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Sensitivity Analysis of Snow Load Distribution to Single-Layer Cylindrical Shell Structures

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***Abstract*—The large - span single - layer reticulated shell structure is a structure sensitive to the load distribution. Different distribution of snow load has an effect on the stable bearing capacity of the reticulated shell structure. The unfavorable snow load distribution may cause the stable bearing capacity of the reticulated shell to decrease greatly. In this paper, a single oblique rod type reticulated shell structure is taken as an example. According to the characteristics of the reticulated shells, eight stripes are divided into a lattice size in the longitudinal direction and span direction, and the snow load distribution is classified according to the permutation and combination. The stability of the reticulated shell structure is determined by the arc-length method, taking into account the sensitivity of the snow load in the longitudinal direction and the span direction. The results show that the maximum sensitivity coefficient of the stability of the reticulated shells with snow loads is 0.083 and 0.404, respectively, along the longitudinal length and the span direction. Compared with the sensitivity coefficient of the snow load distribution position along the longitudinal length direction and the span direction, the most sensitive snow load distribution position of the reticulated shell structure is obtained from the 4th to 8th rows.**

Keywords-cylindrical reticulated shells; snow load; stable bearing capacity; partition combination; sensitivity

I. INTRODUCTION

The space reticulated shell structure is an efficient structure in bearing capacity and transmission force, depending on its form. It is widely used in traditional areas such as commercial buildings, traffic buildings and sports buildings, and has a bright future in emerging areas such as industrial buildings and agricultural buildings. The unfavorable snow load distribution may cause the stable bearing capacity of the reticulated shell structure to decrease sharply and suddenly collapse[1-3], and the accident caused by the snow-induced collapse of the single-layer reticulated shell structure has caused serious loss of life and property. Such as 1963 in Romanian Bucharest, a single-layer spherical reticulated shell with 93.5m span collapse overall in the local snow load[4]. 1978 United States, Connecticut Hartford City Gymnasium also collapsed in heavy snow[5]. 1997 Liaoning Anshan City, China, the snow loads across half-span of five arched roofs of a feed company caused a large area collapse[6]. 2005 Shandong Weihai, a roof of steel plant structure overload and collapse due to snow load sudden increase[6]. Therefore, it is very important to study the anti-snow disaster design of reticulated shell structure deeply.

II. RETICULATED SHELL STABILITY ANALYSIS METHOD

A. Calculation Models

The member bars of reticulated shells are modeled by Beam188 in the ANSYS software. The roof load and the structural weight are transformed into the concentrated load on the nodes of the reticulated shell structure according corresponding to the mass. The snow load applied to each node of the reticulated shell structure can be described as

$$F_{\mathrm{i}}(x,y,z)=S_{\mathrm{k,i}}(x,y,z)A_{\mathrm{i}} \qquad (1)$$

where, F_{i} is the equivalent load force of the snow load at the node i ; A_{i} is the equivalent snow load area at the node i ; $S_{\mathrm{k,i}}$ is the standard value of the snow pressure at the node i , as follow：

$$S_{\mathrm{k,i}}(x,y,z)=\mu_{\mathrm{r,i}}S_0 \qquad (2)$$

where, is the roof snow distribution coefficient at the node , calculated on the basis of norms; is the basic snow pressure of the place where the reticulated shells are located, found from the norms.

Model parameters: The monoclinic type single layer cylindrical reticulated shell structure shown in Figure1 has a length L of 20m, width B of 15m, vector height f of 5m. Three-way fixation is used as a constraint in the longitudinal direction.

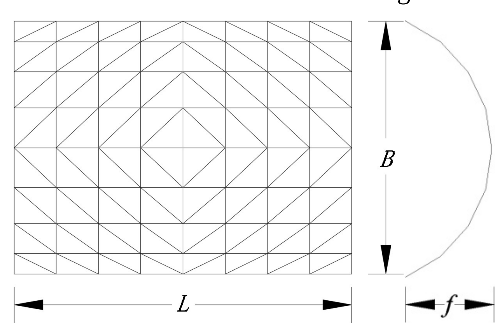

FIGURE I. SCHEMATIC DIAGRAM OF THE SINGLE-LAYER CYLINDRICAL RETICULATED SHELL

Seamless steel pipes with cross-section size Φ83mm × 4.5mm are used for member bars. Material parameters: Steel model is

Q345, material density ρ is7.85 × 10^3kg/m^3, yield strength f_y is 345N/mm^2, Young's modulus E is 2.1 × 105 N/mm^2, transverse deformation coefficient ν is 0.26. Analysis parameters: The ideal elastic-plastic model, the Mises yield criterion and the bilinear isotropic model are used.

