Finite element analysis of building block ark stranded

Lingqi Zeng *, Yu Wang
School of Qingdao University of Science and Technology, Qingdao, China

*Corresponding author e-mail: q15610492017q@163.com

Abstract. Using the direct calculation method based on the finite element theory, based on the reasonable creation of the finite element model, the ANSYS software is used to perform finite element analysis on the blockage of the ark of the building block. This article mainly uses the reef rocking condition of half-angle 45° For example, to simulate the damage of the hull to the hull under the extreme conditions by the stranded reef, and perform finite element analysis to improve the structure of the building block ark and improve the performance of the hull.

1. Introduction
As a new type of ship, the building block ark is the first new ship built by my country with low cost, multiple functions, light weight, and detachability. The building block ark is composed of the floating body of the bow, the floating body, the connecting body of the floating body, the cover, the cover, the deck, the buckle and the stern. The building block ark is based on the development of a catamaran, which is a new type of catamaran made by splicing. Building block ark has a structure and advantages that other ships and aquatic products do not have. The mechanical structure and design of the building block ark is the first. There is no precedent for checking and calculating the dimensional standards such as the structural strength and deformation of the building block ark. Due to the existence of diversified factors, the hull needs to be coexisted with multiple factors. Simulation experiment. Zhang [1] used the finite element method to directly calculate and analyze a wave-piercing hydrofoil, calculated the hull deformation and stress distribution under three working conditions, and verified that the actual ship meets the strength condition through strength verification. Yang and Huang [2] used ANSYS to study the definition of loading mode and boundary conditions of an inland catamaran over 60m and analyzed the stress of the connecting bridge. Foreign Heggelund S [3] analyzed the total transverse strength of the catamaran using the finite element method. Latorre RG [4] designed an aluminum catamaran ferry boat and systematically calculated the structural strength in the design scheme. It laid the foundation for the subsequent design of the catamaran ferry. For the finite element analysis of the composite boat structure, scholars at home and abroad have also carried out some practices. Roberto Ojeda [5] and others calculated the structural response of the small composite catamaran under slamming load, by changing the composite material layer on board. The direction is optimized for the structure. Liu Xue song and Zhou [6] conducted a finite element analysis of the structural strength of a sandwich structured FRP yacht, used laminated shell elements to process the composite sandwich structure, and studied the calculated impact force and hydrodynamic loading method of the hull. The ANSYS software was used to perform finite element analysis on the blockage of the ark of the building block. This article mainly takes the cone-shaped reef as an example to simulate the damage of the hull under the limit conditions.
and the finite element analysis of the ship’s hull under the limit conditions, so as to improve the building block’s ark. Structure, improve the performance of the hull.

2. Finite element analysis of the whole ship stranded

2.1. Stranded equations of motion and solutions

In this paper, the finite element method is used to solve the instantaneous dynamic change problem—show that the integral method \( M\ddot{a} + C\dot{v} + Kd = F \). Carry out the solution to get the equation of motion of the stranded ship:

\[
[M]\ddot{a} + [C]\dot{v} + [K]d = \{F_{ex}\} (1)
\]

In the formula,

\[
[M] \quad \text{Mass matrix;} \\
[C] \quad \text{Damping matrix;} \\
[K] \quad \text{Stiffness matrix;} \\
\{a\} \quad \text{Acceleration vector;} \\
\{v\} \quad \text{Speed vector;} \\
\{d\} \quad \text{Displacement vector;} \\
\{F_{ex}\} \quad \text{External force vector.}
\]

The equation (1) is subjected to explicit kinetic analysis. The analysis process is as follows:

\[
\begin{align*}
\{v_{n+\frac{1}{2}}\} &= \{v_{n+\frac{1}{2}}\} + \{\frac{\Delta t}{n+\frac{1}{2}} + \Delta t_{n+\frac{1}{2}}\} \\
\{d_{n+1}\} &= \{d_n\} + \{\frac{v_{n+\frac{1}{2}}}{n+\frac{1}{2}}\} \cdot \Delta t_{n+\frac{1}{2}} \\
\Delta t_{n+\frac{1}{2}} &= \frac{(\Delta t_n + \Delta t_{n+1})}{2}
\end{align*}
\]

