Model Design and Calculation Analysis of Large Span Space Structure

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Abstract: In order to work out the problem of insufficient bearing capacity for large span space structure, the structural model optimization design and fabrication process were researched by using Structure Analysis Program 2000 (SAP2000) and Finite Element Analysis Software (ANSYS). The model strength, rigidity deformation and stability analysis were calculated respectively according to the software. A series of innovative work during the design and manufacture process of the entire model were carried out, finally by designing and making large-span spatial structure model and loading test, the loading characteristics of large-span spatial structure were gotten, and some design advice were put forward.

1. Introduction
Large-span spatial structure is one of the important symbols of national building science and technology development level. Countries all over the world attach great importance to the research and development of space structure, such as international exposition, Olympic Games, Asian games, etc. All countries show their building science and technology level with new space structure [1]. For this, the structural design competition problem in the engineering background of large span space structure, proposed through the structural model design, production and loading, asked the students for the static load and random load and moving load and other load conditions, the model of force bearing analysis on the spatial structure of production and testing, the three kinds of load conditions respectively corresponding to the actual structure design of the constant load, live load and change the direction of the horizontal load, explore the large span spatial structure under vertical and horizontal to the load of the mechanical performance and failure characteristics, provide reference for the structure optimization design.

By making large-span spatial structure, and using special loading device to simulate different working conditions to apply vertical and horizontal loads, and measuring the displacement of designated parts, the mechanical performance of large-span spatial structure is studied and Suggestions for optimal design are put forward, which has practical scientific significance and engineering practical value. Through this contest, can examine the students' ability of computer modeling, structural optimization under multiple load condition combination abilities of analysis and calculation, complex space node design installation, test students' knowledge of civil engineering structure comprehensive utilization ability, creative introduction of practical engineering problems, to expand students' vision, simulate innovation consciousness, cultivate scientific thinking very useful [2-3]. Starting from the structural design competition, this paper expounds the design and production of the "Sanctuary" of the national competition of Hubei University of Technology from all aspects.
2. Structure system analysis
As architectural engineers, they often pay more attention to the function and appearance of the structure, but from the perspective of structural engineers, they pay more attention to the rationality and practicality of the structural system \[4\]. According to the requirements of the problem and the mechanical properties, we chose the model system based on the reticulated shell structure. On this basis, we simplified the structure and put forward a variety of schemes.

Type 1: Reticulated shell double layer, four loading points were set in the first layer and four loading points were set in the second layer. The upper and lower layers were arched connected by each product. The whole structure was symmetrical in the center, with good structural integrity and uniform force. The corresponding entity model is shown in figure 1.

Type 2: Single-layer arch structure 1. The model had a light dead load of 115g. The size of the model was a space grid with a 460mm outer ring radius at the bottom and a height of 400mm. The mutually perpendicular arch rings transferred the load to the bottom plate. The corresponding entity model is shown in figure 2.

Type 3: Single-layer arch structure 2. The model had a dead load of 86g and consisted of two mutually perpendicular arch rings and a landing strip. The structure node connection was relatively simple, the node was few, the node and the load point position superposition completely, the usage amount of the pull belt was many, the size of the rod was relatively thick, the manufacture process was relatively simple. The corresponding entity model is shown in figure 3.

Based on the design principle of "light weight, high strength, practical and beautiful", we chose the type 3.

3. Mechanical test of materials
According to the requirements of the problem and the selection of structure, we used a large number of bamboo skins in our model, so we mainly tested the performance of bamboo skins. Reference value of mechanical properties of bamboo: elastic modulus is 60000 MPa, tensile strength along the grain is 150MPa, compressive strength is 65MPa.

Compressive performance test: considering that the supporting column component in the model was the main stressed component, the specimen was made according to the length and section size of the supporting column component in the model. The compressive load-displacement curve obtained by the test is shown in figure 4.

