Structural design and optimization of large-span three-centered cylindrical reticulated shell in a coal-fired power plant

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Abstract—Taking the dry coal shed of a coal-fired power plant as an example, the reticulated shell structure model of large-span three-centered cylindrical is established according to the specification requirements, and its design and optimization are carried out. It is to use the full stress design method to establish multiple comparison models by adjusting the thickness of the grid, to do the analysis and calculation for obtaining the comparison results of steel consumption, maximum vertical displacement and overall stability of different models, and then to determine the optimal span ratio of the large-span reticulated shell structure. All of these aim to draw relevant conclusions and provide reference for the design and optimization of similar large-span three-centered cylindrical reticulated shell engineering.

1. Introduction
The control of air pollutants in China is increasing day by day, and the open-air coal yard of coal-fired power plants can no longer meet the requirements of environmental protection. Fully enclosed coal yard can effectively reduce coal dust emissions, improve the quality of atmospheric environment, control dust and alleviate haze problems. Therefore, the construction of fully enclosed coal shed is not only related to the rational use of coal resources, but also related to the construction and development of economic, environmental and other fields, which is of great significance [1]. Among various closed forms, large-span reticulated shell is increasingly applied to the coal yard closure of coal-fired power plants. When the coal yard has a large span and the column cannot be set in the middle due to the operation of reclaimer, the traditional plane rigid frame, plane truss and plane arch structure can no longer meet its functional requirements, while the cylindrical reticulated shell structure perfectly solves this problem. The structure of cylindrical reticulated shell mainly includes two types of cylindrical reticulated shell and three-centered cylindrical reticulated shell. Compared with the former, on the one hand, it can improve the space utilization rate; on the other hand, its landing angle is smaller, and the horizontal thrust of the main structure to the foundation is smaller, which can improve the economy of basic design [2].

2. Project overview
The horizontal span of the coal shed is 130.50m, the longitudinal length is 204.50m, and the total construction area is 26,687.25m$^2$. The vector height of the coal shed is set to 39.94m to meet the reclaimer operation. The enclosure structure of this project consists of purlin and profiled steel plate,
and auxiliary assembly includes lighting, fire-fighting, water supply and drainage, electrical, etc., which meets the normal use requirements of coal yard.

3. Structure form
The plane shape of this project is close to rectangle, showing multi-directional force behaving; the transverse stiffness is relatively weak. The dry coal shed adopts a three-centered cylindrical reticulated shell structure, which has the characteristics of structural system composed of member simple structure and reasonable stress of shell construction, and has beautiful structure, low steel usage, good rigidity, concise form of power transmission. The square quadrangle mesh form selected in this project is conducive to saving the amount of steel used, improving the structural rigidity and achieving better economic effect. The bearing connection node is welded ball node, and the support mode is longitudinal upper chord support.

According to the method in Jin et al. [3], it is to optimize the geometric parameters of the structure, and the final number of transverse grids is 85. Among the three arcs forming the three-centered cylindrical grid, the radius (R) of the large circle is 88.54m, the angle of the arc is 72, the number of grids is 59 grids, and the radius (r) of the two small circles is 32.88m, the arc angle is 48, and the number of grids is 13. The vertical grid is divided into 4.00m. Grid section and axonometric drawing are shown in Fig.1 and Fig.2:

![Fig.1 Grid section drawing](image1)
![Fig.2 Axonometric drawing](image2)

4. Loads and combinations
The reticulated shell bears the following loads:

(1) Dead load: 0.30kN/m², excluding the dead weight of the grid, the roof is closed with single-layer profiled steel plate and purlin;
(2) Live load: 0.50kN/m², act on top chord node;
(3) Wind load: 0.45kN/m² (in 50 years), the ground roughness is class B;
(4) Snow load: 0.20kN/m² (in 50 years);
(5) Seismic: seismic precautionary intensity is 7 degree, design seismic peak ground acceleration is 0.15g, site class: II; seismic group: second;
(6) Temperature load: ±30℃;

According to the Jin et al. [3], 230 combinations should be considered and analysed.

5. Calculation assumption
The spatial structure professional analysis software 3D3S is used for structural analysis, and all members are articulated units.

6. Design parameters
(1) Material: Q355B;
(2) Bearing condition: considering the elastic bearing, the converted stiffness of the input concrete pedestal in the model is as follows: transverse (133.78kN/mm), longitudinal (50.57kN/mm), vertical (6400.00kN/mm);

(3) Stress ratio limit: Key member-0.85, ordinary member -0.90;
(4) Slenderness ratio limit: compression member-180, tensionl member- 250;
(5) Minimum member control: 60*3.5mm.

7. Analysis results and comparison

The above parameters remain unchanged, the steel consumption, maximum vertical displacement and overall stability coefficient are obtained by establishing models with different shell thicknesses and analysing and optimizing. According to the Zhao et al. [4], the thickness of double cylindrical reticulated shell should be between 1 / 20 ~ 1 / 50 of its span. The span of the project is 130.50m. In order to meet the angle between the web member and the chord member between angle 45 and angle 60, the thickness of the grid should be between 2.60m and 6.50m. In this paper, 8 models with thickness of 2.75m, 3.00m, 3.25m, 3.50m, 3.75m, 4.00m, 4.25m and 4.50m are selected for comparison and checking calculation.

Fig.3 Steel consumption per square meter

As can be seen from Fig.3, steel consumption per square meter varies from 41.31kg to 43.26kg with thickness. The minimum value appears when the thickness is 3.50m, compared with 43.26kg when the thickness is 2.75m; the steel consumption is saved by about 4.7 %.

The maximum vertical displacement of space grid structure under constant load and live load should not exceed 1 / 250 [4], that is 130500 / 250 = 522.0mm. It can be seen from Fig.4 that when the thickness gradually increases from 2.75m to 4.50m, the maximum vertical displacement also decreases from 239.7mm to 132.9mm, which is less than the limit value.

The thickness of reticulated shells in this comparison is greater than 1 / 50 of the span, and the overall stability checking shall not be carried out [5]. However, in order to understand the relationship between the overall stability coefficient and the thickness of the reticulated shell, the overall stability is still analysed in this paper.

It can be seen from Fig.5 that when the thickness gradually increases from 2.75m to 4.50m, the overall stability coefficient also increases from 9.36 to 15.22.
8. Conclusions and suggestions

To sum up, through the statistical analysis of eight different thickness models of the reticulated shell, the influence trend of thickness on steel consumption per square meter, maximum vertical displacement and overall stability coefficient are obtained. Some main conclusions are as follows:

(1) In the structural design of the three-centered cylindrical shell with a span of 130.50m, the thickness of shell greatly affects the total steel consumption under the condition that the vertical and horizontal grid division is determined. It is suggested to obtain the most economical steel consumption through trial calculation. Through the comparison of variable thickness models, it is concluded that when the reticulated shell with 3.50m thick three-centered cylindrical is adopted in this project, the steel quantity is the least, and its thickness to span ratio is 1 / 37.

(2) The project has a large span, although the maximum vertical displacement allowed by the specification is 522.0mm. However, considering the operation requirements of reclaimer in the coal shed and the problems of ponding, ash accumulation and rainwater leakage on the roof after excessive deformation, the maximum vertical displacement is controlled according to relatively strict requirements.

(3) For the next research, the author suggests that different grid sizes can be divided according to the support spacing, and then the thickness of reticulated shell can be adjusted according to the principle of optimal included angle, so as to establish more detailed models to further study the effects of grid size and reticulated shell thickness on the total steel consumption, vertical displacement and overall stability coefficient of reticulated shell structure.

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