Numerical Analysis of the Impact of the Ship Dock and the Design of a New-style Mooring Device

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Abstract. As the ships become larger in scale and more efficient, it is of vital importance to improve the dock's efficiency and the safety of mooring the ships. According to the numerical analysis of the impact between a 143600DWT bulk cargo ship and the dock with the conventional mooring method, the damage mainly appears in the local position of the impact, especially in the angular point of the mooring device; The more mooring piers there are, the less impact there will be. Some ideas of the design of mooring device are proposed on the basis of numerical analysis conclusion.

Introduction

Traditional docking way usually uses anchor or cable. Ship motion produces larger mooring and impact load on terminal facilities under wave, the phenomenon that ship cable is broken and dock crashed occurs frequently, a big ship motion and the cable (or fender) force can lead to the decrease of terminal loading and unloading efficiency, even the rupture of mooring rope, the damage of the fender and the strength and stability problem of wharf structure [1]. Mooring ship load is one of the important basis of terminal design, reducing the force mooring ships that are under wave forces exert on terminal and port facilities is vital for the design of terminal and selection of fender. Especially under the condition that the ship’s large scale has become a trend, in order to meet the needs of large ship draft problem, the wharf develops towards the deeper water area. Due to the substantial investment to build breakwater in deep waters, open type wharfs are commonly used, however, the worse wind conditions before the open type wharf makes the collision problem between the ship and the wharf particularly outstanding.

Numerical Analysis of the Ship Dock

In order to find the deficiency of the traditional docking way and provide direction for the design of new mooring way, the article establishes numerical simulation of terminal and ship
collision process, and analyses the simulation results. Given that the open type wharf is in open waters, and the wind, wave and flow conditions are bad, wharf berthing conditions are extremely complicated, it’s difficult to use general theoretical study and calculation [2~3]. Here the influence of wind, wave and flow mainly uses the predecessors’ studies [4~7], and the main calculation are under the condition of the speed of the predecessors' research and generate the impact force of ship berthing in different circumstances.

The Numerical Calculation Model

The article considers three different kinds of dock impact, respectively, ship’s collision with a mooring pier, ship’s collision with two mooring piers and three mooring piers. The calculation model is shown in Figure 1. According to the research on mooring ship’s collision speed before wharf by Liu Changfeng and others[9], the impact speed of ship and the wharf is 0 ~ 0.35 m/s under the mooring condition. So in the docking process because of the influence of the wind flow, the impact speed of ship and the wharf should be around 0.35 m/s, in order to simplify the calculation model, in this article the impact speed is 0.35 m/s. For calculation of a 143600 DWT bulk carrier ship, the principal dimensions are 146.26 * 19.3 * 11.2 m, the draft is 8.8 m, for the calculation the writing simplifies the internal concrete structure and the stern and the bow of a ship, with a rectangular hollow beam, whose dimensions are 150*19.3*8.8m. The internal transverse bulkheads’ influence on the deformation in the process of impact is big, here set up transverse bulkheads within the rectangular hollow beam. The shell is 6 mm thick. The mooring piers are 2 * 1 * 1 m solid cuboids, and the contact surface with ship is a 2 *1 m rectangular.

![Figure 1. A diagram showing the calculation model of ship impacting to dock.](image)

Numerical Calculation

For ship collision calculation, we use nonlinear finite element calculation method. The article uses the Lagrange method to establish the finite element control equations. On the basis of the theory of continuum medium mechanics, the equation of motion must comply with the mass conservation, momentum conservation and energy conservation, and mass conservation equation must satisfy the stress boundary conditions and displacement boundary conditions as well as the jump condition between interfaces. Then the finite element control equation of collision system can be set up using the principle of virtual work. The discretization structure equation of motion is (the damping effect is included):

\[ M\ddot{x} + C\dot{x} + Kx = P^{\text{int}} + H \]  

(1)
M is the mass matrix of the system, K is the stiffness matrix of structure, C is the damping matrix of the structure, \( \mathbf{z}^{\text{int}} \) is the external load vector containing the impact force, H is the hourglass damping force vector.

