

Interference effect on wind pressure of two buildings

Ning Han ^a, Ming Gu ^a, Peng Huang ^a

^a *State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji University, Shanghai, China*

ABSTRACT: The interference effect on wind pressure between two identical buildings was analyzed by wind tunnel tests for different locations of the interfering building. The results show that for the tandem configurations, mean pressure on windward face of the principal building is suction when spacing ratio is less than 3.0, otherwise it is positive. The magnitude of mean negative pressure on the side and leeward faces and fluctuating pressure on all faces get maximums when spacing ratio is 3.0. With an increase in spacing ratio for the side-by-side arrangements, the maximum value of mean and fluctuating pressure coefficient interference factor decreases on the inner and outer face while slightly increases on the front and rear face. Notably, the fluctuating pressure coefficient interference factor on the inner face grows visibly and the maximum value is 2.2 on the top leading corner when the spacing ratio is 2.0.

KEYWORDS: Tandem; side-by-side; interference factor; spacing ratio; square building

1 INTRODUCTION

The wind pressure on isolated building has significant change or even becomes quite complex due to the surrounding tall buildings. Interference effect among tall buildings has been studied by many researchers over the past several decades. Khanduri et al. [1] gave a review of interference effect before 1998. After this; Xie & Gu [2-5] reported interference effect on dynamic response and correlation among three tall buildings. For the side-by-side arrangements, Kumar et al. [6] studied wind-induced responses of the principal building caused by interfering building which was located in different positions and had 4 different size ratios such as 0.5, 1.0, 1.5, 2.0. Then they reported that the critical size ratio is 1.0, the response amplitude has no significant differences when size ratio is smaller than 1.0, but it will increase remarkably when the size ratio is greater than 1.0 and reduced velocity is larger than 12. Interference effect on wind pressure of two buildings placed in staggered arrangements has been studied numerically and experimentally by Zhang et al. [7], but only certain points on certain heights were focused on. Wong et al. [8] reported aerodynamic distribution and flow around two side-by-side square buildings with different cross-section, the spacing ratio is between 1.12 and 2.5. Analogously, Chen et al. [9] found that the spacing ratio has a threshold value; a biased gap flow pattern appears when spacing ratio is smaller than this value. But three dimensional effects of interference between two high-rise buildings haven't been considered in this paper. Sakamoto et al. [10] reported changes on fluctuating pressure of two tandem buildings. They found that fluctuating pressure on principal building increases when the spacing ratio is larger than 3.0. Lam et al. [11] investigated interference effects on three closely arranged buildings in oblique wind direction. Mean pressure contours of the principal building in certain spacing ratio and wind direction were given. They pointed out that high suction appears on leeward side, but they didn't analyze the effect of changing spacing ratio.

This paper focuses on local wind pressure on walls of the principal building with wind pressure coefficient interference factor. Various locations of an identical interfering building are considered.

2 EXPERIMENTAL SETUP AND DATA ANALYSIS

2.1 Wind tunnel tests

Wind tunnel tests were conducted in TJ-2 Boundary Layer Wind Tunnel at Tongji University. Its working section is 3.0m in width, 2.5m in height and 15.0m in length. Wind field of Type C at a length scale of 1/400 which is in accordance with the Chinese code [12] was simulated by passive simulation method. The exponents of the mean wind profile for the terrain category C is 0.22, and the corresponding gradient height is 400m. Figure 1 shows the simulated mean wind speed profile and the longitudinal component profile of turbulence intensities. The figures show that both the experimental mean velocity and turbulence intensity are in agreement with the target profiles from Chinese code and A.I.J. [13], respectively. Figure 2 shows the power spectra of longitudinal fluctuating wind speeds.

The experimental models were a pair of identical square buildings. One was referred as the test building and another was referred as the interfering building which was located at various positions. The test building, at a length scale of 1:400, was $B \times D \times H = 150\text{mm} \times 150\text{mm} \times 900\text{mm}$. A total of 496 pressure taps, 124 on each face were installed, especially the top and leading edges of the test building as shown in Figure 3.

