Flow field analysis of interference effects on external pressures between high-rise buildings

Yi. Hui¹, Y. Tamura¹, A. Yoshida¹, and H. Kikuchi²

¹Department of Architectural and wind Engineering, Tokyo Polytechnic University, Atsugi, Kanagawa, Japan

²Research Institute of Technology, Shimizu Corporation, Koto-ku, Tokyo, Japan

Abstract

Particle Image Velocimetry (PIV) tests were conducted to investigate interference effects between two high-rise buildings. Buildings with the same height but different shapes, rectangular and square in plan, were adopted. PIV tests were used to describe and explain the interference effects that can cause a increase of negative peak pressure on building from the flow field point of view. The results show that the specific flow pattern may lead to enlargement of the negative peak pressure on the principal building.

1 Introduction

From the engineering point of view, the interference effects between high-rise buildings might enlarge wind loads on structures from the isolated building condition. Building damage will result if the interference effects are not appropriately evaluated. Many researches were conducted to determine the interference effects on the total wind load acting on high-rise buildings (Bailey and Kwok, 1985; Zhang et al., 1995; Xie and Gu, 2007; Lam et al., 2008). It is well known that change of wind load acting on a building is due to change of the flow field around it caused by the interfering building. The wind-induced interference effect can also be clarified by a visualization study. Thus, some studies not only investigated wind loads on high-rise buildings but also adopted flow visualization techniques to determine the mechanism of interference effects and to explain the wind load results by studying the flow field around them (Sakamoto and Haniu, 1987; Taniike, 1992). However, because of limitations of the techniques at that time, the flow visualization experiments done in those studies could only qualitatively describe the phenomenon.

Most studies related to wind induced interference effects between high-rise buildings focused on the total wind load, as introduced above. Only a few studies were dedicated to investigating interference effects on external local peak pressures on high-rise buildings (Kim et al., 2011; Hui et al., 2012). However, those studies had limited engineering value because they couldn’t adequately explain the mechanism of the phenomena from the experimental results. In the present study, The PIV system was adopted to investigate the flow field quantitatively. The flow field measurements were combined with the pressure measurement results to explain the phenomena and underling physics and provide an in-depth understanding of the interference effects.
2 Experimental setup

The PIV test in the present study was introduced to explain the interference effects from the flow pattern point of view. Therefore, several configurations were selected to be checked by PIV experiment based on the pressure measurement test results.

The PIV test was carried out in the wind tunnel of Shimizu Corporation, Japan. The test section was 3.5m wide and 2.5m high. A length scale of 1:900 was adopted in the PIV test. Two kinds of model shapes were used during the experiment, the square section model was 0.03m×0.03m×0.12m, and the rectangular section model was 0.03m×0.09m×0.12m. The approaching flow represented an urban wind exposure with a power law exponent of 0.27. The mean wind speed at roof height of the model was set to around 3.7m/s. The mean wind speed and turbulence intensity profiles are shown in Fig. 1. The Reynolds number for the PIV experiment was around $8\times10^3$. For wind tunnel testing of sharp-cornered bodies or building models, this was generally accepted to be sufficiently high for flow to be independent of Reynolds number, although some fine flow details may still be slightly affected. Two building models were used in one experiment test, the arrangements are as shown in Fig. 2, the interfering building was located at the quadrant facing Wall-A and Wall-B of the principal building. Both the rectangular section building and square section building were used as the principal building or interfering building in the study. Four sets of experiment were carried out. For Set-1 the rectangular section building is used as the interfering building, and square section building is principal building. For Set-2 the square section building is used as the interfering building, and rectangular section building is principal building (shown in Fig. 2). In Set-3 and 4 two rectangular section buildings are used, for Set-3 the two buildings are parallel and for Set-4 they are perpendicular.

![Figure 1: Mean wind speed and turbulence intensity profiles.](image1)

![Figure 2: Arrangement of two buildings.](image2)
The PIV system consisted of a high-speed digital video camera (Phantom V7, maximum frame rate: 4800 frame/sec, effective pixels: 800×600, sensor type: SR-CMOS), a double pulse Nd: YAG laser (Lee laser, average power 50W), a laser pulse synchronizer and a particle generator (PivPar40, particle diameter: 1μm). And the sampling frequency was 500 Hz. The sampling time of each sample was 6s. Fig. 3 is a photo of the experimental setup of the PIV test.

Figure 3: Experimental setup of PIV test.

3 Flow field analysis of cases with large $\tilde{\nu}$

Hui et al (2012) studied interference effects on the local peak pressures between two high rise buildings and discusses the phenomenon of the enlargement of $\tilde{C}_p$. They found that the interfering building usually causes high negative peak pressure at 4 kinds of positions on principal building, as shown in Fig. 4. The four positions are located along the edge-AB, which is facing the interfering building during experiment. Therefore, flow field was checked by PIV test to try to find out and explain the underlying physics of the these phenomenon.

Figure 4: Four positions of largest minimum peak pressure usually occurring
3.1 Flow field near top of building

The flow fields at the top of the building measured by the PIV system is at a height of 11 cm above the floor, which is 1 cm below the roof. Figs. 5 and 6 show the information of flow pattern when the rectangular interfering building is located at \((4b, 4b)\) from the square principal building. The mean incident wind direction is 30º, which can cause high negative peak pressure at the leading upper corner of Wall-B (Position III as shown in Fig. 4) of the principal building.

