

Wind Resistance Analysis of Plate-cone Reticulated Shell

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Abstract. Plate-cone reticulated shell is a new type of space steel structure with good mechanical behaviour and technical economy. In this paper, the wind-induced vibration response characteristics of plate-cone reticulated shell are studied. By using the wave superposition method, the fluctuation wind loads are simulated. According to the structural behaviour of plate-cone reticulated shell, by using the large general structural analysis software ANSYS, wind resistance time domain analysis of plate-cone reticulated shell are carried out through simulating wind field variation around plate-cone reticulated shell. After comparing the wind dynamic vibration results of the model with different material, some important conclusions for plate-cone reticulated shell are obtained for practical design.

Introduction

Plate-cone reticulated shell is a new type of space structures, in which cone elements are composed of plates and made up into a whole based on the surface shape of reticulated shell, then the tops of cones are connected by members. Plate-cone reticulated shell has good mechanical behavior, technical economy and architectural appearance. Research for plate-cone reticulated shell in China and abroad is not very sufficient, the research abroad [1] focuses on static analysis and approximate equivalent method. In China, plate-cone reticulated shell is analyzed with composite structures FEM [2]. The dynamic problem of plate-cone reticulated shell is also a very important problem in engineering design, but due to complexity of the structure, the wind vibration response analysis for plate-cone reticulated shell has not been seen at present, not adapting to the needs of engineering application.

In this paper, wind resistance time domain analysis of plate-cone reticulated shell is carried out based on artificial simulation of pulsation wind and numerical wind tunnel test. The wind load factors of plate-cone reticulated shell are discussed under horizontal pulsation wind, the internal force and deflection compared with no wind, the wind vibration response characteristics of plate-cone reticulated shell are studied deeply.

Wind Load Factor of Plate-cone Reticulated Shell

In this paper, by using the wave superposition method, the Davenport horizontal pulsation wind spectrum is simulated. The finite element model of 8 units division for the plate flange is selected for time domain analysis of the following example.

The geometric parameters of plate-cone cylindrical reticulated shell with quadrangular pyramids are: span is 30m, length is 45m, vector height is 5m, thickness is 1.5 m, mesh is divided into 10×15, the top connecting members are taken as steel pipes of $\Phi 108 \times 5.0$, the triangle plates of cones are taken as steel plates of 3mm thickness, the reticulated shell is put on the 10m high maintenance structure.

Wind Load Factor on Central Point of Different Ranks of Cone Plates

By carrying on the statistics and processing of the computed result, the wind load factors of plate-cone cylindrical reticulated shell are attained (Figure 1, Figure 2). In the figures, the abscissa express separately cone serial number along the span direction and along the length direction, the y-coordinate express the wind load factors of internal force.

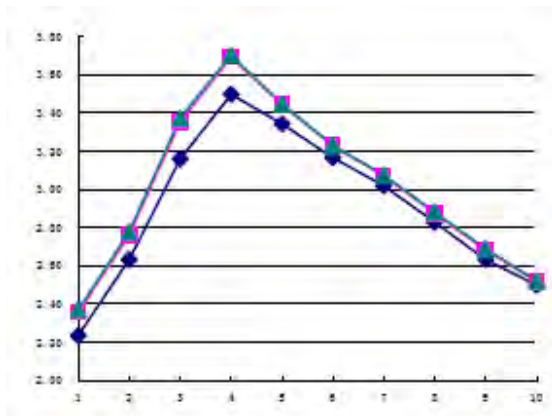


Fig. 1 Wind Load Factor on Center Point of Different Span of Cone Plate

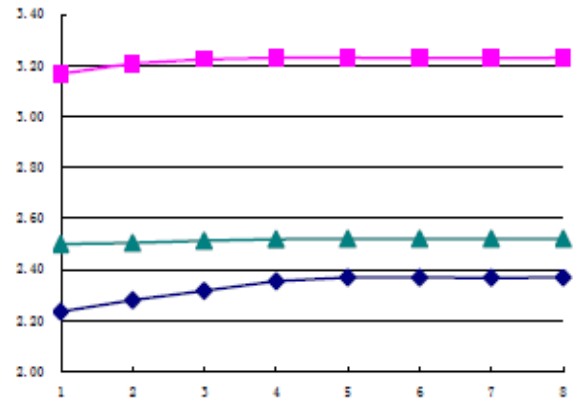


Fig. 2 Wind Load Factor on Center Point of Different Row of Cone Plate

By analysing the biggest wind load factor on central point of different ranks of cone plates in Figure 1 and Figure 2, the following can be obtained:

1) Along span direction, the internal force wind load factors change approximately along with the shell's height, the internal force wind load factor nearby the net umbo to achieve the biggest: 3.70. The internal force wind load factors on center points of different spans of cone plates slightly are different, the internal force wind load factors nearby the shell's center are bigger, the internal force wind load factors of edge spans are small, but the difference is not big, the biggest differential value appears in the third cone of intermediate span and the first span, its differential value is 0.21, only is 5.7% of the biggest internal force wind load factor.

2) Along length direction, the internal force wind load factors don't change much, the biggest differential value appears between cones of the first row of edge span and cones of the intermediate span (the eighth span), its differential value is 0.13, only is 3.5% of the biggest internal force wind load factor. Therefore it can be thought that along length direction, the internal force wind load factor is consistent. By taking the mean value of each row, it can be obtained that the first row of internal force wind load factor is 2.33, the sixth row of internal force wind load factor is 3.22, the tenth row of internal force wind load factor is 2.51, consistent with Figure 1.

3) Because of strong restraint, the internal force wind load factor nearby support is small, even if in the tenth row, which shape factor is biggest, the differential value of mean value of internal force wind load factor with the first row is only 0.18, 4.9% of the biggest internal force wind load factor. But for the middle row far away from the support, such as the fourth row, the internal force wind load factor achieves 3.7, 147% of the internal force wind load factor on the biggest shape factor. Obviously the support's restraint has much more influence on the internal force wind load factor than the shape factor.

Wind Load Factor of Top Member in the Span Direction

By carrying on statistics and processing of results of the above example, internal force wind load factors of top members in the span direction of different rank's cones are obtained, which are shown as Figure 3 and figure 4.

By analysing the internal force wind load factors of top members in the span direction of different rank's cones in Figure3 and Figure4, the following can be obtained:

1) Along the span direction, wind load factors of top members change along with the shape factors. In the tenth row, which shape factor is biggest, the wind load factor of top member is also biggest, which is 1.47. In the first row, which shape factor is smallest, the wind load factor of top member is also smallest, the minimum value is 1.02.

2) In Figure 3, wind load factors of top member of different rows are slightly different. Wind load factor of top member is biggest nearby the shell's center, wind load factor of top member is small for edge span, but their differential value is not big, the biggest differential values appear in top members of the ninth row and tenth row of cones, which shape factor are biggest, the biggest differential value is 0.09, 6.1% of the biggest wind load factors of top member.

