Time-domain Numerical Simulation of Flooding ship

Miao Xia, Guan Qun Xia, Xin Xia

Abstract— In the past 100 years, countless accident cases have shown that ship damage will directly pose a serious threat to personal and property safety. Therefore, research on important parameters such as water stability and sunk time of damaged ships has been the focus of industry research. Ship damage and water inflow is an extremely complicated process, involving the interaction of various factors such as hull movement, internal and external flow field and exchange, and it is difficult to establish an accurate theory based on its typical nonlinear flow model, Due to the increasing maturity of computational fluid dynamics, it is not difficult to simulate the damage influent process. Many scholars have used FLUENT software to simulate it, which is consistent with the experimental comparison, indicating the feasibility of CFD for broken water. However, FLUENT relies on the characteristics of UDF and its single monitoring and setting complexity has been increasingly exposed. With the advent of STAR-CCM+, this defect is completely compensated, and its overlapping modules in the motion module have greatly improved Grid quality and calculation speed.This paper briefly introduces the calculation process and makes theoretical preparations. Then based on the commercial software STAR-CCM+ and reference to the experimental results, the comparison between numerical simulation and experiment is carried out to verify the effectiveness of the calculation method.Then select a DTBT5415test model for foolding process simulation.

Index Terms— Damage Ship; flooding; overlapping; modules; checking

I. INTRODUCTION

At present, the mathematical mechanics model and numerical calculation methods for the behavior of ship damage flow and motion response mainly include: using the potential flow theory to simultaneously process the hull movement and the damage of the damaged chamber (internal and external liquid exchange, internal flow); the method is simple, but the method is simple, but Simplified methods are used to handle the influent and ingress water, ignoring the unsteady characteristics of internal tank sloshing.

Vassalos[1], Letizia [2], and Zaraphonitiset [3] developed a numerical simulation method based on potential flow theory in the early stage, using a simple model to simulate the flow problem. In these models, the potential flow theory is used to calculate the hydrodynamic load of the ship caused by external waves; the semi-empirical formula is used to deal with the viscous effect; the inflow and outflow at the opening are treated by the modified Bernoulli formula. Ignore the non-linear effects of internal cabin sloshing, assuming that the

liquid level of the internal compartment is horizontal or a freely moving plane. This method can obtain more practical results when the influence of sloshing is relatively small. Therefore, many scholars have adopted this method.In order to simulate the physical characteristics of the flow inside the cabin, Chang[4], Valant and Santos [5]used the shallow water wave equation to calculate the dynamic characteristics of the internal flow. This improved model can reflect the nonlinear characteristics of the internal flow.TA Santos and C.Guedes Soares [6] used the six-degree-of-freedom time domain method to calculate the transient inflow and hydrostatic stability of a Ro-Ro ship during asymmetric damage, focusing on the lateral asymmetrical water inflow of the ro-ro ship. The damage range of the cabin, the lateral inflow of the double bottom, the height of the ship's center of gravity and the influence of the side tanks on the lateral asymmetric water inlet, etc., finally resulted in the damage of the ro-ro cabin, and the lateral asymmetric water in the still water. A conclusion that may be overturned.G. E. Hearn and D. Lafforgue [7] constructed a damage model based on the damage statistics. Considering the influence of the free surface in the damage chamber, the ship motion equation was constructed and the Matthew software was used for numerical calculation.Zhao Weiping and Guo Chen [8] on the basis of the analysis of the ship's symmetrical damage, the mathematical model of the roll after the ship is broken is established by the groove type tank theory, and the ship is horizontally different under different damage levels and flow damping. The shaking characteristics are analyzed and the absolute stability conditions of the system under the condition of ship damage are given.In addition to the pure potential flow method, many scholars have used viscous flow CFD to study the process of entering and exiting the tank and the tank sloshing inside the cabin. For example, based on the NS equation, VOF processes free liquids, based on the NS equation, SPH processes free liquid surfaces.Liu Qiang [9] and other research methods for time domain simulation of the influent water inflow process were discussed. The time domain simulation of the large-scale two-dimensional and three-dimensional calculation models was carried out with Fluent software; the influence of air flow on the influent process was discussed. Discuss and discuss the changes in the water inlet velocity at the damaged port of the ship. And analyze the motion response.Gao, Z and Gao, Q [10], using the method of mutual coupling of viscous flow and potential flow to study the motion response of a damaged ship in waves. The scholars calculate the hull motion in waves based on the potential flow method of slice theory, using the NS equation. The method of processing the free surface with VOF simulates the flow inside the cabin and numerically simulates the damaged ship in the transverse wave. Subsequently, Gao, Z [11] based on such a method, studied the mutual coupling of