Figure 4 shows the detailed experimental plan indicating the different locations of the interfering building and wind directions in wind tunnel. The interfering building was orientated with its face normal to the test building and was placed in 16 different arrangements with respect to the test building at origin of coordinates (0, 0). The center-to-center spacing between them was varied by spacing ratio $S_x = x/B$ longitudinally and $S_y = y/B$ laterally. The wind direction was varied in 15° steps in the range from 0° to 345° .

In this paper, only tandem and side-by-side arrangements at wind direction 0° were investigated. The sampling frequency and sampling time of the wind pressure were 312.5 Hz and 48s.

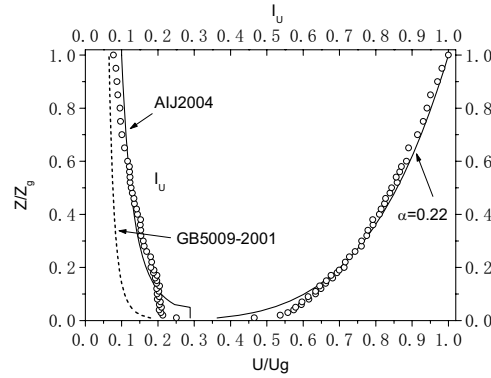


Figure 1. Mean velocity and longitudinal turbulence intensity profile.

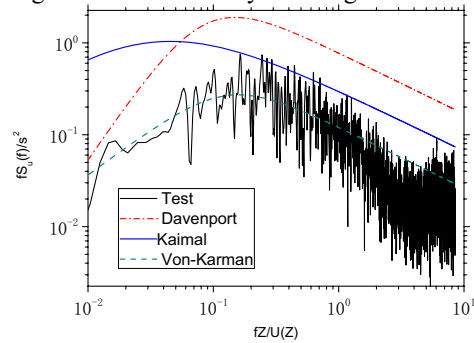


Figure 2. Longitudinal fluctuating velocity spectrum.

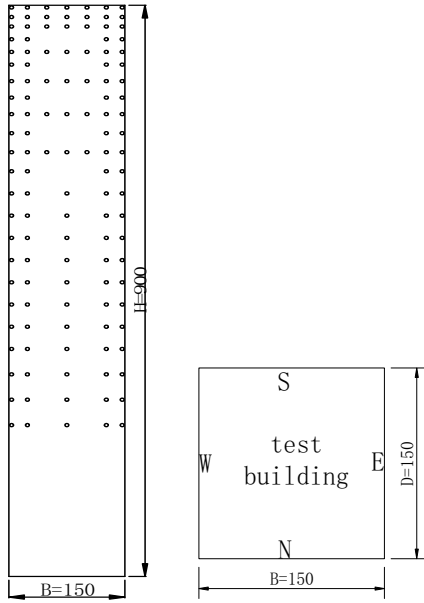


Figure 3. Locations of pressure taps on the test building.

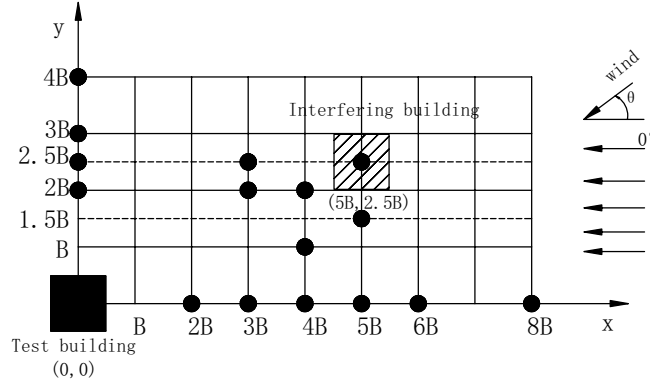


Figure 4. Configurations of interfering building and wind directions.

2.2 Test data processing

The pressure coefficient is defined as [14]

$$\bar{C}_p = (\bar{p} - p_0) / 0.5 \rho \bar{u}_r^2 \quad (1)$$

$$C'_p = \sqrt{\overline{p'^2}} / 0.5 \rho \bar{u}_r^2 \quad (2)$$

Where $\bar{C}_p$ is mean pressure coefficient, $\bar{p}$ is mean pressure, C'_p is r.m.s. fluctuating pressure coefficient, $\sqrt{\overline{p'^2}}$ is r.m.s. fluctuating pressure, p_0 is static pressure, ρ is the density of air, $\bar{u}_r$ is mean longitudinal velocity at the reference point. The reference height is selected at the top of the building.

