Numerical Simulation of Nonlinear Wave Systems around the Bow and Stern of Ships

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This paper investigates the nonlinear wave phenomena generated by the ship hull through numerical simulations employing Marker-density Method (IUBW) to determine the complex free surfaces developed near the bow and stern of the ship in navigation. The Navier-Stokes equations with the usual continuity equations are the governing equations. This equation set with the modeled boundary conditions applying the Marker-density are numerically solved by a slightly modified finite difference method based on the rectangular variable staggered mesh system described in the contents. The free surfaces were tracked to be determined by the Marker-density Method. A Series 60(C_B=0.6) hull form was used for the validation of the calculated solutions as well as for the numerical simulations. In addition, a preliminary hull form design having the Series 60(C_B=0.8) was performed applying this numerical simulation technique. The results are compared with the experimental results tested in a towing tank.

1. INTRODUCTION

Among the phenomena involved in the ship and wave problem, the generation and its development of nonlinear waves become more apparent and critical as the ship speed increases, and so is true for the special attention from naval architects and hydrodynamic experts. The interaction between an advancing ship and the nonlinear waves generated by the ship is an extremely complicated subject among many difficult problems related with free surfaces.

There have been performed many numerical approaches and schemes according to various research efforts using the Panel Method[1,2] and others, among which Park and Miyata[3] once investigated the nonlinear wave generation through numerical simulation using the Marker-density Method to track down the complicated nonlinear free surface effectively.

This present research aims at the successful numerical simulations of the nonlinear wave system generated around the ship hulls in motion using the Marker-density Method (IUBW)[4] and Panel Method[2]. A Series 60(C_B=0.6) hull form was used to verify the numerical simulations. Experimental simulations were also carried out to verify the present numerical approaches by comparing the obtained numerical simulations with the model tests.

2. NUMERICAL SIMULATION

2.1 Marker-density Method

Assuming that the fluid consists of two layers, water and air, and that they are incompressible, at least, in the neighborhood of the interfacial free surface, the viscous governing equations become the Navier-Stokes equations and the continuity equations obtained from the law of mass conservation as below:

$$\frac{\partial \vec{u}}{\partial t} = -\frac{\nabla p}{\rho_i} - (\vec{u} \circ \nabla)\vec{u} + \nu_i \nabla^2 \vec{u} + \vec{f} \tag{1}$$

$$\nabla \circ \vec{u} = 0 \tag{2}$$

where i = 1, or 2 for the two fluid layers (1 for the air above and 2 for the water below the interface), $\vec{u} = (u, v, w)$ is the velocity, t is the time, ∇ is the gradient operator, ρ_i are the densities, p is the fluid pressure, ν_i are the kinematic viscosities, and $\vec{f}$ is all the external forces. Nonlinear free surface boundary conditions were used to determine the free surface configuration. The nonlinear dynamic and kinematic boundary conditions are:

$$p_1 = p_2 \tag{3}$$

$$\frac{D(M_\rho)}{Dt} = 0 \tag{4}$$

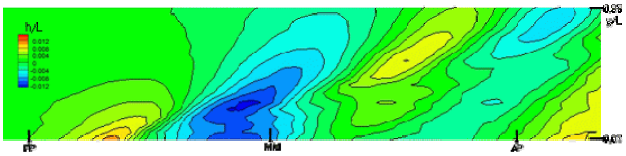
where D is substantial derivative operator, and Mρ is the density function. Equation (3) is the dynamic condition requiring that there is no pressure jump at the interface between the two fluid layers. Equation (4) is the Marker-density condition replacing the ordinary condition requiring that water particle moves attached to the free surface. Because the usual kinematic boundary requirement can hardly track down such complicate free surfaces as breaking waves, the Marker-density function equation (4) was developed to overcome such difficulties using the Marker-density concept. The density function takes values between P_1 and P_2 in the domain during computation, and this represents the volume fraction of water in a cell. The location of free surface is determined to be the point where the Marker-density function takes the mean value of P_1 and P_2 calculated at each time step. The free surface profile obtained using the mean value is supposed to coincide with the surface elevation from the usual kinematic boundary condition. Thus equation (4) can be a generalized condition replacing the original boundary condition.

3. NUMERICAL SIMULATION RESULTS

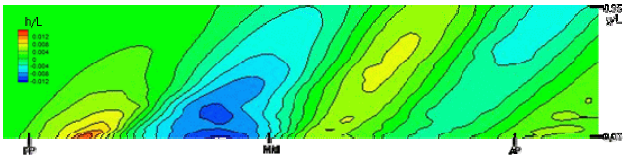
The domain of computation was discretized into 70x60x50 meshes in the present Marker-density approach. The sizes of the meshes differed to meet the local behaviors, in other words, smaller meshes were distributed as the domain approached closer to the ship hull and to the free surface with local extreme geometries due to nonlinearity. In the Panel Method approach, the domain was discretized into 50x31 panels along the ship hulls and into 119x17 panels at or beneath the free surface.

