Study on Collision of Ship Side Structure by Simplified Plastic Analysis Method

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Abstract. During its lifetime, a ship may encounter collision or grounding and sustain permanent damage after these types of accidents. Crashworthiness has been based on two kinds of main methods: simplified plastic analysis and numerical simulation. A simplified plastic analysis method is presented in this paper. Numerical methods using the non-linear finite-element software LS-DYNA are conducted to validate the method. The results show that, as for the accuracy of calculation results, the simplified plasticity analysis are in good agreement with the finite element simulation, which reveals that the simplified plasticity analysis method can quickly and accurately estimate the crashworthiness of the side structure during the collision process and can be used as a reliable risk assessment method.

1. Introduction

For many years, ship engineers have been committed to making ships more safer reduce the casualties, the property damage and the environmental pollution caused by accidents such as collision. In 1912, a ship accident, known as the unsinkable Royal Titanic, has had disastrous consequences. Before the accident, ship design engineers around the world had little or no maritime security cooperation. After the accident, the International Maritime Organization (IMO) developed an International Convention on the safety of life at sea in 1914. To this day, many international conferences, international projects and international studies are conducted to enhance maritime safety and avoid the occurrence of various types of maritime accidents.

In the past ten years, with the increase of the number and tonnage of ships, maritime traffic has become more and more busy, and the number of ship collision and contact accidents has increased significantly. Therefore, the research work of modern maritime safety is mainly focused on the ship collision and ship grounding. Ship collision is the focus of most of the research. Risk assessment and safety management of ship collision has become a hot research direction.

To prevent the collision of ships and method of bottom accidents, there are two types: active methods and passive methods such as: the management of shipping traffic and the improvement of hull structure crashworthiness. And the most effective way to reduce the risk of accidents is to use various methods to minimize the possibility of collision with the bottom of the accident. There are many ways to achieve this, for example, the management of shipping traffic, the enhancement of ship traffic service, the use of effective navigation aids, etc.. These methods have been implemented in the shipping industry, but in the long run, these methods do not meet the needs of today's development. So in order to reduce the possibility of accidents, while using the passive method to reduce the possibility of accident, it is necessary to use the passive method to minimize the damage degree of the hull structure after the accident, and reduce the loss to the minimum.

There will be a wide range of structural damage in the event of collision and bottom contact. Many scholars have been trying to analyze the response of ship structure in the course of collision. Ship
collision analysis methods can be divided into: simplified analysis method, finite element analysis method, experimental method and empirical formula method. They have their own characteristics, complement each other, and jointly promote the continuous development of ship collision research. The main characteristic of ship collision simplified analysis method is according to the specific characteristics of ship collision, simplifying assumptions are made through a series of calculation model of collision, more concise analytical expression is given to make a reasonable assessment of ship collision. In this paper, a new simplified analytical method called Simplified plastic analysis method is introduced.

2. Simplified plastic analysis method

When the simplified method is used to analysis complex structures, such as ships, the general structure is divided into several basic structures. The collision force of each basic structure is calculated, and then the collision response of the whole structure is obtained. A typical double hull structure is shown in figure 1a. The structure consists of an outer plate, an inner layer plate and a beam structure between the two layers. The beam structure includes transverse ribs and longitudinal beams. In the simplified plastic analysis method, beam structure is divided into two parts, one part of transverse ribs and longitudinal cross, referred to as the cross structure; the other part is the beam structure in the wide girder structure outside the cross section. In the study of Haris and Amdahl [1], the span of the beam cross section is defined to be equal to half of the height of the beam system, and the rest of the beam structure is a wide truss structure (as shown in figure 1c, d).