Interference effect is presented in the form of non-dimensional Interference Factor (IF). IF can be expressed as

$$IF = \frac{C_{p_infer}}{C_{p_iso}} \quad (3)$$

Where C_{p_infer} represents the mean or R.M.S. pressure coefficients on the building with interference, C_{p_iso} is relative to the mean or R.M.S. pressure coefficients on the isolated building.

$|IF| > 1$ represents the increase and $|IF| < 1$ represents decrease on the test building due to interference. $IF = 1$ suggests that interfering building has no effect on the test building. $IF = -1$ suggests that the sign of wind pressure on the test building changes, but the value doesn't change.

3 RESULTS AND DISCUSSION

3.1 Mean pressure in tandem configurations

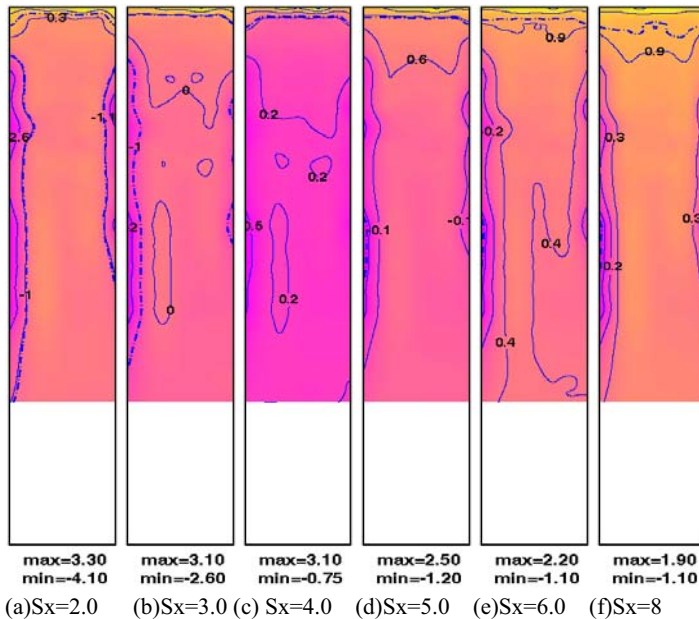


Figure 5. IF contours of mean pressure coefficient on face N for the test building ($\theta = 0^\circ$, $S_y = 0$).

Figure 5 shows IF contours for mean pressure coefficient on face N for the test building at different spacing ratio S_x at 0° wind angle. From the figure we can see that the critical S_x is 3.0, when S_x is smaller than 3.0, IF on most part of face N is negative, otherwise negative IF only appears on leading edges. Therefore, there are two different flow patterns when spacing ratio changes in tandem arrangements. When spacing ratio is smaller than the critical value, vortex streets behind the upstream building are inhibited, otherwise vortex streets are formed behind each building and lead to complex vortex street interactions. This is in accordance with the results of Chen et al.[15] and Hasebe et al.[16]. As spacing ratio S_x is smaller than 3.0, negative pressure appears on face N and IF for mean pressure coefficient lies between -1.0 and 0 on most parts of the face. When spacing ratio S_x is beyond 3.0, the range of $0 < IF < 1.0$ appears on face N and increases with S_x . IF lies between 0.3 and 1.0 when S_x is equal to 8.0. It is noteworthy that extrema of IF appear mainly on top and leading edges of face N, respectively. The extremum is beyond 1.0 and becomes smaller with the larger S_x . In a word, mean pressure on most zones of front face of the test building decreases due to the upstream building. Khanduri et al. [17] reported similar results. Differently, in this paper the mean pressure is amplified significantly on certain local zones on front face, for example, the top and leading edges.

