Application of finite element method in strength analysis of ship connecting parts

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Abstract. In the design stage, the strength and rigidity of general marine connectors can be calculated according to the relevant ship standard. However, some special nonstandard connections cannot be calculated by ship standard. The finite element method provides us another feasible option. In this paper, the finite element method is used to analyze the strength of the ship connecting flange, and the results are compared with the calculation results of the ship standard.

1. Introduction
The finite element method is a numerical method for solving partial differential equations. It approximates the true solution of the element by discretizing the continuous solution area into a finite solution element, and representing the unknown field function to be solved in each element as an approximate function, so that a continuous infinite degree of freedom problem becomes a discrete finite degree of freedom problem [1].

The finite element method has sprouted since the 1940s. In 1943, R. Courant first proposed the application of the principle of minimum potential energy and combined with the piecewise continuous function defined in the triangle region to solve the torsion problem [2]. Its core idea is to introduce shape function to represent unknown field function in triangle region. In 1956, Turner et al. Published the first paper of the finite element method, proposed to use the approximate displacement function in the element to obtain the stiffness matrix of the element and then get the overall stiffness matrix, dealt with the problem of two-dimensional plane and gave the correct answer to solve the stress problem with triangular element, which is considered as the first successful attempt of modern finite element method [3]. The term "finite element method" was first used by clough in 1960 [4]. Then, in 1961, Melosh established the matrix element grid for the two-dimensional plane problem, and established the bending element stiffness matrix of the plane rectangular plate [5]. In 1963, Grafton and Strome studied the axisymmetric and surface bending problems, and established the bending element stiffness matrix of axisymmetric and curved shells [6]. Martin et al. Extended the finite element method to three-dimensional problems, used tetrahedral element mesh and established stiffness matrix to solve the problem [7].

As a scientific calculation method which has been developed for decades, finite element method has many advantages. It can discretize very complex geometric models, and solve problems in a systematic and standardized way. It can develop a flexible and general computer program, which can be widely used in various occasions. So far, a lot of computer programs have been developed that can be applied
to various scenes, and it plays an important role in the practical engineering application of all walks of life.

2. Strength calculation of marine connecting flange based on shipbuilding standard

Due to the need of installation, it is necessary to enlarge the bolt hole of some flanges by 2mm or 1mm during the design. After the expansion, the stress area of the bolt hole of the flange is correspondingly reduced, and its strength must be reduced. In the case of constant fastener torque, it is necessary to check the local strength through calculation, and check whether the strength of the reamed part meets the requirements under normal tightening torque.

At present, there are standards for checking and calculating the strength of flange, but this standard can only calculate the checking of flange neck strength (circumferential, axial and axial strength as well as torsional strength) and fastener strength under the action of internal fluid pressure of flange. However, according to the calculation standard, it is impossible to check the strength of non-standard connectors after flange reaming.

Figure 1 is a structural diagram of a marine connecting flange. Firstly, according to the strength checking calculation standard of the flange, the axial stress, radial stress and circumferential stress of the flange are calculated, the three-dimensional model of the flange is drawn and the finite element model is established for modal analysis. The stress obtained is compared with the calculated stress to verify the correctness of the method.

Flange shape constants are shown in the following table:

\[ \delta_0 = \delta_1 = 15, \quad \frac{\delta_1}{\delta_0} = 1, \quad D_1 = 70, \quad D_0 = 190, \quad K = \frac{D_0}{D_1} = \frac{190}{70} = 2.71 \]

\[ h_0 = \sqrt{D_0\delta_0} = \sqrt{70 \times 15} = 32.4, \quad \frac{h}{h_0} = 1.5\delta_1 = 22.5, \quad \frac{h}{h_0} = \frac{22.5}{32.4} = 0.694 \]

\[ T = 1.28, \quad U = 2.27, \quad Y = 2.066, \quad Z = 1.315, \quad F_1 = 0.9, \quad V_1 = 0.55, \quad f = 1 \]

