Three-dimensional simulation of ship bow slamming

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Abstract. The bow flare slamming load was studied by using the software Ls-dyna. A coupling finite element model including air, water and 3d bow was established. Flare slamming pressure was picked up from the finite element model in order to discuss the relation between flare slamming pressure and the velocity as well as the distribution rule of slamming pressure in different velocity and different water entry angle along the length and height of the ship.

1 Numerical simulation of three-dimensional bow slamming

Slamming is a highly non-linear phenomenon caused by the interaction between the moving hull and the waves. Generally, there are three types: bottom slamming, floating slamming and upper wave slamming. Floating slamming is a phenomenon in which a large impulse hydrodynamic force is often generated when a wave impacts the floating area of the bow when a ship is moving at sea, which causes a sudden change in the acceleration of the hull. Outward slamming is affected by many factors, such as wave characteristics, ship motion, and bow linearity. Usually container ships, aircraft carriers and other ships with large bows, need to consider the threat of floating slamming. For example, in the North Pacific close to Japan, due to the monsoon from the west, it is usually in rough seas in winter. Container ships sailing from North or South America to Japan are often damaged by floating slamming^[1].

1.1. Software description

Ls-dyna is the world's most famous general-purpose explicit dynamic analysis program. It can simulate various complex problems in the real world. It is especially suitable for solving various two-dimensional and three-dimensional nonlinear structures such as high-speed collisions, explosions, and metal forming nonlinear dynamics. Impact problems can be solved at the same time as heat transfer, fluid and fluid-solid coupling problems. It is widely recognized as the best analysis software package in the engineering application field. Numerous comparisons with experiments have confirmed the reliability of its calculations. Ls-dyna is mainly based on Lagrange algorithm, combined with ALE and Euler algorithms^[2].

1.2. Simulation calculation model

River-to-sea direct ships are ships that can navigate both inland rivers and coastal navigation areas. In order to increase the cargo capacity of ships, many river-to-sea direct ships use the form of container ships, and the first part has a large drift. Using Ls-dyna display dynamic analysis software, according to a 1:1 ratio, select a river-sea direct ship from the 155th frame to the bow to establish a three-dimensional hull simulation model. The design draft of the ship is 5.5m.

Place the model in a water area of 100m×80m×60m and an air area of 100m×80m×20m. The fluids (water and air) all adopt the Gruneisen equation of state, and the model is regarded as a rigid body. Table 1 is the parameter table of the state equation of water and air. The Gruneisen equation of state incorporates the tertiary impact velocity—the particle velocity, which defines the compressed material pressure in air and water as:

$$P = \frac{\rho_{0}C^{2}\mu\left[1+\left(1-\frac{\gamma_{0}}{2}\right)\mu-\frac{a}{2}\mu^{2}\right]}{\left[1-(S_{1}-1)\mu-S_{2}\frac{\mu_{2}}{\mu+1}-S_{3}\frac{\mu^{3}}{(\mu+1)^{2}}\right]^{2}} + (\gamma_{0}+a\mu)E$$
(1)

Among them: C is the impact speed; μ_z is the intercept of the particle velocity μ_p ; a is the first-order volume correction to γ_0 ; S₁, S₂, S₃ are corrections to the slope of the μ_z — μ_p curve; E is the initial internal energy;

Define compression state with relative volume:

$$\mu = \frac{1}{V} - 1 \tag{2}$$

V is the initial relative volume; The particle velocity μ_p is related to the impact velocity μ_s using the following formula.

$$\mu_s = C + S_1 \mu_p + S_2 \left(\frac{\mu_p}{\mu_s}\right)^2 \mu_p + S_3 \left(\frac{\mu_p}{\mu_s}\right)^3 \mu_p \quad (3)$$

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Table 1. Parameter table of water and air state equation

Name	$\rho/(kg/m^3)$	C/(m/s)	S_1	S ₂
Water	1025	1480	1.29	-0.096
Air	1.29	340	0	0

The water and air are modeled by Euler grids, and the unit uses the single-point integration multi-material ALE algorithm; the structural model is modeled by Lagrange grids. The ALE general coupling algorithm is used between the structure and the fluid, and the interface between the structure and the fluid is defined as a fluid-solid coupling surface. The grids of the air and water areas are divided according to the unequal density grids that are dense in the center, and the air and water areas close to the model are denser. Non-reflective boundary conditions are used around the air and water areas. The coordinate axis adopts the right-hand rule, along the ship's length direction as the x axis, along the height direction as the y axis, and along the ship width direction as the z axis. The structure model is placed in the water area with a design draft of 5.5m. The overall model is shown in Figure 1, the air area and water area are shown in Figure 2, the blue area is the air area, the red area is the water area, and the structure model is shown in Figure 3.



