

Wind pressure acting on flat roofed buildings

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ABSTRACT: The wind pressure distributions on flat roofed steel frame buildings with and without parapet are studied by wind tunnel tests. At first, the magnitudes and distributions of the mean, fluctuating and minimum wind pressure coefficients on the surface of the models are analyzed. Then, wind pressure distributions derived from wind tunnel test and main country codes are compared in transverse wind direction, not considering wind-induced internal pressure and gust effect factor due to such low-rise building with enough rigidity. Finally, the characteristics of the proper orthogonal decomposition results of the measured wind pressure field are analyzed. The investigation can provide some basic understanding and reference for clauses about wind loads.

KEYWORDS: Flat-roofed buildings; parapet; wind tunnel test; wind pressure distribution; shape coefficient; code; proper orthogonal decomposition

1 INTRODUCTION

Flat roofs with and without parapet are widely used for commercial and residential low-rise buildings with steel frames. Their relatively light dead load and flexibility make them susceptible to wind load. There have been relatively few studies on the effects of parapet on wind load for low-rise building, this is likely due to the conclusion in Ref [1] that the code provisions for buildings without parapet are equally applicable to buildings with parapet, which may lead to unnecessary cost waste in structural design. The current codes have no recommendations about considering the effects of parapet in wind-resistant design. The present study is first to examine the general distribution of wind loads on flat-roofed buildings with and without parapet, secondly to compare wind pressure distribution obtained from wind tunnel test and main country codes, and thirdly to analyze the characteristics of the proper orthogonal decomposition results of the measured wind pressure field.

2 EXPERIMENTAL PROCEDURE

The experiments were carried out in the Boundary Layer Wind Tunnel at State Key Laboratory for Disaster Reduction in Civil Engineering at Tongji University. The wind tunnel working section is 2.5m high, 3m wide and 15m long. The exposure category of the ground roughness can be regarded as Category B according to *Load code for the design of building structures* GB50009-2001 of China [2]. Model A without parapet and model B with 1.2m high parapet commonly used in China were made at a geometric scale of 1:40, and they have the same full scale dimensions. Figure 1 shows the prototype buildings. 235 taps were arranged on the roof and walls of the models to measure wind pressure simultaneously. Due to wind load on parapet is beyond the scope of this study, no tap was arranged on the parapet. Figure 2 shows the layout of pressure taps on the roof and walls. The wind attack angle is varied from 0° to 360° in 45° in steps (Figure 2). Wind speed and corresponding velocity pressure at the eave heights of the models are taken as the reference wind speed and reference pressure in analyzing the wind pressure coefficients. The reference wind speed at the reference height is near to 8m/s.

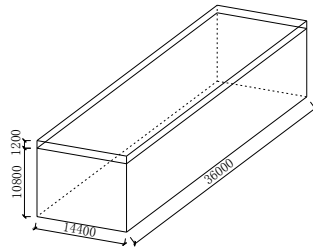


Figure 1. Prototype of flat-roofed buildings

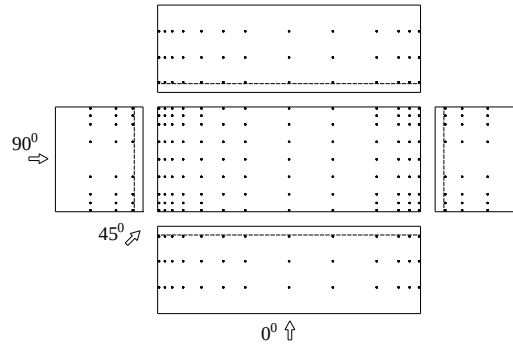


Figure 2. Layout of pressure taps for the models

3 RESULTS AND DISCUSSION

3.1 The characteristics of wind pressure

Figure 3 and figure 4 show the magnitudes and distributions of mean and fluctuating wind pressure coefficients on model A and model B with 0° , 45° , and 90° wind directions, respectively, in consideration of the symmetric conditions of the models. The distributions of mean wind pressure coefficient on the walls of model B are similar to those of model A, and the magnitudes of mean wind pressure coefficient on the walls of model B are close to those of model A in the same wind direction. Wind pressure on the walls is little affected by the presence of parapet. The distributions of mean wind pressure coefficient on the roofs of model A and model B are similar in the same wind direction; however a significant decrease in the magnitudes of wind pressure coefficient on the roof of model B, compared with those of model A, is observed due to the presence of 1.2m parapet. The effects of parapet on the roof and the walls are consistent with the findings in Ref [3]. The magnitudes and distributions of fluctuating wind pressure coefficients on model B are similar to those of model A in the same wind direction.