The materials of ship and mooring pier are respectively bilinear model and elastic-plastic material model. The equation (1) together with the dynamic constitutive equation of the material and the boundary conditions constitute the control equations of the collision problem. The equation of motion (1) can be solved by using the explicit central difference method.

\[
\ddot{X}(t_n) = M \left[ F(t_n) - F(t_{n-1}) + H(t_n) - C\ddot{X}(t_{n-1/2}) \right]
\]

(2)

\[
\ddot{X}(t_{n+1/2}) = \dot{X}(t_{n-1/2}) + \ddot{X}(t_n) \left( \Delta t_{n-1} - \Delta t_n \right) / 2
\]

(3)

\[
\dot{X}(t_{n+1}) = \dot{X}(t_n) + \ddot{X}(t_{n+1/2}) \Delta t_n
\]

(4)

In these equations, \( t_{n-1/2} = (t_n + t_{n-1}) / 2 \), \( t_{n+1/2} = (t_n + t_{n+1}) / 2 \), \( \Delta t_{n-1} = t_n - t_{n-1} \), \( \Delta t_n = t_{n+1} - t_n \).

\( \ddot{X}(t_n) \), \( \dot{X}(t_{n+1/2}) \) and \( X(t_{n+1}) \) are the node’s acceleration vector at the moment \( t_n \), node’s velocity vector at the moment \( t_{n+1/2} \), node’s coordinates vector at the moment \( t_{n+1} \), the rest can be deduced by that analogy.

**The Calculation Result and Discussion**

**The Deformation and Stress Analysis Results of the Mooring Pier**

Calculate the deformation condition of the mooring pier when ship collides with one mooring pier. As is shown in Figure2, extract number 121, 127, 858, 420, 780 five nodes with deformation value changing with impact time, and draw the deformation curve changing over time. The deformation curves along the X, Y, Z direction of the five nodes are distributed as curves in Figure 3, 4, 5. The mooring pier’s compression along the X direction is negative direction, and the larger the absolute value of deformation along X, Y, Z direction is, the larger the deformation is.

![Figure 2](image.jpg)

**Figure 2.** A diagram showing how to extract nodes on mooring pier.
It can be seen from the deformation time-history curves of the mooring pier nodes in the above figures along each direction that, the deformation of the mooring pier edge node is larger, especially the corner point. And it can be seen from the deformation curves of node 121 and node 780 that the deformation mainly concentrates in the small areas of the corner, when the area is close to the center, the deformation changes greatly. It can be seen from the deformation curves of node 127 and node 420 that the edge deformation along the direction of the ship’s length is larger than the deformation along the direction of the ship’s height. It is mainly because that the overall bending deformation appears along the direction of the ship’s length in the process of the impact, so excessive extrusions and collisions appear along the direction of the ship’s length. Therefore, in the design process of mooring device, more attention should be paid to reduce the impact force and deformation along the direction of the ship’s length.

The Deformation and Stress Results of the Ship

In case one, the ship collides with a mooring pier, in the process of the ship colliding with the mooring pier the stress nephograms of the ship in all directions and the total stress nephograms are shown in Figure 6-9. The figures from left to right show the stress distribution changes with time in the same direction. It can be seen from the Figure 6 that, in the process of ship collision the stress on its surface along the X direction is mainly born by the deck and the bottom plate, at the beginning of the impact the maximum stress appears on the side deck, and with the passage of time the stress passes from the side deck to the internal deck, and the stress value increases gradually. The stress of the ship along the Y and Z direction mainly concentrate in the impact areas in the side, and the maximum values appear in the outline of the impact areas, at the beginning they appear in a small piece of the impact areas, subsequently eradiate to the surroundings by wave. It is different that the stress along the Y direction eradiates along the direction of the ship’s height in the side, but the stress...
along the Z direction eradiates along the direction of the ship’s length in the side; And the stress along the Y direction spreads slowly to the deck, and the stress along the Z direction quickly spreads to the deck. And the impact on the ship's total stress distribution shows the trend that maximum value spreads in the direction of the ship’s length. It is mainly because that the overall bending appears along the direction of the ship’s length due to the effect of inertia of the ship, the bending stress appears, too.

