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Characteristics of internal pressures of cylindered roof structures with rectangular openings

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SUMMARY
Internal pressures of cylindered roof structures with rectangular openings are measured through model-scale tests. Effects of opening areas, opening locations, and wind directions on internal pressures were studied, and the area ratio of the single opening to the whole wall is within 25%. Peak internal pressures occur when the opening is on the windward or side wall. Internal pressures of cylindered roof structures with one opening on the windward and leeward walls respectively are much lower in magnitude than that with the same opening only on a windward wall in wind directions of θ= 0°~60°.

Keywords: cylindered roof structures, influencing factors of internal pressures, two openings

1. GENERAL INSTRUCTIONS

Cylindered roof structures are applied widely in large-span coal storage sheds to reduce environmental pollution. Effects of openings like doors or windows over the roof are usually ignored in wind loads design. However, this may underestimate fluctuations of internal pressures and may make structural elements under large wind pressures unsafe.

To find the relationship between internal and external pressures in a building with one windward opening, Holmes derived a nonlinear differential equation to describe the response of internal pressures (Holmes, 1979). As wind directions changed, fluctuations of internal pressures were much higher than external pressures under oblique flow (Sharma and Richards, 2003). Background porosity in the leeward wall could substantially weaken internal pressures when its total area was more than one-tenth of the windward opening (Yu S.C., 2006). The shape of the roof opening also influenced fluctuations of internal pressures (Yuan Y.J., 2021). Peak net pressures in a building with one opening were largely different from that on an enclosed envelope (G.G et al., 2022).

These studies were based on low-rise buildings with one windward opening. However, the relationship between internal and external pressures would be more complex if wind directions change. Multiple openings over the envelope of large-span cylindered roof structures would make internal pressures more difficult to calculate, compared with the case of a single opening. This article analyses the influencing factors of internal pressures in one cylindered roof structure with a single wall opening and studies the characteristics of internal pressures when two openings are in different locations on the envelope of the structure.

2. EXPERIMENT SETUP

The model-scale test is conducted in the boundary layer wind tunnel at Harbin Institute of Technology. The model prototype is 150m long and 80m wide. The tip of the roof is 30m high. Fig. 1 shows a rigid model at a length scale of 1/250, and the reference height is 0.5m. The wind flow is simulated as terrain category A profile specified in Chinese load codes, considering that large-span coal storage yards are usually constructed in open areas. Experimental cases are shown in Table 1, and wall-1, wall-14 are shown in Fig. 1. Wind directions are shown in Fig. 2. Locations of two openings included the same wall, opposite walls, adjacent walls, and a combination of roof and wall. The mean wind velocity at the reference height is about 10.5m/s, and turbulence intensity at the reference height is about 10.1%. Fig.3 shows the profile of mean wind speed and turbulence intensity. The model to full-scale volume ratio is $V_r = L_r^3/U_r^2$ and the velocity scale ratio is assumed to be 1. The volume scale ratio is determined without adding the volume under the turntable (Holmes, 1979).

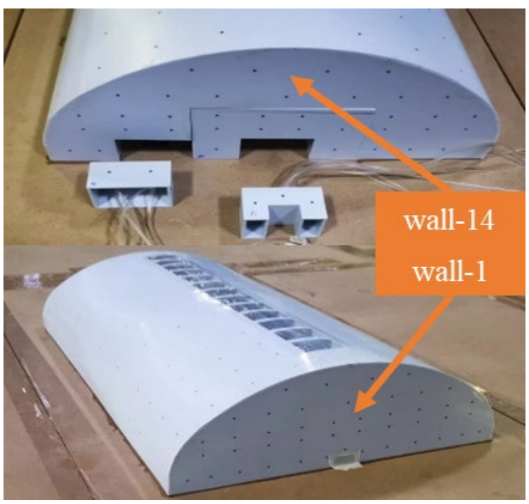

Figure 1. Picture of the test model

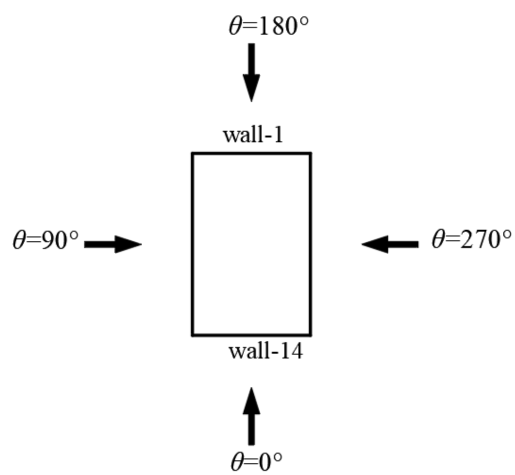

Figure 2. Wind directions of the test

Table 1. Details of wind tunnel test cases

Case	Opening locations	Opening sizes	Wind directions	$\overline{U}_h$ (m/s)	I_h
1	The center of wall-14	5×3m	0°-195°		
2	The center of wall-14	13×7m	0°-195°		
3	The center of wall-14	30×16m	0°-195°		
4	--	--	0°-105°		
5	The border of wall-14	13×7m	0°-195°	10.5	10.1%
6	The center of wall-14 and wall-1	13×7m; 5×3m	0°-195°		
7	The center of wall-14 and roof	13×7m 10×8m	0°-195°		
8	The center and border of wall-14	13×7m; 13×7m	0°-360°		
9	The center of wall-14 and the side of roof	13×7m; 10×6m	0°-360°		

3. Results and Discussions

Internal pressures were averaged over pressure taps in the internal surface of the model, considering that pressures measured at all these taps give identical fluctuations with time and similar statistical values.