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the motion and internal flow of a Ro-Ro ship in the transverse waves, including the complete state with and without internal flow and Working conditions in the state of damage to the ship.Li Yuemeng et al. [12] used three different grids for the convergence analysis of box ships (multi-chambers) and rectangular cabins, simulated the damage of free-floating ships, and used the VOF method to deal with water and gas freedom. The liquid level uses a six-degree-of-freedom (Six-DOF) solver and dynamic mesh technology to handle the slewing and heave motion of the hull. The results of the study were compared with the existing results, and the degree of agreement was higher Procedure for Paper Submission.

II. CHECKING

This paper refers to the experiment published by Zhang[13] at the 2013 International Conference. Firstly, the intrusion process simulation of the bottom damaged hull is carried out, and the hull of the side damaged is numerically simulated. The correctness of the calculation method is verified by comparison with the experimental results.
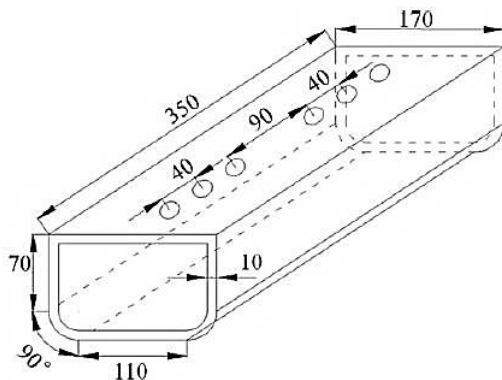
.Figure 1 test model

The experimental equipment mainly includes a high-speed motion analysis system (high-speed camera and related post-processing software), a U-shaped plexiglass floating body, a pulley system and a cubic transparent groove, as shown in FIG. The type of high-speed camera is Phantom V12.1, and the shooting frequency in this experiment is set to 1000 frames per second. The outer cabinet has a size of 0.5 m × 0.5 m × 0.5 m and an internal liquid level of 0.4 m. The basic size of the model is 0.35 m × 0.17 m × 0.13 m, the wall thickness is 0.01 m, and there is an opening with a diameter of 0.09 m at the wide side or the bottom. There are five small holes of the same size at the top of the model at the bottom opening for reduction. The effect of small air compressibility on the influent process. Detailed parameters are shown in Figure 1.

A. Calculation settings

Since the experimental model is relatively simple, the 3D CAD built-in template block modeling is directly adopted by the software. The grid is divided by AOTUMATED MESH. Since the software generates a diamond mesh, the generated mesh quality is poor, which has a great influence on the calculation accuracy of the later stage. Therefore, the division form of the cutting unit mesh is directly adopted. For the setting of the overlapping grid area, first create a new BLOCK outside the model to wrap it, subtract the BLOCK and the

model, and then create the outer basin, mesh the two areas separately, and set the BLOCK boundary to Overlapping grid areas. Since the overlapping area mesh is close to the outer flow area mesh, in order to save the mesh, a new area is created to encrypt the area of the overlapping mesh motion. The meshing is shown in Figure 2.
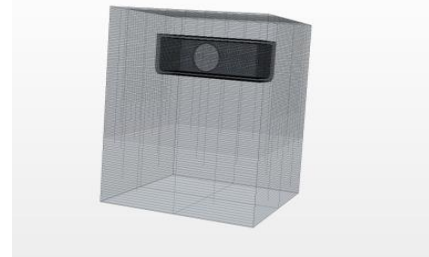

Figure 2 mesh

Three physical models of laminar flow and K-W and K-E turbulence models are available in the software. Since the damage into the water is a nonlinear process, the laminar flow is difficult to simulate. After comparison, the K-W turbulence model is selected. The broken water is a typical three-dimensional motion, three-dimensional flow, gas-liquid two-phase flow problem, and the water and air VOF separation flow model is directly selected in the software calculation. Since the compressibility of the air in the cabin during the inflow process of the empty tank will have a significant delay effect on the influent process, and there is an open hole at the top of the experimental model, we can approximate it as an incompressible fluid in the air model selection. Greatly saves computational efficiency. For the division of the two flow regions, the software's own field function function is used to define it. The solver uses an implicit variable length with a time step of 0.005S and a maximum iteration step size of 20.

