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Design and Static Analysis of Cellular Double-Layer Grid Roof Structure with Hexagonal Cone System

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Abstract. All The architectural structure system generally consists of three parts, namely the roof structure, the support structure and the basic structure. The rational design of the roof structure is the key to ensuring the realization of the ideal interior space, and is also the key to constructing a beautiful image of the building. In this paper, two structural systems, namely the upright and inverted hexagonal pyramid systems were initially selected. The selection of the cross-section characteristics of the members was then introduced. After modeling, loads under several conditions is applied, and then the most unfavorable load combination is selected. After determining the better structure, calculating the total amount of steel used in this structure and the amount of steel used per unit could provide an important reference for our study and engineering needs.

1. Introduction

In the past 20 years, the reticulated shell structure has developed rapidly, and various forms of reticulated shell structures have been widely used. It includes both single and double layer reticulated shell structures as well as combined reticulated shell structures and even single layer double layer hybrid structures. Among them, the application and examples of the cellular reticulated shell structure are few. However, the structural members that are tiled by the hexagonal grid are relatively sparsely distributed, which can significantly save the building materials, and can provide a transparent visual effect when covering a material with good transmittance which has a good development prospects.

L.Dai has established a general-purpose platform based on computer-aided design (CAD) system for parameterized shape design optimization of shell structures [1]. Michalak models a cylindrical thin-shell shallow shell structure [2]. Garcia uses a hexagonal shell element to simulate a thin composite structure and analyze the mechanical properties [3]. József found the optimal size of the annular reinforced cylindrical shell affected by external pressure, thereby minimizing the structural cost [4]. Ge Zhilong et al. used ANSYS for parametric design and structural stress analysis for cellular spherical reticulated shells [5]. Zhang Yumu conducted a parametric analysis of the cellular cylindrical reticulated shell structure [6].

In this paper, a new type of hexagonal cone system double-layer cellular reticulated shell is constructed. Based on the structural features and structural parameters of the two methods, the finite element model is established. The force characteristics of the two roof reticulated shell structures are



adopted. After the static analysis, a better one is selected. Finally, the section is optimized to obtain the final structure and calculate the amount of steel used.

2. Modeling of shape cellular double-layer shell structure

The double-layer cellular type reticulated shell structure is divided into two categories, the flat hexagonal cone system and the inverted hexagonal cone system. The top view is shown in Figure 1.

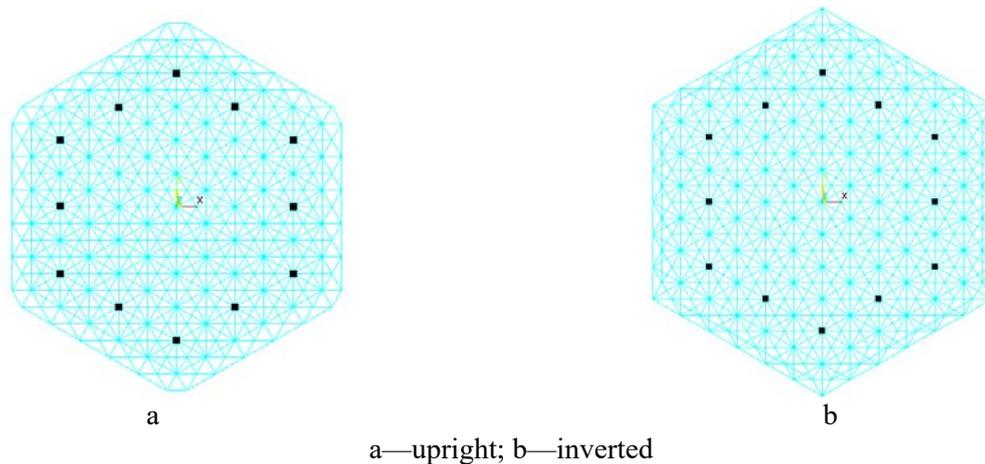


Figure 1. Double-layer cellular reticulated shell structure.

The main geometric features of the two primary structures are tiling according to the law. The bottom side of the hexagonal cone unit is 2m and the busbar length is 3.464 m. The upright hexagonal cone system cannot completely cover the lower structure, so a circle is added outward on the basis of the inverted hexagonal cone system. The maximum span is 41.5m and 38m respectively. According to the provisions in the "Handbook of Steel Structure Engineering Installation and Use", the three-dimensional truss vector height is generally calculated from 1/12 to 1/16, which is 2.59~3.45m and 2.38~3.12m. In order to reduce the length of the rod member and facilitate the subsequent calculation, the length of the web is taken as 3.464 m, so according to the height of the tetrahedron. Since $h = 0.817$, the thickness is calculated about 2.83m.

Table 1. Length and number.

Types	L(m)	Number	Total
a	2	1-56, 63-118, 125-180, 187-242, 249-330	1122
	$2\sqrt{3}$	57-62, 119-124, 181-186, 243-248, 331-1122	
b	2	1-56, 63-118, 125-180, 187-242, 249-330	1196
	$2\sqrt{3}$	57-62, 119-124, 181-186, 243-248, 331-1196	

The roof grid material is selected as Q235 steel, which is characterized by light weight, good tensile and compressive performance, good seismic performance and moderate price. It is widely used in most buildings with a density of 7850kg/m^3 .

