Numerical Analysis and Optimization Design of the Crossbeam Structure of the Wave-maker

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Abstract. In order to reduce the redundancy of the crossbeam structure on the wave-maker and achieve lightweight design, numerical analysis was conducted on the crossbeam, and the results showed that there was a significant margin in both stiffness and strength. Based on the results of structural strength analysis, structural optimization design was carried out on the crossbeam model. The optimization results showed that under the premise of ensuring that the allowable deformation is less than 2mm and stress is less than 325Mpa, the crossbeam steel and layout were optimized. After improvement, the crossbeam mass was reduced by 14.0%, achieving the design goal of "light weight and good performance". This research method provides a basis for the design and optimization of crossbeams.

Keywords: Wave-maker; Crossbeam; Numerical Analysis; Optimization.

1 Introduction

In the design phase of national marine engineering, marine defense engineering, and military equipment construction, as well as in the research process of marine disaster prevention and control, in order to reduce risks and costs, physical model experiments are needed to obtain the interaction rules between the physical model and waves[1-4]. Therefore, the wave-maker which generates waves manually is required. The wave-maker drives the push plate to move back and forth through a driving device to produce waves that meet specific needs. It is necessary to ensure sufficient stiffness and strength of the wave-maker, and to reduce the structural redundancy of the equipment. The design of the Muping push wave-maker is based on experience, and there is no relevant data on the weak links and deformation of various parts[5,6]. Based on the current domestic and international situation and existing problems[7,8], this article conducts numerical analysis on the crossbeam of the wave-maker and optimizes the layout of the beam steel, providing a theoretical basis for relevant designs.

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The crossbeam component is one of the key components in the water tank wave-maker, and its function is to install servo motors, ball screw mechanisms, linear guide mechanisms, and wave pushing plates. Due to the cantilever structure of the cross-beam components, the rear and middle parts are welded (or bolted) to the fixed frame, making it difficult to arrange support at the front end. When the wave pushing plate moves to the front, it is easy to generate deflection[9,10]. Therefore, sufficient stiffness and strength are required to ensure that the wave making system can operate normally under various loads. At the same time, it is also necessary to reduce weight and facilitate manual movement, the structure of the wave-maker is shown in Figure 1.

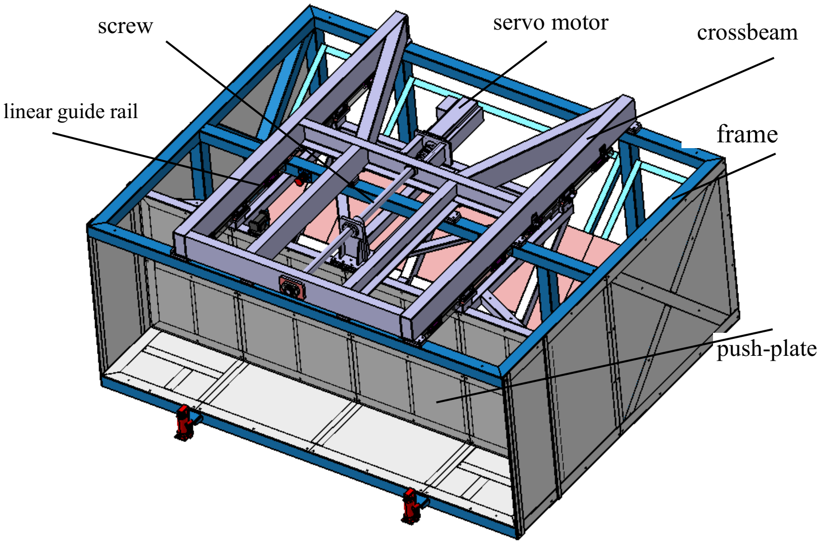

Fig. 1. Structure of wave-maker.

2 Finite element analysis model of the crossbeam

The crossbeam is composed of rectangular square tubes, channel steel, and steel plates welded together, with an overall size of 2.8 m in length, 2.02 m in width, and a weight of 413 kg. The crossbeam is welded together in various parts and can be considered as rigid connections. According to the structural and mechanical characteristics of the beam components, the steel plate wall thickness is only two thousandths of the length and width. Therefore, using shell element modeling is the most ideal modeling method. Due to the complex geometric structure of the crossbeam, necessary simplification operations are required to achieve high computational accuracy. To ensure smooth simulation, it is necessary to perform the glue operation in Boolean operations on each face in the model, connecting the faces together to form a rigid body, so that the load can be transmitted in the model. After the model is established, the material properties are assigned, and the values of various parameters such as material model, elastic modulus, Poisson's ratio, density are shown in Table 1. Set the unit size, perform grid division, and obtain the finite element analysis model, as shown in Figure 2. The finite element model consists of 57529 elements and 114221 nodes.

