

Interference effect on local peak pressure between two high-rise buildings with rectangular shape

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ABSTRACT: This study investigates the interference effects between two rectangular-section high-rise buildings by wind tunnel experiments, focusing on local peak pressure coefficients. Wind tunnel experiments were carried out under all possible wind incidence angles for many configurations. The parallel building arrangements were considered. To evaluate the interference effects for local peak pressures in detail, interference factors for maximum positive and minimum negative peak pressures are presented and discussed. The results show that interference effects greatly depend on the configurations. The interfering building has stronger effects on the smallest minimum negative peak pressure of the principal building than the largest maximum positive peak pressure. The wind direction that causes the largest peak pressure varies with the changing of interfering building's location.

KEYWORDS: high-rise building; interference effects; wind tunnel experiment; Local peak pressure.

1 INTRODUCTION

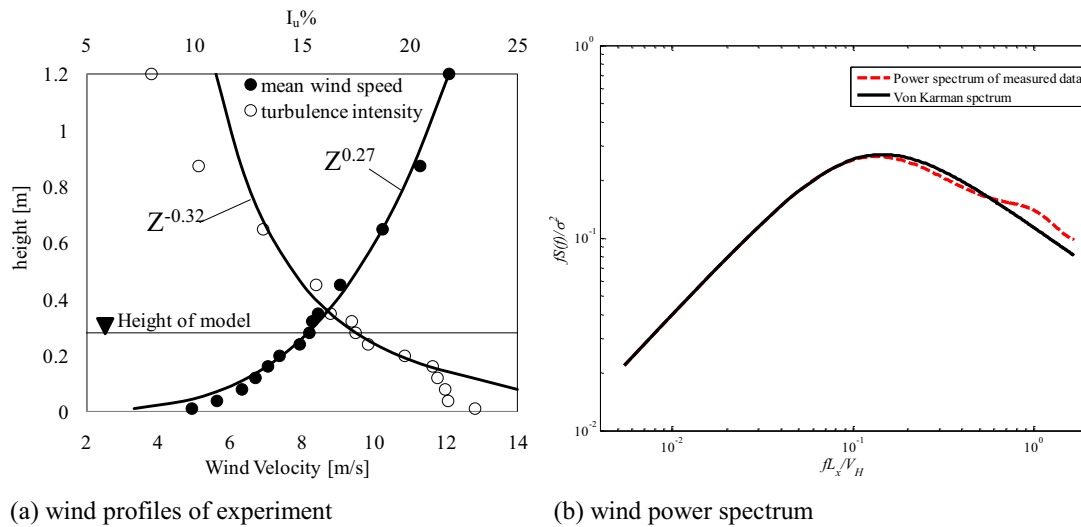
Modern tall buildings are often built in groups in urban areas. This results in flow interference and wind loads on buildings are modified from the isolated building situation. Catastrophic incidents may result if the interference effect on load has is not considered in design. An investigation of interference effect is complicated by the large number of variables needed to describe the broad set of possible situations – sizes and shapes of buildings, relative locations of adjacent building(s), wind directions, upstream terrain conditions and so on.

Tang and Kwok (2004) investigated interference excitation mechanisms of translational and torsional responses of a pair of identical tall buildings. They found that amplified along-wind, cross-wind and torsional responses were largely induced by the wake of an upstream interfering building. Lam et al. (2011) studied wind-induced interference effects on a row of five square-plan tall buildings arranged in close proximity, and clarified that the design values of peak dynamic responses of a tall building are not significantly magnified when placed in a row. Kim, et al., (2009) discussed interference effect on local peak pressures between two identical square-section tall buildings from the viewpoint of cladding design. They found that the local peak pressure coefficients on the walls of a principal building largely depended on the location of an interfering building.