In the ANSYS/LS-DYNA based on the central difference method, it is not necessary to perform matrix decomposition or inversion in the dynamic analysis process. Since the accuracy of the displayed integral is closely related to the time step, it is especially important to determine the integral time step for solving the ship stranding problem with the displayed integral algorithm. It should be ensured that the time step cannot be greater than a critical time step. The critical time step is the ratio of the characteristic length of the model element to the sound velocity of the material. The specific expression is as follows:

\[
\Delta t_{cr} = \frac{L_c}{c} \geq \Delta t
\]

\[
c = \sqrt{\frac{E}{\rho(1-\mu^2)}}
\]

In the formula, \( L_c \) represents the characteristic length of the model element; \( c \) represents the sound velocity of the material; \( E \) represents the elastic modulus; \( \rho \) represents the density of the material; \( \mu \) represents the Poisson's ratio. In the ship stranding problem, the most important factor that affects the time step is the size of the unit, because the material of the ship structure is mostly the same, so controlling the unit size and simplifying the finite element model have a great impact on improving the calculation efficiency. The definition of element size and the simplification of the finite element model will be mentioned below.
2.2. Stranded empirical formula

As early as 1950, Minorskv [7] first proposed the empirical formula for ship stranding, and it has been widely used. However, the formula does not reflect the differences in material properties, damage modes, and structural arrangements, but only establishes a simple linear relationship between energy absorption and material damage volume. Until 1999, Zhang [8] proposed a simple method for ship stranding analysis based on Minorskv. In fact, the deformation modes of ship structures are often combined by a variety of complex deformation modes. The following mainly introduces the energy absorption expressions of the three basic deformation modes.

1) Crushing or wrinkle deformation mode

\[ E = 3.50 \left( \frac{t}{d} \right)^{0.67} \sigma_o R_T \]  \hspace{1cm} (5)

\[ R_T = L_{\text{dam}} B_{\text{dam}} t_{eq} \]  \hspace{1cm} (6)

In the formula, \( t \) represents the average thickness of the crushed plate, \( d \) represents the average width of the crushed section, and \( R_T \) represents the loss volume of the material. And \( L_{\text{dam}} \) 、 \( B_{\text{dam}} \) represent the damage length and width, respectively, and the equivalent plate thickness.

2) Tensile deformation mode

\[ E = 0.77 \varepsilon_c \sigma_o R_T \]  \hspace{1cm} (7)

\[ E = 0.10 \frac{\varepsilon_f}{0.32} \]  \hspace{1cm} (8)

In the formula, \( \sigma_o \) represents the flow stress of the material, \( \varepsilon_c \) represents the critical fracture strain, \( \varepsilon_f \) represents the ductility of the material, and \( R_T \) represents the loss volume of the material.

3) Torsion deformation mode

\[ E = 3.21 \left( \frac{t}{l} \right)^{0.6} \sigma_o R_T \]  \hspace{1cm} (9)

In the formula, \( t \) represents the equivalent thickness of the plate, including the ribs and girders in the tearing direction, and \( l \) represents the critical tearing length, which is generally 2 times the damage width or the length of the wedge. The sum of formula (5) and formula (7) is generally used to solve the estimation of the deformation energy of the ship's side collision. Equation (9) is used to solve the estimation of the grounding deformation energy when the ship is grounded.

3. Finite element analysis of the whole ship stranded

When the building block ark travels in the water, the conditions in different waters are also very different. Then the building block ark is subjected to very different forces in the water. When it hits the reef, the actual deformation and stress of the ship in the water should be reconsidered and calculated manually. These data are obviously unrealistic. We can use ANSYS finite element software to analyze the ship's dynamics, input the ship's data in the grounding state into the system, and then draw the total deformation diagram and equivalent stress diagram of this working condition. From the various data obtained, the specific situation of stress can be obtained, and the structural strength can be obtained. To determine whether it meets the requirements, the mechanical properties of the same pp material can be compared.

In order to simulate the situation of real reef hitting as far as possible, we use rigid materials to create reefs of different sizes and shapes, and then use pp materials with good elastoplasticity to create hulls. When the reefs are designed to be tapered, the ship's stress after impact is often It will rupture and there are scars on the surface of the hull. Considering the effect of subsequent water pressure on the scars, the situation will become complicated. When the reef is platform and spherical, the larger contact area will share the pressure, although it will not make the two There is severe deformation, but the bottom of the
ship will still be dented to varying degrees. Considering that the cone-shaped reef is more damaging to the ship, we must focus on the study of collisions in this situation. When using the finite element method to analyze the ship stranding, it often takes a long time to build the model, and the calculation is relatively complicated. Although the calculation result is more accurate than other methods, this method is not so perfect, so it is particularly important to find another method to simplify modeling and calculation.