Many scholars have put forward the analytical formulas for the impact force of the above basic structures, in which the collision force between the cross structure and the wide truss structure is usually assumed to be constant. The collision force increases with the increase of deformation displacement. The collision force formulas of various structures are as follows:

Formula (1) for calculating impact force of cruciform structure (put forward by Hayduk and Wierzbicki in 1984) [2]), Plastic bending moment is defined by formula (2) and (3):

\[
P_{ef} = \frac{20.05}{\lambda} M_0 \left( \frac{C}{t_{ef}} \right)^{\frac{1}{2}}
\]

\[
M_0 = \frac{\sigma_0 \cdot t_{ef}^2}{4}
\]

\[
\sigma_0 = \frac{\sigma_y + \sigma_u}{2}
\]

\(M_0\) is a plastic bending moment of the plate width, \(C\) and \(t_{ef}\) are the width and thickness of the cross structure. Length factor \(\lambda\) is 0.73, \(\sigma_0\) is static yield stress of material, \(\sigma_y\) is dynamic yield stress of material, \(\sigma_u\) is Ultimate strength of material.

Formula (4) for calculating impact force of wide truss structure (put forward by Zhang [3]), The formula to calculate the concentrated load impact force of the center of the plate (figure 1b) is by formula (5) (put forward by Zhang [3]):

Figure 1. (a) typical ship side structure, (b) plate, (c) cross structure, (d) 4 wide truss structures.
\[ P_{wg} = \frac{11.26}{\lambda} M_{0} \left( \frac{b}{t_{wg}} \right)^{\frac{3}{2}} \]  

\[ P(\delta) = \frac{8}{3\sqrt{3}} \sigma_{0} S_{x} S_{y} \left( \frac{t_{px}}{S_{x}} + \frac{t_{py}}{S_{y}} \right) \delta \]  

b represents the span of wide truss, \( t_{wg} \) is the width of wide truss. Length factor \( \lambda \) is 0.73; The plastic bending moment is the same as the formula (2). \( S_{x} \) and \( S_{y} \) are the dimensions of the plate as shown in figure 1, \( t_{px} \) and \( t_{py} \) are the equivalent thickness of the plate in the X direction and the Y direction, \( \delta \) is the displacement of the center position of the plate. But it is not reasonable to calculate the impact load of the bow equivalent to a concentrated force or a uniformly distributed load. So, it is necessary to have a more optimized formula, which can take into account the different shapes of the bow, such as the bow of an Elliptical Parabolic surface. In the recent study, the formula for calculating the impact force of a specific shape of rigid bow has been derived [4]. The geometry of the bow is defined by the following formula:

\[ z = \frac{x^{2}}{\alpha \cdot S_{x}} + \frac{y^{2}}{\beta \cdot S_{y}} \]  

\( \alpha \) and \( \beta \) are the curvature the X direction and the Y direction. Curvature is not only related to the shape of the bow, but also to the size of the plate. The formula of the impact force of a flat plate subjected to an elliptical paraboloid is as following:

\[ p(\delta) = \frac{8}{3\sqrt{3}} \sigma_{0} S_{x} S_{y} \left( \frac{t_{px}}{S_{x}} \left( 1 - \frac{\alpha \delta}{S_{x}} \right)^{\frac{3}{2}} + \frac{t_{py}}{S_{y}} \left( 1 - \frac{\beta \delta}{S_{y}} \right)^{\frac{3}{2}} \right) \]  

When \( \alpha \) and \( \beta \) are equal to 0, the formula (7) is the same as the formula (5). The failure displacement of the plate is affected by the shape of the impact head. The displacement formula for the impact of a flat plate subjected to a circular parabolic head is:

\[ \delta_{f} = \frac{1.316 S_{x} S_{y}}{\sqrt{S_{x}^{2} + S_{y}^{2}}} \sqrt{\varepsilon_{f}} \times \sqrt{\alpha} \]  

