Parametric design and static behavior analysis of single-layer hemi-ellipsoida latticed shell

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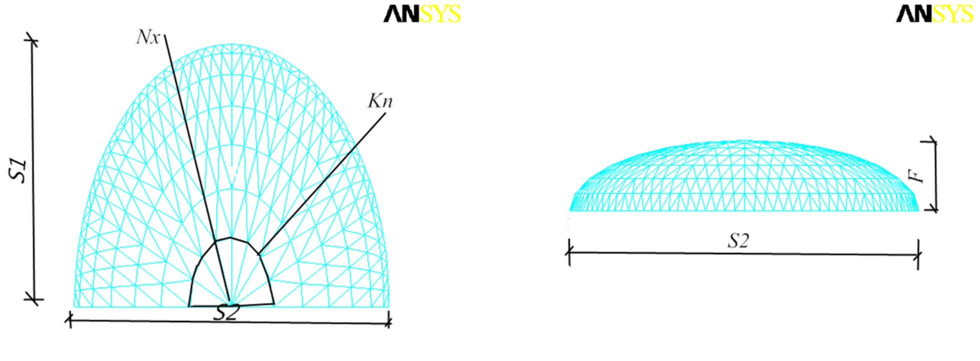
Abstract. The parametric design macro programs of two basic types of single-layer hemi-ellipsoidal latticed shell are developed by using APDL (Ansys Parametric Design Language) parameterized design language. The parametric design of single-layer hemi-ellipsoidal latticed shell structures can be built under the condition of giving the macroscopic geometric parameters such as specifical parameter t, parameter k, span S1, span S2, rise f, valley number Kn, radial node number Nx etc. Ansys software is applied to study comparison of characteristics of the Kewitte type net shell structure of different vector height f, radial node number Nx and boundary constraints. The results show that modeling design of hemi-ellipsoidal latticed shell can be built conveniently and quickly by the application of parametric design of macro program. The three-way grid type is more reasonable force performance, and it’s mechanical performance is better when the span ratio is 1/2. Thus it is suggested to give priority in the project.

1. Introduction

Reticulated has been proposed higher requirements on structural forms, with the rapid development of it at home and abroad and the continuous improvement of people's aesthetic standards [1]. The surface of the semi-ellipsoidal shell that is formed by the plane and the ellipsoid lattice shell is smooth, and the interior space is beautiful and reasonable. The representative building is the American Air Museum at Duxford, Cambridge, England. Many scholars at home and abroad have conducted more in depth research and discussion of spherical shells and cylindrical shells etc there common reticulated shell structures [2,3,4]. However, for the single-layer hemi-ellipsoidal latticed shell, Xiuli Wang [3] studied the nonlinear dynamic analysis of an equilateral triangular three-dimensional grid-type flat-cone single-layer lattice shell. The current research on this type of reticulated shell is not systematic enough and comprehensive. In this paper, the parametric design language APDL [5] was used to develop two kinds of parametric design macros for single-layer conical mesh shells, which improved the efficiency of structural modeling and force analysis. Ansys software was used to analyze the mechanical behavior of structure with vector heights and boundary constraints.

2. Geometric Descriptions of Structures

According to mesh division of spherical mesh shell, the hemi-ellipsoidal latticed mesh shell is divided into six types: ribbed ring type, joint type, Schweidler, Kewitte, three-way grid and Geodesic. The macroscopic geometric parameters [1,6] are the parameter t, the span S1, span S2, the vector height f, the number of the circular region Kn and the number of radial nodes Nx. Then taking the Kewitte for example to describe the method of parametric design (Figure 1).



(a) plan view (b) vertical view

Figure 1 Geometric Diagram

3. Parametric design of single-layer hemi-ellipsoidal latticed shell

Taking Kewitte for example to describe parametric design of single-layer hemi-ellipsoidal latticed mesh shell due to space limitations. (i and j are continuous positive integer)

3.1. Calculate the node coordinates and define the node number

In Cartesian coordinate system, the central axis of the cone is defined Z axis, and the surface is divided into Kn sectors. Then define the most vertex node is No.1. Its coordinates are (0, 0, f). And define the parameter t=1- i×(i+1)/(Nx×(Nx+1)). Dividing the radial length of the ellipsoidal bar to determine the z coordinate is z=t×f, (i=1~Nx), k=Kn/2. Calculating the x and y coordinates of each node: x=S1/2×cos(360×(j-1)/(Kn×i)) ×(1-t2)1/2, y= S2/2×sin(360×(j-1)/(Kn×i))×(1-t2)1/2. The APDL loop statement [7] is used to number the nodes of circle i and number j. The number is 1+Kn×(i-1)×i/2+j, (i=1~Nx,j=1~Kn×i)

3.2. Connect related nodes to form rods

Firstly, connecting Loop unit of the i circle.1 to K×i symmetry area node number are 1+Kn×(i+1)×i/2+j and 1+Kn×(i+1)×i/2+j+1. (i=1~Nx, j=1~K×i).