As against front face N, interference effect on mean pressure of face E follows a regular trend when spacing ratio changes. IF is positive for all tandem configurations as shown in Figure 6. This indicates that mean pressure on face E is still negative when the interfering building is around. It is worth noting that the IF on top leading corner of face E has greater values which are larger than 1. An increase in mean pressure coefficient of 40% is obtained when S_x is equal to 5.0. The reason of this situation is that with spacing ratio increasing, the separated flow from upstream building impinges on top of face N which leads to re-separation of the separated flow from the leading top corner of face E. As a result, velocity of the separated flow from the leading edge of face E increases and suction on face E becomes larger.

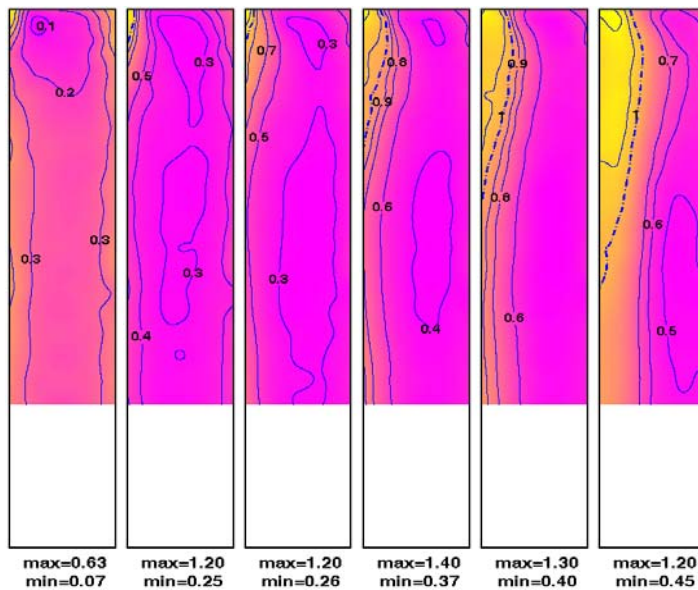


Figure 6. IF contours of mean pressure coefficient on face E for the test building ($\theta = 0^\circ$, $S_y = 0$).

