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Structural dsign of the Erdos Museum Evelope

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Abstract

The Erdos Museum's envelope is designed as a very irregular and huge stone, with an approximate diameter about 110m, altitude of about 40m. The level projection area is 10000m^2, and the surface area is 20000m^2. As the museum's envelope is a spatial free form shell, its curvature changes at random. Many long or huge skylights are decorated on the envelope with strict limits that only one direction members can traverse the skylights. In order to reflect the architect's vision faithfully, the structural model is built completely relying on the 3-D model that architect provides. In this paper, the modeling and calculating methods of a spatial free form shell is developed valuably.

As the shell shape of this project is unique, the structural systems of space-truss, single-layer shell and double-layer shell are compared in the paper, and the shortcomings of the three structural systems will affect the function, or result in construction difficulty. In order to meet the demands on bearing capacity and deformation capacity of the structure, and reduce the construction difficulty as far as possible, this paper presents a new structural system: stiffened single-layer latticed shell, which combines the advantages of before-mentioned structural systems. It cuts down the working procedure of the secondary structural form-finding processes between the roof (walls) trusses grid areas in space-truss system, and solves the problems of the large deformation and poor stability in single-layer shell system. At the same time, the total number of the components in the stiffened single-layer latticed shell system is less than half of that in double-layer shell system. The difficulty in structural installing and shortening the construction period can be solved by adopting the new structural system.

Keywords: steel shell spatial irregular curved face stiffened single-layer latticed shell

1. Project introduction

The building area of Erdos Museum is 41610m^2, the height is 40m, and the span is 110m with respect to longitudinal and latitudinal direction. Its projection area is about 10000m^2, while the surface area is approximately 20000m^2. The structure is composed of one underground storey and five up-ground storeies. The effect picture is shows in Figure 1.

The envelope is supported on the concrete-filled steel tubular columns of the inner towers and the concrete beam of the basement. The support condition is shown in Figure 2.

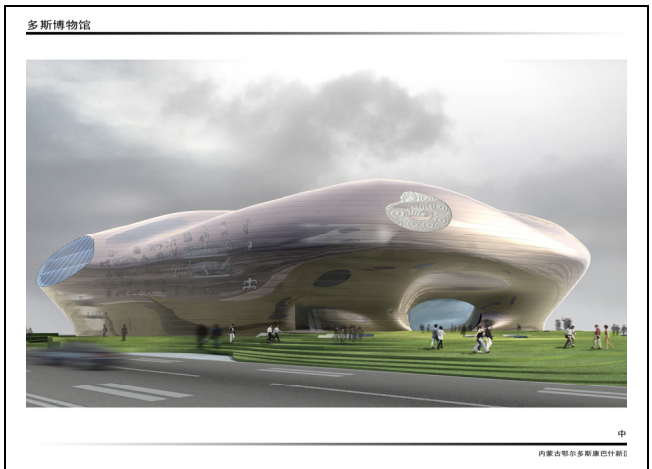

Fig.1 Effect picture of Erdos Museum

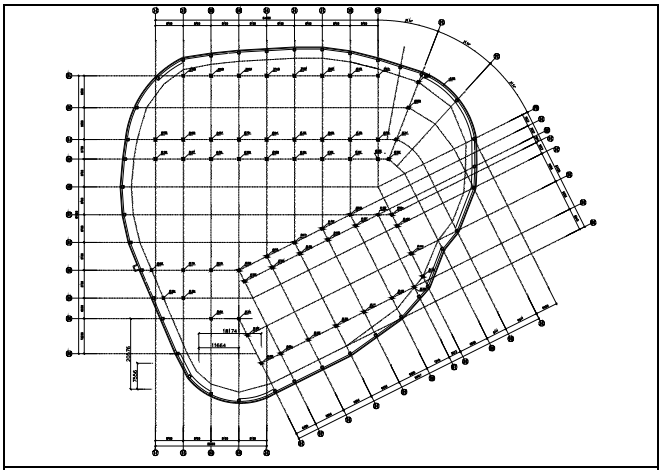

Fig.2 Support condition

The structural security class is 1st class, the seismic fortification intensity is 7(0.1g), the group of seismic design is 3rd group, II site, the reference wind pressure is 0.60kN/m^2, the reference snow pressure is 0.40kN/m^2, the temperature load is ±30℃, and the design service life is 100 years.