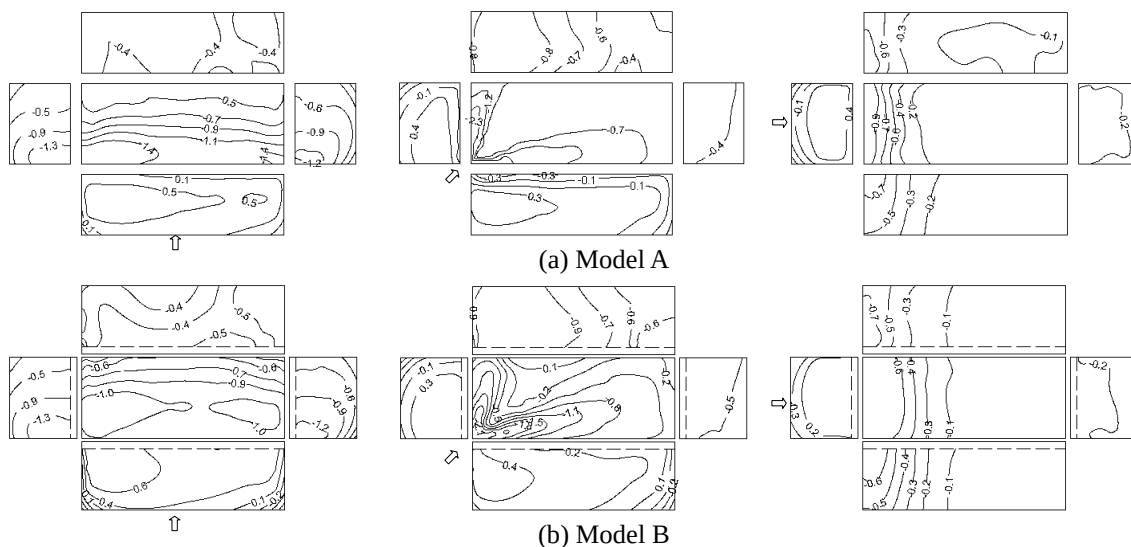


Figure 3. Mean wind pressure distributions

