Study on Seismic Response of Single-layer Cylindrical Reticulated Shell Due to Horizontal One-dimensional Earthquake

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Abstract. A single-layer cylindrical reticulated shell structure model was established by selecting real seismic waves and using ANSYS structural analysis module, and the structural model was subjected to multi-point earthquake input and consistent input time history response calculations. The result shows that in the seismic design of large-span space structures, the traveling wave effect must be considered. When the traveling wave effect is studied, if we only pay attention to the maximum axial force of the structural member, horizontal one-dimensional input can be performed.

1. Introduction
The reticulated shell structure has a series of characteristics such as light weight and good structural rigidity, and it is one of the fastest-growing structural types at present. As a main form of long-span space structure, the reticulated shell structure is widely used in stadiums, convention centers and other public buildings, and its span is gradually increasing [1]. After the earthquake, such long-span public buildings are often used as earthquake shelters and disaster relief command sites, playing an important role in earthquake relief.

In recent years, the dynamic performance and design of reticulated shell structures under earthquake have attracted the attention of many scholars. Li Yugang et al. [1] calculated the structural response of a 90m K8 single-layer reticulated shell structure under multiple support excitations, considering different effects, by the method of time history analysis, and a comparison with the ones under simple support excitations was also made. Zhi Xudong et al. [2] made an analysis about the seismic response of super-large span reticulated dome (800 m span using the time-history analytic method considering complexity effects such as ground motion with spatial coherency and wave-passage effect, soil-structure interaction and material damage accumulation. Fan Feng et al. [3] conducted a large number of horizontal 1-D and vertical 1-D seismic time-history response analyses of the Kiewitt-8 type single-layer spherical reticulated dome, and calculated the correlation coefficients between ground motion intensity parameters and structural responses. Qian Hongliang et al. [4] simulated the seismic ground motions of 338 points within the area covered by FAST based on available excellent model of seismic ground motion, obtained the seismic ground motions at the 2395 bearing of FAST via linear interpolation between the 338 points and calculated the time-history responses of supporting structure of FAST under multiple-support excitations and uniform excitations with ANSYS.

The suitable ground motion field is particularly important for studying the seismic response of single-layer cylindrical reticulated shell structures. In this paper, the single-layer cylindrical reticulated
shell structure is taken as the research object, real seismic waves are used, and the time-history analysis of the reticulated shell structure with consistent input and multi-point input is performed to analyze the influencing mechanism of different ground motion fields on the structural response.

2. The establishment of a structural model

The structural model of this paper adopts a single-layer, three-way grid-type cylindrical reticulated shell. The supporting conditions are supported along two longitudinal sides. The ratio of rise to width is 1/5, and the damping ratio is 0.02. The cross-section dimensions of the vertical and edge rods of the 7 models are $\phi 194 \times 08$, and the cross-sectional dimensions of the diagonal rods are $\phi 245 \times 10$. In the numerical simulation, the universal finite element software ANSYS was used. The PIPE20 element was used to simulate the rods. Each rod was divided into 3 elements. The nodes were rigidly connected. The MASS21 element was used to simulate the roof quality concentrated on the nodes. With the ideal elastic constitutive relation, the elastic modulus is $E = 2.06 \times 10^5$ N/mm$^2$, the Poisson's ratio is $\nu = 0.3$, and the mass distribution is 60 kg/m$^2$. This paper uses a single-layer cylindrical reticulated shell model with a width of 45m and a length of 180m, as shown in Figure 1.

![Figure 1. Single-layer cylindrical reticulated shell with the length of 180m.](image)

3. Ground motion field considering traveling wave effect

The “Code for Seismic Design of Buildings” (GB 50011-2010) provides [5]: For special irregular buildings and Class A buildings that use time-history analysis to calculate under multiple earthquakes, when taking seven or more sets of time-history curves, the structure of calculation can take the average of the time-history method. In this paper, the analytic method of time-history is used to analyze the single-layer cylindrical reticulated shell structure, and the displacement method is applied to the displacement time history, and the structural damping ratio is taken as 0.02. In seismic analysis, seven actual seismic waves are selected in this paper and the results of calculation are compared with the average of the time-history method.

The traveling wave method is based on a certain seismic wave, and the input of seismic wave is adjusted according to the distance between different bearings. This involves two different directions. First of all, in the phase adjustment, the different direction of earthquake propagation leads to different conditions for the phase adjustment of different support points. A schematic diagram of the support for a single-layer cylindrical reticulated shell with a length of 180m, as shown in Figure 2. The chart of displacement time-histories of number 1 support (A point) and No. 98 support (B point) of 180m single-layer cylindrical reticulated shell structure with the same wave velocity and different propagation direction are shown in Figure 3. The difference in the direction of propagation can be clearly seen from Figure 3, and the phase difference is distinctly different. Secondly, one support involves three directions (length direction X, span direction Y, and vertical direction Z), and the influence of the ground motion input in different directions on the structure is also not the same. In this paper, the ground motion input can be divided into three directions; in the seismic wave propagation direction, it can be divided into two directions. There are a total of six different ground motion fields in which the horizontal one-dimensional ground motion input including XX, YY, XY, YX, as shown in Table 1.
Figure 2. The support location of No.1 and No.98.