The museum's envelope is a spatial irregular curved face with many huge holes, without any regulation, and there are many strict limits at holes which is adverse to the structure.

2. **The structural scheme comparison**

2.1 Space-truss scheme

The two tower roof and its one side elevation adopt tube beam, while the roof out of the two towers and the elevation adopt truss structure. The interval of truss is mainly 8.1m. The span of the skylight is about 19m, with a circle truss around it. The elevation of the shell also adopt circle truss and tube beam. The force transfer system of the truss scheme is very clear and concise[1], and the stiffness of this truss plan is very strong. However, the shape of the shell is very irregular, and the positive and the negative curvature change continually in one district. If this plan is adopted, the roof should do much shaping work, so this scheme is very difficult to achieve.

2.2 Single-layer shell scheme

Since the shape of this structure is very irregular, the structure model absolutely comes from the model of the architect supplied in order to decrease the difficulty of construction and reflect the architect's vision faithfully. Considering the superficial material, the structure model is achieved by offsetting 500mm from the architectural model. The roof is carved up by three direction grid, and the grid is equilateral triangle, which side length is 3m. Since the distance is 2.6m, the purlin of the curtain wall can support on the shell, it is very simple to achieve the precise shape. However, the stiffness is not enough owing to the irregular shape[2], the deformation is too large, and the stability is very weak.

2.3 Double-layer shell scheme

According to the grid of the single layer shell, the lower chords surface can be obtained by offsetting the upper chord surface 1.0m to inner or below, while the braces are achieved by connecting the upper and lower chords' end-points and mid-points, and then gain the double-layer shell. Because of the big stiffness, the double layer shell is very effective at anti-deformation and the maintenance of stability[3]. As the same as the single-layer shell, secondary shaping work are not need, and also the construction difficulty is reduced. But the number of the components is about 6 times of the single layer shell; therefore the construction period must be delayed. Since the length of some components is very similar, it is very easy to get confused during construction.

3. New structural scheme

Aiming at the particularity of this project, and after the comparison of the truss plan, the single layer shell plan and the double layer shell plan, some shortcomings of each scheme are found, such as the achieving of structural function or the increasing of construction difficulty. In order to satisfy the precondition of the deformation and decrease the construction difficulty to a certain extent, a new structure is developed in this paper--stiffened single-layer latticed shell.

3.1 Definition of the stiffened single-layer latticed shell

According to some character of the curved surface, such as span, space configuration, demand of stiffness, support condition and manufacture and installation condition, the stiffened trusses are laid on the single-layer latticed shell at special region, direction and

interval. The character of force transfer is the same as the single-layer latticed shell by adjusting the intension of the stiffened truss.

In this project, according to the analysis of the former schemes, the stiffened trusses are arranged at an interval of 2 or 3 grids on the basis of the single-layer latticed shell. At the elevation the stiffened trusses are arranged at an interval of 3 grids, while on the roof, the stiffened trusses are arranged at an interval of 2 or 3 grids. The structural arrangement is shown in Figure 3 and Figure 4.