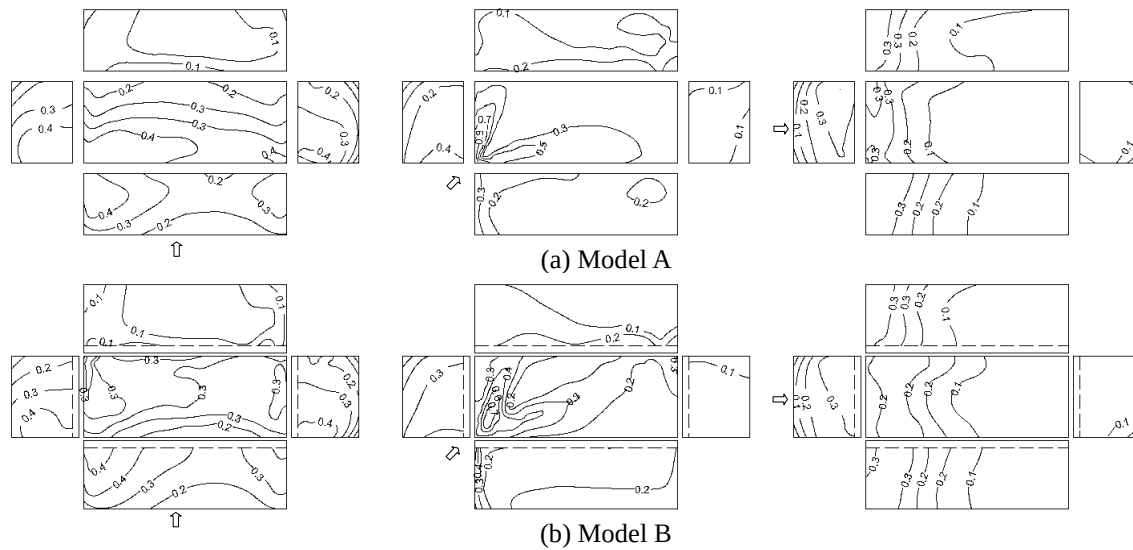
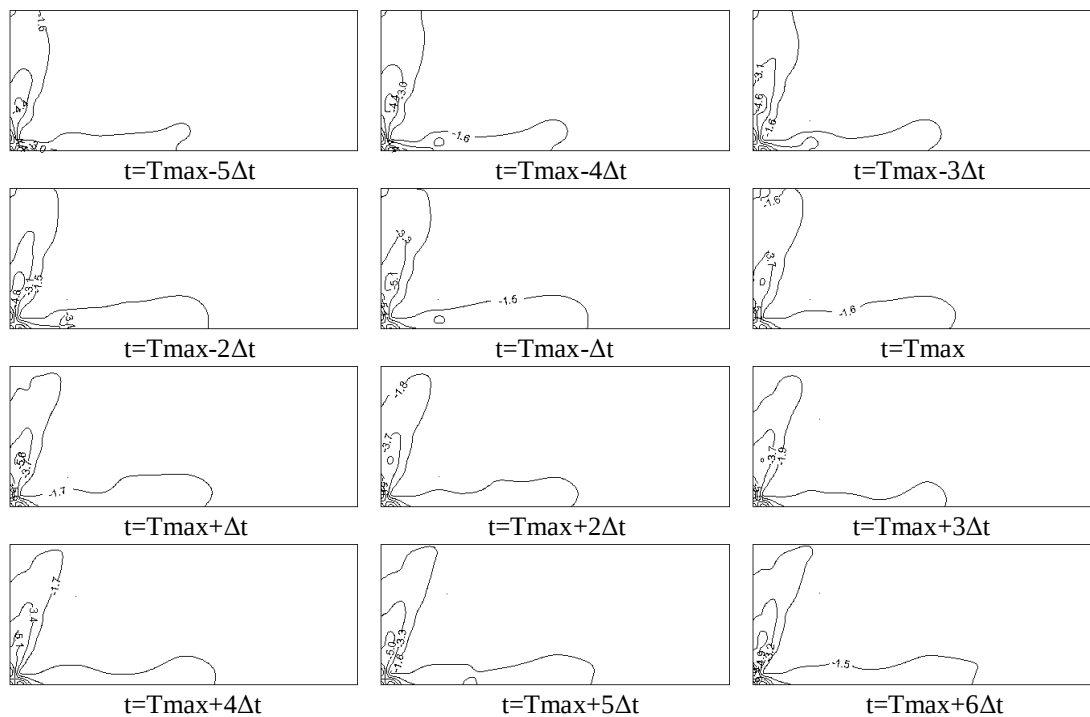
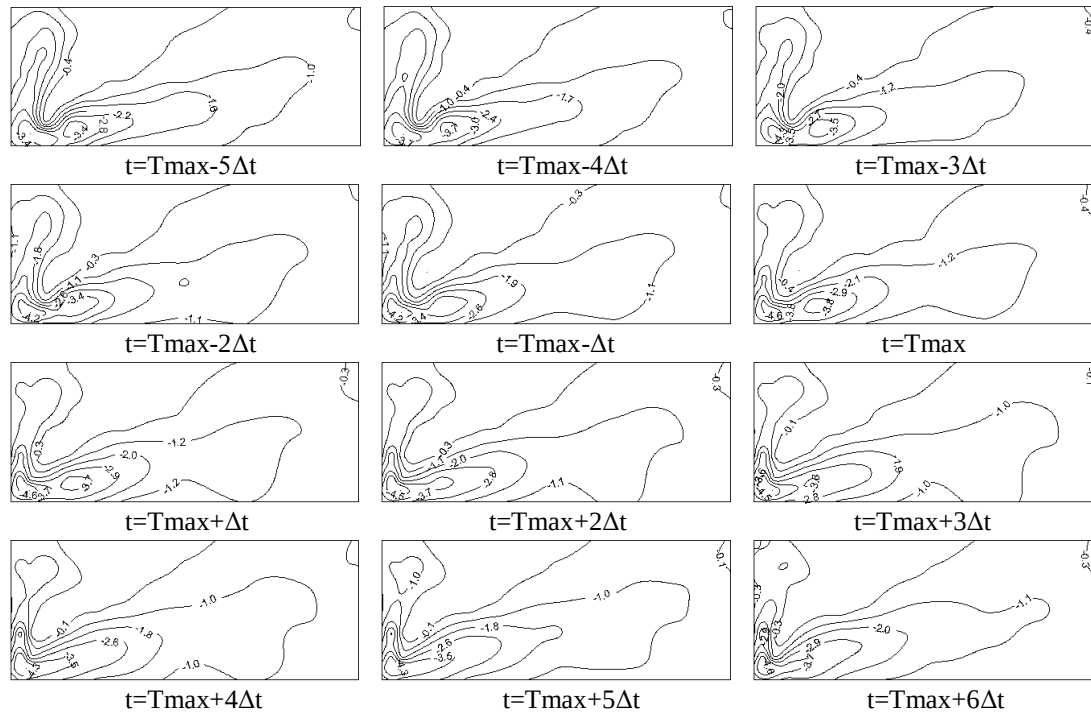