(a)  (b)

Figure 3. Displacement time in different propagation directions.

Table 1. Representation of six ground motion fields.

| Vibration | Propagation | The direction of X | The direction of Y |
|-----------|-------------|--------------------|--------------------|
| The direction of X | X-X | Y-X |
| The direction of Y | X-Y | Y-Y |
| The direction of Z | X-Z | Y-Z |

4. The analysis on seismic response of structures under horizontal one-dimensional ground motion input

4.1. The direction of propagation and vibration is in the X direction.
Firstly, the displacement wave of each bearing is established through MATLAB. At each bearing, the input along the length of the structure is performed. A single-layer cylindrical reticulated shell structure with a length of 180 m was subjected to multi-point input time-history analysis and consistent input time-history analysis to obtain the maximum axial force of each rod and the maximum displacement of each node, as shown in Fig.4.
As can be seen from Figures 4(a) and 4(b):

1. Whether it is multi-point input or consistent input, the three parts (vertical rod, edge rod and diagonal rod) show inconsistent changes. The maximum axial force of the vertical rod is the smallest, the edge rod is the second, and the maximum axial force of the diagonal rod is the largest, especially edge diagonal rod, which has reached 180 kN.

2. The maximum displacement of the nodes in the crossover reaches 60mm, while the spans on both sides only reach about 50mm. Because of the symmetry of the structure, the displacement changes on both sides exhibit similarities.

4.2. The direction of propagation is X direction and the direction of vibration is Y direction.
The seismic displacement wave whose propagation direction is X direction is input along the Y direction of the structure, and the seismic response of the structure is obtained.

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Table 2. The maximum value of the maximum axial force of the rods under horizontal ground motion one-dimensional input (kN).

|                      | Y-Y   | Y-X   | X-Y   |
|----------------------|-------|-------|-------|
| The maximum axial force of the rods | 162.83 | 164.34 | 161.74 |
| Multi-support excitaton | 138.98 | 141.55 | 133.61 |
| Simple support excitaton |

Table 3. The maximum value of the maximum displacement of the nodes under horizontal ground motion one-dimensional input (m).

|                      | Y-Y   | Y-X   | X-Y   |
|----------------------|-------|-------|-------|
| The maximum displacement of the nodes | 0.0493 | 0.054 | 0.062 |
| Multi-support excitaton | 0.0412 | 0.043 | 0.040 |
| Simple support excitaton |

From Figure 4 to Figure 7 and Table 2 to Table 3, it can be seen that:

1) Regardless of the YX ground motion field or the XY ground motion field, the internal force distribution of the entire structure is symmetrical; the maximum axial force of the vertical rod under the multi-point input is almost equal to the maximum axial force of the input vertical rod, but the maximum axial force of the sway rod under the multi-point input is significantly greater than that...
under the same input. This shows that the traveling wave effect has little effect on the structure of the vertical bar under these two ground motions, but it has a greater impact on the structure of the diagonal bar. In addition, the maximum axial force of the cross-members of the reticulated shells significantly increased.

(2) It can be seen from Fig. 5(a) and Fig. 6(a) that the maximum axial force of the cross-members of the structure is obviously increased. Compared with the previous YY ground motion field, the maximum value of the cross-middle slant rod is increased by 15%, but it is still smaller than the maximum axial force of the cross-slope diagonal rod. From the comparison of the maximum axial force of the members in the three seismic motion fields, the maximum axial force of the diagonal structure of the overall structure caused by the latter two seismic motion fields significantly increased. This shows that X-Y ground motion field and Y-X ground motion field have a great influence on the overall structural response.

(3) As can be seen from Fig. 5(b) and Fig. 6(b), the maximum displacement of the structural node under multi-point input is greater than that under the same input. In terms of structure, the maximum displacement of the mid-span node is relatively greater than that of the span-side node. From Table 2 and Table 3, in terms of the maximum axial force of the rod, the structural responses of the consistent input in the three seismic fields are basically the same, while the response of the multi-point input structure shows the minimum under the Y-Y ground motion field and the largest under the Y-X ground motion field. In terms of nodal displacement, the structural response under multi-point input presents the maximum under the X-Y ground motion field.

5. Conclusion

When the propagation direction of ground motion is along the span direction and the vibration direction of ground motion is along the length direction, the structural response is very obvious under the horizontal one-dimensional seismic input. In the seismic design of large-span space structures, the traveling wave effect must be considered. When the traveling wave effect is studied, if you only pay attention to the maximum axial force of the structural member, horizontal one-dimensional input can be performed.

References

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