Structure Design and Finite Element Analysis of the 24m Array Truss

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**Abstract.** In this paper, one type of 24m underwater array truss structure have been designed. Based on the array structure, analysis the force condition, the structure strength and stiffness were calculated, and the establishment of the array structure finite element model, combined with ANSYS analysis, truss strength and stiffness meet the specification requirements, the structure safe and reliable.

1. Introduction

The Rayleigh criterion states that the larger the scale of the array, the higher the operating frequency, the narrower the beam width, and the more accurate the orientation of the target. In order to improve the target orientation, positioning accuracy, and target resolution, the array aperture needs to be increased. Or increase the number of array elements, and a large array of arrays will often increase production costs, and for practical considerations, the matrix scale is not likely to be very large. Determining the most economical array aperture is the most critical issue for array design. The scale of the array depends mainly on the base frame. The base frame mainly provides the installation platform for the passive underwater acoustic tracking system array. The structure of the base frame Strength and engineering implementation limit the scale of the array. At present, the traditional base frame scale is small, generally not more than 10 meters. This paper designs a large-scale array with a scale of 24m. The structure diagram is shown in Figure 1.

![Figure 1. Schematic diagram of 24m array structure](image-url)

1 buoy; 2 matrix truss unit; 3 lifting point; 4 watertight barrel; 5 universal joint; 6 vertical bracket; 7 cement base; 8 baffle and hydrophone assembly
2. Structure Form of Array Frame
The three-dimensional truss with rectangular cross-section is used in the truss structure. The cross-section of the truss is shown in Figure 2. The 10 equal-angle steel with 100mm side length and 7mm thickness is used as the four main bearing members of the truss. The connecting frame is 6.3 equal-angle steel, which is arranged every 1m.

![Figure 2. Section form of truss](image)

Each side of the truss adopts the structural form as shown in Figure 3. The two sides and the same plane form are adopted. The top and bottom sides adopt the same form. The diagonal brace and vertical brace between the upper and lower chords of the truss as webs are made of 6.3 equal-angle steel.

![Figure 3. The structural form of each plane of the truss is adopted.](image)

3. Force Analysis of Array Frame
The total length of the truss structure is 24m. The main forces acting on the truss are as follows: the truss weight $G_{\text{truss}}$, the weight $G_{\text{float}}$ of the three buoys, the weight $G_{\text{baffle}}$ of the baffles at both ends, the upward traction force $F_t$ applied at the two suspension points on the truss, and the vertical bracket at the lower part of the truss Center (including the weight of the watertight bucket, simple). The weight of $G_{\text{pedestal}}$ in the center of the truss) and the concrete base.

![Figure 4. Force Analysis of Array Frame](image)

From the stress analysis, it can be seen that the dangerous stress conditions of the truss mainly include: (1) during hoisting, the middle truss is subjected to bending action and the traction force of
the cable, which is one of the most easily destroyed situations of the structure. (2) The lower central part of the truss is subjected to bending and downward gravity, which is also prone to damage. Therefore, the structural strength of the above two places is used as the criterion of whether the whole structure meets the requirements.

3.1. Force Analysis of Left End of Array Frame
Because the lifting mainly depends on the two side structures of the truss, and because the left and right ends of the truss are symmetrical, only one end can be analyzed. For conservative calculation, the mass of buoys and heavy objects on both sides of the truss is taken into account as the concentrated mass acting on the end of the truss. As shown in Figure 5.

![Figure 5. Schematic diagram of force analysis of left segment structure](image)

When hoisting, the support point is 1-2 of symmetrical axis, and the truss is in extreme stress state. Relative to the support point 1-2, the moment balance is as follows:

$$2M_{\text{one side}} = G_{\text{baflle}} \times 8 + G_{\text{truss}} \times 4 + G_{\text{float}} \times 8$$

In the formula, $M_{\text{one side}}$ is the moment applied to a unilateral longitudinal plane truss. $G_{\text{baflle}} = 500\text{kg}$, $G_{\text{truss}} = 792.42\text{kg}$, $G_{\text{float}} = 1156.3\text{kg}$.

It is calculated by the formula above. $M_{\text{one side}} = 8210\text{kg m}$.

From the force analysis, we can see that, $M_{\text{one side}} = F_{1-3} \times 0.7$, $F_{1-3} = 11728.66\text{kg}$.

$$\sigma_{1-3} = \frac{F_{1-3}}{A} = \frac{11728.66}{13.796 \times 10^{-4}} = 85.4\text{MPa}$$

In the formula, $F_{1-3}$ is the internal force of 1-3 bar segments, $\sigma_{1-3}$ is the stress of 1-3 bar segments and $A$ is the cross-sectional area of No.10 Angle Steel.

According to the slenderness ratio of 1-3 bars, the stability coefficient of axially compressed members is chosen $\Psi = 0.842$, so,

$$\sigma_{\text{pressure}} = \frac{\sigma_{1-3}}{\Psi} = \frac{83.55}{0.842} = 99.22\text{MPa} < \sigma_f$$

The 1-3 section of the rod meets the strength requirements and has a safety factor of 2.3 times.