B. Zoning Programs

In this paper, taking the single oblique rod reticulated shell structure as an example the distribution scheme of snow load is determined by using the combined zoning method. The details are as follows:

(1) A grid is divided into eight columns in the longitudinal direction as shown in figure 2. The distribution of snow load is determined by permutations and combinations and represented by an 8-dimensional sequence number of "12345678". When the value of a dimension is 0, the snow load is not arranged in the column.

(2) In the span direction a grid is divided into 8 rows of stripes (shown in Figure 3). The same as above, the distribution of snow load is determined by permutations and combinations and represented by an 8-dimensional sequence number of "12345678". When the value of a dimension is 0, the snow load is not arranged in the column.

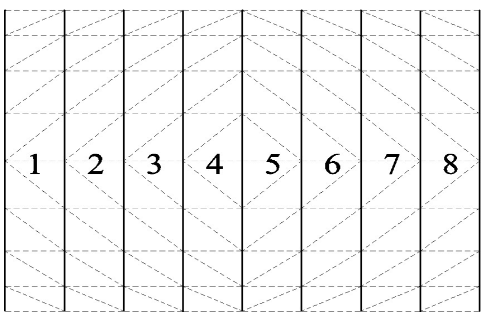

FIGURE II. SNOW LOAD PARTITION ALONG LONGITUDINAL LENGTH

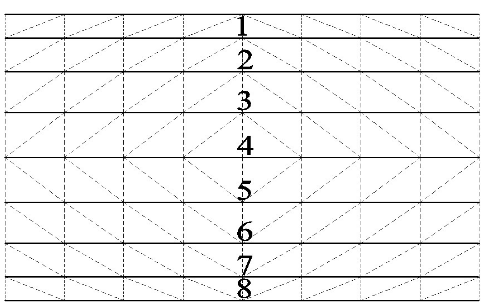

FIGURE III. SNOW LOAD PARTITION ALONG SPAN DIRECTION

C. Tracking Balance Path of the Structure

Arc length method is used for nonlinear solution. In the analysis process, assuming that the load is independent of the deformation and is proportionally loaded in the structure, the equilibrium equation of the incremental form at any time is:

$$ {}^{t}K\Delta U^{(i)} = {}^{t+\Delta t}\lambda^{(i)}R - {}^{t+\Delta t}F^{i-1} \tag{3}$$

where, ${}^{t}K$ is the tangent stiffness matrix of the structure at time t, $\Delta U^{(i)}$ is the iteration increment of the current displacement, ${}^{t+\Delta t}\lambda$ is the load proportional coefficient at time , ${}^{t+\Delta t}F$ is the internal force vector of the bar node at time $t+\Delta t$, R is the load distribution vector.

If the square sum of λ and U is used as a variable, the generalized form of the arc length constraint equation is:

$$\alpha\left\{\left({}^{t+\Delta t}\lambda^{i+1} - \Delta\lambda^{(i)}\right) + \Delta\lambda^{(i)}\right\}^2 + U^{(i)\mathrm{T}}U^{(i)} = \left(\Delta l\right)^2 \tag{4}$$

where, Δl is the arc length increment of each iteration; α is the scale factor. When α =1, the equation is the spherical arc length method.

III. SENSITIVITY ANALYSIS OF SNOW LOAD DISTRIBUTION POSITIONS

The influence of different positions of snow load distribution on the stable bearing capacity of reticulated shells is reflected by the sensitivity coefficient. The sensitivity coefficient is calculated as follows[9]:

$$S_{\mathrm{F,i}} = \frac{F_0 - F_\mathrm{i}}{F_0} \tag{5}$$

where, F_i and F_0 are the stable bearing capacity of the reticulated shell structure under the snow load distribution scheme i and the full-span distribution scheme. $S_{\mathrm{F,i}}$ is the sensitivity coefficient of the snow load distribution scheme i, that the smaller the numerical value is, the smaller the influence of the snow load distribution on the stability of the reticulated shell structure.

