

Parametric Design and Comparing Analysis of Mechanical Behavior of Circular Spherical Reticulated Shells

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Abstract: Taking the Jinan National Games Stadium as an example, according to the characteristics of the hoop-shaped spherical reticulated shell, the APDL language (Ansys Parametric Design Language) was used to program the parametric macro design of the single-layer reticulated shell, and the ANSYS software was used. This structure (different spans S_1 , S_2 , different top opening diameters d , different vector heights f , different numbers of circumferential area parts kn , different radial node turns N_x) was subjected to force analysis. The results show that the application of the parameterized design macro program can facilitate the modeling design and performance comparison of the reticulated shells, which provides great convenience for the reticulated shell structure design. According to the analysis of 4 groups of 21 examples, the structural performance is better when the span S_1 is 100 meters, the opening diameter is $d=60$ meters and the vector height is $f=30$ meters (vector span ratio $f/S_2=1/3$). For this kind of reticulated shell structure optimization design and engineering application provides a useful reference.

Keywords: circular zigzag spherical shell; parametric design; mechanical analysis;

1 Preface

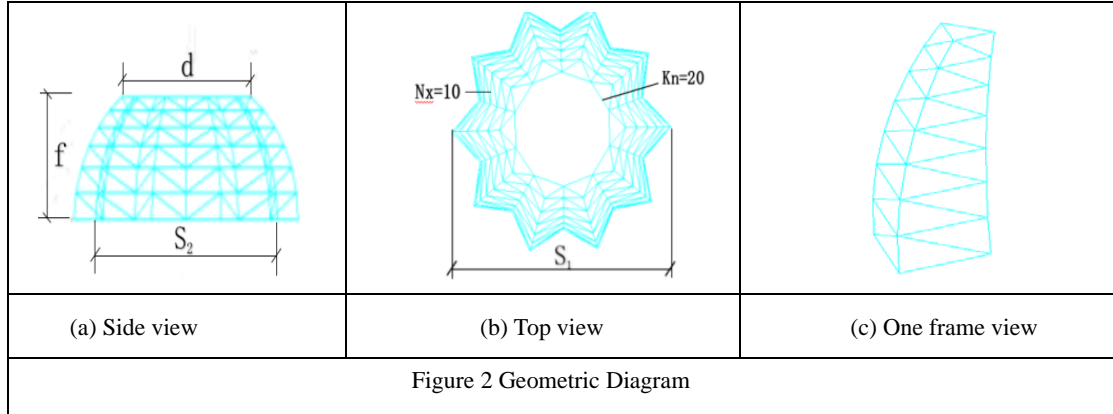
Circular zigzag spherical reticular shell is the application of zigzag truss in curved space construction. Due to the omission of part of the truss ring upward and downward chord, the type and number of structural members are greatly reduced, and the configuration closely matches the architectural styling; It has been widely used in large and medium-span spatial structures (see Figure 1). The basic stress element of this structure is composed of triangular meshes, which can be used for open domes (such as open-air sports, cultural and art venues) and large cantilever structures^[1-2].



Figure 1 Jinan National Games Stadium

2 Reticulated shell geometry description

The main geometric parameters of this type of single-layer spherical reticulated shell are: outer edge span S_1 , inner edge span S_2 , top opening diameter d , vector height f , proportionality coefficient t , number of circumferential area parts kn , radial node number Nx (see Figure 2).



3 parametric design of loop-shaped single-layer spherical lattice shell

First determine the reticulated shell spans S_1 , S_2 , the top opening diameter d , the vector height f , the number of circumferential region elements kn , and the number of radial node turns nx ; then determine the basic type, cross-sectional area A , and material properties of the rod or beam element; apply APDL The cycle statement, spherical shell space geometric relations and node distribution rules generate the coordinates of each node; the connection of each node is connected to each node according to the distribution rules of the shell type bars, which completes the model establishment^[3-4].