Figure 1. Seabed Topology with reference to bottom size

Figure 2. Simplified model of building block ark in case of grounding

According to the angle of the half-top angle of the cone reef, the following is a simulation analysis of a working condition when the building block ark runs aground with different cone reefs:

3.1. Reef stranding at a half-top angle of 45°
The simplified building block ark model was used to simulate the stranding at a speed of 10m/s when it hit a reef with a half-top angle of 45°, and the working condition within 5.0 seconds of stranding was analyzed.
As shown in Fig. 3, it is the working condition when the hull is at a reef with a half angle of 45°, the impact depth is 100mm, and it is stranded for 0.2, 0.4, 0.6, 0.8, 1.0, and 5.0 seconds. The building block ark directly hits a cone-shaped reef with a half-top angle of 45° at a speed of 10m/s. The degrees of freedom of the upper edge of the hull in the Y and Z axes are restricted, and the degrees of freedom of the target reef in the X, Y, and Z directions are 0. Analyze the stress and deformation within 5.0 seconds.

After the finite element analysis of the situation of grounding depth of 100mm, it can be seen that the amount of deformation is small, and the equivalent stress is also within the scope of the allowable stress. But this is the magnitude of the stress generated when the sailing speed is 10m/s. If the ship is stranded when it hits the cone-shaped reef under high-speed sailing, the concentrated stress may be excessive.

Through the broken line diagram 4, we find that the equivalent stress is maximum when the travel time is 0.6 seconds at a half vertex angle of 45°. It is not difficult to see that the equivalent stress caused by the reef on the hull fluctuates with the passage of the stranding time. This is due to the assembling characteristics of the building block Ark. The bottom of the building block Ark hull is composed of 2 bows, 12 floating bodies, and 12 floating body connecting bodies, and the bottom surface is non-uniform. However, the hull should also try to avoid sailing in waters with reefs, especially those with sharp reefs. Under this condition, the reef impact load on the bow of the building block ark meets the initial navigation conditions, that is, when the ark is traveling at a regular speed in a small wave, the reef impact load is limited. The equivalent stress experienced by the hull at 0.6 seconds reaches a maximum value of about 5.2 MPa. At this time, the impact stress on the bow is slightly higher than the impact stress on other positions. In this section, the building block ark is stranded at the rated speed of the hull, and the equivalent stress is less than 39 MPa, the minimum allowable stress of the hull material.

Keep the other boundary conditions and constraints unchanged, adjust the impact depth to 20mm, and analyze the working conditions of the building block ark at a time when the reef with a half-top angle of 45° is stranded. Analyze the change of stress on the hull when the hull is grounded, as the length of grounding increases.
As shown in Figure 4, it is a reef with a hull angle of 45° at a half-top angle, impact depth of 20mm, and grounding within 1.0 second. The building block ark directly hits a cone-shaped reef with a half-top angle of 45° at a speed of 10m/s. Analyze its stress and deformation within 1.0 second.

Under this condition, due to the reef impact load on the bow of the building block ark and the design sailing conditions of the building block ark, that is, under low wave conditions and at rated speed, the reef impact load is limited. The maximum stress of the hull is about 12.4MPa.

After the finite element analysis of the grounding depth of 20mm, the equivalent stress is within the range of allowable stress. But this is the magnitude of the stress generated when the sailing speed is 10m/s. If the ship is stranded when it hits the cone-shaped reef under high-speed sailing, the concentrated stress may be excessive.

4. Conclusion
This section mainly studies the deformation and failure mechanism of the ship floor under the impact of sharp reefs. By observing and studying the process of ship bottom deformation in numerical simulation, a theoretical model of ship bottom deformation is proposed. The bottom of the ship will be plastically deformed when it is stranded by sharp rocks. Using ANSYS software, a dynamic impact simulation was carried out on the reef type cone model, and the reef half-angle was 45° at 0.2 seconds, 0.4 seconds, 0.6 seconds, 0.8 seconds, 1.0 seconds, and 5.0 seconds, and the grounding depth was 100 mm. The equivalent stress of stranding at the working condition of 20mm and the maximum stress under the condition of stranding are all less than the allowable compression stress of 45MPa. Therefore, the building block ark satisfies the strength condition when stranded.

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