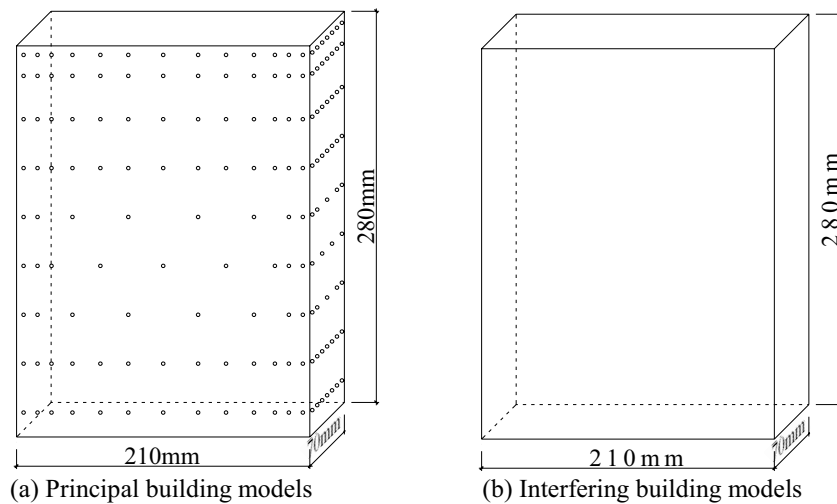
However, investigating only buildings with the same cross section is not enough for a comprehensive understanding of interference effect. It is apparent that the flow pattern surrounding two buildings will change with building shapes, and this will lead to a change in local peak pressures on buildings. In the present study, in order to obtain more information about the interference effects between two high-rise buildings on the local peak pressure, two rectangular-section building were used to conducted wind tunnel experiments. The experimental results are presented and discussed in this paper.

2 WIND TUNNEL EXPERIMENTS

Wind tunnel experiments were carried out in a Boundary Layer Wind Tunnel located at Tokyo Polytechnic University, Japan. The test section of the wind tunnel was 2.2m wide and 1.8m high. The approaching flow represented an urban wind exposure using the spire-roughness technique with a power law exponent of 0.27. The wind speed and turbulence intensity at the roof height of the model were 8m/s and 17%, respectively. The velocity scale was set to 1/5. Measured longitudinal mean wind velocities and turbulence intensity profiles are shown in Fig. 1. Fig. 1 also shows the power spectrum of longitudinal wind speed at the roof height.



(a) wind profiles of experiment (b) wind power spectrum
Fig. 1. Characteristics of longitudinal wind in experiment.



(a) Principal building models (b) Interfering building models
Fig. 2. Building models for pressure measurement.

The model size was 210mm wide, 70mm deep and 280mm high. Two models of the same shape were used (Fig. 2). The one with pressure taps was used as the principal building, the one without pressure taps was used as the interfering building. A total of 318 pressure taps were installed on the walls of the principal building: 103 on each wide face and 56 on each narrow face. The target geometric scale was set to 1:400, so that the models represented full-scale buildings 112m high and 84m×28m in plan.

The parallel and perpendicular arrangements were considered, as shown in Fig. 3. Both models were rigidly mounted on a turn-table. The distance between the two models was varied longitudinally, Y/b , and laterally, X/b , on the Cartesian coordinates shown in Fig. 3, where “ b ” indicates the depth of the model. Wind tunnel tests were carried out on 54 different configurations by moving the interfering building’s location from one spot to another shown in Fig. 3. For each configuration, the angle of incidence wind was varied from 0° to 360° at 5° intervals and the fluctuating wind pressures on the building faces were simultaneously measured at all taps using a multi-channel simultaneous fluctuating pressure measurement system for each wind direction.

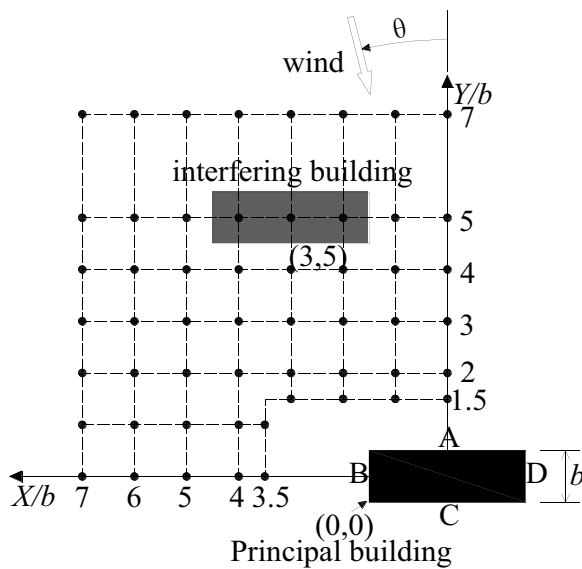


Fig. 3. Experimental arrangements

The sampling frequency for the pressure data was 781Hz. For each wind direction, fifteen 7.5s-long samples were collected, which corresponded to fifteen 10min-long samples in full scale. The time histories of fluctuating pressure were filtered by means of a moving average filter (Holmes 1997) as follows:

$$\tau = 1.0 \times L / \bar{U}_H \quad (1)$$

where τ is the averaging time corresponding to 0.2s in full scale, L is the length of the cladding diagonal in full scale (6m in this study) and $\bar{U}_H$ is the mean wind speed at the roof height of the principal building.