Tensile performance test: in the model structure, the amount of tensile belt was relatively large. The load-deformation curve obtained by the test is shown in figure 5.
Figure 4 Compressive load-displacement curve

Figure 5 Load-deformation curve

Through the performance test, the following conclusions can be drawn:

(1) Under the condition of the same section, the longer the length of the component is, the weaker the corresponding bearing capacity under compression will be. This is mainly because the length of the specimen increases and the slenderness ratios increases accordingly, making the specimen more vulnerable to instability. Since the column members supporting the roof in this model are mainly compression, and the slenderness ratios of the members are relatively large, it can be seen from the test analysis that the buckling failure rather than strength failure is more likely to occur in the form of compression failure of the model members.

(2) There is no significant proportional relationship between the tensile strength and the cross-sectional area of the specimen. The analysis show that the average tensile strength of the tension belt is 65N/mm², which is slightly smaller than the 150N/mm² tensile strength of bamboo provided by the competition organizer. Combined with the experimental analysis, it is shown that the average elastic modulus of the tension belt is 6000N/mm², which is completely consistent with the elastic modulus of bamboo provided by the organizer of the competition. Based on the above test analysis, it is also shown that, in order to ensure that the tensile members have enough bearing capacity, bamboo strips can be directly used as the tensile members.

4. Structural modeling and force calculation

SAP2000 was adopted for structural modeling and analysis of this model structure. All the 8 joints were the loading locations, and hinge constraints were applied at all the column feet and the landing strip. See figure 6 for the three-dimensional axial mapping of the structural analysis model.

4.1 Stress analysis

According to the loading requirements, SAP2000 software should be used to point out the loads under the six full load conditions of the structure model. Due to many possible working conditions, only some representative working conditions were selected. There was only one working condition for the first-stage loading, and there were six possible working conditions for the second-stage loading, and five possible working conditions were selected for the third-stage loading full load based on the first two loading stages.

First-stage loading: according to the results of internal forces analysis, the maximum axial force and maximum bending moment borne by each component were 129.76N and 122.60N·mm respectively. The shear force and torque were relatively small, which can be almost ignored. Therefore, the component was mainly subject to axial force, reaching the expected design goal.

Second-stage loading: according to the results of internal forces analysis, the maximum axial force was 279.18 N, and the maximum bending moment was 209.57N·mm. Shear and torque were still relatively small, which were approximate negligible. Compared with the first-stage load, components caused by internal force under secondary load increased, but components were still mainly by the axial force, achieving the desired design goal.

Third-stage loading: according to the results of internal force analysis, under the three-stage loading condition selected above, the maximum axial force and maximum bending moment borne by
each member were 310.35N and 252.68N·mm respectively. The shear force and torque were still relatively small and can be approximately ignored. Compared with the first-stage and second-stage loading, the overall internal forces of the components under the third-stage loading are further increased, but the overall components were still subject to axial forces, reaching the expected design goal.

Since this model was faced with many working conditions, starting from the basic idea of improving the efficiency of structural design, it was more instructive to analyze the most unfavorable internal forces of main stressed members under various possible working conditions, i.e. to find out the internal force envelope diagram of structural members under various working conditions, compared with the analysis of internal forces under each working condition. Table 1 shows the most unfavorable internal forces of main bearing members under various possible working conditions.

Table 1 The most unfavorable internal forces of main bearing members under various possible working conditions.

| No | Axial force(N) | 2-2 Bending Moment (N·mm) | 3-3 Bending Moment (N·mm) |
|----|----------------|---------------------------|---------------------------|
| 10 | 21.60          | 1.56                      | -0.09                     |
| 11 | 38.41          | 10.16                     | -0.43                     |
| 13 | 34.53          | 18.74                     | -0.41                     |
| 14 | 73.96          | 6.64                      | -0.38                     |
| 15 | -324.50        | 0.00                      | 0.00                      |
| 16 | -310.35        | 0.00                      | 0.00                      |
| 17 | -251.86        | 0.00                      | 0.00                      |
| 18 | -144.49        | -203.95                   | -247.81                   |
| 19 | -160.67        | -62.36                    | -267.82                   |
| 20 | -174.46        | -46.65                    | -357.87                   |
| 21 | -170.59        | -37.31                    | -302.89                   |
| 22 | -183.20        | -10.89                    | -292.11                   |
| 23 | -104.67        | -35.08                    | -489.69                   |