The general range of failure strain is 5-10%. For the beam strengthened plate structure, the contact part between beam and plate is the first failure due to strain concentration. While the formula (8) only considers the membrane strain and neglects the bending strain. When the failure strain is 8%. When the failure strain is 8%, the similarity between the results of finite element analysis and theoretical results is the highest. So, it is suggested that the failure strain of 8% is reasonable. Figure 2 to figure 3 is the comparison of the results of the calculation of the impact of the plate with a rigid impact head with two different curvatures. The equivalent curvature coefficients of the two kinds of impact heads are equal and the shapes are different. Circular parabolic head (\( \alpha=0.5, \beta=2 \)), Circular parabolic head (\( \alpha=\beta=1 \)), flat plate model shown in figure 1 b, \( S_{x}=S_{y}=4000 \text{mm}, t_{px}=t_{py}=20 \text{mm} \). As can be seen from the graph, the simplified calculation results are in good agreement with the finite element results. The peak value of impact force is less than 3%, and the failure displacement is approximately equal.
3. Ship side structure collision analysis

The broadside structure of the 120 thousand ton oil tanker is composed of six double hull compartments. The cross section is shown in figure 4.

In the hypothetical collision process, the impact bow is rigid and does not absorb energy. We want to calculate the collision response of the rigid bow to the side of an oil tanker. The bow geometry is described by formula (6). The bow’s horizontal curvature coefficient $\alpha=0.8$, vertical curvature coefficient $\beta_1=1.325$, $\beta_2=1$. The intent of the bow is shown in figure 5. In the model, the material is ordinary steel, density $7.89\text{e-9t/mm}^3$, Young’s modulus $2.07\text{e5MPa}$, yield stress $235\text{MPa}$, Poisson’s ratio 0.3. RTCL failure criterion for material failure criterion [5]. Material constitutive relationship using power law plasticity. Among them $k=740$, $n=0.24$ [6]. In order to simulate the actual ship collision process, it is necessary to define the appropriate boundary conditions and loads. When the actual boundary conditions can not be determined, the appropriate simplified boundary conditions can be used. In the process of calculation, the translational degrees of freedom of the broadside structure should be constrained, fully constrained degrees of freedom of the end of the interior broadside structure. The initial velocity of the 8m/s loaded to the bow. The assumptions made in the process of analysis and calculation: a) the bow is rigid, only the side structure is involved in energy consumption; b) the collision process is quasi-static; c) the collision is a right angle to the heart collision. d) the density of bow increased by 10%. In order to determine the calculation model of the simplified method, a simplified calculation model method to determine the two conditions, need to analyze the deformation mode and load distribution of tanker side structure, the side structure is divided into two parts: the first part called main area, includes the direct collision point and adjacent area; the second part is expansion area, is the adjacent regions of the main area. The regional distribution is shown in figure 6. The deformation and energy variation of the outer shell of the side structure is shown in figure 7, figure 8.
It can be seen from the results of finite element calculation, only the deformation of node 1 is obvious, and all the deformed elements are in the main area. The main energy absorption area size is approximately equal to the overall structure of energy absorption size. Therefore, the simplified analysis method is used to calculate only consider the structure of the main area, the calculation model and the related dimensions are shown in figure 9. The dimension parameters are substituted into the formula, and the results are compared with the results of finite element calculation as shown in figure 10. As can be seen from the figure, the results of simplified plastic analysis method are above the finite element curve, the calculated results of failure displacement are the same as those of finite element method, and the ultimate impact force is 14% higher than that of the finite element method.

4. Summary
In this paper, a finite element software is used to simulate the process of rigid bowls hitting the side of the oil tanker. The bow shape is defined by an elliptical parabolic formula. The energy consumption of the two sides of the bow side impacted side structure is given in detail. The calculated collision force displacement curve and the failure displacement are used as reference, compared with the simplified method. From the finite element calculation results, it is concluded that the reinforcement structure on the beam structure and the energy absorption of the inner shell in the collision process are negligible and can be neglected. The simplified method divides the side structure into several basic components, including: plate and shell structure, cross structure and wide girder. The collision force of each component is calculated by the formula, and the total collision force of the side structure is obtained. The calculated results are in good agreement with the simulation results. It is revealed that the simplified plasticity analysis method can quickly and accurately estimate the crashworthiness of the side structure during the collision of the ship and can be used as a reliable risk assessment hand.
5. Reference

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