The Cook-Mayne method (Cook and Mayne, 1979) was adopted to obtain the extreme pressure coefficient. The extreme pressure coefficient representing the 50-year return period was calculated using Eq. (2).

$$\hat{C}_p = C_p + 1.4/a_c \quad (2)$$

where C_p and $1/a_c$ are the mode and scale parameter of the extreme pressure coefficient.

3 RESULTS AND DISCUSSION

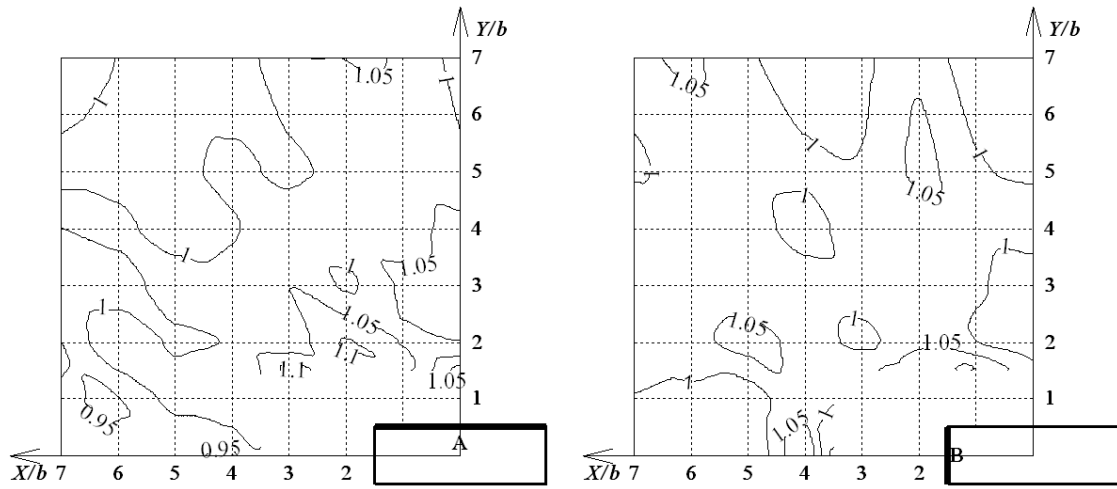
3.1 Interference factor for local peak pressures and unfavorable regions

As mentioned, the interference effects on the local peak pressures were studied. And it's known that an interfering building might cause different effects on different faces of a principal building. Thus, in order to check in detail and find the difference among them, the interference effects on different faces were checked individually in terms of the largest maximum peak pressure coefficient of Wall-X— $\hat{C}_p^X$ and smallest minimum peak pressure coefficient of Wall-X— $\check{C}_p^X$, where $X \in (A, B, C, D)$. Interference Factor (IF) was introduced into this study as follows:

$$\hat{IF}(X) = \frac{\hat{C}_p^X \text{ with interfering building}}{\hat{C}_p^X \text{ without interfering building}} \quad (3)$$

