Interference effects of local peak pressures acting on walls of tall buildings

Wonsul Kim¹, Yukio Tamura², Akihito Yoshida³

¹Ph.D. candidate Department of Architectural Engineering, Tokyo Polytechnic University, Atsugi, Kanagawa, Japan, d0784201@st.t-kouge.ac.jp
²Professor of Department of Architectural Engineering, Tokyo Polytechnic University, Atsugi, Kanagawa, Japan, yukio@arch.t-kougei.ac.jp
³Associate Professor of Department of Architectural Engineering, Tokyo Polytechnic University, Atsugi, Kanagawa, Japan, yoshida@arch.t-kougei.ac.jp

ABSTRACT

This paper describes results of wind tunnel experiments performed at Tokyo Polytechnic University to determine interference effects of local peak pressures on an identical pair of tall buildings to establish design cladding pressures. Measured local wind pressure coefficients for a principal building (one located near an identical building) were compared with those for an isolated building. The results show that the distribution of maximum (minimum) wind pressure coefficients on walls of a principal building with critical locations of an interfering building, as well as the largest maximum (smallest minimum) wind pressure coefficients on the side walls of the principal building due to interference. The authors deal with the shielding effect and channeling effect for various relative locations of the interfering building.

INTRODUCTION

Wind loads on tall buildings in a group in real environments can be quite different from those on an isolated building. Such surrounding buildings or upstream building(s) can significantly increase or decrease local wind loads as well as overall wind loads on a subject building due to interference effects. Where there are surrounding buildings, it is difficult to predict wind loads because there are a large number of variables involved, such as sizes and shapes of buildings, relative locations of adjacent building(s), wind directions, upstream terrain conditions and so on. Interference effects have been studied by many researchers for several decades [1-9]. These studies have been carried out to try to codify wind loads caused by interference effects. In several limiting conditions, for example, one or two terrain conditions, several wind directions, and heights and sizes of one or two interfering buildings such as small, medium and large buildings, they produced not only a comprehensive database for purposes of codification by a huge number of wind tunnel experiments, but also a database produced by wind tunnel experiments that could provide empirical formulas for evaluating wind loads on adjacent buildings [10-11]. Such a database and equations could be used for an approximate estimation of wind forces on a building under interference for preliminary design purposes. Khanduri [10] reported behaviors of mean and fluctuating forces on a principal building through a huge amount of experimental work, for varying square sizes and heights of an interfering building, several wind directions and various upstream terrain conditions. Then, using interference influence grids, they simplified and generalized their results obtained from wind pressure experiments to provide guidance for structural design. Xie and Gu [11] reported the effects of upstream terrain conditions, relative heights of interfering buildings, and spacing between two and three buildings on mean and dynamic interference factors through a huge amount of wind tunnel experimental work. Then they proposed regression equations that reflected the inherent complex relationship
to simplify the expressions of interference effects, as well as how to use their results in design of real tall buildings.

However, unfortunately most past studies have focused mainly on wind loads (mean along-wind and across-wind or dynamic wind responses) on the principal building for structural design. Although these studies utilized pressure experiments, they focused on wind load behavior. In order to determine cladding pressures, Surry and Mallais [12] reported on high suction near the ground and at the top of a building for spacing between two buildings and a building of unusual geometry such as a sharp-cornered tower. They pointed out that for buildings of unusual geometry, special care should be taken to examine the likely effects of current and future environments. However, their research also had immensely limiting conditions.

This paper investigates interference effects for the largest maximum and the smallest minimum wind pressures on walls of an identical pair of high-rise buildings by wind tunnel experiment to quantify cladding wind loads. Various locations of interfering buildings of identical cross-section and height are considered. For detailed interference effects for specific cases of interest including physical meaning, the authors deal with shielding effect and channeling effect for various dispositions of the interfering building. Furthermore, interference effects are represented by local interference factor \( LI_{\text{min}} \) of the smallest minimum wind pressure coefficient.

**EXPERIMENTAL ARRANGEMENTS**

Wind tunnel experiments for measurement of wind pressures on two tall buildings were preformed in a boundary layer wind tunnel of the Wind Engineering Research Center at Tokyo Polytechnic University. The main test section was 2.2m wide and 1.8m high. The approach flow represented an urban wind exposure using the spire-roughness technique with a power law exponent of 0.33 classified as terrain category A in the Korean Building Code (KBC 2005 [13]). The wind velocity and the turbulence intensity at the height of the model were 7.4 m/s and 19.5%, respectively. Measured longitudinal mean wind velocity profile, \( \bar{U} / \bar{U}_g \) and turbulence intensity profile, \( I_w(\%) \) were as shown in Figure 1, where \( \bar{U}_g \) and \( Z_g \) are the mean wind velocity at the gradient height and reference height for exposure category A, respectively.
PRESSURE MODEL AND DATA PROCESS

Figure 2 shows the coordinate system and the grid used to define the relative locations of the buildings and the configuration of pressure taps on the model. The considered twin building configuration comprised two identical buildings, 28 m by 28 m in plan and 112 m in height. A geometrical model scale of 1:400 was employed in the study. 252 pressure taps were installed on the walls of the principal building. They were non-uniformly distributed in the vertical direction and generally spaced at 10 mm in the horizontal direction with 5 mm to the corners. The principal building was kept at the same location while the interfering building was considered at 100 different relative locations. The wind direction considered was for 0° aligned with the x-axis. The pressure data were obtained by sampling at 781 Hz in full scale for a period. In order to determine accurate coefficients of wind pressure acting on the surface area of the principal building, the time histories of wind pressures were filtered by means of a moving average filter and each test case was sampled 20 times.