Figure 4. Fluctuating wind pressure distributions

The variations of the instantaneous pressure distribution on the roofs of the two models in 45° wind direction with time from $t = T_{\max} - 5\Delta t$ to $t = T_{\max} + 6\Delta t$ are shown in figure 5, where $T_{\max}$ represents the time when the maximum peak suction is observed at the reference height during the whole record. These results show that the pressure distribution, which causes very severe suctions in the leading edge and corner regions, last only 4-6 time steps, or 0.2-0.3s in very case that was tested. The pressure distributions on the roofs change significantly with time during such a short period around $T_{\max}$. The area of severe suctions at $t = T_{\max}$ is small as up to $0.5\text{m} \times 1\text{m}$, which covers the connections in self-drilling screws of profiled steel sheets commonly used in China. These results indicate that the time and/or spatial averages of wind fluctuations lead to a remarkable decrease in the peak suction.





(b) Roof with parapet

Figure 5. Variations of the instantaneous pressure distribution on the roofs in 45° wind direction

3.2 Comparison with current codes

The magnitude and distribution of wind pressure on model A in transverse wind direction, obtained from wind tunnel test is compared with those from current codes, including GB 50009-2001, *Architectural Institute of Japan Recommendations for Loads on Buildings* AIJ2004 [4], *Minimum Design Loads for Buildings and Other Structures* ASCE/SEI7-05 of American [5] and *Structural Design Actions* AS/NZS1170.2:2002 of Australian/New Zealand [6]. Not considering wind-induced internal pressure and gust effect factor due to such low-rise building with enough rigidity, design wind pressure from current codes can be estimated in uniform equation as:

$$w_d = 0.5 \rho_{air} v_d^2 C_s C_h \quad (1)$$

where, w_d is design wind pressure; ρ_{air} is the air density, which normally lies in the range 1.20 to 1.25 kg/m³; v_d is design wind speed, determined by the height, exposure category, time duration and return period. C_s is the shape coefficient a modifying coefficient for the place of the point on the surface; C_h is the height coefficient, a modifying coefficient for the height of the point. In AIJ2004 and AS/NZS1170.2:2002, C_h is concluded in the calculation of v_d , which has little effect on wind pressure on such low-rise building.

The parameters of the estimation on design wind pressures from different country codes are given in table 1. Wind pressures in all codes are evaluated at an elevation of 10 m. Time duration of wind speed in GB 50009-2001 and AIJ2004 are 10 minutes; while 3 seconds in ASCE/SEI7-05 and AS/NZS1170.2:2002. Return period of wind speed in AIJ2004 is 100 years; while 50 years in other codes. Conversion coefficients of time duration and return year are used in determination of wind speed between different codes. The zone of the shape coefficient, C_s , in table 1 is shown in figure 6. H is the eave height of the building and a equals to 1.44 m according to ASCE/SEI7-05. For the flat-roofed building, the shape coefficient distributions from GB 50009-2001 are the same as those from AIJ2004. The roof end, windward wall end and leeward wall end suffered higher pressure are considered in

ASCE/SEI7-05. The shape coefficients decreasing along wind direction on the roof and side walls are considered in AS/NZS1170.2:2002, which is more consist with experimental results.