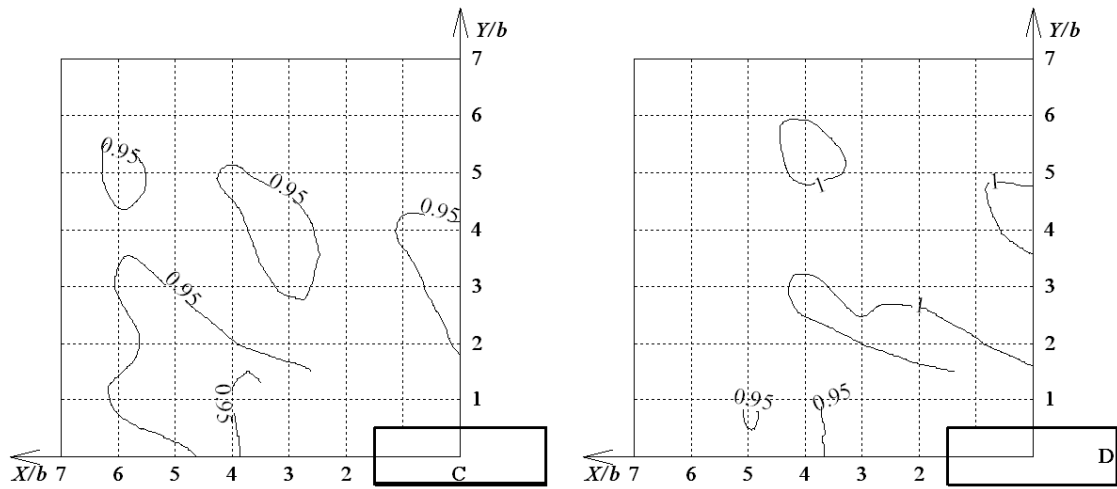
$$\check{IF}(X) = \frac{\check{C}_p^X \text{ with interfering building}}{\check{C}_p^X \text{ without interfering building}} \quad (4)$$

Based on our experiment, the value $\hat{C}_p^X$ of isolated condition was 2.6. $\check{C}_p^X$ of isolated condition was -4.6 for Wall-A and Wall-C (the narrow faces), and it was -5.7 for Wall-B and Wall-D (the wide faces). These results were used as the basic reference values for evaluating the interference factor.



(a) Contour of $\hat{IF}(A)$

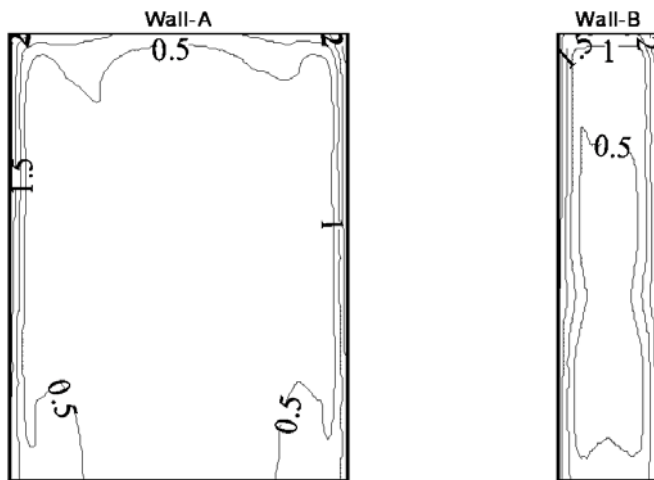
(b) Contour of $\hat{IF}(B)$



(c) Contour of $\hat{IF}(C)$

(d) Contour of $\hat{IF}(D)$

Fig. 4. $\hat{IF}(X)$ results of experiment.



(a) $\hat{C}_p^A(i)$ of case $(0, 1.5b)$

(b) $\hat{C}_p^B(i)$ of case $(3.5b, 0)$

Fig. 5. $\hat{C}_p^X(i)$ distributions of some configurations in parallel arrangement.