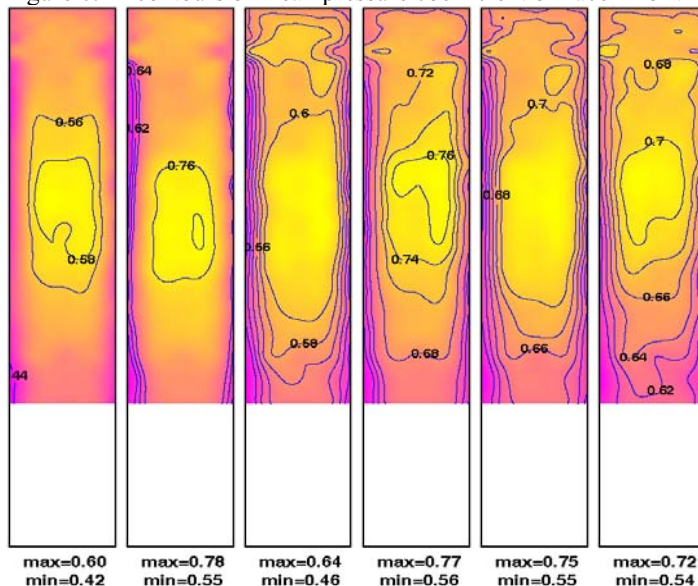


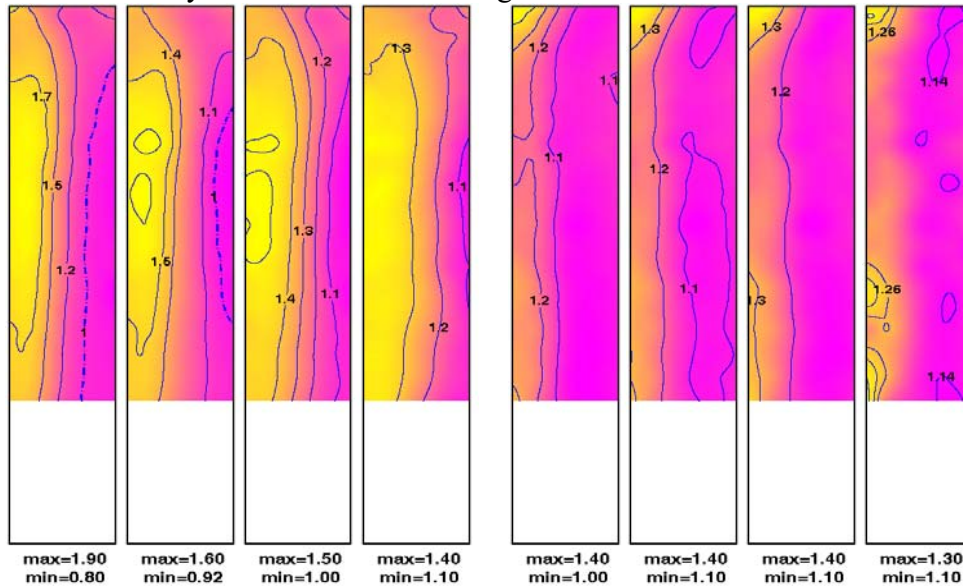
Figure 7. IF contours of mean pressure coefficient on face S for the test building ($\theta = 0^\circ$, $S_y = 0$).

Figure 7 shows IF contours for mean pressure coefficient on face S for the test building at different S_x at 0° wind angle. From the figure we can see that IF is positive and smaller than 1 at any spacing ratio. This indicates that mean pressure on face S is still negative, but it shows a reduction compared with that of the isolated building. This maybe ascribe to the presence of interfering building which leads to decrease in wake velocity from the test building.

3.2 Mean pressure in side-by-side configurations

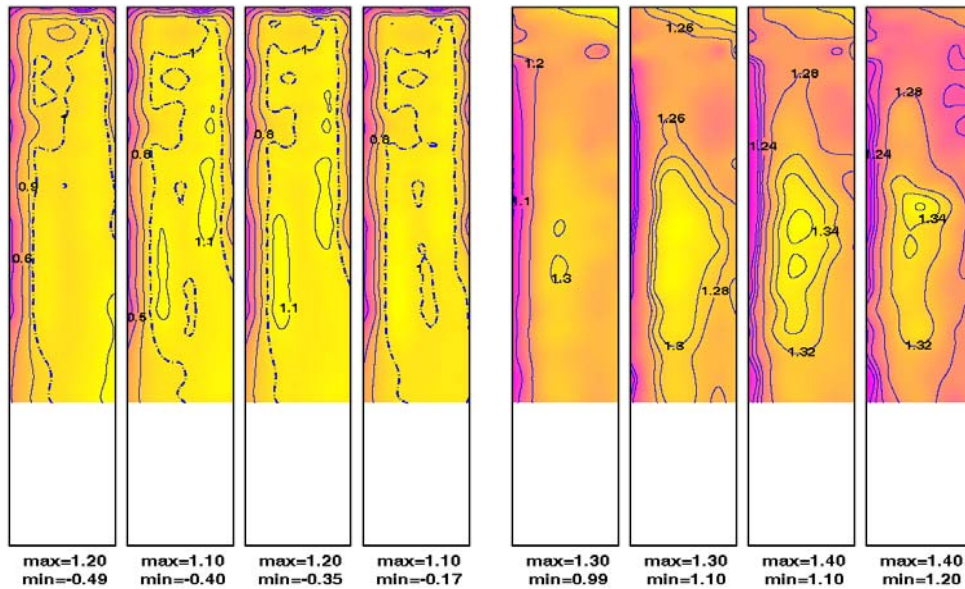
Figure 8 shows IF contours for mean pressure coefficient of the test building at different S_y at 0° wind angle. In Figure8a, IF on face E decreases gradually from leading edge towards trailing edge and the intensity of decrease is mild with an increase of spacing ratio. This is because gap flow forms between the two buildings. The smaller the spacing ratio, the faster the gap flow passes through the channel which leads to larger suction. The extremum of IF becomes smaller with the larger S_y and it gets maximal value 1.9 which locates on the $(2/3)H$ of face E when $S_y=2.0$. Figure8b shows IF of face W. From the figure we can see that IF gets extremum on trailing top corner. This maybe ascribe to presence of the interfering building which changes the flow pattern of the test building that aggravates the vortex shedding from trailing top corner on face W. Chen et al. [9] reported similar results.