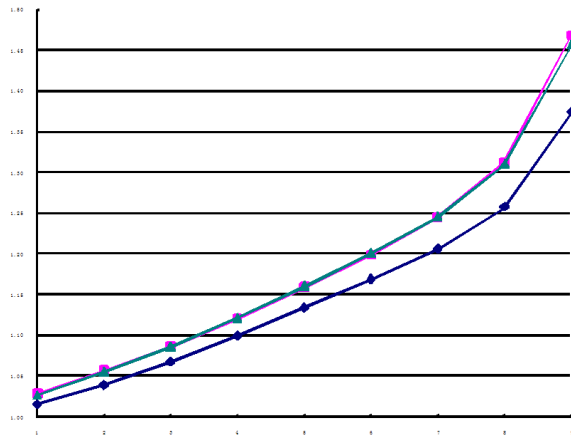


Fig. 3 Wind Load Factor of Top Member in the Span Direction

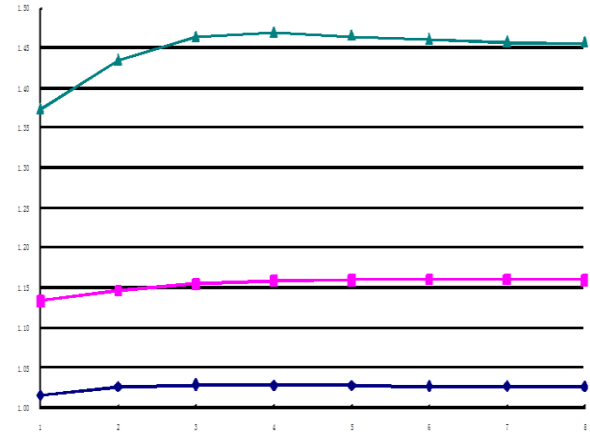


Fig. 4 Wind Load factor of Top Member in the Length Direction

According to the wind load factors of the above model, the wind load factors of this type of model are processed by comparing in this paper, the following wind load factors are recommended:

The wind load factor of top member is suggested as 1.5.

The wind load factor of cone's plate in the span direction changes along with the shell's height, but the wind load factor in the different span doesn't change largely, therefore the simplified principle is used for the small span shell, the wind load factor is taken as the max 3.7. For the large span shell, the different row of cone's the wind load factor is calculated through the shape factor, and should be selected according to actual computation situation.

Wind Resistance Analysis of Plate-cone Reticulated Shell

By using the geometry size and the constraints of above example, plate-cone cylindrical reticulated shells with the 3mm steel plate and the 18mm cement plate are calculated in this paper, firstly the largest wind vibration internal force is compared with the static internal force (Table 1, Table 2), then the dynamic displacement and static displacement are also compared (Table 3).

Tab. 1 Conversion Stress of Plate and Dynamic- static Internal Force Ratio

span number	Static internal force		Wind vibration internal force		Wind vibration / Static internal force	
	3mm steel plate	18mm cement plate	3mm steel plate	18mm cement plate	3mm steel plate	18mm cement plate
1	1.52E+07	1.61E+06	2.54E+07	1.45E+06	1.662	0.900
2	1.41E+07	1.38E+06	2.25E+07	1.17E+06	1.599	0.847
3	1.26E+07	1.12E+06	2.30E+07	9.87E+05	1.832	0.883
4	1.08E+07	8.63E+05	2.73E+07	6.83E+05	2.523	0.791
5	8.99E+06	6.41E+05	3.88E+07	9.58E+05	4.313	1.495
6	8.99E+06	6.41E+05	4.84E+07	1.30E+06	5.387	2.025
7	1.08E+07	8.63E+05	5.18E+07	1.55E+06	4.788	1.796
8	1.26E+07	1.12E+06	5.44E+07	1.85E+06	4.326	1.652
9	1.41E+07	1.38E+06	5.29E+07	2.06E+06	3.751	1.494
10	1.52E+07	1.61E+06	9.49E+07	3.44E+06	6.223	2.134

Tab. 2 Axial Force of Top Member and Dynamic- static Internal Force Ratio

Axial force (N) Member No.	Static internal force		Wind internal force		Wind internal force/ Static internal force	
	3mm steel plate	18mm cement plate	3mm steel plate	18mm cement plate	3mm steel plate	18mm cement plate
1	-2.40E+04	-2.81E+04	-2.39E+04	-2.80E+04	0.997	0.996
2	-5.03E+04	-5.90E+04	-4.98E+04	-5.83E+04	0.991	0.987
3	-7.31E+04	-8.57E+04	-7.20E+04	-8.43E+04	0.985	0.984
4	-8.84E+04	-1.04E+05	-8.65E+04	-1.01E+05	0.978	0.979
5	-9.38E+04	-1.10E+05	-9.12E+04	-1.07E+05	0.973	0.975
6	-8.84E+04	-1.04E+05	-8.55E+04	-1.01E+05	0.967	0.970
7	-7.31E+04	-8.57E+04	-7.04E+04	-8.28E+04	0.963	0.965
8	-5.03E+04	-5.90E+04	-4.81E+04	-5.66E+04	0.957	0.959
9	-2.40E+04	-2.81E+04	-2.26E+04	-2.66E+04	0.945	0.946