3.1.1 Interference effects for positive peak pressure

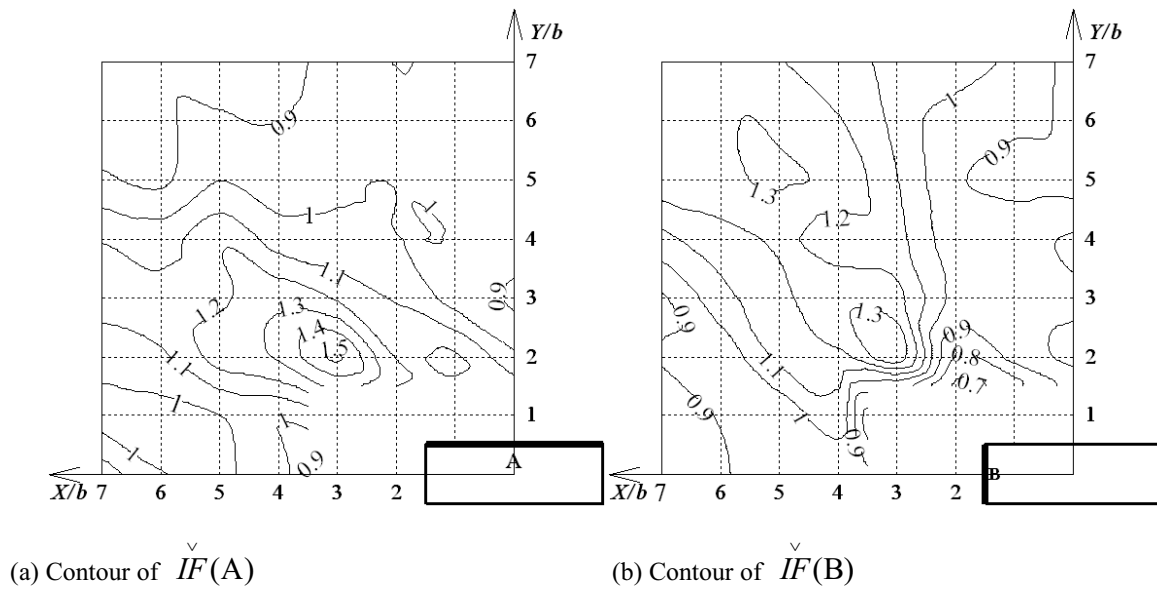
Fig. 4 clearly shows that the interfering building only slightly affects the $\hat{C}_p^X$ value on the principal building. Most of the $\hat{IF}(X)$ values are in the range of 0.9 to 1.1. Even when the interfering building is located just in front of the principal building with small separation, there is no dramatic decrease in $\hat{C}_p^A$, which was assumed to appear due to the shielding effects. The $\hat{C}_p^A(i)$ distribution shown in Fig. 5(a) shows that the $\hat{C}_p^A(i)$ values are very low, around 0.5, except in

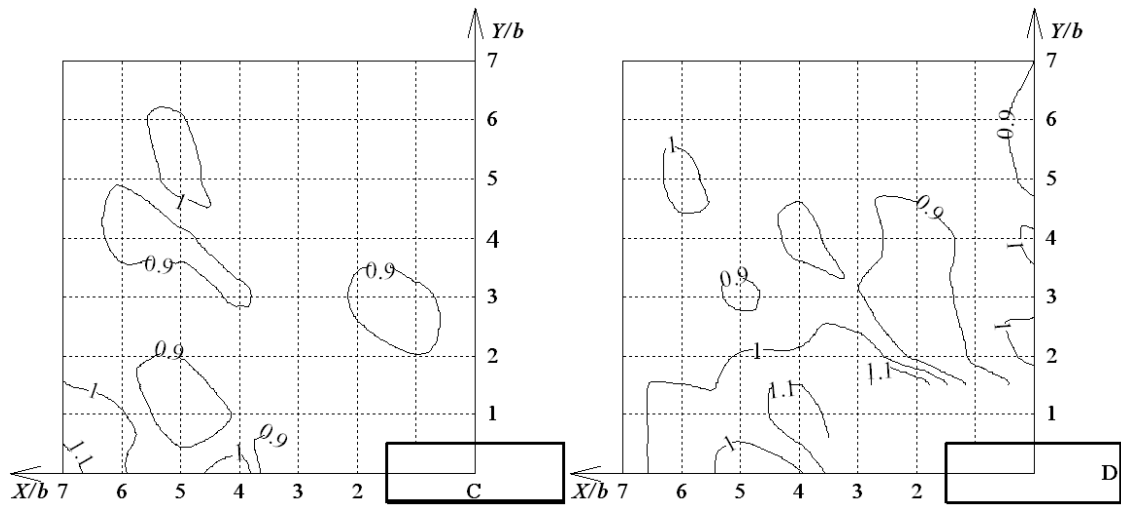
small regions near the edges and corners when the interfering building was at $(0, 1.5b)$. Similar results are also obtained for Wall-B when the interfering building was located at $(3.5b, 0)$ which was just beside the principal building (Fig. 5(b)). Fig. 5 indicates that the interfering building decreases most of the $\hat{C}_p^x(i)$ values on the face facing it when the two buildings are placed in a row with the same orientation. However, the principal building's edges and corners cannot be totally under the shielding offered of the upstream building at all wind angles.