B. Side damage water inlet process

First, the lateral damage condition is calculated. As shown in Figure 3, the hydrodynamic grid is encrypted in the overlapping grid area and the opening, and a new area is created as the background area of the overlapping grid. A total of 400,000 grids, including 150,000 grids in the background area and 250,000 grids in the overlapping area.
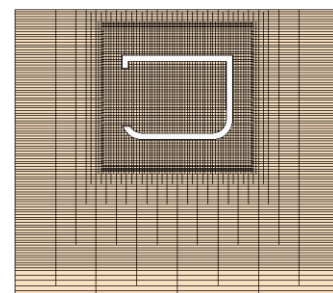

Figure 3

Since the model inlet water is symmetrical along the length direction, this paper directly reduces the motion into roll and heave motion during the calculation process. The comparison between the calculation results of the rolling and heaving speeds and the experimental results are shown in Figures4 and Figures5.
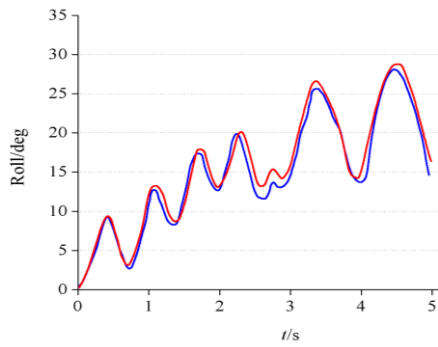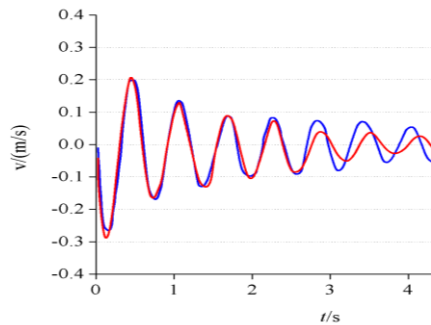
Figure 4

Figure 5

At the initial moment, the hull is flush with the free surface. When t=0s, the vertical binding force of the hull is released, and the hull begins to fall under the action of gravity. The hull mainly performs roll and heave motion during the whole falling process. As shown in Figures d, at t = 0.15 s, the hull sinks to the opening and the level of the free liquid level is flush, and the cabin begins to enter the water. At this time, the hull continues to fall under the action of gravity. When t=0.25s, the maximum depth is reached. Under the reaction of hydrodynamics and buoyancy, the velocity in the vertical direction is equal to 0. At this time, the internal water sloshing caused by the inflow causes the hull to tilt to the right, and the inclination angle increases big. At t = 0.55 s, the opening is on the outer free surface while the internal inlet water hits the starboard side. When t=0.7s, the roll motion enters the next cycle. Due to the change of the position of the floating center, the tilt angle to the right reaches the minimum value of the first cycle. When t=0.85s, the vertical velocity decreases to 0, and the water inlet is obvious. Increase, the hull tilts to the right to increase the speed, t = 1.05s, the heave into the next cycle. In general, the heel angle of the floating state caused by internal water sloshing and water inflow changes periodically but the overall is increasing. The heaving gradually stabilizes after decaying to t=3.2 seconds. The calculation results are basically consistent with the experimental comparison, indicating that this calculation method can accurately solve such problems.

C. bottom damage water intake process

Then calculate the working conditions of the bottom opening, the method of meshing and parameter setting is the same as that of the side opening, and will not be repeated here.Due to the bottom opening, the inlet water is symmetrical along the length and width directions, so this calculation simplifies the movement only considering the heave motion. The comparison of the inlet water at different time points is

shown in Figure 6. The results of the heave calculation are compared with the experimental results.
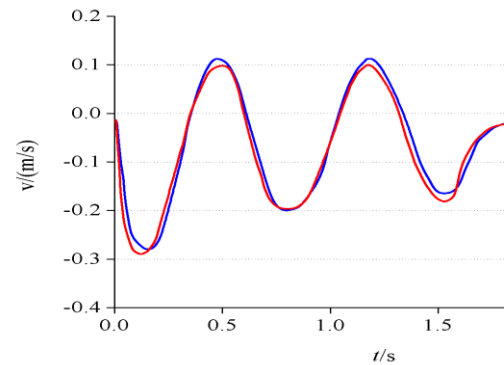