Table 1. The material parameters of crossbeam.

Material model	Elastic modulus (Mpa)	Poisson's ratio	Density (kg/mm^3)
Q345b	2.1×10^5	0.3	7.85×10^{-6}

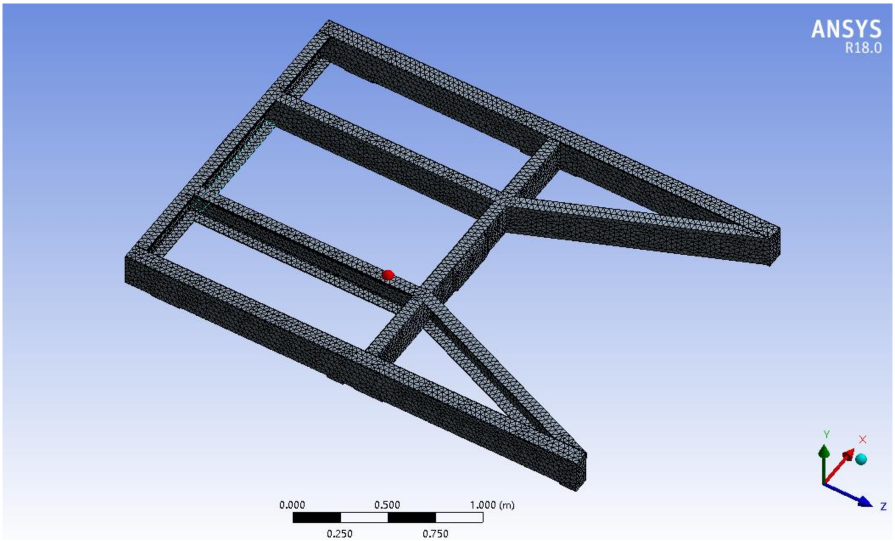

Fig. 2. The finite element analysis model of crossbeam.

3 Constraint and load analysis

Set the boundary conditions for the crossbeam, with the rear and middle of the upper crossbeam connected to the fixed frame bolts respectively, which can be considered as no relative motion. Therefore, full constraints are set at the back and middle parts, namely Ux=0, Uy=0, and Uz=0. The load surface of the crossbeam of the wave-maker is located on the surface of four sliding blocks that are matched with the guide rail, and the main load is the gravity of the wave push-plate. The weight of the wave push-plate is 1200 kg, and the force of crossbeam mechanism subjected to a vertical downward pull is:

$$F_1 = m_{plate} \times g = 1200 \times 9.8 = 11760\,\mathrm{N} \tag{1}$$

The center of gravity is located at the back 1/3 of the wave push-plate surface, that is, the force of front 2 sliding blocks is:

$$F_{front} = F_1 \times \frac{\;}{3} \div 2 = 3920\,\text{N} \tag{2}$$

and the force of rear 2 sliding blocks is:

$$F_{back} = F_1 \times \frac{1}{3} \div 2 = 1960\,\text{N} \tag{3}$$

4 Numerical analysis

Select the static option in the analysis type, apply boundary conditions according to the constraints and loads mentioned above, and perform a static analysis to obtain the strain and stress cloud maps of the upper crossbeam, as shown in Figure 3 and Figure 4. From Figure 3, it can be seen that under the applied load, the rectangular tube at the front end of the crossbeam deforms the most, with a maximum deformation of 0.614 mm, which is 2 mm less than the allowable deformation. In the node stress contour map 4, it can be shown that the maximum stress is 9.12 MPa, which is much smaller than the maximum yield stress of Q345b, which is 325 MPa. From this, it can be seen that the stiffness and strength of the crossbeam structure can meet the design requirements.