3.1.2 Interference effects for negative peak pressure

The results of the interference factor of each face are shown in Fig. 6. It can be seen that the interfering building had significant interference effects on the $\check{C}_p^x$ of the principal building, especially on Wall-A and Wall-B, which faced the interfering building. The maximum value of $\check{IF}(A)$ can be larger than 1.5 when the interfering building is located at $(3b, 2b)$, and the maximum value of $\check{IF}(B)$ can also be larger than 1.3 when the interfering building is at $(3b, 2b)$ and $(5b, 5b)$. However, the $\check{IF}(C)$ and $\check{IF}(D)$ values are all between 0.9 and 1.1, which means that the effects on Wall-C and Wall-D are weaker than on the other two faces.

In this study, the region where $\hat{IF}(X)$ or $\check{IF}(X)$ is greater than 1.1 is nominated as the unfavorable region of Wall-X. If the interfering building is located in an unfavorable region for Wall-X, that means the tested largest maximum peak pressure or smallest minimum peak pressure of Wall-X is more than 10% larger than the design value which is obtained based on the isolated condition, and the design value of the pressure coefficients on Wall-X of the principal building should be modified for safety. The unfavorable regions of Wall-A and Wall-B can also be much larger than those of the other two faces for the parallel arrangement.





(c) Contour of $\check{IF}(C)$

(d) Contour of $\check{IF}(D)$

Fig. 6. $\check{IF}(X)$ results of experiment.

3.2 Effect of wind direction

Wind direction is a very important parameter as well. Engineers are not only interested in $\hat{C}_p^x$ and $\check{C}_p^x$, but also want to know what wind directions cause these $\hat{C}_p^x$ and $\check{C}_p^x$ values. In this study, the wind direction under which the $\hat{C}_p^x$ or $\check{C}_p^x$ of Wall-X is observed is defined as the Unfavorable Wind Direction (UWD) of Wall-X, where $X \in (A, B, C, D)$.

3.2.1 Unfavorable wind direction for positive peak pressure

Fig. 7 gives the positive UWD of four faces of parallel arrangement. The arrow at each position indicates the unfavorable wind direction of the target wall when the interfering building is located there. For Wall-A and Wall-B, the UWD varies with change of the interfering building's position. For most cases of the two faces, the unfavorable winds tilt towards the interfering building from the direction normal to the target face, that means the wind causing high positive pressure attacks the principal building after passing the interfering building. But for the other two faces (Wall-C and Wall-D), it can be seen that although the unfavorable winds also shift a little from the direction normal to the target face, the direction of shifting are random and doesn't depend on the location of the interfering building. This is because when the wind blows directly to the Wall-C and Wall-D, the interfering building is mainly at the downstream direction of the principal building in this experimental setup. Thus the interfering building couldn't affect the coming wind of the principal building.