Figure 6

As shown in Figure 6. At the initial moment, the hull falls at an extreme speed under the action of gravity and vertical water inflow. At t = 0.1 s, the influent water passes through the opening in the bottom of the hull, and a mushroom-shaped water flow column is formed at the opening. As the hull falls, the drainage volume gradually increases. Under the reaction of buoyancy and hydrodynamics, the speed of the hull's falling gradually decreases, tending to zero at t=0.3s, and then the velocity direction is upward, and the model begins to float. The influent water in the cabin continues to increase until the first peak is reached at t = 0.6 s, and the inlet volume is approximately half of the cabin volume. The next heave period begins at t=0.85s and eventually sinks completely around t=2s. By comparing with the experimental results, it can be seen that the numerical simulation accuracy is good here. This method can provide a basis for the ship sinking process prediction, and provides a basis for the later sea rescue.

III. NUMERICAL SIMULATION OF BROKEN WATER IN ACTUAL SHIP MODEL

In order to be closer to the actual situation this calculation uses the 1/24.83 model of the ITTC resistance model DTBT5415 as the research object, and uses Pro.E software to model, the model is shown in Figure 7. The Model 5415 has long been recognized as the most original model for naval ship design. The hull geometry includes sonar domes and beam sterns. Propulsion is provided by a double-open water propeller driven by a shaft supported by the strut. This paper has limited computing power. Take the ship's possession into consideration.
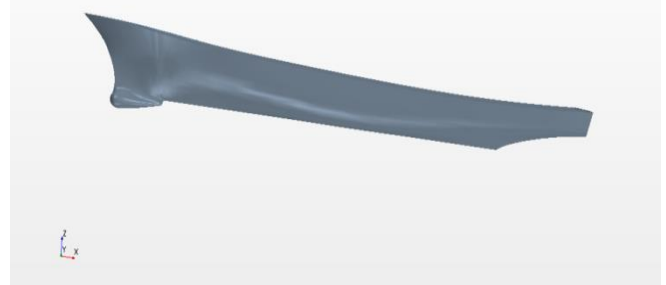

Figure 7

The parameter selection of the damage location is as shown in the figure. The ship's waterline is taken as the Z coordinate starting point of the origin of the coordinate system, and the X-axis coordinate starting point of the ship is backward-0.026 as the coordinate, and the origin of the ship's coordinate axis is taken. The starting point of the Y axis. The entire compartment is a trapezoidal body with a side view as shown in the figure. The specific dimensions are shown in the figure below.
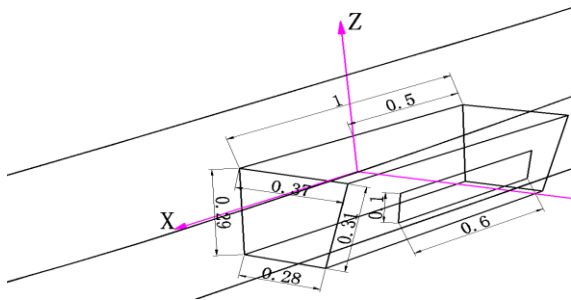

