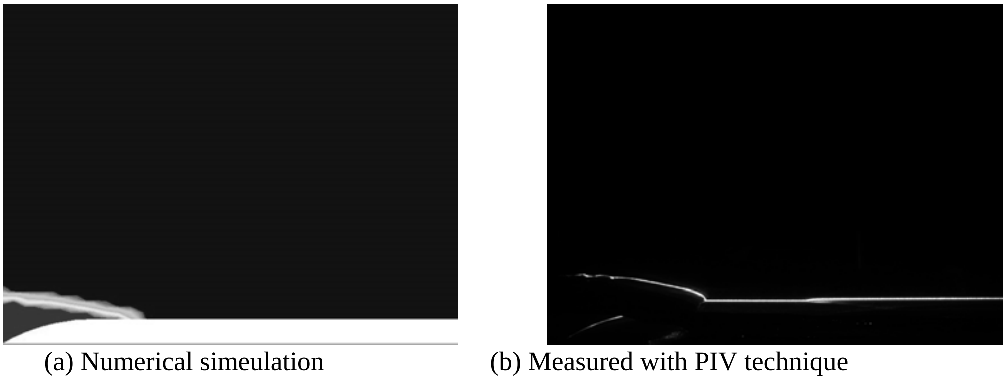
$$N_m = \frac{1}{\cosh^2 k_m d}\left(\frac{d}{2} + \frac{\sinh 2k_m d}{4k_m} \right) \qquad 9b$$

Here, m =1,2,……, ω is circular frequency, k_0 and k_m are wave number, *d* is depth, S is the stroke of wave maker, namely Xo, g is gravity acceleration and C_g is group speed.

Using dynamic boundary condition on the wave maker, the numerical wave tank can generate linear wave.

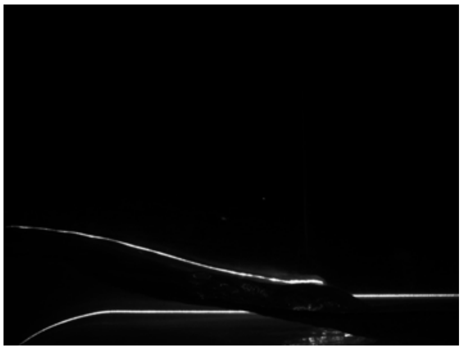
3.4 *Results and compared with the ones of test*

The history of wave profiles on deck are obtained at different time for the case of h= 0.16m, λ =4.0m, T=1.6s when the model is upright(see Figure 6.-8.)



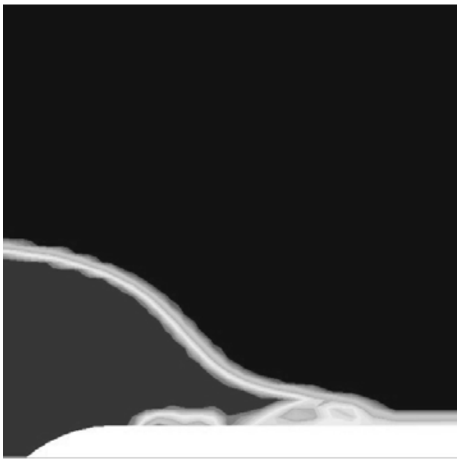
(a) Numerical simeulation (b) Measured with PIV technique

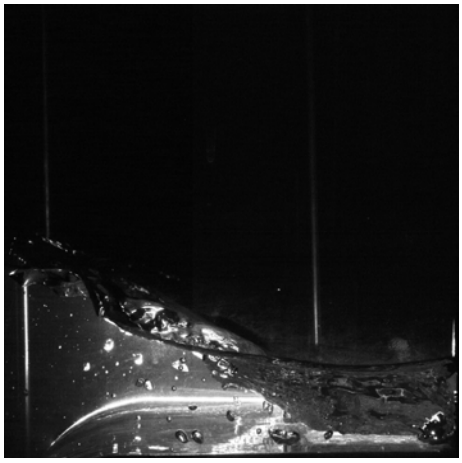
Figure 6. Wave profile at t=14s



(a) Numerical simeulation (b) Measured with PIV technique

Figure 7. Wave profile at t=15.9s





(a) Numerical simeulation (b) Measured with PIV technique

Figure 8. Wave profile at t=17.2s

4 CONCLUTIONS

1) The amount of green water increases with the increment of wave height.
2) The freeboard is an important factor which influences the green water.
3) The amount of green water decrease with the increment of wave length when the wave height is the same. But its influence on the green water is less than the wave height.
4) Numerical simulation of green water based on VOF method is available and reliable.

ACKNOWLEDGEMENTS

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