3.1. Influencing factors of internal pressures with a single opening

Table 2. lists measured internal pressures from case 1 to case 4 in wind directions of 0° and 90°. The area ratio of the single opening to the whole wall is 0%, 0.78%, 4.75%, and 25.1%. Both positive and negative internal pressures increase in magnitude as the opening enlarges.

When the opening location is changed from the center (case 2) to the border (case 5) of the wall, internal pressures fluctuate violently from 75° to 90°, as shown in Fig. 3 and Fig. 4. The largest standard deviation of internal pressures in case 5 is at 90° and highly larger than that in case 2. The positive and negative peak internal pressures still occur from 0° to 15° and from 75° to 105°, although the opening location has changed. The opening is on the windward wall and side wall respectively in these wind directions.

Table 2. The effect of opening areas on internal pressures

Opening areas (m^2)	0°		90°	
	$\bar{C}_{pi}$	σ_{pi}	$\bar{C}_{pi}$	σ_{pi}
0	-0.07	0.03	-0.08	0.03
15	0.21	0.08	-0.13	0.06
91	0.41	0.14	-0.17	0.10
480	0.47	0.18	-0.35	0.15

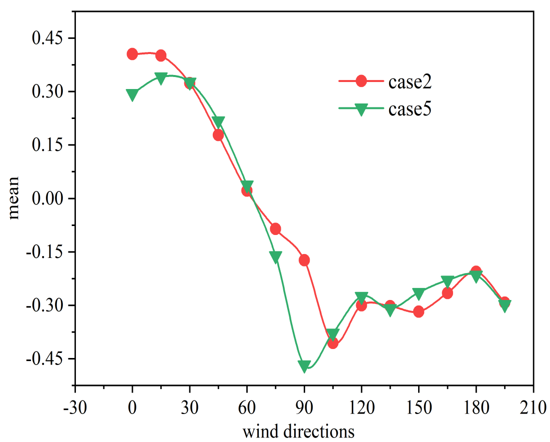

Figure 3. Effects of opening locations on $\bar{C}_{pi}$

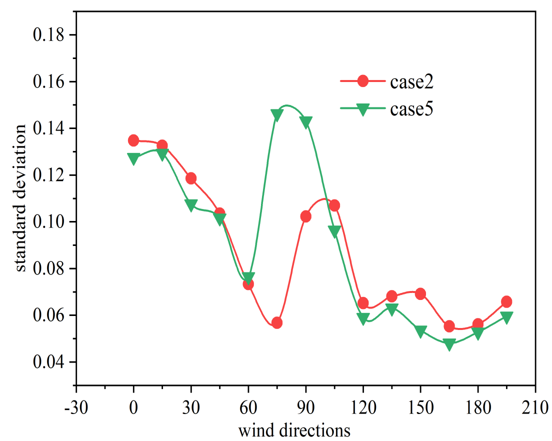

Figure 4. Effects of opening locations on σ_{pi}

3.2. Difference between two openings and a single opening

Table 3. show the difference between case 2 and case 6. These two cases have the same opening on wall-14, and its size is 13m wide and 7m high. One smaller opening is added on the center of wall-1 in case 6, and its size is 5m wide and 3m high. The mean of internal pressures in case 6 is largely reduced from 0° to 60°, and its standard deviation is slightly lower than that in case 2. However, these two cases are similar in other wind directions, which means that the smaller opening does not work on the side wall or windward wall.

Table 3. The difference in internal pressures between case 2 and case 6

wind directions	case 2		case6	
	$\bar{C}_{pi}$	σ_{pi}	$\bar{C}_{pi}$	σ_{pi}
0°	0.41	0.13	0.30	0.12
30°	0.32	0.12	0.23	0.10
60°	0.02	0.07	-0.04	0.06
90°	-0.17	0.10	-0.17	0.09
120°	-0.30	0.07	-0.29	0.06
150°	-0.32	0.07	-0.30	0.06
180°	-0.21	0.06	-0.20	0.05

4. Conclusions

Internal pressures in the cylindered roof structure with a single opening on the wall increase as the opening enlarges, and peak internal pressures occur from 0° to 15° and from 75° to 105°.

Adding another smaller opening on the leeward wall of the cylindered roof structure reduces internal pressures from 0° to 60° when the windward wall only has one single opening.

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