3.1 Calculate Node Coordinates, Define Node Numbers

According to the spherical equation in the Cartesian coordinate system and the number of parts in the circumferential direction, the ball radius $R_1=S_1/2$, $R_2=S_2/2$ is determined, and the coordinate (x,y,z) of each node is obtained, and the proportional coefficient $t=1-i*(i+1)/(nx*(nx+1))$. Outer node $x_1=R_1*\cos(360*(j-1)/kn)*(1-t*t)^{1/2}$, $y_1=R_1*\sin(360*(j-1)/kn)*(1-t*t)^{1/2}$, $z_1=f*(1-x_1^2/R_1^2-y_1^2/R_2^2)^{1/2}$, inner node coordinates $x_2=R_2*\cos(360*(j-1)/kn)*(1-t*t)^{1/2}$, $y_2=R_2*\sin(360*(j-1)/kn)*(1-t*t)^{1/2}$, $z_2=f*(1-x_2^2/R_1^2-y_2^2/R_2^2)^{1/2}$, and then use the APDL loop statement to number the nodes and number the i -th and j -th nodes in turn.

3.2 Bar connection

The ring members are connected to establish the first to Nx circle node $DO, i, 1, Nx$, and the first to $Kn-1$ symmetrical area node cycles $DO,j,1, Kn-1,1$ and the last The symmetry zone needs to be dealt with separately; connect the nodes $1+Kn*(i-1)+j$ and $1+Kn*(i-1)+j+1$, and then make the ring rod connection $DO,j,3$ on the first circle on the top $Kn-1$, connecting node $j, j+2$. The last area loop of the i circle is formed by connecting node $1+Kn*i$ and node $1+Kn*i-Kn+1$.

The connection of the radial rod establishes the node of the i ($i=1,...Nx-2$) loop node $DO,i,1,Nx-2,j$ ($j=1,3...Kn-1$) symmetry zone Loops $DO,j,1,Kn-1$, connecting nodes $1+Kn*(i-1)+j$ and node $1+Kn*i+j$ generate residual radial bars. The remaining radial rod connection establishes a node in the i ($i=1,...Nx-1$) loop node cycle

DO, $i, 1, N_x - 1, j$ ($j=2, 4, 6 \dots K_n$) symmetry zone Loops DO, $j, 2, K_n$, connecting nodes $1 + K_n \times (i-1) + j$ and nodes $1 + K_n \times i + j$ generate residual radial bars.

The slanting rod connection is established to establish the cyclical DO of the $i(i=1, \dots, N_x-1)$ loop node DO, $i, 1, N_x - 1, j$ ($j=1, 2 \dots K_n-1$) symmetry zones. $j, 1, K_n-1$, connecting the left oblique node of the i circle and the $i+1$ -th ring, and the connecting node $1 + K_n \times (i-1) + j$ and the node $1 + K_n \times i + j + 1$ are generated. Unit diagonal rod. Connect the i circle and the $i+1$ th circle right slanting node, and connect the node $1 + K_n \times (i-1) + j$ and the node $1 + K_n \times i + j - 1$ to generate the unit bar.

4 Analysis of Mechanical Behavior of Looped Single-layer Spherical Shells

4.1 Apply structural restraints and loads

The structural member was a Q235 $\Phi 299 \times 16$ round steel tube with a material density of 7850 kg/m³, an elastic modulus of 2.06×10^{11} N/m², and a Poisson's ratio of 0.3. [5-6].

4.2 Influence of top opening diameter d on stress performance

Take $K_n = 20$, $N_x = 10$, vector height $f = 30$ m, $S_1 = 100$ m, $S_2 = 90$ m and $S_1 = 90$ m, $S_2 = 80$ m, opening diameter $d = 30, 40, 50, 60$ m. Figure 3 shows the calculated displacement cloud map and stress cloud map. The calculated data is shown in Table 1.

