Analysis on the Selection of Prefabricated Box-Shaped Steel Grid-Concrete Composite Thin-Shell Roof Structure

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Abstract. The new fabricated box-shaped steel grid-concrete composite thin-shell roof structure is a new structure based on the large-span steel-concrete composite thin-shell roof. An assembly unit composed of thin-walled steel ribs with bolt holes, a steel bottom plate, and concrete, and a thin-shell roof structure formed by assembly connection between the assembly units. A comparative analysis of the deformation and stress of the flat roof and arched roof structure shows that when the span is less than 30m, the difference between the deformation and stress of the two structures is not large, and it is more reasonable to choose the flat assembled composite roof structure. The construction difficulty is lower. When the span is 40m, the maximum vertical displacement of flat roof and arched roof are 53.73mm and 17.81mm respectively, and the difference gradually increases from 40m. After the span exceeds 40m, the stress between the steel box and concrete of the flat roof structure. The ratio increases sharply, and the arched roof shows a uniform change trend. The material utilization rate of the arched roof is higher than that of the flat roof.

Keywords. Fabricated, thin shell structure, flat roof, arched roof.

1. Introduction
The fabricated building structure system mainly includes: fully fabricated and fabricated monolithic concrete structures, fabricated steel structures, fabricated wooden structures and fabricated steel-concrete composite structures [1]. For a long time, concrete structures have played a dominant role in my country’s building structure system, with good durability and fire resistance. However, due to its long construction period, difficult theoretical calculations, complex template support and other problems, it is less used. Compared with our country, foreign prefabricated technology developed earlier, especially in North America and Western Europe [2], mainly including composite beam slabs [3], laminated double T slab floor cover [4-6] and other prefabricated combinations However, there are few researches on the combined grid structure. The main steel hollow grid structure is the "CUBIC Space Frame" system. The overall force performance of this structure is good, but the chord and web are eccentrically loaded. Force member [7]. In China, the open-web sandwich panel [8], a new type of spatial grid structure, was first proposed by Academician Kejian Ma. It not only has the advantages of open-web grids, but also solves the shortcomings of open-web grids with poor shear stiffness.
It is difficult to meet the requirements of building usability, economy and construction convenience to adopt traditional beams and slabs and truss structures in large-span spatial structures. Most of the assembled structures are concentrated in grid shells, tubular truss structure systems and derived chord supports. In the structural system. Among them, there are bolt balls and welded hollow spheres in the grid shell structure that have a large proportion of their own weight, the overall deformation of the structure is difficult to control, the deviation of the geometrical size of the rods and nodes, and the deviation of the curved surface affect the internal force, overall stability and construction accuracy of the structure Larger issues [9]. In view of the above problems, this paper proposes a new type of structure based on the long-span steel-concrete composite thin-shell roof. The structure is composed of an assembly unit composed of thin-walled steel ribs with bolt holes on the upper and lower ribs and a bottom plate, and concrete is used as a filler. The assembling connection between the panels forms the ribbed shell roof structure. The bottom plate of the assembly unit is straight, and the curved surface of the overall structure is realized by changing the assembly angle of the thin-walled ribs [9].

2. Construction Form
As shown in figure 1. The new prefabricated combined roof structure is a grid-shaped roof structure system formed by welding steel plates to form a box-shaped assembly structural unit with an open upper part, and then assemble these assembly structural units together in pairs. The box-shaped assembly structure unit is composed of multiple thin-walled steel ribs with bolt holes, flat or slightly curved steel bottom plates, studs and precast (cast-in-place) concrete blocks. A special-shaped roof structure with an arbitrary curved surface shape is formed by assembling and connecting two or two bolts of the assembly structure unit.

1-Precast (cast in place) concrete blocks; 2-High-strength bolts; 3-Thin-walled steel ribs; 4-Thin-walled steel floor; 5-Bolt hole; 6-Pegs; 7-Flange ribs

Figure 1. Schematic diagram of assembly structure unit structure.

3. Structural Selection Analysis
This paper studies the two structural forms of the new prefabricated composite roof structure system, namely, the orthogonally placed flat panel prefabricated composite roof structure and the arched prefabricated composite roof structure. Since the structure is fixed and constrained at both ends, the lateral force transmission of flat-plate and arch-shaped assembled composite roof structures are the same. Therefore, this chapter takes a structural study. The span of the two is between 30 m and 70 m, and the amplitude increases every 10 m. The grid size is 3 m×3 m, the structure height is 800mm, the thickness of the concrete slab is 200 mm, the thickness of the steel plate is 6mm, and the upper and lower flange heights are both Take 200 mm, and use 2 m×2 m reinforced concrete side beam for the
support. In addition, the rise-span ratio of the arched roof structure is controlled by 1/10. The steel material constitutive model adopts the von-Mises analysis model provided by the program, the strength grade is HPB235, the initial yield strength is 215 N/mm$^2$, the elastic modulus is 2.06×10$^5$ N/mm$^2$, and the Poisson’s ratio is 0.3; the concrete adopts the total strain cracking model. Structural model, the strength grade is C40, the compressive strength $f_c$ is 26.8 N/mm$^2$, the tensile strength is $f_t$ is 2.39 N/mm$^2$, and the Poisson’s ratio is 0.2. A load of 10 kN/m$^2$ is applied to the structural grid.