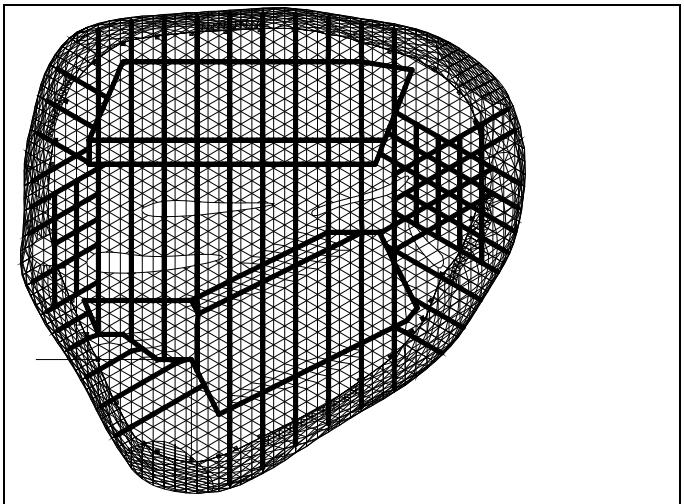

Fig.3 Plane layout of stiffened single-layer latticed shell scheme

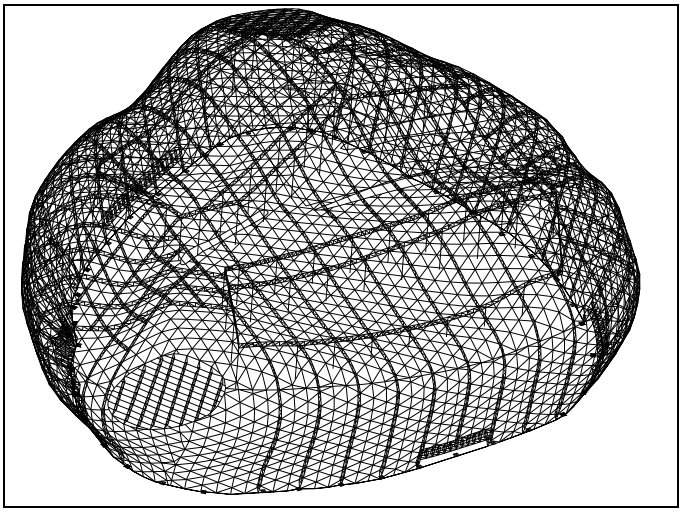

Fig.4 Three-view diagram of Stiffened single-layer latticed shell 3-D figure

3.2 Effect theory of stiffened single-layer latticed shell

The truss of the stiffened single-layer latticed shell only works as the "stiffener", the internal force of truss and shell are similar. The stiffness of the truss can't be too weak, or else the deformation of the structure can't be well controlled, and the stability of the shell can't be enhanced either; The stiffness of the truss can't be too strong, or else the internal force of the shell will be too small, and then the section of the truss will be too big while the section of the shell will be too small. As a result, since the stiffness of the truss is of greatness and the interval is too large, the stiffness of the shell is weakened severely, and the structural character of the stiffened single-layer latticed shell is much close to the truss system, the spatial integrity is weakened, and the change of the temperature will greatly influence the force of the component and fixation.

In this project, the structural deformation can be controlled into an acceptable range by means of adjusting the stiffness of the stiffened truss; in the meantime the stability of the shell can be improved greatly. The section of the truss chord and the shell are same, the height of the truss is 1.0m. In order to decrease the stiffness of the truss at the fixation, the truss chords are pooled together, and are connected to the concrete beam by hinge fixation. Braces are fixed to the underside-chord distantly to make sure that the underside-chord is of great stability.

3.3 Application range of stiffened single-layer latticed shell

The stiffened single-layer latticed shell not only can be applied to all kinds of traditional single-layer shell, such as sphere shell、cylinder shell、hyperboloid shell、saddle shell and etc, but also is fit to the structures with irregular roof that can't be dealt with single-layer shell. Since the stiffened single-layer latticed shell is better than the single-layer shell on the ability of anti-deformation and maintaining stability, it can greatly improve the adaptive span of the regular roof. As an inherent defect, the single-layer shell can't satisfy the irregular surface structure, while the stiffened single-layer latticed shell can solve the problem. In order to exert its maximum function, the stiffened truss must be laid straight. The method of mesh partition has some restriction. For example, the sunflower-type mesh can't be used in the stiffened single-layer latticed shell.

In this project, three-dimensional mesh is used, stiffened truss are laid along the direction of the mesh, so the stiffened single-layer latticed shell is feasible.

4. Result and economic analysis

The stress ration nephogram of the total structure can be seen in the figure 5. As can be seen from the figure, the distributing of component's stress is even, and stress ration are all in the range of 0.4 to 0.6, while the stress of stiffened truss and shell are similar, so the structure still has the structural character of shell. The vertical deformation under the standard load combination can be seen from figure 6. The maximum of deformation is -

76.8mm, occurring at the location of hall, where the span is 42.1m, and 76.8/42100 = 1/548 < 1/400，satisfying the correlative code.