Secondly, connecting Radial Lever. Connection node 1and 1+j, (j=1~K+1).1 to K-1 symmetry area node number are 1+Kn×(j-1)×j/2+(M-1)×j+i and 1+Kn×(j+1)×j/2+(M-1)×(j+1)+i. K symmetry area node number are 1+Kn×(j-1)×j/2+K×J+1 and 1+Kn×(j+1)×j/2+k×(j+1)+1, Positive link connection node number are 1+Kn×(j-1)×j/2+(m-1)×j+i and 1+Kn×(j+1)×j/2+(m-1)×(j+1)+i. Negative link connection node number are 1+Kn×(j-1)×j/2+(m-1)×j+i and 1+Kn×(j+1)×j/2+(m-1)×(j+1)+i+1
(j=1~Nx-1, m=1~K, i=1~j+1).

4. Structural force performance comparison analysis

The single-layer reticulated shell members are subject to greater axial forces, non-negligible bending moments and shear forces. So using hollow ball just nodes and space beam element. In this article, Beam4 is used for the structural members, and Q235 seamless circular steel pipe (Φ299×10) is used for the structural members of the shell structure. The steel density is p=7850kg/m3, the elastic modulus is E=2.06×1011MPa, the Poisson's ratio v= 0.3, and allowable stress [σ]= 215 MPa. The uniformly distributed load of the roof is 2.35kN/m2[7] and comparative analysis of its mechanical properties. The allowable displacement of the structure is 1/400[8] of the span, and the allowable stress [σ] = 215 MPa. The ideal elasto-plastic material model is used. The material's strength and yield strength are not considered.

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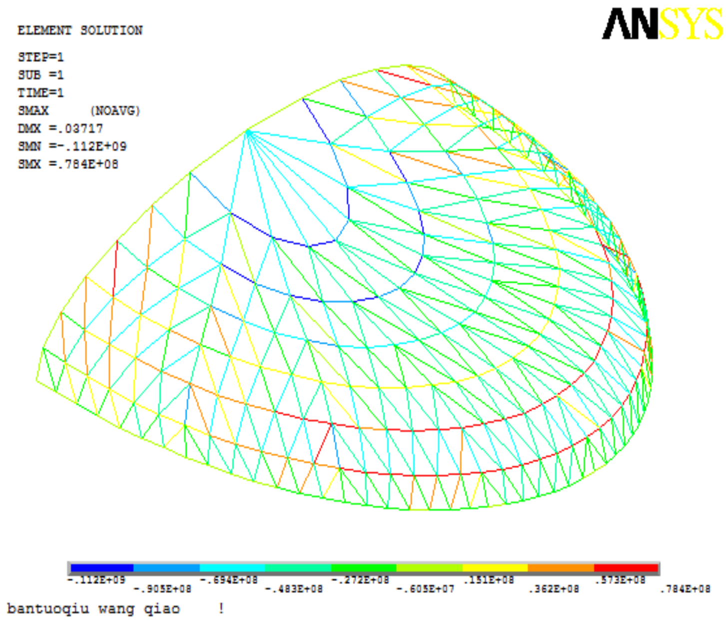
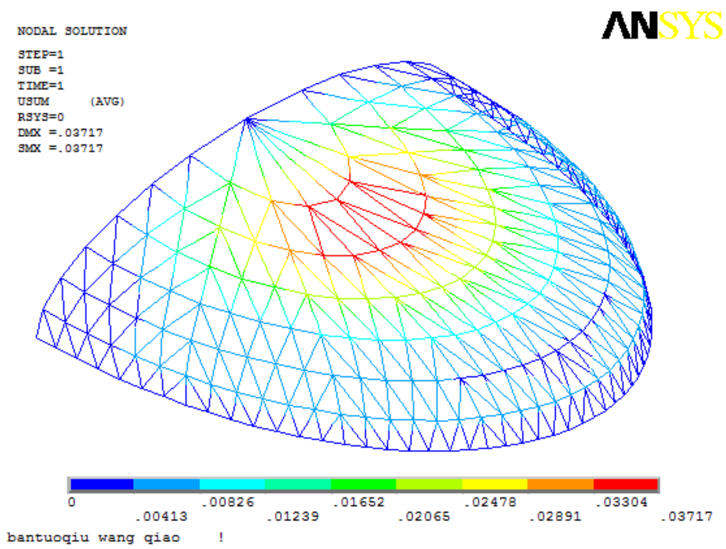
5. Force performance