3.1. Deformation Analysis

As shown in figure 2, the displacement cloud diagram of the 30 m-span flat-panel and arch-shaped prefabricated composite roof structure is extracted. Under the constraints of both ends, the deformation trend of the two structures is the same, and the maximum vertical displacement occurs at the mid-span position.

As shown in table 1, with the increase of the span length, the displacement of the flat-panel prefabricated composite roof structure shows an obvious upward trend, and the upward trend of the displacement of the arch prefabricated composite roof structure is almost insignificant. When the span is 30 m, the mid-span vertical displacement of the two meets the requirements of the long-span space structure for the deflection-span ratio specification. If the span is continued to increase, the gap between the vertical displacements of the two mid-span increases significantly.

![Deformation Analysis](image-url)
Table 1. Maximum vertical displacement of structure under different spans.

| Span (m) | Maximum displacement in span (mm) | Torsion span ratio |
|---------|----------------------------------|-------------------|
|         | Flat type | Arched | Flat type | Arched |
| 30      | 14.97     | 10.04  | 1/2004    | 1/2988  |
| 40      | 53.73     | 17.81  | 1/558     | 1/1684  |
| 50      | 151.58    | 27.80  | 1/198     | 1/1079  |
| 60      | 370.67    | 36.80  | 1/81      | 1/815   |
| 70      | 777.76    | 54.36  | 1/39      | 1/552   |

Under the same economic level, it is more reasonable to choose flat-panel assembly roof structure for roof structure below 30 m, and the construction difficulty is lower. After the span exceeds 50 m, the two-end constrained flat assembled composite roof no longer meets the requirement of large-span to deflection-span ratio. The arched assembled composite roof structure constrained at both ends can meet the design requirements of a larger span.

3.2. Stress Analysis

As shown in figure 3 and figure 4, the maximum stress of the flat structure occurs near the side beam supports at both ends and the middle of the span, and the stress at the 1/4 span position is the smallest; the maximum stress of the arch structure is mainly concentrated at the support, but the overall stress The distribution is more uniform than the stress distribution of the flat structure. Due to the fixed restraint at both ends, the horizontal rigidity of the arched structure is infinite, resulting in greater maximum stress than the flat roof structure. Therefore, the arch assembly type combined roof structure requires higher rigidity of the side beam support.

![Mises stress cloud diagram of 30 m flat roof structure steel plate](image1)

![Mises stress cloud diagram of 30m arched roof structure steel plate](image2)

Figure 3. Cloud map of Mises stress on steel plates with 30m span plate and arch structures.

![Mises stress cloud diagram of 30 m flat roof structure concrete](image3)

![30 m arched roof structure concrete Mises stress cloud diagram](image4)

Figure 4. Mises stress cloud map of concrete with 30m span slab and arch structures.
Under the same conditions, the average stress values of the concrete and steel box of the two structures are extracted as shown in Table 2. The analysis shows that the ratio of the concrete stress to the steel box stress of the flat roof structure increases with the increase of the span, and the arched roof the stress ratio of the cover structure concrete to the steel box hardly changes with the span. It shows that the force of arched roof structure is more reasonable than that of flat roof structure.

Table 2. Stress averages of flat and arched roof structures with different spans.

| Span (m) | Flat stress mean (Mpa) | Mean value of arch stress (Mpa) |
|---------|------------------------|-------------------------------|
|         | Concrete | Steel box | Ratio | Concrete | Steel box | Ratio |
| 30      | 3.35     | 42.17     | 0.0696 | 6.27     | 90.41     | 0.0694 |
| 40      | 8.74     | 135.07    | 0.0647 | 7.70     | 107.87    | 0.0714 |
| 50      | 19.58    | 250.30    | 0.0782 | 9.16     | 125.62    | 0.0729 |
| 60      | 28.24    | 311.24    | 0.0907 | 11.25    | 141.70    | 0.0794 |
| 70      | 42.61    | 321.37    | 0.1326 | 12.01    | 160.12    | 0.0750 |

As shown in Figure 5, when the span is less than 40 m, there is little difference in the stress ratio between the two. When the span exceeds 40 m, the stress of the flat roof structure increases significantly, and the stress ratio increases sharply. The stress ratio between steel box and concrete showed a uniform trend. It shows that after the span exceeds 40 m, the material utilization rate of the flat roof structure is low; when the structure span is continued to increase, the arched roof structure can still make full use of materials, which is consistent with the structural deformation trend analysis.

Figure 5. Graph of the influence of span length on structural stress.

4. Conclusion

- Based on the strain analysis of the two structures at different spans, it is more reasonable to choose the flat-panel assembly roof structure for the roof structure below 30m, and the construction difficulty is lower. The arched assembled composite roof structure constrained at both ends can meet the design requirements of a larger span.

- The ratio of concrete stress to steel box stress of flat roof structure increases with the increase of span, while the ratio of concrete to steel box stress of arched roof structure hardly changes
with span. It shows that the force of arched roof structure is more reasonable than that of flat roof structure.

- When the span is less than 40m, there is little difference in the stress ratio between the steel box and concrete of the two roof structures. When the span exceeds 40m, the ratio of the flat roof structure increases sharply, while the arched roof shows a uniform change trend. It shows that after the structural span exceeds 40m, the material utilization rate of the arched roof is higher than that of the flat roof, and the arched roof is more reasonable.

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