In order to validate the numerical solutions obtained employing the Marker-density Method, present results are compared with the experimental results from the Series60 (C_B=0.6) hull form at Fn=0.316 and with the results using the Panel Method. The experimental data used in the comparison were from the data basis in the IOWA University [5]. It has been turned out that the wave patterns from the calculations by the two methods, on the whole, well match the experiments. However, in the case of the local complex behaviors around the ship bow and stern, the numerical simulations applying the Marker-density concept showed

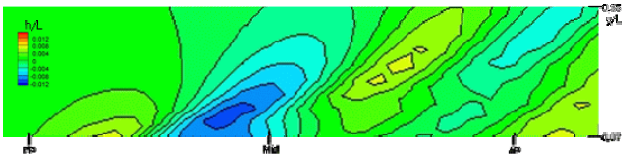
excellent similarity to the experimental results, far better than the results obtained using the Panel Method. The comparisons were made with the experimental results obtained using the Series 60(C_B=0.6) hull form, at Fn=0.316.



(a)Experimental simulation



(b) Numerical simulation (Marker-density Method)



(c) Numerical simulation (Panel Method)

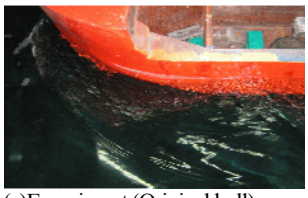
Fig .1 Comparison of free surface contours at breaking at Fn = 0.316 between an experimental simulation and numerical simulations

Figure 1 displays two numerical results of the problem obtained from different methods, the upper one of which was by the Panel Method and the other was by the Marker-density Method. The figure 1(b) by the Marker-density function shows waves with higher and steeper crests and flatter troughs than those by the Panel Method in the figure 1(c). In addition, the nonlinearity simulated near the ship bow in the figure 1(b) is more realistic to the experiment in the figure 1(a) than in the figure 1(c), which confirms that the Marker-density approach seems superior to the Panel Method in this case. The numerical simulations at the ship stern display similar characteristics to the above ship bow case. The results by the Marker-density concept show better and more accurate free surface contours because the viscosity effects in 1(b) was taken into account more rigorously than in the Panel Method approach in 1(c).

4. APPLICATION

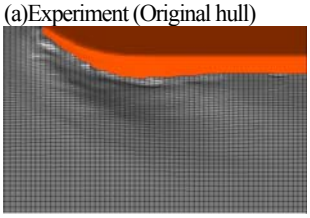
Here in this section, the results from actual designs are compared having the hull form of Series 60(C_B=0.8) with different bow shapes, since a bluffer body is apt to generate stronger nonlinearities, in order to find the better design generating less nonlinear waves or smoother surface contour due to the bow shape change. The results here were also confirmed through numerical simulations and experiments.

The numerical simulations by the Marker-density Method are compared with the experimental simulation in figure 2. The photos 2(a), 2(b) are the experimental results, and 2(c), 2(d) are the numerical results by the Marker-density Method obtained at Fn = 0.2. Stronger nonlinearities are observed in 2(a) and 2(c) of the original hull form than in 2(b) and 2(d) of the modified bow design case. Those nonlinear waves are also observed at shoulder areas as well as the ship bow in both experiments and numerical calculations.

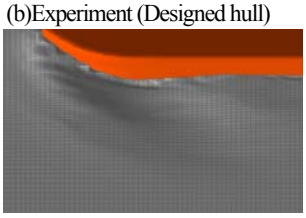


(a)Experiment (Original hull)

(b)Experiment (Designed hull)



(c)Numerical simulation(Original)



(d)Numerical simulation(Designed)

Fig .2 photographs of model tests and simulation results at Fn=0.2

5. CONCLUSION

The numerical simulations of the nonlinear waves generated near the hulls of advancing ships are studied here in this paper employing the Marker-density Method. In order to confirm the present Marker-density approach, the results are compared with the results by the Panel Method using the already existing experimental data of the Series 60 (C_B=0.6) hull form. Both Marker-density and Panel Methods showed, on the whole, similar results close to experimental results. However, at local spots like bows and sterns with complex geometries, the Marker-density approach shows more realistic free surface contours than the Panel Method since it can take the viscous effects into account more effectively.

In addition, actual hull designs were performed having the hull forms of Series 60(C_B=0.8) with different bow shapes. The Marker-density Method was again employed to simulate the free surface. The simulated free surface contours were compared with the model tests, which assures again that the Marker-density approach is superior to other approaches in investigating the nonlinear free surface wave phenomena that occur near the hulls of ships in navigation.

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