Table 1. The parameters of the estimation on design wind pressures from different country codes

Parameters			GB 50009-2001	AIJ2004	ASCE/SEI7-05	AS/NZS1170.2:2002
Wind speed at 10 m height (m/s)			23.71	26.08	35.09	35.09
C_h			1.022	1.009	1.017	1.008
v_d (m/s)			23.71	26.31	35.09	35.72
C_s	Windward wall	W	+0.80	0.60	+0.48	+0.80
		WE	+0.80	0.60	+0.72	+0.80
	Leeward wall	L	-0.50	-0.40	-0.34	-0.50
		LE	-0.50	-0.40	-0.51	-0.50
	Side wall	S1	-0.70	-0.70	-0.53	-0.65
		S2	-0.70	-0.70	-0.53	-0.50
	Roof	R1	-0.60	-0.87	-0.81	-1.10
		R2	-0.60	-0.87	-0.81	-0.80
		R3	-0.60	-0.87	-0.81	-0.50
		R1E	-0.60	-0.87	-1.26	-1.10
		R2E	-0.60	-0.87	-1.26	-0.80
		R3E	-0.60	-0.87	-1.26	-0.50

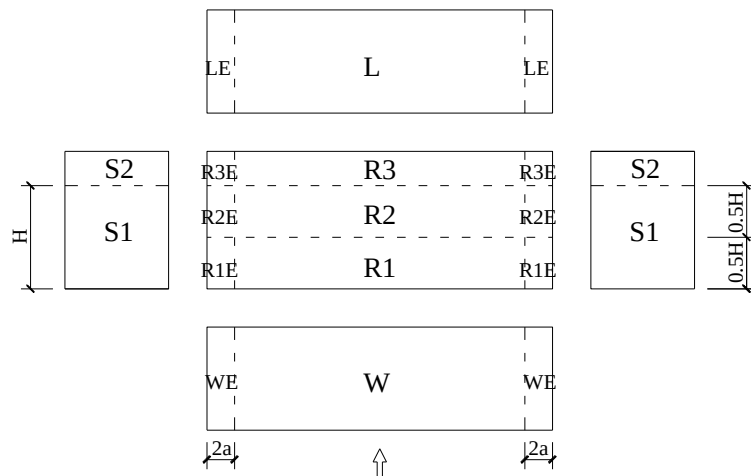
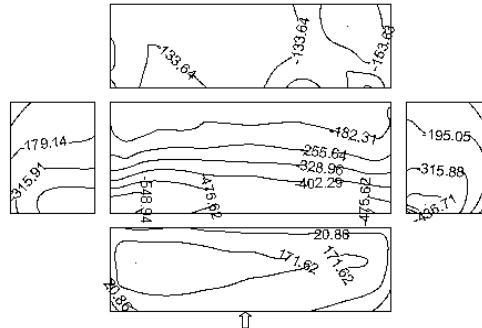


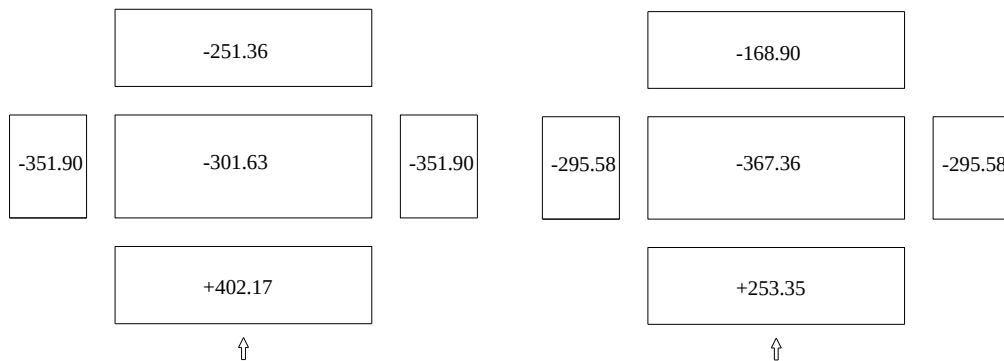
Figure 6. The zone of the shape coefficient according to the codes