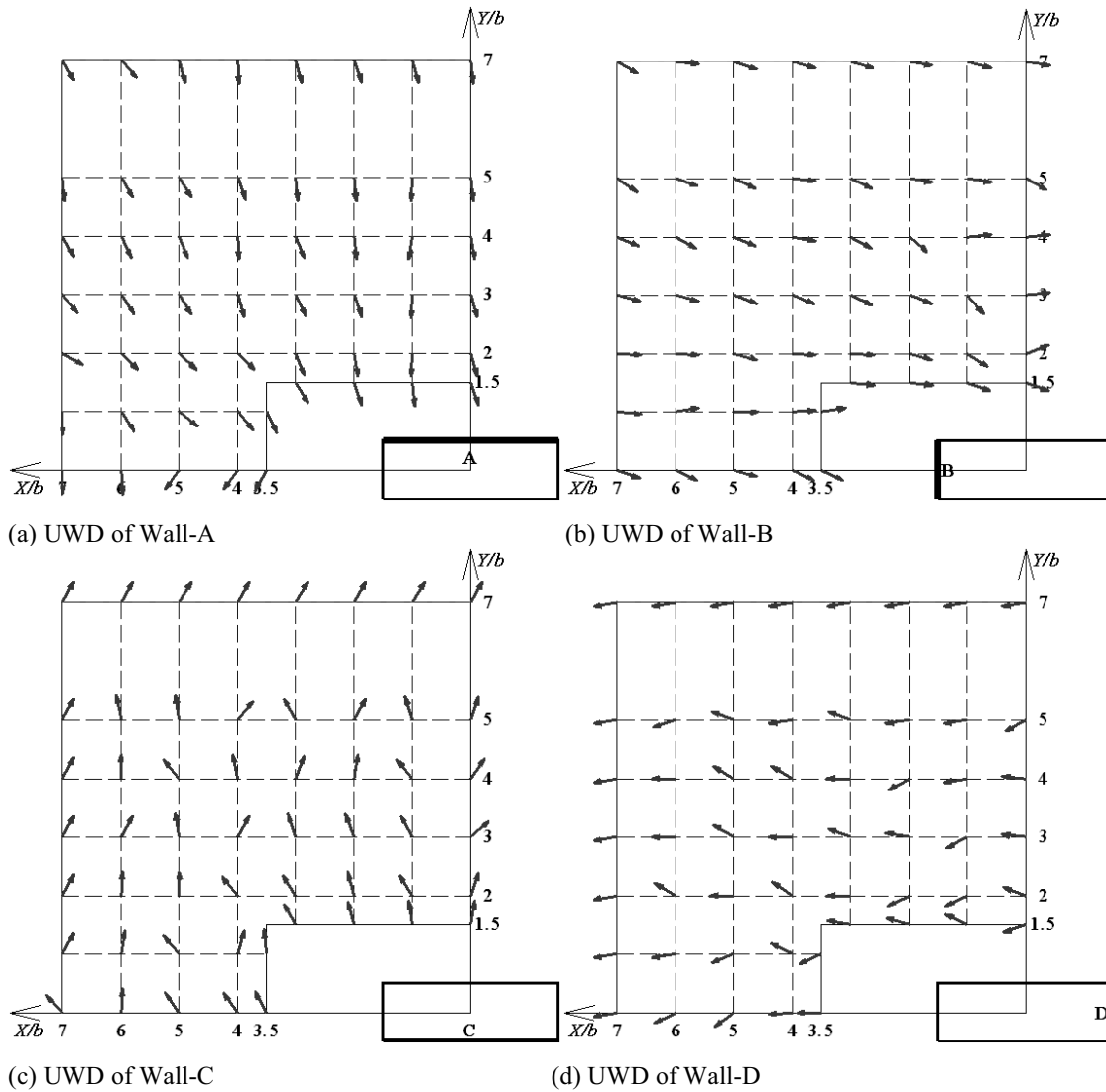


Fig. 7. Positive UWD of four faces.

3.2.2 Unfavorable wind direction for positive peak pressure

Fig. 8 shows the UWD of the parallel arrangement. According to these figures, for Wall-A and Wall-B, the unfavorable wind mostly attacks the principal building from the direction approximately along with the target face after passing the upstream interfering building. The UWD also changes with changing position of the interfering building. But for the other two faces the dependence of unfavorable wind direction on the location of interfering building cannot be clearly found.

Some results in Fig. 8(b) show that in the parallel arrangement when the interfering building is located in the area along the Y-axis where $X \in (0, 2b)$ the unfavorable wind always comes from the back side of Wall-A. But when it is out of the range where $X > 2b$, the unfavorable wind changes almost 180° which comes from the front side of Wall-A. This is because when the interfering building is located in the range where $X \in (0, 2b)$, Wall-B is just in the wake of interfering building if wind comes from the front side of Wall-A and consequently the negative pressure on

it is low. If the wind comes from the back side of Wall-A, there is no shielding from the interfering building to protect Wall-B, so the negative peak pressure on Wall-B becomes higher. From Fig. 6(b), it can be checked that the $\check{IF}(B)$ values are all lower than 1 when $X \in (0, 2b)$. The smallest value among them is only 0.7 when the interfering building is at $(2b, 1.5b)$. These results imply that even when the interfering building is located in the downstream direction it also affects the $\check{C}_p^B$ value by changing the flow field around the principal building.