As against the side faces, changes on spacing ratio have little influence on IF on face N. The value of IF has a little increase on most zones of face N. Mean pressure coefficients increase by about 10%~20% compared with those of the isolated building, as shown in Figure8c. In Figure8d, values of IF on face S are larger than 1.0 at any spacing ratio. This indicates that suction on face S increases due to the interfering building. Changes on spacing ratio have little influence on IF on face S as that on face N. It shows that flow pattern behind the test building doesn't change qualitatively. This is in accordance with the results of literatures [8-9]. There is a critical spacing ratio less than 2.0 for two buildings placed side-by-side. As spacing ratio is larger than the threshold, flow patterns have transition from asymmetric flow to symmetrical flow and binary vortices behind buildings are formed.



(a) Face E $S_y=2.0, 2.5, 3.0, 4.0$

(b) Face W $S_y=2.0, 2.5, 3.0, 4.0$



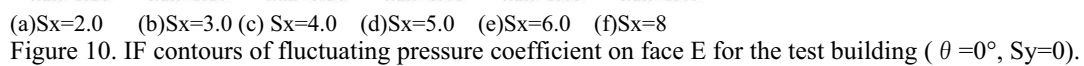
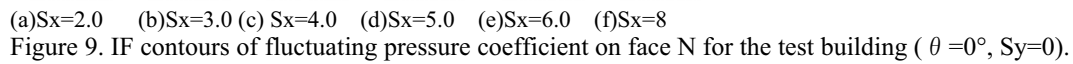
(c) Face N $S_y=2.0, 2.5, 3.0, 4.0$

(d) Face S $S_y=2.0, 2.5, 3.0, 4.0$

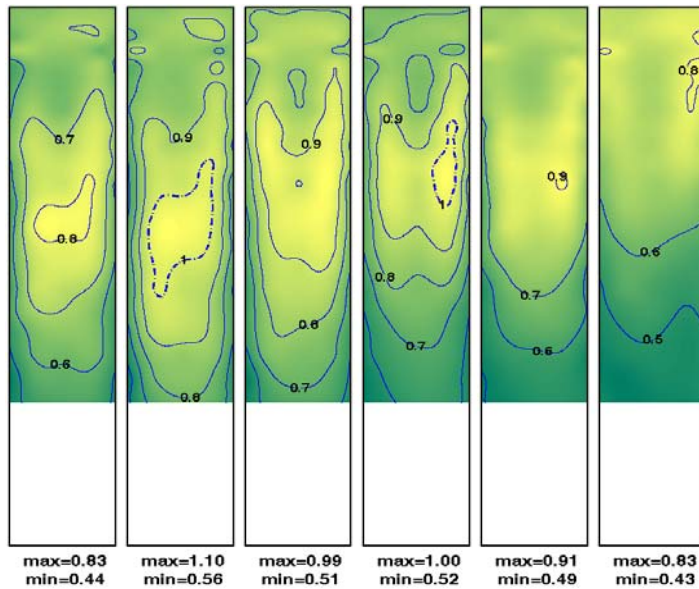
Figure 8. IF contours of mean pressure coefficient for the test building ($\theta = 0^\circ$, $S_x = 0$).

3.3 Fluctuating pressure in tandem configurations

Figure 9 shows IF contours for fluctuating pressure coefficient on face N for the test building at different S_x at 0° wind angle. From the figure we can see that the zone of $IF > 1.0$ increases with S_x . It is noteworthy that extremum of IF decreases with S_x and it gets maximal value 3.8 which locates on top leading edges of face N when S_x is equal to 3.0. The reason for this situation is that when spacing ratio S_x is smaller than 3.0, steady vortex zones form between the two buildings. Shear layers separated from the leading edges of the interfering building reattach fast to the side faces of the test building due to the closely spacing, then re-separation happens at the trailing edge of the test building which forms quasi-periodic vortex shedding behind it. This can be observed in Figures 10a-10b, the value of IF is larger than 1.0 on the leading edge of face E due to reattachment of shear layers. Vortex shedding forms behind upstream and downstream building respectively when spacing ratio S_x is beyond 3.0, fluctuating pressure on face N increases compared with that of the isolated building due to the turbulent of the incoming flow increases. So the zone of $IF > 1.0$ expands as shown in Figures 9c-9f. Fluctuating pressure on face E increases correspondingly. The reason is, vortices in the wake of the upstream interfering building impinge directly on the front face N of the downstream test building which increases the velocity of shear layer separation and leads to intense turbulences as shown in Figures 10c-10f. The zone of $IF > 1.0$ on face E expands when the spacing ratio increases. The extremum of IF becomes smaller with the larger S_x and gets maximal value 2.7 when S_x is equal to 3.0.