Therefore, according to the calculation formula of flange check, the following results are obtained:

\[ e = \frac{F_1}{h_0} = \frac{0.9}{32.4} = 0.028 \]

\[ d_i = \frac{U}{V_i}h_0\delta_0^2 = \frac{2.27}{0.55} \times 32.4 \times 15^2 = 30087.81 \]
\[
\psi = \delta_f e + 1 = (27 - 3 - 2) \times 0.028 + 1 = 1.616, \quad \beta = \frac{4}{3} \delta_f e + 1 = 1.821.
\]
\[
\gamma = \frac{\psi}{T} = 1.263, \quad \eta = \frac{\delta_f^3}{d_1} = \frac{22^3}{30087.81} = 0.354, \quad \lambda = \gamma + \eta = 1.617.
\]

Before calculating the allowable stress of flange neck, it is necessary to calculate the design moment \(M_0\) of flange in two states of pre-tightening and operation.

\[
M_0 = F_D L_D + F_T L_T + F_G L_G
\]

Among them:
\[
F_D = 0.785 D_1^2 P_c = 0.785 \times 70^2 \times 3.5 = 13462.75N
\]
\[
L_D = L_A + 0.5\delta_1 = (73 - 35 - 15) + 0.5 \times 15 = 30.5mm
\]
\[
F_T = F - F_D = 0.785 D_1^2 P_c - F_D = 0.785 \times \left(110 - 2 \times 2.53 \sqrt{7.25}\right)^2 \times 3.5 - 13462.75 = 12056.69N
\]
\[
L_G = \frac{D_b - D_G}{2} = \frac{146 - 96.37}{2} = 24.81mm, \quad L_T = \frac{L_A + \delta_1 + L_G}{2} = \frac{23 + 15 + 24.81}{2} = 31.40mm
\]

The gasket material is brass, and the coefficient \(m=3.5\) is obtained according to table 9-2 of \(GB 150-1998\), therefore:
\[
F_G = F_p = 6.28 D_1 b p_n = 6.28 \times 96.37 \times 2.53 \sqrt{7.25} \times 3.5 \times 3.5 = 50504.19N
\]

Therefore, the design torque of the flange under working condition is:
\[
M_0 = 13462.75 \times 30.5 + 12056.69 \times 31.40 + 50504.19 \times 24.81 = 2042202.89N\cdot mm
\]

Therefore, the three-dimensional stress of flange neck is obtained:

Axial stress:
\[
\sigma_H = \frac{BM_0}{\lambda \delta_f^2 D_1} = \frac{1 \times 2042202.89}{1.617 \times 15^2 \times 70} = 80.18MPa
\]

Radial stress:
\[
\sigma_R = \frac{BM_0}{\lambda \delta_f^2 D_1} = \frac{1.821 \times 2042202.89}{1.617 \times 22^2 \times 70} = 67.88MPa
\]

Tangential stress:
\[
\sigma_T = \frac{YM_0}{\delta_f^2 D_1} - Z \sigma_R = \frac{2.066 \times 2042202.89}{22^2 \times 70} - 1.315 \times 67.88 = 35.27MPa
\]

3. Strength check of connector based on finite element method

According to the analysis flow of finite element method. Firstly, the above flange geometric model is meshed in Hyper Mesh software, and the boundary conditions and loads are established in ABAQUS, so as to establish the finite element analysis models of the two flanges, as shown in Figure 2.
Figure 2. Finite element model of a flange

Figure 3. Cloud chart of flange stress

It can be seen from figure 3 that the maximum stress of flange obtained by finite element analysis is 77.9MPa respectively. Its position is located in the contact area between the flange neck and the flange plate. The maximum axial stress of the two kinds of flange calculated by theory is 80MPa respectively. The calculated results are basically consistent with each other, which proves the correctness of the above theoretical calculation process.

4. Conclusion
In this paper, the finite element method is used to analyze the strength of marine connections, and the calculation results in the ship design standard are compared. Through comparative analysis, it is found that the results of the finite element analysis are in good agreement with the results of the calculation method recommended by the code. The feasibility of the finite element method in the strength analysis of ship connections is verified.

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