Figure 8

The meshing method adopts the division method of the upper section. The grid size of the hull surface and the overlapping grid area is 0.035m, and the motion area is listed as 5:5:2 in the x, y, and z directions, and the grid size is 0.01. m, 0.01 m, 0.04 m. The pool grid scale is the same as the motion area, with a total of 1.35 million grids. The time step is t=0.005s, and the implicit indefinite length is used, and the maximum number of iterations per step is 20.
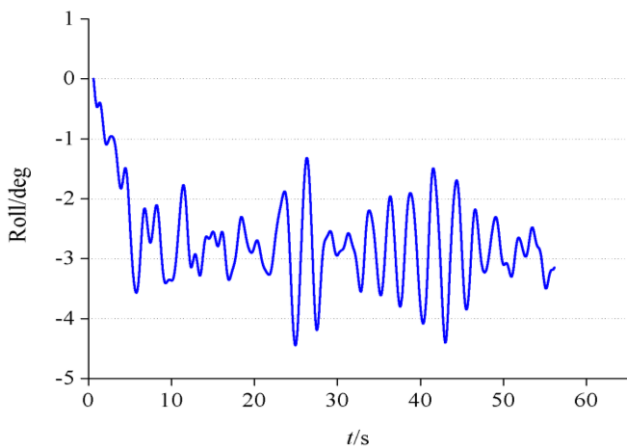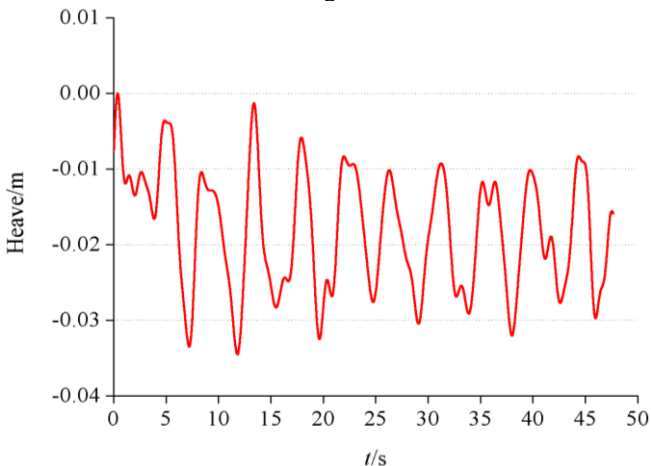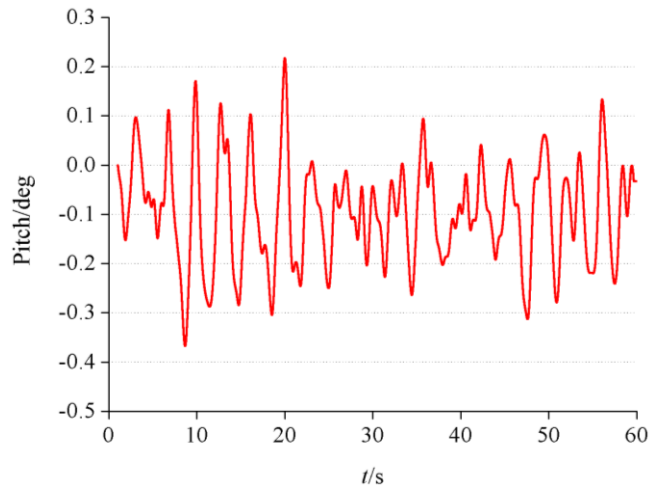

Figure 9

Figure 10

Figure 11

As shown in the figure above, the inlet water flows through the opening and reaches the inner compartment edge at t = 0.2 s. Then continue to slowly flow in, when t = 0.9s, reach the bottom of the cabin, at this time the angle of inclination to the right reaches -0.5 degrees, then the increase of the inclination angle caused by the increase of the weight of the inlet water directly leads to the rapid increase of the water inlet speed After that, both the heave and the roll curve can observe a tendency of instantaneous decline. At t = 1.2 s, the area in the bottom of the compartment along the opening direction is saturated with water. At t = 2.5 s, the tank sloshing caused by the inlet water reaches the first peak, and both the roll and pitch motions are very intense. When t=2.9s, the inlet water reached about one-third of the maximum water intake. At this time, the sloshing of the inlet water was obviously weakened, the right inclination angle reached -1.8 degrees, and the draught increased by -0.17m. At t=3.5s, the inlet water volume reaches about one-half. At this time, the right dip angle continues to increase, and the water intake continues to increase. Until t=4.8s, the influent phase is basically completed. The ship is tilted to the right -3.2 degrees, and the inlet water reaches a relative maximum value. After that, the ship continues to tilt to the right under the action of the inlet water until the maximum heel angle of -3.6 degrees is reached at the inflow stage at t=5.3s.After t=5.3s, the hull movement did not immediately enter a stable state due to the kinetic energy generated during the inflow process and the disturbance of the surrounding liquid level during the influent stage. At this time, due to the flushing of the free liquid surface in the inner and outer watersheds, the internal and external exchange phases gradually begin. Under the action of various external factors, the ship rolling motion gradually enters a relatively stable state after t=50s.

Observing the several sets of motion curves of the ship, it can be concluded that after the transient inflow phase is completed, the roll angle of the ship has been oscillating up and down at 3 degrees. The ship's heave motion curve is symmetrical about -0.02m, and the pitch curve is about -0.008 degrees. Symmetrical, the amplitude is about 0.4 degrees,

IV. CONCLUSION

In this paper, Firstly, the experiment was compared with the experiment, and the feasibility of the calculation method was verified. Then the US Navy DTBT5415model was

selected for numerical calculation. The transient influent process and the steady-state effects of internal and external water exchange on the completion of the damaged ship's water ingress were studied. It can be conclude that:

1. Overlapping grid technology can simulate the influent process of damaged ship well.

2. In the process of numerical simulation of nonlinear problems such as tank sloshing, nonlinear factors should be considered, and the complicated motion model cannot be simply simplified.

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