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(a) $S_x=2.0$ (b) $S_x=3.0$ (c) $S_x=4.0$ (d) $S_x=5.0$ (e) $S_x=6.0$ (f) $S_x=8$

Figure 11. IF contours of fluctuating pressure coefficient on face S for the test building ($\theta = 0^\circ$, $S_y=0$).

3.4 Fluctuating pressure in side-by-side configurations

Figure 12 shows IF contours for fluctuating pressure coefficient on walls of the test building at different S_y at 0° wind angle. In Figure 12a, IF on face E is the same as that for mean pressure coefficient on face E which decreases gradually from leading edge towards trailing edge. The extremum of IF becomes smaller with the larger S_y and locates mainly on leading top corner and $(0.6 \sim 0.8)H$ on face E. Interference effect tends to average overall as spacing ratio increases. IF on face E gets maximal value 2.2 which locates on leading top corner of face E when $S_y=2.0$. This is because the position lies in the high-velocity region due to fast separation which leads to the turbulent increases. So these positions are dangerous zones and should be paid much attention to. As against face E, in Figure 12b, changes on spacing ratio have little influence on the extremum of IF which mainly lies in the trailing top corner on face W. It is around 1.2. In addition, the flow separated from the leading edges of face N tends to symmetry, as a result, the zone of $IF > 1.0$ increases slightly with S_y increases.

Changes on spacing ratio have little influence on IF for fluctuating pressure coefficient on face N, as shown in Figure 12c. The value of IF mostly lies between 0.9 and 1.1, which are very uniform distribution when spacing ratio is equal to 4.0. It illustrates that the interference effect decrease with spacing ratio increases. In Figure 12d, the zone of $IF > 1.0$ expands slightly with spacing ratio increases and the location on which IF gets extremum gradually approaches the $(2/3)H$ on face S. The value of IF on most part of face S is still larger than 1.0 when S_y is equal to 4.0. This is because the three-dimensional interference leads to turbulences around the test building increase, that is to say interference effect is still significant when spacing ratio is 4.0.

4 CONCLUSIONS

The interference effect for mean and fluctuating pressure on the test building for various locations of an identical interfering building at 0° wind direction has been studied by interference factor contours. The following results were obtained:

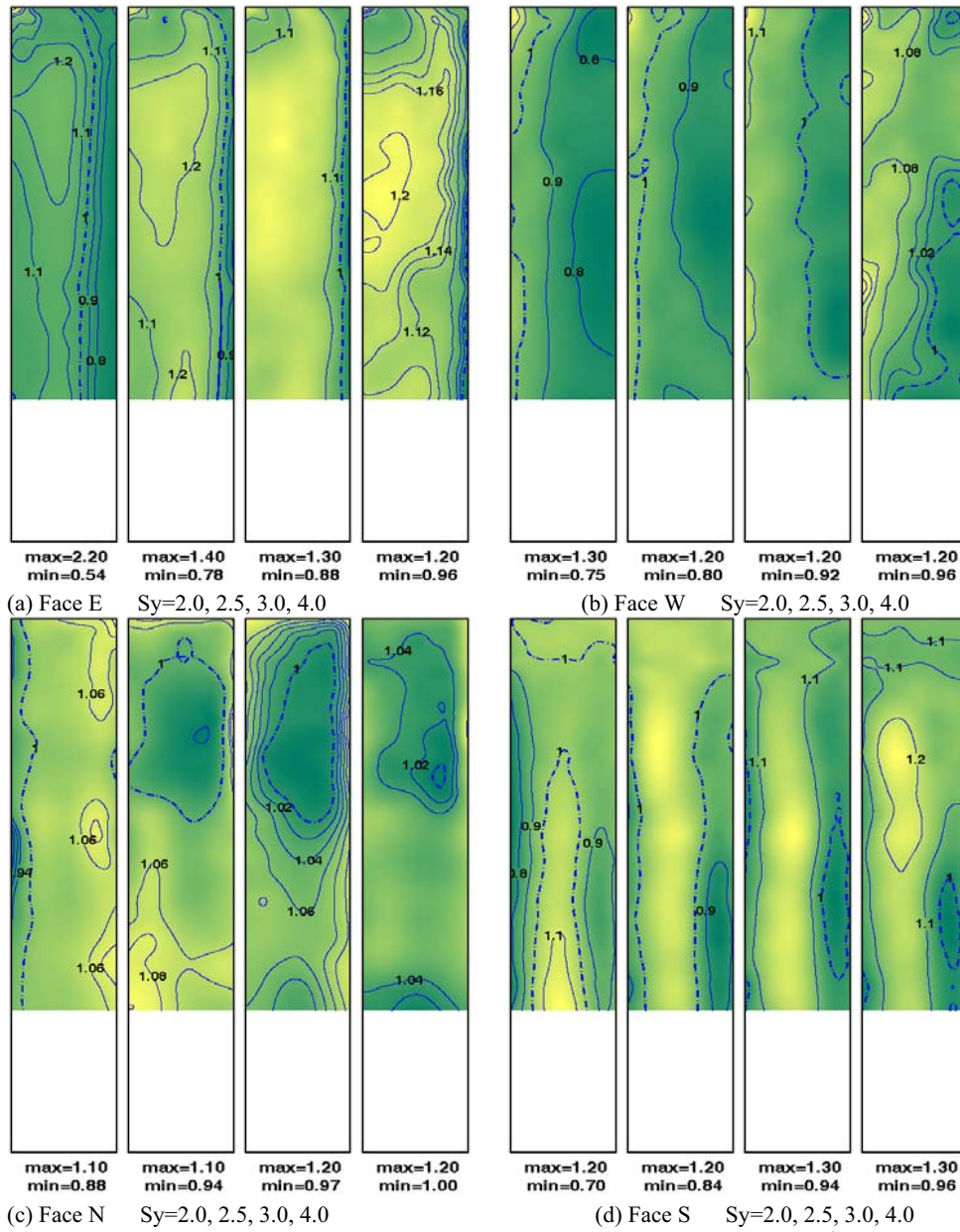


Figure 12. IF contours of fluctuating pressure coefficient for the test building ($\theta=0^\circ$, $S_x=0$).

- 1 In tandem configurations, mean pressure on front face of the test building is negative as spacing ratio is smaller than 3 and positive when spacing ratio is larger than 3.0. The test building experiences considerable shielding due to an upstream interfering building and the extent of shielding is obviously weakened with spacing ratio increases. IF for mean pressure coefficient on front and leeward face is positive, in addition, it gets maximal value when spacing ratio S_x is 3.0. Fluctuating pressure has moderate change with spacing ratio compared with that of mean pressure. Variations of IF for fluctuating pressure coefficient on all faces are similar, they all get maximal value as spacing ratio S_x is 3.0.
- 2 In tandem configurations, the leading top corner on side faces of the test building should be pay special attention to, especially when spacing ratio S_x is 3.0.

- 3 In side-by-side configurations, the extrema of IF for mean and fluctuating pressure coefficient on outer and inner face of the test building decrease with spacing ratio increase. However, the extremum of IF for fluctuating pressure coefficient was influenced significantly by the interfering building and gets maximal value 2.2 on inner face when spacing ratio S_y is 2.0. Changes on spacing ratio have little influence on the extrema of IF on front and leeward faces, but IF on leeward face which gets maximal value 1.4 is greater than that on front face.
- 4 In side-by-side configurations, pressure on inner face of the test building changes significantly, especially on leading top corner of the inner face. So, envelops of these positions in which mean and fluctuating pressure is obviously enlarged should be strengthened when there are adjacent buildings.

5 ACKNOWLEDGEMENTS

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