3.2. Force Analysis of the Central and Lower Part of the Array Frame
Connecting the vertical support rod and the cement base at the lower part of the center of the array will produce bending moment at the two suspension points of the truss. The force analysis is shown in Figure 6.
The moment balance shows that:

\[ M_{\text{Hang}} + M_A + M_B + M_{\text{truss}} + M_{\text{middle}} = 0 \]

In the formula, \( M_{\text{truss}} \) is the bending moment produced by the self-weight of the middle section of the base frame at each suspension point, and \( M_A \) and \( M_B \) are the bending moment produced by the vertical support rod and the cement base at each suspension point, respectively. Taking the vertical support rod (including the weight of the watertight bucket) and the total weight of the cement base as 4000kg, then \( M_A + M_B = 4000 \times 0.5 = 2,000 \text{kg.m} \). \( M_{\text{Hang}} \) is the total bending moment at the hanging points on both sides of the array truss, and \( M_{\text{Hang}} = 2M_{\text{side}} = 2 \times 8210 = 16420 \text{kg.m} \). So,

\[
M_{\text{middle}} = \frac{M_{\text{Hang}} + M_A - M_B - M_{\text{truss}}}{2} = \frac{16420 - 8000 - 800}{2} = 3810.06 \text{kg.m}
\]

\[
F_{\text{middle}} = \frac{M_{\text{middle}}}{0.7} = \frac{3810.06}{0.7} = 5442.94 \text{kg} < F_{\text{1,1}} = 11728.66 \text{kg}
\]

The strength of the lower part of the middle truss is safe because its size is much smaller than that of the left truss member 1-3.

4. Finite Element Analysis of Array Frame

The base frame truss is the key force unit of the base frame. It is necessary to carry out finite element analysis. Before establishing the finite element model, the following assumptions and simplifications are proposed.

1. It is assumed that the material is evenly distributed isotropic;
2. The buoyancy force acting on the truss is simplified as the uniform load acting on the top of the truss;
3. The force of the baffle on the truss is simplified to the uniform distribution of the truss, the lower string and the diagonal bracing.
4. The force of the watertight cylinder and the tie rod on the truss is simplified to the uniform load acting on the lower chord;
5. The self-weight of the frame is applied by the inertial force;
6. The restraint is applied at the lifting point of the truss, the left hanging point limits the displacement in the UX and UZ directions, and the force in the Y-axis direction is applied \( F_{\text{Displacement}} = 34000 \text{N} \) (where the \( F_{\text{Displacement}} \) is a virtual load, the size of which is the lifting cable acting at the lifting point) The force component in the Y direction assumes that the hoisting rope is at an angle of 45° with the truss. The position of the hoisting point on the right side limits the displacement in the UX and UZ directions. Similarly, the force in the Y-axis direction is \( F_{\text{Displacement}} = 34000 \text{N} \).

The simplified model is shown in Figure 7, and the mesh model is shown in Figure 8. The finite element model load table is shown in Table 1. The application scheme of load and constraint is shown in Figure 9. After solving by ansys, the total deformation cloud diagram of the matrix truss is shown in Figure 10, and the stress cloud diagram is shown in Figure 11.
Figure 7. Simplified model

Figure 8. Mesh model

Figure 9. Application scheme for load and constraint

Table 1. Matrix truss finite element model load table

| project | Frame weight | Float 1  | Float 2  | Float 3  |
|---------|--------------|---------|---------|---------|
| value   | 18000N       | 12000N  | 12000N  | 12000N  |
| project | Baffle 1     | Baffle 2| Tie rod and cement base | electronic cabin |
| value   | 5000N        | 5000N   | 40000N  | 3000N   |
It can be seen from the figure that the maximum stress point is at the position of the left end suspension point, the maximum stress is $\sigma_{\text{max}} = 142.6 \text{MPa}$, $\sigma_{\text{allow}} = \frac{235}{1.43} = 161.8 \text{MPa}$, and the maximum deformation (deflection) is about $\delta_{\text{max}} = 8000/750 = 10.6 \text{mm}$, meeting strength and stiffness requirements. It can be seen from the figure that some members are relatively less stressed, and the force in the hoisting area is relatively large. It is recommended to strengthen the welding at the hoisting point or change the cross-sectional dimension of the structural reinforcing member.

5. Summary

According to the results of calculation analysis and finite element analysis, under the hoisting condition, the compressive stress of the 1-3 section of the maximum force of the truss is smaller than the allowable stress of the material, and the axial force of the lower angle of the truss is much smaller than that of the axial force of the 1-3 section. Combined with the results of ansys analysis, the maximum stress point is located at the location of the truss lifting point. The finite element analysis results of the truss bar section are similar to those of the force analysis. The maximum deformation value meets the requirements of the specification, and the designed truss structure is safe and reliable.

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