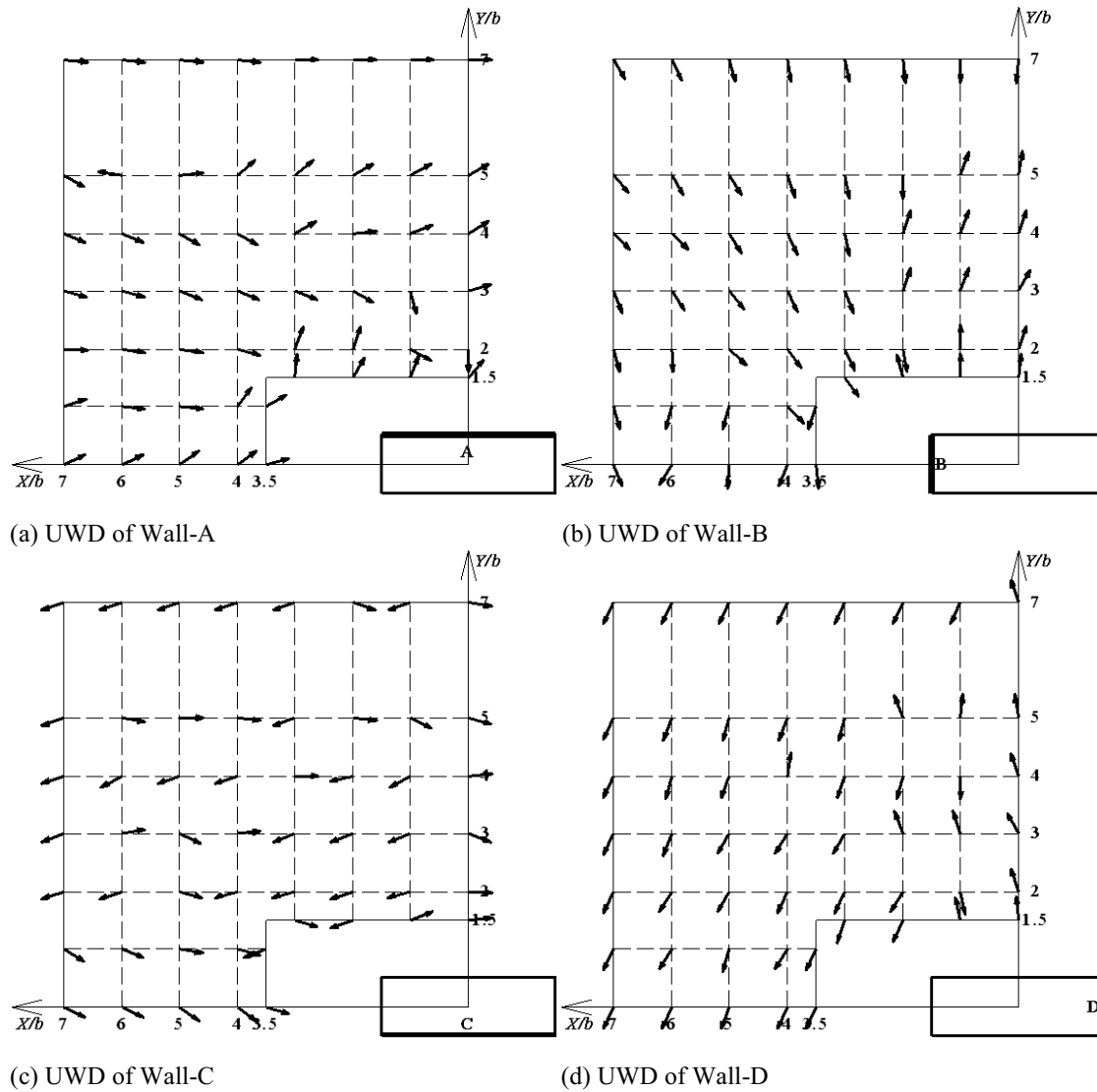


Fig. 8. Negative UWD of four faces.

4 CONCLUDING REMARKS

Experiments were carried out to investigate the interference effect on local peak pressures between two identical rectangular-cross-section high-rise buildings. The aspect ratio of the build-

ings was Width: Depth: Height=3:1:4. Parallel arrangement of the two buildings was checked. The interference effects on the external local peak pressures were evaluated and analyzed.

Based on the study, on one hand, the interfering building doesn't have a significant effect on maximum positive peak pressure. For most configurations of the interfering building, the interference factors for the largest maximum positive peak pressure were in the range of 0.9-1.1. On the other hand, the interfering building has a strong effect on the smallest minimum negative peak pressure. The unfavorable regions on Wall-A and Wall-B of the two arrangements were very large. The largest interference factor was greater than 1.5, which means the absolute value of the smallest minimum negative peak pressure coefficient is 50% higher than the design value of the isolated building situation.

Wind direction is one of the most crucial parameters. For most cases, the interference effect was stronger when the interfering building was located upstream of the principal building. The unfavorable wind directions depend strongly on the configurations of the two buildings.

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