The comparison of design wind pressure from different country codes with experimental results is shown in figure 7. Load combination coefficient, 1.4, is considered by GB 50009-2001 to compare with design wind pressure by other codes. Experimental results show that the wind pressures on the windward wall and the leeward wall are close to constant; while the wind pressures on the roof and the side walls decrease along wind direction. Wind pressures on the windward wall and the leeward wall obtained from GB 50009-2001, ASCE/SEI7-05 and AS/NZS1170.2:2002 are much larger than experimental results, which may result from two factors: (1) larger shape coefficient on the windward wall given by the codes; (2) 3-s wind speed, close to gust wind speed, used in ASCE/SEI7-05 and AS/NZS1170.2:2002. Wind pressures on side walls and the roof obtained from GB 50009-2001 and AIJ2004 are somewhat smaller than experimental results, not considering higher suction on the windward end. Although wind pressure on the

roof obtained from ASCE/SEI7-05 is much larger than experimental result, it does not reflect actual wind pressure distribution. Wind pressure distributions on the roof and side walls given by AS/NZS1170.2:2002 are suitable to experimental results. The reason of larger wind pressure on the roof and side walls given by AS/NZS1170.2:2002 than experimental results is mainly 3-s wind speed in AS/NZS1170.2:2002.

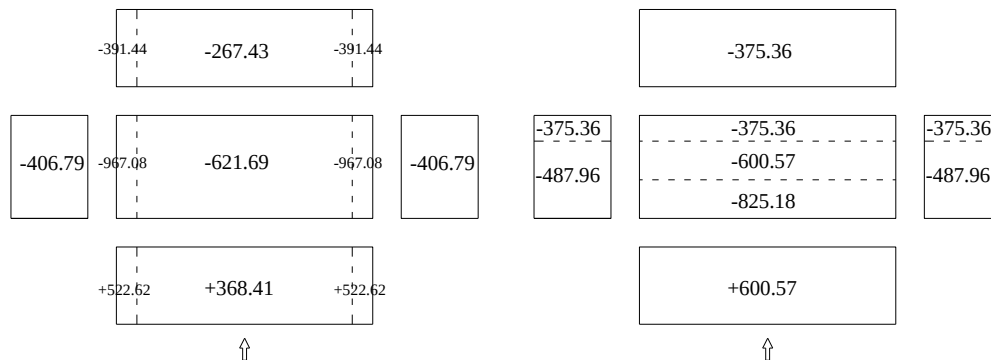


(a) Mean wind pressure at 10 m height based on wind tunnel test



(c) Wind pressure from GB 50009-2001

(d) Wind pressure from AIJ2004



(e) Wind pressure from ASCE/SEI7-05

(f) Wind pressure from AS/NZS1170.2:2002

Figure 7. The comparison of design wind pressure from different country codes with experimental results

3.3 The characteristics of proper orthogonal decomposition

Proper Orthogonal Decomposition (POD) is a method used to derive the most efficient coordinate system for observing individual phenomena [7]. It can be applied to the analysis of random phenomena. As an example, contribution proportion of each mode from proper orthogonal decomposition on model B is given in table 2. It can be seen that, when wind direction is 90° , the contribution of the first mode, as well as the cumulative contribution of the first several modes is a little larger in comparison with the results corresponding to 0° or 45° wind direction. For an expected cumulated contribution approximate to 90%, at least

more than 50 modes should be considered. The first twelve eigenvectors of the measured wind pressure on model B in 90° wind direction are shown in figure 8. The contribution proportions of each mode to the global wind pressures field are given in the brackets under the contours of corresponding mode. Wind pressure on the model has good spatial correlation. The first several modes give a global description of wind pressure distribution on the model surface, while the other high-order modes just represent local distributions.

Table 2. Eigenvalues, proportions and cumulative proportions for the pressure field on model B

Mode	0°			45°			90°		
	Eigen-value	Proportion(%)	Cumulative proportion (%)	Eigen-value	Proportion (%)	Cumulative proportion (%)	Eigen-value	Proportion (%)	Cumulative proportion (%)
1	40.98	17.44	17.44	41.39	17.61	17.61	49.48	21.05	21.05
2	21.82	9.29	26.72	27.24	11.59	29.20	21.56	9.17	30.23
3	18.43	7.84	34.57	26.03	11.08	40.28	17.18	7.31	37.54
4	15.10	6.43	40.99	15.56	6.62	46.91	13.60	5.79	43.33
5	13.91	5.92	46.91	10.10	4.30	51.20	12.31	5.24	48.56
6	10.90	4.64	51.55	9.06	3.85	55.06	10.14	4.32	52.88
7	8.69	3.70	55.25	8.21	3.49	58.55	8.37	3.56	56.44
8	8.36	3.56	58.81	6.83	2.90	61.45	6.65	2.83	59.27
9	6.11	2.60	61.41	6.02	2.56	64.01	5.77	2.45	61.73
10	5.63	2.40	63.80	4.89	2.08	66.10	4.97	2.12	63.84
20	1.96	0.83	76.73	1.72	0.73	77.47	1.86	0.79	75.74
50	0.53	0.23	89.17	0.54	0.23	89.58	0.57	0.24	87.97
100	0.17	0.07	95.87	0.17	0.07	96.02	0.22	0.09	95.26
150	0.09	0.04	98.48	0.08	0.03	98.50	0.10	0.04	98.43
200	0.03	0.01	99.72	0.03	0.01	99.66	0.03	0.01	99.74
230	0.01	0.00	99.98	0.02	0.01	99.97	0.01	0.00	99.99
235	0.01	0.00	100.00	0.01	0.00	100.00	0.00	0.00	100.00