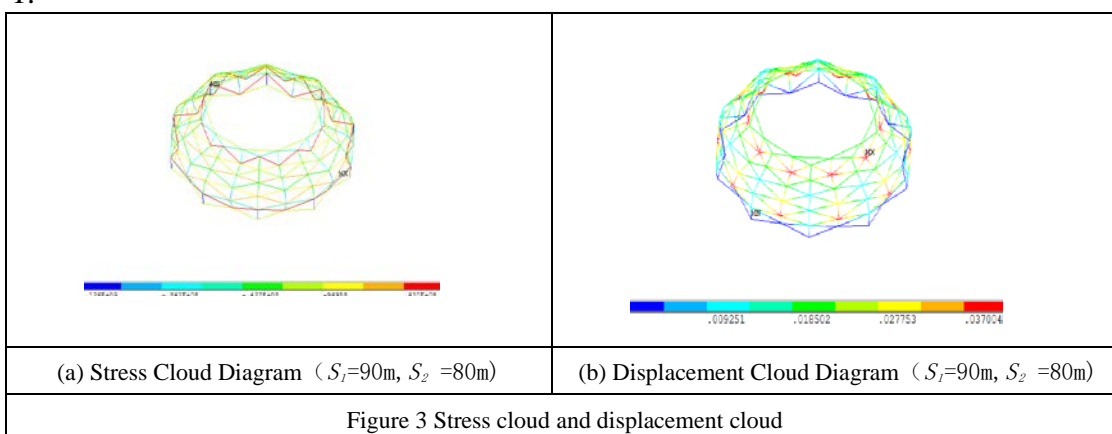


Table 1 Effect of different opening diameter d on the maximum displacement and the most unfavorable stress of the reticulated shell

Outer edge span S_1	inner edge Span S_2	vector height f/m	top diameter d/m	Maximum displacement t/cm	Allowable displacement t/cm	most unfavorable stress/Mpa	allowable stress/Mpa
90	80	30	30	7.87	20.0	142.4	215
			40	5.61		134.5	
			50	4.12		126.3	
			60	3.84		117.1	
100	90	30	30	8.97	22.5	151.6	215
			40	6.41		143.5	
			50	5.22		135.1	
			60	4.94		128.2	

4.3 The influence of the difference between the outer edge S_1 and the inner edge S_2

When $K_n=20$, $N_x=10$, vector height $f=30$ meters, opening diameter $d=60$ m, take $S_1=100$ m, $S_2=100, 95, 90, 85$ m. Table 2 shows the static analysis of the structure.

Table 2 Effect of different S_2 on maximum displacement and worst stress of reticulated shell

Outer edge span S_1	inner edge Span S_2	vector height f/m	top diameter d/m	Maximum displacement /cm	Allowable displacemen t/cm	most unfavorable stress/Mpa	allowable stress/Mpa
100	100	30	60	10.5	25	152.6	215
	95			7.41	23.75	139.4	
	90			4.94	22.5	128.2	
	85			4.84	21.25	123.1	

5 Conclusion

(1) According to the actual project requirements, enter the relevant geometric parameters (spans S_1 , S_2 , top opening diameter d , vector height f , number of circumferential region k_n , number of radial node turns N_x), application of circular zigzag spherical shell parameters The design macro program can be used to build the required calculation and analysis model; this macro program is easy to apply and has high efficiency, which provides great convenience for the optimization design of such reticulated shell structures, comparison of mechanical properties and building selection.

(2) The design and application of openings for sports and cultural venues can effectively use daylight, accelerate air circulation, and reduce indoor noise. When the span is 100 meters and the top opening diameter is 60 meters, the structural performance is better, which provides a reference for practical engineering applications.

(3) The values of outer edge span S_1 and inner edge span S_2 , when $S_1=S_2$, the structure meets the requirements of strength and stiffness; but as the difference between the two increases, the static performance of the structure becomes better. The specific value should be determined according to the actual structure using the function.

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