Tab. 3 Displacement of Top Node and Dynamic- static Displacement Ratio

Displacement (mm) Node	Static displacement		Wind displacement		Wind displacement / Static displacement	
	3mm steel plate	18mm cement plate	3mm steel plate	18mm cement plate	3mm steel plate	18mmceme nt plate
1	0.05	0.07	0.04	0.05	0.735	0.790
2	-1.95	-2.32	-2.30	-2.70	1.179	1.167
3	-5.22	-6.28	-5.19	-6.24	0.994	0.994
4	-8.42	-10.16	-8.29	-10.01	0.984	0.985
5	-10.36	-12.51	-10.12	-12.25	0.977	0.979
6	-10.36	-12.51	-10.06	-12.19	0.972	0.974
7	-8.42	-10.16	-8.13	-9.84	0.965	0.968
8	-5.22	-6.28	-5.00	-6.03	0.957	0.960
9	-1.95	-2.32	-1.83	-2.18	0.939	0.941
10	0.05	0.07	0.32	0.36	6.046	5.244

The following can be found from the results:

1) Under fluctuating wind load, using 3mm steel plate, change of the plate stress is relatively higher, the largest dynamic- static internal force ratio can achieve 6.2, while using of 18mm cement plate, the largest ratio of dynamic- static internal force is only 2.134, indicating the pulse of the wind has larger influence for the sheet.

2) Under fluctuating wind load, maximum stress of 3mm steel plate's central node is only 94.9Mpa, maximum stress of 18mm cement plate's central node is only 3.44Mpa, it shows that fluctuating wind will bring bigger wind vibration internal force, but the structure still has sufficient strength surplus.

3) As shape factors of the model in this example are negative, the wind loads attract on structure, it has a great impact on the structural force form. The axis force of top member under wind loads is less than no wind, but the values are little different, the maximum difference is 5.5% for 3mm steel plate, the maximum difference is 5.35% for 18mm cement plate, the maximum difference appears in the location where shape factor is maximal.

4) Wind load's attraction on the structure has beneficial effects on the deflection of the shell. In the absence of wind, the maximum deflection of shell appears in the middle, the maximum deflection of shell

with 3mm steel plates is 10.36mm, the maximum deflection of shell with 18mm cement plates is 12.51mm. Under the wind load, due to wind's suction, deflection of the shell is reduced, the maximum deflections of the shell decrease to 10.12mm and 12.25mm.

5) The change of plate material has affect only on the local internal force of plate itself, but has little affect on the whole mechanical properties of shell. Heavier material results in the deflection increasing, but the effect is little.

Conclusion

In this paper, wind resistance analysis of plate-cone reticulated shell is carried out based on artificial simulation of pulsation wind and numerical wind tunnel test. The wind load factors of plate-cone reticulated shell are discussed under horizontal pulsation wind, the internal force and deflection compared with no wind, the following conclusions can be attained:

a) The wind load factors of plate-cone reticulated shell change greatly, the internal force wind load factors in the single span change generally along with the height in the span direction of plate-cone reticulated shell, the minimum internal force wind load factor is 2.24, the maximum is 3.7, the difference of internal force wind load factors between each span is not great, so for the small span shell, the wind load factor can be taken as the maximum. For the large span shell, the structure can be divided into different zones according to the span direction, the different wind load factors should be selected.

b) The wind load factors of top members along the span direction range from 1.02 to 1.5, the wind load factors are larger where the shape factors are larger. Due to the unpredictability of the wind direction, the wind load factors of top members can be taken as 1.5.

c) Orthogonal square tapered column panel cone reticulated shell under wind load with no wind cone slabs under the cone slabs much difference, mainly due to fluctuating the impact of wind on the result sheet; due to wind load suction effect, so that plate-cone shell structures under static load deflection than a decrease in the deformation of the shell is beneficial impact. Due to the impact of fluctuating wind on the sheet, the internal force of plates under wind load is different greatly with that of no wind load. Wind load's attraction on the structure has beneficial effects on the deflection of the shell.

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