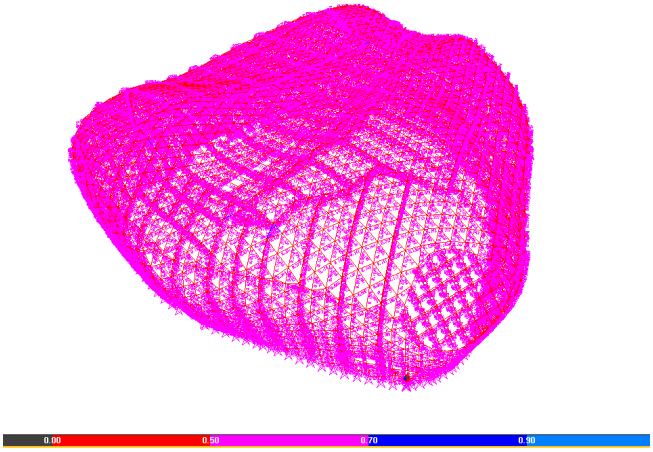

Fig.5 Stress ratio nephogram of the whole structure

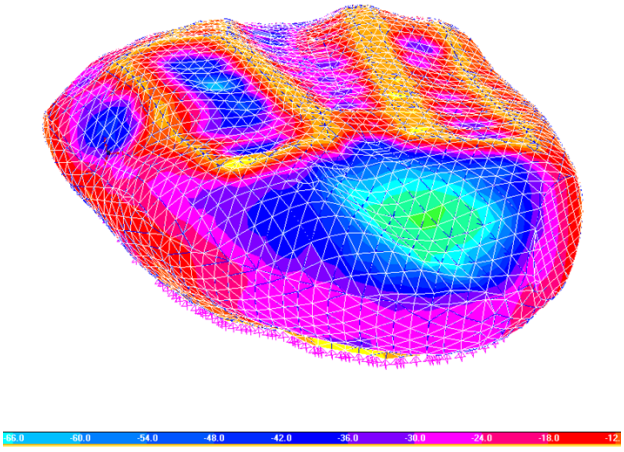

Fig.6 Vertical deformation under standard load combination

The X-direction deformation under the load of rising temperature is -21mm, while the Y-direction and Z-direction is 24mm and -32mm respectively. The X-direction deformation under the load of lowering temperature is 21mm, while the Y-direction and Z-direction is -24mm and -36mm respectively. The X-direction deformation under the load of wind is

60mm, while the Y-direction is 50mm. The X-direction deformation under the load of X-direction earthquake is 13.7mm, while the Y-direction is 9.2mm. The X-direction deformation under the load of Y-direction earthquake is 4.4mm, while the Y-direction is 14.8mm. The X-direction deformation under the load of bidirectional earthquake is 13.8mm, while the Y-direction is 15.9mm.

The modal result of the anterior 20 steps is shown as the table below.

Analysis Case	Modal	Step	Period (s)	Analysis Case	Modal	Step	Period (s)
Modal	Mode	1	0.586202	Modal	Mode	11	0.443753
Modal	Mode	2	0.528063	Modal	Mode	12	0.441815
Modal	Mode	3	0.520959	Modal	Mode	13	0.435211
Modal	Mode	4	0.517011	Modal	Mode	14	0.433415
Modal	Mode	5	0.508192	Modal	Mode	15	0.427533
Modal	Mode	6	0.493932	Modal	Mode	16	0.422569
Modal	Mode	7	0.493283	Modal	Mode	17	0.414291
Modal	Mode	8	0.472108	Modal	Mode	18	0.411578
Modal	Mode	9	0.452706	Modal	Mode	19	0.410108
Modal	Mode	10	0.448077	Modal	Mode	20	0.409106

In this project, steel gross of the whole structure is about 45kg/m^2 by the sequence of adopting the structure system of stiffened single-layer latticed shell, and is of great economy[4]. The scene can be seen from figure 7 and figure 8.

Fig.7 Panorama of the structure under construction

Fig.8 Detail of the structure under construction

5. Conclusion

The structural system of stiffened single-layer latticed shell is novel, the advantages of truss and shell are combined together, and also the disadvantages of the former systems are made up. Firstly, the problems of large deformation and inferior stability are solved. Secondly, the procedure of figuration of the secondary structure is removed. In the meantime, the number of the component is much less than the structural system's of double-layer shell,

As a novel structural system, stiffened single-layer latticed shell not only solves the problems in this project, but also more and more complicated large-span structures can be solved by this structural system.

References

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