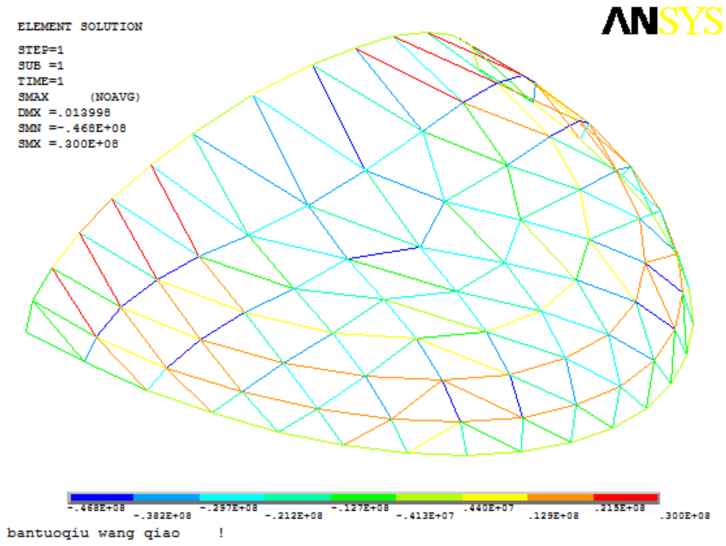
Selecting the span S1=36 m, span S2=60 m, the vector height f=15 m, the number of circumferential regions Kn=16, and the number of radial node turns Nx=7.The stress performance analysis is performed on the Kewitte and three-way grid structures. Fig. 2 gives the stress cloud and displacement cloud map. The relevant data is shown in Table 1.



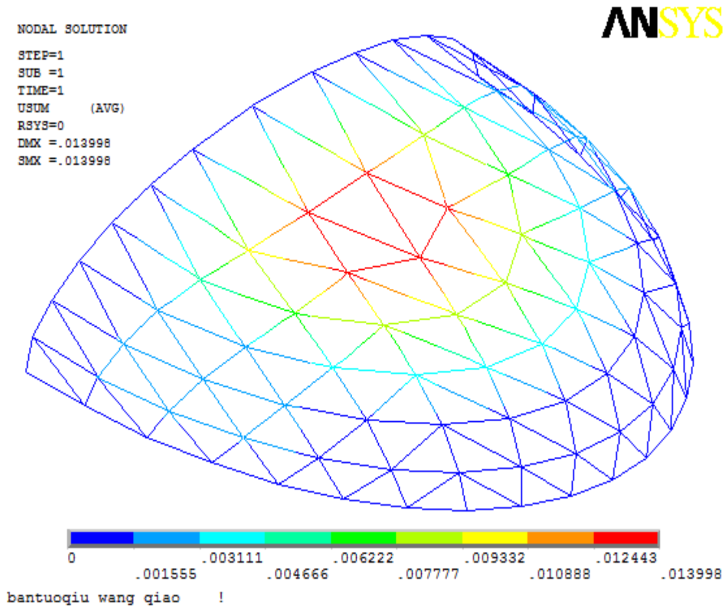
(a)stress cloud



(b)displacement cloud



(c)stress cloud



(d)displacement cloud

1) stress cloud and displacement cloud of Kewitte

2) stress cloud and displacement cloud of Three-way grid

Fig. 2 Stress cloud and displacement cloud diagram of two types of hemi-ellipsoidal latticed reticulated shells

Table 1 Maximum Displacement and Maximum Stress of Two Types of Single-layer Cone Reticulated Shells

<table>
<tr><th>Shell type</th><th>Maximum displacement(cm)</th><th>allowable displacement (cm)</th><th>Maximum stress(Mpa)</th><th>Allowable stress(Mpa)</th></tr>
<tr><td>Kewitte type</td><td>3.17</td><td rowspan="2">9.0</td><td>112.0</td><td rowspan="2">215</td></tr>
<tr><td>Three-way grid type</td><td>1.39</td><td>48.6</td></tr>
</table>

We can know from Figure 2 and Table 1 above:

The maximum displacement of two structures are far less than the allowable displacement of 90mm, so they meet the stiffness requirements. The most unfavorable stress is also far less than the allowable stress of 215Mpa, so they meet the strength requirements. The structure is mainly subjected to compressive stress. We find that the structure of Kewitte type has less with the maximum displacement and unfavorable stress. therefore, the structure of Kewitte is the best structure on their force performance.

6. Effect of Macroscopic Geometric Parameters on Mechanical Behavior of Structures

The factors affecting the static performance of the reticulated shell structure include span, vector height, number of radial nodes, number of circumferential regions, and boundary constraints. In this paper, the influences of vector height and boundary constraints on structural stress and displacement are studied.