Since the rod member is made of hollow steel tube, the cross section is two concentric circles, which are determined by the outer diameter d and the thickness t .

According to the GB8162-1999 standard for the cross-section characteristics of hot-rolled seamless steel tubes [7], the primary selection is shown in Table 2.

3. Modeling of static analysis

The seismic fortification intensity of Shijiazhuang (six municipal districts) is 7 degrees. The basic seismic acceleration of the design is 0.10g. According to the relevant specifications in GB 50011-2010 "Code for Seismic Design of Buildings" and JGJ 7-2010 "Technical Regulations for Space Grid Structures" [8, 9], it is not necessary to carry out seismic verification. Therefore, it is not necessary to perform seismic proofing when the load of the double-layer roof structure is combined.

According to the provisions of the GB 50009-2012 "Building Structure Load Code" on the load combination working conditions [10], the live load is not evenly distributed on the roof, and may not be combined with the wind load and the snow load, so the live load only considers the snow load.

Condition 1: 1.35* rods weight +1.35* nodes weight;

Condition 2: 1.35* constant load;

Condition 3: 1.35* constant load +1.4*0.7* roof live load;

Condition 4: 1.35* constant load +1.4*0.7* roof live load +1.4*0.7* snow load;

Condition 5: 1.35* constant load +1.4*0.7* roof live load +1.4*0.7* snow load+1.4*0.6* wind load.

Table 2. Stress and strain.

Conditions	Type a			Type b		
	Max Stress (MPa)		$x(\text{mm})$	Max Stress (MPa)		$x(\text{mm})$
1	$\sigma_t = 7.90$	$\sigma_c = -7.82$	1.165	$\sigma_t = 6.67$	$\sigma_c = -9.74$	1.44
2	$\sigma_t = 13.1$	$\sigma_c = -11.8$	2.422	$\sigma_t = 9.04$	$\sigma_c = -16.5$	2.633
3	$\sigma_t = 22.5$	$\sigma_c = -21.5$	3.495	$\sigma_t = 15.3$	$\sigma_c = -27.6$	4.043
4	$\sigma_t = 28.1$	$\sigma_c = -27.2$	4.372	$\sigma_t = 20.0$	$\sigma_c = -35.3$	5.178
5	$\sigma_t = 24.5$	$\sigma_c = -23.0$	3.867	$\sigma_t = 16.7$	$\sigma_c = -29.5$	4.305

It can be seen from the data in Table 3 that under the normal use limit state, the most unfavorable load combination is the working condition 4. The structure is used as a net roof structure, and the allowable deflection is $w=L/400=38/400=95$ mm. The maximum deflection of the two structural structures is 5.178 mm respectively, which satisfies the allowable deflection requirement, and therefore the rigidity conforms to the specification.

For type a: maximum compressive stress is 27.2 MPa, occurs in the lower chord. The length of the rod is 2 m. $i=2.30$ cm, $\lambda = 150.6$. Look up the section parameters and use the interpolation method to get $\varphi=0.3706$.

$$\sigma_{c \max} = -27.2 \text{ MPa} \leq f\varphi = 70.414 \text{ MPa} \quad (1)$$

For the middle web: $l=3.464\text{m}$, $i = 2.27$ cm, $\lambda = 152.6$. Look up the table type a section and use the interpolation method to get $\varphi=0.386$.

$$\sigma_{c \max} = -27.2 \text{ MPa} \leq f\varphi = 73.34 \text{ MPa} \quad (2)$$

Overall stability.

For type b: maximum compressive stress occurs the upper chord neared the support. $l=2$ m, $i = 2.27$ cm, $\lambda = 88.11$.

When $\lambda = 88$, $\varphi = 0.728$;

When $\lambda = 89$, $\varphi = 0.721$.

Using the interpolation method, we can get $\lambda=88.11$ and $\varphi=0.727$.

$$\sigma_{c \max} = -35.3 \text{MPa} \leq f\varphi = 138.13 \text{MPa} \quad (3)$$

For the middle web: $l=3.464\text{m}$, $i = 2.27 \text{ cm}$, $\lambda = 152.6$, $\varphi=0.386$.

$$\sigma_{c \max} = -35.3 \text{MPa} \leq f\varphi = 73.34 \text{MPa} \quad (4)$$

The overall stability is comply with specifications. Although it is conforms with the specifications in terms of stability, the compressive stress of the hexagonal cone structure is smaller and less likely to be unstable. The maximum compressive stress of the mid-layer web of the type b is very close to the maximum allowable stress. Thus, we can select the upright hexagonal cone system.

4. Conclusion

The structural model is established by using the parametric design language APDL of ANSYS finite element analysis software, so that the geometric parameters of the input structure can generate the required structural model, which greatly simplifies the modeling process.

Through the exploration of the roof structure design, we can know that the upright hexagonal cone system exhibits more excellent stability under almost the same footprint and the most unfavorable load compared to the inverted hexagonal cone system. The rods of the most dangerous section of the hexagonal pyramid are more prone to buckling. Therefore, in the later study and work, we are more inclined to choose the right hexagonal cone as the preferred system.

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