Fig. 5(a) shows the mean wind velocity field around the two models. It can be seen that the whole downstream principal building is basically located in the low wind speed region, which is the wake region of the upstream building. The mean wind speeds around it are less than 2 m/s, which is much lower than the mean incident wind speeds of 3.6 m/s. The wind field in very close proximity around the buildings could not be measured due to the effect of the models on the laser. The flow field also elucidates that the mean attacking wind of downstream building comprises flow that is separated from the upstream building. Fig. 5(b) and (c) show the turbulence intensities of the along-wind and cross-wind flow at each position of the flow field, respectively. Turbulence intensity of each position of the flow field is obtained by normalizing the standard deviation of along wind and cross wind speed at each position by the mean incident wind speed at that height. The strong turbulences in the area between the two buildings are due to the upstream interfering building, as in the isolated condition this kind of concentrated strong turbulence cannot be observed in the area upstream of the building. From Fig. 5(c), it can be seen that the greatest turbulence intensity area in the whole flow field is just surrounding Wall-B of the downstream building.

Fig. 6 shows the instantaneous flow field. As the separated shear layer from the leading edge of a building is not a stationary process, it swings in the cross-wind direction behind the building. Thus a kind of extreme flow field condition occurs when the high speed separated shear layer passes between the two buildings, as shown in Fig. 6(b). In this case the attacking wind speed of the downstream building becomes high (Fig. 6(a)), thus inducing higher pressure at the leading edge of Wall-B. The vorticity field shown in Fig. 6(c) shows another big difference from the isolated condition. As can be seen, the interaction of the separated shear layer from the upstream building and the separated shear layer from the downstream building occurred beside the leading edge of Wall-B. This interaction might cause large negative peak pressures at the leading edge of Wall-B.
Figure 5: Flow field information of configuration (4b, 4b) Set-1, $\theta=30^\circ$

(a) Wind speed field (m/s)  
(b) Streamtraces  
(c) Vorticity field

Figure 6: Instantaneous flow field information of configuration (4b, 4b), $\theta=30^\circ$
3.2 Flow field near bottom of building

Another phenomenon found from pressure measurement tests is that a large $\ddot{C}_p^X$ occurs at the lower corner of Wall-A or Wall-B (Position II and IV in Fig. 4). The flow fields of some cases near the bottom (1cm above the floor) were measured in the PIV experiment.

Fig. 7 shows the flow field of configuration (4b, 2b) in Set-1, where the attacking wind angle is $350^\circ$. This wind direction is the UWD of Wall-B of that configuration. In this case, $\ddot{C}_p^B$ appears at the lower corner of the leading edge of Wall-B (Position IV). Fig. 7 clearly shows that the mean wind velocity beside Wall-B is much higher than the mean incident wind speed, which is around 2.4m/s at 1cm above the floor. The high wind speed is mainly due to the influence of the configuration of the two buildings to the flow passing between them. The high mean speed wind will surely result in a high negative $|\ddot{C}_p|$ on Wall-B. And after checking the turbulence intensity of the flow field, a strong turbulence area around Wall-B generated by the upstream building can not be found, which was discussed in Section 3.1. Fig 8(a) show that at this moment the high speed shear layer flow of the upstream building passes beside the downstream building. The vorticity field is shown in Fig. 8(b). As with the cases discussed in Section 3.1, the interaction of the flow reformed by the upstream building and the separated shear layer of the downstream building might cause high negative peak pressure at this moment.

Fig. 9 shows the flow field of one case in experiment Set-3. The interfering building is located at (4b, 2b), and the wind direction is $160^\circ$. In this condition large $\ddot{C}_p$ appears at the lower corner of the leading edge of Wall-A. A similar phenomenon can be observed in Fig. 9, that is, the mean wind speed beside the leading edge of Wall-A can be greater than 4m/s. It can be seen that high wind speed also occurs due to the configuration of the two buildings. The coming wind was deformed and steered through the gap between the two buildings. After that, the wind is nearly $90^\circ$ from the original incident wind, and can be seen to be almost parallel to the leeward face (Wall-A) of the upstream building. Because of both the high wind speed and the local wind direction near the leading edge of Wall-A, the...
wind causes a high negative mean pressure coefficient. An instantaneous flow field is shown in Fig. 10. The high wind speed and the influence of the downstream building on the flow passing beside Wall-A might tend to cause the high negative peak pressure at the leading edge of Wall-A at that moment.

(a) Wind speed field (m/s)  (b) Vorticity field

Figure 8: Instantaneous flow field information of configuration (4b, 2b) Set-1, \( \theta = 350^\circ \)

Figure 9: Mean wind velocity field of configuration (4b, 2b) Set-3, \( \theta = 160^\circ \) (m/s)

4 Concluding remarks

PIV experiments were performed to check the flow patterns of several cases that cause high negative peak pressures. Where large negative pressure appears at the upper corner of the principal building, the principal building is usually downstream of the interfering building and it is attacked by the shear layer flow separated from the upstream interfering building. The mean wind speeds near that target corner are relatively low. But the strong turbulence of the attacking wind caused by the upstream interfering building can increase the fluctuating pressure coefficient. When high negative peak pressure appears at the lower corner of the leading edge of the principal building, the flow pattern results indicate that the high mean negative pressure at the leading edge of principal building is mainly due to the high speed wind blowing parallel to the target face. The high mean wind velocity occurs is
because the configuration of the two buildings can speed up the wind by inducing it to pass through the channel between them.

For both the upper corner cases and the lower corner cases, data of the extreme instantaneous flow field is also investigated. High speed shear layer wind from the upstream building and the strong interaction of the flow fields of the two buildings near the leading edge of target face of the principal building might be the reason for large minimum peak pressure.

![Wind speed field and Vorticity field](image)

**Figure 10:** Instantaneous flow field information of configuration (4b, 2b) Set-3, $\theta=160^\circ$

**References**