Figure 6. Stress contours along the X direction which reflect how stress changes with the changing of the time in the process of ship impacting.

Figure 7. Stress contours along the Y direction which reflect how stress changes with the changing of the time in the process of ship impacting.

Figure 8. Stress contours along the Z direction which reflect how stress changes with the changing of the time in the process of ship impacting.

Figure 9. Stress contours all directions added which reflect how stress changes with the changing of the time in the process of ship impacting.
Figure 10 shows the extracting nodes on the side and side deck to measure the ship deformation. Seven nodes are taken on the ship to monitor the deflections of the different parts due to the impact. The specific deformation time-history curves of the deformation values changing over time are shown in Figure 11 to 13.

Figure 10. A diagram showing how to extract nodes on ship.

Figure 11-13. Time-history curve about deformation of the extracted nodes on ship along.

It can be seen from the Figure 11, the displacements of node 14196, 19161 and node 3347 along the X direction are larger, but the other four nodes’ displacements are smaller. It is mainly because that when the ship impacts the mooring pier, the nodes E, F, G curve represents of move with the inertia of the ship to the impact direction, while the other four nodes due to the obstacles of the mooring pier appear deformation but don’t appear large displacements. So the deformation along X direction is mainly focused on the local area of the impact. It can be seen from the Figure 12 that the displacement of node 3347 along the Y direction is larger, mainly because that it is located on the deck, and is sensitive to the displacement in the direction of ship’s height. It can be seen from Figure 13 that, the deformation along Z direction is mainly focused on the local edge areas of the impact. So in
order to prevent the impact damage to the ship, the local structure of the ship's side need to be strengthened in the docking place, also the side deck also requires certain structure strengthening.

**Comparison of the Deformation of the Mooring Pier under Different Situations**

Figure 14-16 shows deformation time-history curves along the X direction of the same nodes extracted from the mooring pier under three different circumstances.

![Deformation Time-history Curves](image)

(a) situation 1  
(b) situation 2  
(c) situation 3

Figure 14-16. Time-history curve about deformation of the extracted nodes on mooring pier along the X direction in.

It can be seen from the comparison of three groups of curves: the deformation distribution forms of the mooring piers under different impact conditions are nearly the same, the deformation along X direction mainly concentrates in the edge of the mooring pier, especially the corner position. So for the design of the mooring device the edges need to be rounded no matter for what kind of situation, in addition, the angular point transitions need to be strengthened very well. It is different that from the case one to case three, the deformation of the same node decreases gradually, because the contact scope of the impact gradually expands from the case one to case three. In case one a mooring pier collision, two in case two, while in the case three ship collides with three mooring piers. So it can be seen from the following deformation curves that, when designing the mooring device the contact surface needs to be enlarged, so that the impact damage can be greatly reduced, so the mooring device is designed to synchronously control the multiple sets of mooring device mainly from the angle of intelligent control, to look for the biggest mooring contact area to reduce the impact damage.
Conclusion and Prospect

According to the numerical analysis of the impact between a 143600DWT bulk cargo ship and the dock with the conventional mooring method, the damage mainly appears in the local position of the impact, especially in the angular point of the mooring device; And the more mooring piers there are, the less impact there will be. In the process of mooring device design attention should be paid to reduce the impact force and deformation along the direction of the ship’s length; In order to prevent the impact damage to the ship, the local structure of the ship's side need to be strengthened in the docking place and the side deck also requires certain structure strengthening, then in the side deck also require certain structural strengthening; When designing the mooring device the contact surface needs to be enlarged, so that the impact damage can be greatly reduced, so the mooring device is designed to synchronously control the multiple sets of mooring device mainly from the angle of intelligent control, to look for the biggest mooring contact area to reduce the impact damage.

The design of the new-type mooring device not only can be applied to open-type wharf, its characteristics of high docking efficiency, good economic benefits, high safety coefficient and adapting to the more severe sea condition are also suitable in the docking system of very large artificial floating island, offshore platform that will appear in the process of human’s development and utilization of marine action in the future.

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References