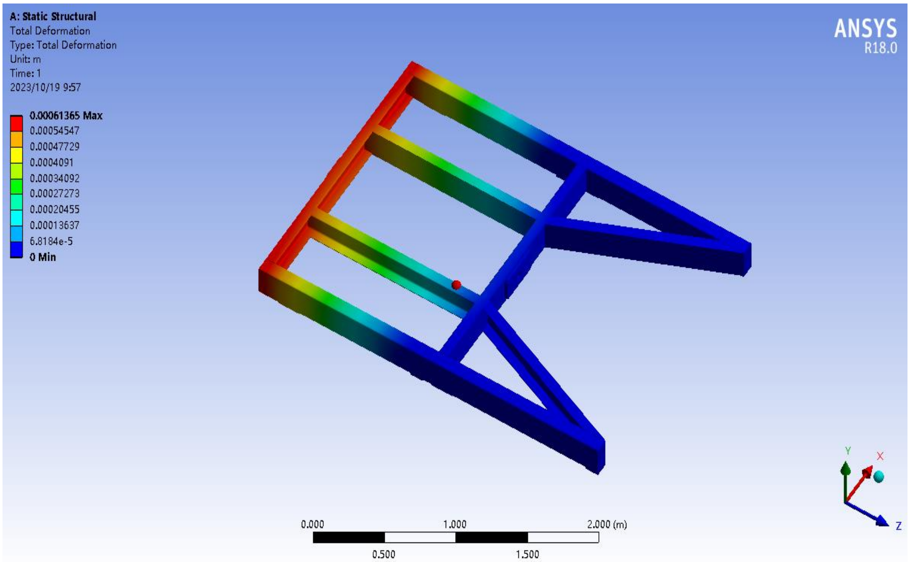

Fig. 3. Displacement nephogram.

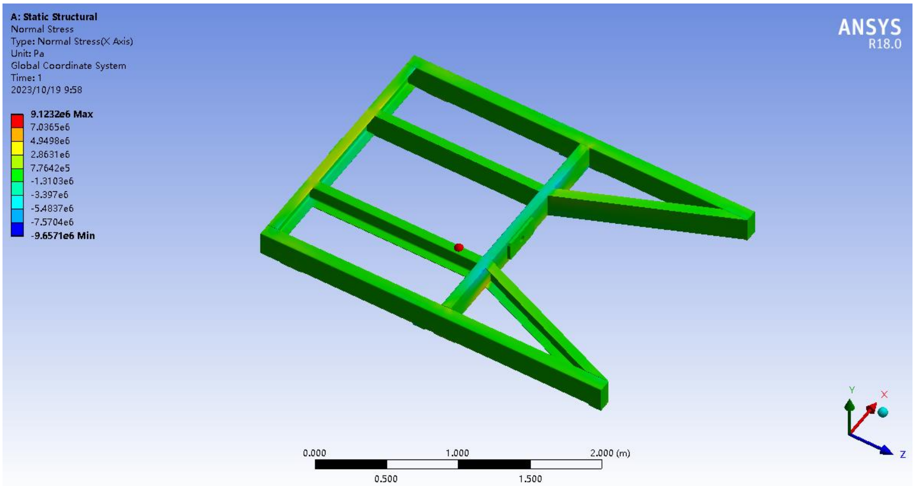

Fig. 4. Stress nephogram.

5 Optimization

From the numerical analysis above, it can be seen that the structure of the crossbeam is safe enough to be excessive. From the perspective of reducing costs, while ensuring the safety of the crossbeam structure, it is entirely possible to use fewer materials and optimize its structure without losing reliability. On the premise of meeting the stiffness and strength requirements, different sizes of steel sections are used to optimize their structure. The comparison of analysis results is shown in Table 2. It can be seen that the crossbeam structure uses different profiles, and their strain, stress, and weight are different. Under the conditions of meeting the allowable strength and stiffness, the group 3 has the best results, with a maximum deformation of 1.235 mm and a maximum stress of 39.12 MPa, all of which do not exceed the allowable value, and the weight is reduced by 14.0% compared to the original structure, achieving the optimization goal of light weight and good performance effectively.

Table 2. The calculation results of optimization plan.

Group	rectangular tube	channel steel	Maximum deformation（mm）	Maximum stress（MPa）	Weight（kg）	Reduction percentage
Original	200×100×8	20#B	0.614	9.12	413	—
Group 1	200×100×6	20#B	0.866	17.33	389	5.8%
Group 2	160×100×8	16#B	1.235	39.12	371	10.2%
Group 3	160×100×6	16#B	1.774	66.33	355	14.0%

6 Conclusion

This article conducts numerical analysis of the crossbeam of the wave-maker to obtain the displacement and stress cloud maps under constrained load conditions, and evaluates the static characteristics of the structure such as stiffness and strength. The analysis results show that the original design of the crossbeam is relatively conservative, and its structure is safe enough to be redundant, so it is necessary to carry out structural optimization design. By selecting different size profile combinations for improvement, the optimal optimization effect of reducing the weight of the upper crossbeam structure by 14% was ultimately achieved. This not only ensures the rigidity and strength requirements of the crossbeam, but also reduces the cost of raw materials, which has great guiding significance for the overall design of the wave-maker.

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