7. The influence of vector height on the mechanical properties of hemi-ellipsoidal latticed reticulated shells

Select: S1=50m, S2=36m, f=10m,15m,18m,25m,30m,35m, Nx=7, Kn=16.Investigating the effect of vector height variation on structural stress and displacement. Table 2 gives the maximum displacement and the most unfavorable stress of the structure.

Table 2 the most unfavorable stress and maximum displacement of Structure

Shell type	vector height *f*	10	15	18	25	30	35
Kewitte type	**Maximum stress (Mpa)**	146	102	88.6	72.3	71	79.8
Three-way grid type		183	133	102	106	103	103
Kewitte type	**Maximum displacement (cm)**	3.79	1.9	1.43	1.5	1.6	1.7
Three-way grid type		4.78	2.51	1.96	1.4	1.5	1.6

We can see from Table 2:

7.1. Increase of vector height

The structure of kewitte type of the most unfavorable stress and maximum displacement has a trend of boost, then it has a current of decrease current. The optimal height is at 30m (the vector span ratio f / S = 1/2), better stress performance. With increasing vector height, the difference between the most unfavorable stress and the maximum displacement of the structure is small, and the height of the changed vector shows that the influence on the strength and stiffness of the structure is relatively close.

7.2. Stress effect

The maximum stress values of the kewitte and tri-directional grid structures are 146 Mpa and 183 Mpa, respectively, which are 67.9% and 85.1% of the structural allowable stress. The maximum displacement values of the kewitte reticulated lattice structure and the tri-directional grid structures are 38 mm and 48 mm, respectively, which are 41.1% and 53.1% of the allowable displacement of the structure. It can be seen that for the cone-shaped reticulated shell, stress is the key to affect its stress performance, so the strength of the entire structure can be improved by enhancing the strength of the corresponding rod.

7.3. Compare in the same situation

Under the same working conditions, the kewitte is the least attractive and the maximum displacement is smaller than the three-dimensional grid type. This is because the kewitte type lattice shell of force is relatively reasonable, so the actual project, you can preferentially use kewitte mesh cone-type reticulated shell.

8. Influence of bearing form reticulated shell structure

Respectively using movable articulated joints and rigid joints (restricting all 6 degrees of freedom) to constrain two types of bearings, and other conditions are the same as in Section 4.2. Through static performance analysis, the most unfavorable stress, maximum displacement, and most unfavorable stress values are shown in Table 3 as shown.

Table 3 Effect of bearing form on structural static performance

structure type	Bearing form	Most adverse stress(MPa)	Allowable stress(MPa)	Maximum displacement(cm)	Allowable displacement(cm)
Kewitte type	Articulated	73.1	215	2.2	12.5
	Just connected	104		1.88	
Three-way grid type	Articulated	84.8		2.54	
	Just connected	113		2.44	

It can be seen from Table 3, we can see:

The two types of single-layer hemi-ellipsoidal latticed reticulated shell structures are hinged or rigidly connected in two types of bearings, which have little effect on the maximum displacement of the structure, and have a significant impact on the most adverse structural stress. When the bearings are just attached, the most unfavorable stresses of the two types of structures increase, and the maximum displacement decreases. The most unfavorable stresses of the Kewitte and the three-way increased by 48.37% and 52.56%, respectively, and the maximum displacements decreased by 20.89% and 27.11%, respectively. It can be seen that the change of the bearing type has the most obvious influence on the most unfavorable stress. In summary, the use of a hinged support is more advantageous to the structure.

9. Conclusion

The APDL parameterized design language was used to develop two kinds of design programs for single-layer hemi-ellipsoidal latticed shell structures. The corresponding structural design model was established, which provided great convenience for the mechanical performance of the structure. The influence of different geometrical parameters on the static performance of hemi-ellipsoidal latticed shells was investigated. The results show that:

9.1. Increase of vector height

With the increase of vector height, the most unfavorable stress and maximum displacement of the two types of reticulated shells decrease. With the increase of vector height, the most unfavorable stress and maximum displacement of the three-dimensional reticulated reticulated shells decrease first and then increase. For the large trend, the optimal vector height is at the 1/2 span ratio, and the stress performance is better.

9.2. Stress effect

For hemi-ellipsoidal latticed reticulated shells, stress is the key to affect the stress performance of the reticulated shells. Therefore, the strength of the entire structure can be improved by increasing the strength of the corresponding rods.

9.3. Kewitte shell benefits

Since the kewitte type lattice shell is relatively uniform and the stress is reasonable. Therefore, in practical engineering design, kewitte type hemi-ellipsoidal latticed lattice shells can be preferentially considered.

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