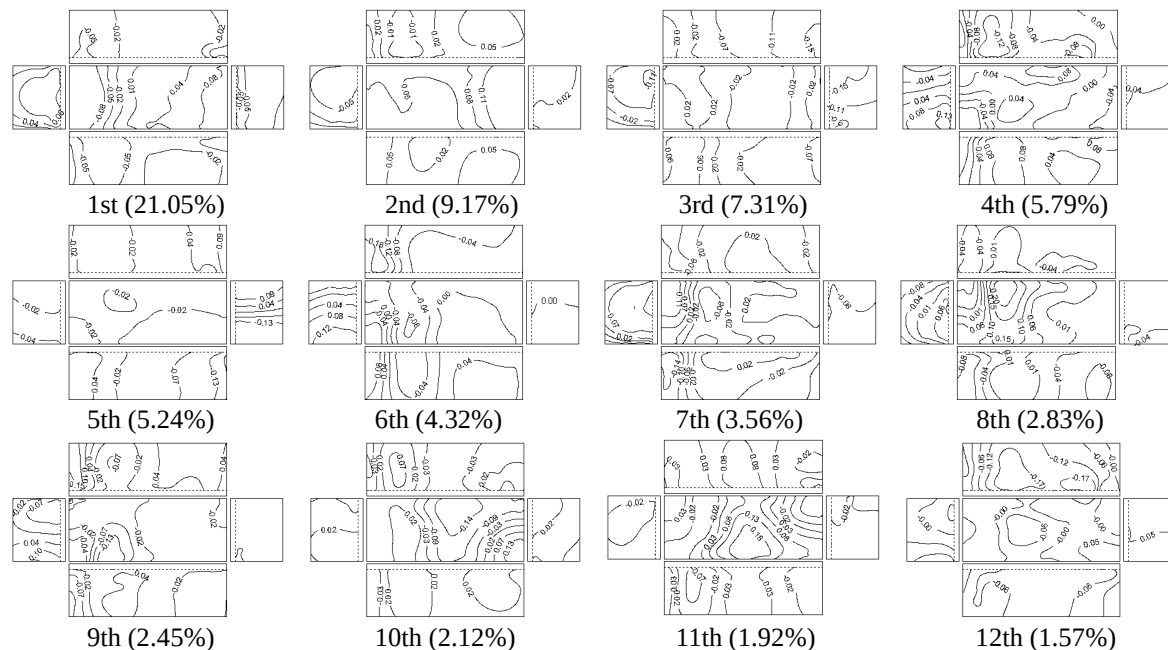


Figure 8. First twelve modes from POD on model B in 90° wind direction

4 CONCLUSIONS

Flat-roofed buildings with and without parapet have been tested in a wind tunnel to investigate the characteristics of wind pressure distribution. 1.2m high parapet, commonly

used in China, reduces mean suctions and extreme suctions by up to 50% on the roof edges, and wall loads remain unaffected by the presence of parapet. The variations of the instantaneous pressure distribution with time indicate that the time and/or spatial averages of wind fluctuations leads to a remarkable decrease in the peak suction. Wind pressure distributions on the flat roofed steel frame building without parapet in transverse wind direction given by AS/NZS1170.2:2002 are suitable to experimental results that wind pressures on the windward wall and the leeward wall are close to constant; while the wind pressures on the roof and the side walls decrease along wind direction. Wind pressure on the models has good spatial correlation. The first several modes give a global description of wind pressure distribution on the model surface, while the other high-order modes just represent local distributions.

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