Fig. 1. Overall model



Fig. 2. Air and water model



Fig. 3. Structure model

2 Analysis of the slamming pressure law of the bow floating

2.1. The structure enters the water vertically

The slamming pressure of the bow is mainly composed of two parts. One is the water entry pressure Pi between the impact surface and the wave caused by the normal component of the relative velocity between the hull and the wave on the water surface; the other is the relative velocity between the hull and the wave. The impact pressure Ps between the impact surface and the water mass point caused by the tangential component of the water surface. The impact pressure is much smaller than that of the water. Now let the structure model enter the water vertically at a speed of 5m/s, 6m/s, and 7m/s. Figure 4 shows the spray caused by the structure model entering the water vertically at a speed of 7m/s when t=0.6s.



Fig. 4. The structure enters the water vertically at 7m/s

2.1.1 The relationship between floating slamming pressure and speed

The schematic diagram of the slamming pressure calculation point of the finite element model is shown in Figure 5.



Fig. 5. Schematic diagram of the slamming pressure calculation point of the finite element model

Taking the peak slamming pressure at the No.170 rib position of the structural model and comparing the peak slamming pressure at the points 7wl, 9wl, and 11wl with the square of the water entry speed, it can be seen that the peak slamming pressure is basically in a linear relationship. The relationship between the peak slamming pressure and the square of the velocity is shown in Figure 6.



Fig. 6. The relationship between the peak slamming pressure and the square of the water entry velocity

2.1.2 Distribution law of floating slamming pressure along the ship's length

Figure 7 shows the variation of the slamming pressure at each rib at 6.3wl, 7wl, 9wl, and 11wl when the model enters the water vertically at 7m/s.



Fig. 7. The distribution of slamming pressure along the ship's length

It can be seen from the above figure that along the length of the ship, the slamming pressure changes roughly from the No. 160 rib to the No.185 rib. The closer to the bow, the greater the slamming pressure.

2.1.3 Distribution law of floating slamming pressure along the height direction

Figure 8 shows the structure model with 7m/s vertical water entry, from the No. 170 rib position to the No. 185 rib position, and the distribution law of each rib position along different water lines.



Fig.8.Distribution law of floating slamming pressure along the height direction

It can be seen from the above figure that the slamming pressure is along the height direction, and the closer to the design draft, the greater the slamming pressure. The slamming pressure at each point of rib 185 near the bow varies greatly. The slamming pressure at the point close to the design draft is greater than the slamming pressure at the point far away from the design draft.

2.2. Structure oblique to water

In order to better simulate the effect of the slamming pressure of the ship in the waves, the structure model is now placed on the water surface obliquely. Since the river-to-sea direct ship mainly sails in the E1 sea area, the statistical data shows that the significant wave height in the E1 sea area is $6m\sim7.5m$, and the average zero-crossing period is $8s\sim10s$. From this, we can get the steep wave under dangerous conditions. size. Therefore, the model is rotated by 5° , 10° , 15° , and 20° to compare the slamming pressure at different angles at the same speed (5m/s).

2.2.1 Calculation model

The structure model is 20° with the water surface as shown in Figure 9. When t=0.6s, the splashes aroused are shown in Fig. 10.



Fig. 9. The structure model is 20° to the water surface



Fig. 10.The structure and the water surface are at 20° to arouse spray

2.2.2 Analysis of the law of slamming pressure from different angles along the length of the ship

Under different angles, the change of the slamming pressure of the bow floating at each point of 7wl and 9wl is shown in Figure 11 and Figure 12.



Fig. 11.Slamming pressure changes at various points along the 7wl at different angles



Fig. 12.Slamming pressure changes at various points along the 7wl at different angles

It can be seen from the figure that the slamming pressure of the outer float is roughly the same along the length of the ship under different angles. The larger the angle, the greater the slamming pressure. When the bow is inclined to 20 degrees, at 7wl, the slamming pressure varies greatly.

2.2.3 Analysis of the law of slamming pressure along the height direction from different angles

When the model enters the water at the same speed and at different angles, the slamming pressure curve at the No. 175 rib position and the No. 180 rib position are shown in Figure 13 and Figure 14.



Fig. 13. Changes in slamming pressure at various points along the No.175 rib at different angles



Fig. 14. Changes of slamming pressure at each point of the No.180 rib position at different angles

It can be seen from the figure that the external slamming pressure is roughly the same along the height direction under different angles. The larger the angle, the greater the slamming pressure. When the bow is inclined to 20 degrees, the slamming pressure varies greatly along the NO.180 rib.

3 Conclusion

Floating slamming pressure is a non-linear problem with a certain degree of complexity. At present, there are few domestic literatures on floating slamming pressure. Some articles are based on probability stochastic theory to study the floating slamming characteristics of the side of a container^[3]. The article studies the probability distribution of the effective slamming angle of the ship drifting^[4]. In this paper, using Ls-dyna software, considering the effect of fluid-structure interaction, the floating slamming pressure at each point is obtained, and the following conclusions are obtained:

•With the increase of speed, the outward slamming becomes bigger and bigger, and the slamming pressure is proportional to the water entering speed at each point.

•Outer drift slamming decreases with the increase in height. Near the design draft, the outer drift slamming is larger.

•Along the length of the ship, near the bow of the ship, the outward slamming is generally larger.

As the angle of entry into the water changes, the drifting slamming will change. Generally, the greater the angle of entry, the greater the drifting slamming will be.

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