A. Sensitivity Coefficient of Snow Load Distribution Position along the Longitudinal Length Direction

In order to study the sensitivity of the snow load distribution position along the longitudinal length direction to the stable bearing capacity of the reticulated shell structure, a grid is divided into 8 columns in the longitudinal direction, and the snow load distribution position is determined according to the permutation and combination. The stability of the reticulated shell structure is determined by arc-length method, and the sensitivity in different positions along longitudinal direction is investigated. The sensitivity coefficient of the stability of the reticulated shell structure to the different distribution positions of the snow load is shown in Table 1. The maximum coefficient of sensitivity of the reticulated shell structure is 0.083 when snow load is arranged in only the 1th column bar area, which means that this snow load distribution in the longitudinal span direction has the greatest effect on the stable bearing capacity of the reticulated shell structure.

TABLE I. SENSITIVITY COEFFICIENT OF SNOW LOAD DISTRIBUTION POSITION ALONG LONGITUDINAL LENGTH DIRECTION

Snow load distribution location	*Sensitivity coefficient*	*Snow load distribution location*	*Sensitivity coefficient*	*Snow load distribution location*	*Sensitivity coefficient*	*Snow load distribution location*	*Sensitivity coefficient*
10000000	-1.715	10040008	-1.208	10305070	-0.585	10345608	-0.183
02000000	-2.697	10005600	-1.088	10305008	-0.670	12005678	-0.086
00300000	-3.683	10005070	-1.258	10300670	-0.688	12040678	-0.150
00040000	-4.236	10000670	-1.191	10300608	-0.757	12045078	-0.198
12000000	-0.621	02340000	-0.634	10045600	-0.583	12300678	-0.188
10300000	-0.868	02305000	-0.786	10045070	-0.698	00045678	0.007
10040000	-1.095	02300600	-0.935	10045008	-0.742	00305678	-0.050
10005000	-1.316	02300070	-1.054	10040670	-0.755	00340678	-0.092
10000600	-1.523	02045000	-0.937	10005670	-0.634	00345078	-0.154
10000070	-1.756	02040600	-1.134	10000678	-0.286	00345608	-0.228
10000008	-2.151	02040070	-1.302	02345000	-0.395	00345670	-0.265
02300000	-1.143	02005600	-1.225	02340600	-0.479	02005678	-0.073
02040000	-1.464	00345000	-0.945	02340070	-0.548	02040678	-0.133
02005000	-1.763	00340600	-1.131	02305600	-0.574	02045078	-0.202
02000600	-2.115	12340000	-0.084	02305070	-0.672	02045608	-0.283
02000070	-2.474	12305000	-0.149	02300670	-0.723	02045670	-0.320
00340000	-1.636	12300600	-0.203	02045600	-0.643	02300678	-0.185
00305000	-2.036	12300070	-0.247	02045070	-0.729	02305078	-0.268
00300600	-2.344	12300008	-0.286	00345600	-0.567	02305608	-0.347
00045000	-1.820	12045000	-0.226	02345678	0.083	02305670	-0.368
12300000	-0.249	12040600	-0.289	10345678	0.055	02340078	-0.326
12040000	-0.363	12040070	-0.341	12045678	0.018	02340608	-0.413
12005000	-0.436	12040008	-0.388	12305678	-0.019	02345008	-0.362
12000600	-0.532	12005600	-0.377	00345678	0.056	10005678	-0.105
12000070	-0.611	12005070	-0.437	02045678	0.023	10040678	-0.169
12000008	-0.683	12005008	-0.497	02305678	-0.019	10045078	-0.244
10340000	-0.499	12000670	-0.516	02340678	-0.067	10045608	-0.329
10305000	-0.631	12000608	-0.586	02345078	-0.116	10300678	-0.226
10300600	-0.750	12000078	-0.704	02345608	-0.158	10305078	-0.313
10300070	-0.856	10345000	-0.328	02345670	-0.148	10305608	-0.417
10300008	-0.948	10340600	-0.409	10045678	-0.005	10340078	-0.398
10045000	-0.766	10340070	-0.470	10305678	-0.050	12000678	-0.273
10040600	-0.920	10340008	-0.530	10340678	-0.103	12005078	-0.387
10040070	-1.059	10305600	-0.494	10345078	-0.161	12345678	-

B. Sensitivity Coefficient of Snow Load Distribution Position along the Span Direction

Similarly, in order to study the sensitivity of the snow load distribution position along the span direction to the stable bearing capacity of the reticulated shell structure, a grid is divided into 8 columns in the span direction, and the snow load distribution position is determined according to the permutation and combination. The stability of the reticulated shell structure is determined by arc-length method, and the sensitivity in different positions along span direction is investigated. The sensitivity coefficient of the stability of the reticulated shell structure to the different position of the snow load is shown in Table 2. The maximum coefficient of sensitivity of the reticulated shell structure is 0.404 when the snow load is arranged in the stripe area of the 4th to 8th rows, which means that this snow load distribution in the span direction has the greatest influence on the stable bearing capacity of the reticulated shell structure.