According to the internal force analysis results given in table 1, it can be seen that:

(1) According to various working conditions, the maximum pressure to be faced by the supporting component of the large-span structure is 324.50N, and the corresponding stressed component is No.15. The maximum bending moment of the section is 489.69N·mm, and the corresponding stressed component is No. 23. Most of the components can be regarded as "bidirectional bending" components. In the design of the whole large-span structure, special attention should be paid to the design of No.15 and No.23 to ensure that their bearing capacity meets the requirements.

(2) No. 14 component is a tensile belt, which can only withstand the tensile force. Table 1 shows that the maximum axial tensile force is 73.96N, the sectional area is 4mm², and the corresponding tensile stress is 73.96/4= 18.49MPa, indicating that the tensile force of this model meets the requirements of expected bearing capacity.

4.2 Analysis of bearing capacity

Due to the different internal forces at different positions of each component, the stress at the corresponding section was also different. Considering the existence of a variety of possible working conditions, the stress of the corresponding component at different sections under each working condition was calculated. The maximum tensile stress to be borne in the components was no more than 60MPa and the tensile strength was no more than 65Mpa, which can meet the strength requirements. According to the stress cloud diagram analysis function of SAP 2000, the most adverse stress cloud diagram along the axial direction of main stressed components under various possible working conditions was given, as shown in figure 7.
In the design of the structure, intensity, stiffness and stability were three conditions that must be satisfied. Structural stability can usually be determined by eigenvalue buckling analysis, which can give the overall safety coefficient and instability mode of the structure and provide an effective reference for structural design. Due to the existence of tension belt, we chose ANSYS software to analyze the stability of the structure model. Through calculation, the maximum safety coefficient of the structure was 1.64 and the minimum safety coefficient was 1.15 under six loading conditions, and the stability met the requirements. The 2-3 working condition was the most dangerous situation, and the safety coefficient was only 1.15. But in the finite element analysis according to simplify of hinge support column foot, and the actual structure column foot through screws, bearing a certain rotational stiffness, to some extent, improving the safety coefficient. According to the above analysis, carried out many experimental tests, results showed that the structure was safe and reliable.

Comprehensive structural modeling and stress analysis showed that:

(1) From the analysis results of internal forces of components, the shear force and torque were relatively small and can be almost ignored. Therefore, the overall components were subject to axial force, reaching the expected design goal. Meanwhile, the maximum pressure to be faced by the supporting components of the large-span structure was 324.50N. The maximum bending moment of the section was 489.69N·mm. Most of the components can be regarded as "biaxial eccentric compression" components. In the design of the whole large-span structure, special attention should be paid to the No.15 and No.23 to ensure that their bearing capacity meets the requirements.

(2) From the perspective of structural deformation: under the first-stage and second-stage loading, the maximum vertical displacement at the designated part of the structural model were about 0.16mm and 1.31mm respectively. The deformation values were all within the control range, indicating that the rigid weight ratio of the structure met the expected requirements.

(3) The bearing capacity of the structure was affected by the uncertainty of calculation mode, material size and material performance [5], which should also be paid attention to.

5. Conclusion

The National Structural Design Competition for College Students is the highest-level discipline competition for civil engineering disciplines to cultivate college students' innovative spirit, team spirit and practical ability, which is known as "the brightest pearl in the crown of civil engineering". Through this taking part in this competition, we applied knowledge in design and production of the models, not only enhanced the ability of software modeling, also improved our hand-made and thinking ability, developed good scientific spirit, stimulated innovation and team cooperation ability. In addition, it can further consolidate the knowledge of civil engineering professional knowledge and improve ability of practical application.

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