TABLE II. SENSITIVITY COEFFICIENT OF SNOW LOAD DISTRIBUTION POSITION ALONG SPAN DIRECTION

Snow load distribution location	*Sensitivity coefficient*	*Snow load distribution location*	*Sensitivity coefficient*	*Snow load distribution location*	*Sensitivity coefficient*	*Snow load distribution location*	*Sensitivity coefficient*
10000000	-10.450	10040008	-0.448	10305070	-0.797	10345608	0.184
02000000	-1.825	10005600	0.188	10305008	-0.306	12005678	0.262
00300000	-0.476	10005070	-0.164	10300670	-0.459	12040678	-0.256
00040000	-0.426	10000670	-0.002	10300608	-0.387	12045078	-0.155
12000000	-1.315	02340000	0.339	10045600	0.294	12300678	-1.369
10300000	-0.386	02305000	0.004	10045070	0.058	00045678	0.404
10040000	-0.398	02300600	-0.413	10045008	-0.048	00305678	0.213
10005000	-0.491	02300070	-0.144	10040670	-0.035	00340678	-0.254
10000600	-0.524	02045000	0.076	10005670	0.328	00345078	0.175
10000070	-1.959	02040600	-0.623	10000678	0.042	00345608	0.206
10000008	-12.927	02040070	-0.435	02345000	0.392	00345670	0.287
02300000	0.023	02005600	0.073	02340600	0.180	02005678	0.274
02040000	-0.126	00345000	0.308	02340070	0.253	02040678	-0.203
02005000	-0.872	00340600	-0.016	02305600	-0.272	02045078	-0.126
02000600	-0.885	12340000	0.362	02305070	-0.270	02045608	0.211
02000070	-3.220	12305000	0.032	02300670	-1.651	02045670	0.308
00340000	0.200	12300600	-0.306	02045600	0.199	02300678	-0.815
00305000	-0.289	12300070	-0.069	02045070	-0.143	02305078	-0.322
00300600	-2.620	12300008	0.042	00345600	0.210	02305608	-0.293
00045000	-0.018	12045000	0.094	02345678	0.149	02305670	0.009
12300000	0.069	12040600	-0.554	10345678	0.274	02340078	0.236
12040000	-0.090	12040070	-0.365	12045678	0.307	02340608	0.158
12005000	-0.917	12040008	-0.116	12305678	0.021	02345008	0.379
12000600	-0.977	12005600	0.049	00345678	0.300	10005678	0.350
12000070	-2.022	12005070	-0.487	02045678	0.320	10040678	0.019
12000008	-1.417	12005008	-1.030	02305678	0.045	10045078	0.078
10340000	0.216	12000670	-0.160	02340678	-0.030	10045608	0.304
10305000	-0.254	12000608	-0.785	02345078	0.295	10300678	-0.361
10300600	-1.634	12000078	-2.247	02345608	0.260	10305078	-0.710
10300070	-0.737	10345000	0.318	02345670	0.136	10305608	-0.026
10300008	-0.430	10340600	0.010	10045678	0.390	10340078	0.070
10045000	-0.041	10340070	0.097	10305678	0.182	12000678	-0.088
10040600	-0.363	10340008	0.204	10340678	-0.370	12005078	-0.429
10040070	-0.892	10305600	-0.057	10345078	0.189	12345678	-

IV. CONCLUSION

(1) Based on the structure of the single oblique rod reticulated shell, the distribution scheme of snow load is determined by combining the characteristics of the reticulated shell and the combined zoning method. The sensitivity coefficient of stable bearing capacity of reticulated shell structures is obtained when the snow load distribution is distributed along the longitudinal length and span direction, and they were 0.083 and 0.404, respectively. It can be seen that the sensitivity of the snow load distribution position along the span direction is significantly greater than that in the longitudinal direction.

(2) By comparing the sensitivity of the snow load distribution position along the longitudinal length direction and the span direction, the most sensitive snow load arrangement is the 4th to 8th rows, which is the most unfavorable arrangement of the snow load. It may result in a significant reduction in the stable bearing capacity of the reticulated shell structure. Therefore, it is necessary to consider the most unfavorable snow load arrangement to ensure the safety of the reticulated shell structure. In particular, it is necessary to consider the influence of the most unfavorable combination of wind load and snow load on the safety of the reticulated shell structure.

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