The maximum wind pressure coefficient, \( C_{p,\text{max}} \) and minimum wind pressure coefficients, \( C_{p,\text{min}} \) were defined as \( C_{p,\text{max}} = \hat{p}_i / q_H \) and \( C_{p,\text{min}} = \bar{p}_i / q_H \), respectively, where \( \hat{p}_i \) and \( \bar{p}_i \) are maximum and minimum wind pressure at point \( i \), \( q_H = 1/2 \rho U_H^2 \) is the velocity pressure at the reference height and \( U_H \) is the horizontal wind velocity at the top of the model. In this paper, maximum and minimum wind pressure coefficients are represented for simplicity by \( C_{p,\text{max}} \) and \( C_{p,\text{min}} \), respectively.

RESULTS AND DISCUSSIONS

PEAK WIND PRESSURE COEFFICIENTS FOR TWO BUILDINGS

In the wind patterns around a rectangular building, the windward wall is generally subjected to positive wind pressure due to the direct impact of approaching flow, and the other walls are
subjected to negative wind pressure due to flow separating from the edges, as shown in Figure 3. In Figure 3, the largest $C_{p,max}$ of 2.68 on the windward wall occurred at about $0.8H$ of the building, and the smallest $C_{p,min}$ of -3.89 on the surfaces of the side walls occurred near the base of the wall for flow separating from the windward wall and generating strong vortices. However, when the interfering building was located upstream, the smallest $C_{p,min}$ of -4.88 on the surface of side walls of the principal building occurred near the top of the side walls, and $C_{p,min}$ dramatically decreased or increased for various relative locations of the interfering building, as shown in Figure 4. For critical positions of the interfering building, the results of this study represented $C_{p,max}$ on the windward wall and $C_{p,min}$ on a negative wall of a building, as shown in Figure 4. Figures 5 and 6 show the distributions of largest $C_{p,max}$ and smallest $C_{p,min}$ on the principal building for various relative locations of the interfering building and without the interfering building.

Figure 3: Distribution of wind pressure coefficients on an isolated building for wind direction $0^\circ$

Figure 4: Distribution of peak wind pressure coefficients on a principal building with an interfering building at $(S_x, S_y) = (1.5B, 0)$, $(1.5B, 0.5B)$ and $(0, 1.5B)$ at wind direction, $0^\circ$
As seen in Figures 5 (a) and (b), when the interfering building was located upstream, the largest $C_{p,\text{max}}$ on the wall slightly increases compared with that for the isolated building. The largest $C_{p,\text{max}}$ of 2.68 was observed when the interfering building was located at $(S_x, S_y) = (1.5B, 0.5B)$, as shown in Figure 4 (a). This suggests that the increased wind speed from the edges of the upwind interfering building causes direct impact around the right part of the windward wall. Another notable observation is that, when the interfering building was located in tandem, the largest $C_{p,\text{max}}$ on the windward wall slightly increases although the along-wind response dramatically decreases due to shielding effects. However, when the interfering building was located at $(S_x, S_y) = (1.5B, 0B)$, the largest $C_{p,\text{max}}$ decreased to 2.09, and the distribution for that case is shown in Figure 4 (a). It is speculated that at this normal to wind direction, wind separates at the upwind interfering building, and the principal building is inside its wake. Wind pressure on a point inside the building wake depends on the distance from the separated flow streamlines extending from the upwind interfering building. The windward wall of the principal building is

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**Figure 4:** Distribution of peak wind pressure coefficients on a principal building with an interfering building at $(S_x, S_y) = (1.5B, 0)$, $(1.5B, 0.5B)$ and $(0, 1.5B)$ at wind direction, $0^\circ$ (continued)
immersed in the wake caused by the interfering building, and thus the largest $C_{p,max}$ is decreased, and the smallest $C_{p,min}$ on side walls is also decreased, as shown in Figures 4 (a) and (b). It is noted that when the interfering building was located between $S_y/B = 1.5$ and $S_y/B = 4$ in Figure 5 (b), there are no interference effects on the largest $C_{p,max}$.

As shown in Figure 6 (a), when the interfering building was located upstream, the smallest $C_{p,min}$ on the wall overall increased significantly. This is particularly apparent when the interfering building was located at $S_y/B = 0$ and 0.5. The peak value of -4.82 occurred at $(S_y, S_y) = (4.0B, 1B)$, while the smallest $C_{p,min}$ on the wall of the isolated building was -3.89. However, when the interfering building was located downstream at $(S_y, S_y) = (1.5B, 0B)$, the smallest $C_{p,min}$ decreased to -3.17. As shown in Figure 6 (b), when the interfering building was located at $S_y/B = 1.5$, the smallest $C_{p,min}$ overall decreased, even though the interfering building was located downstream. In the other cases, the smallest $C_{p,min}$ values were similar to that of the isolated building. It is noteworthy that when the interfering building was located beside the principal
building, that is, \((S_x, S_y) = (0, 1.5B)\), the smallest \(C_{p,\text{min}}\) on the wall increased to -4.88. This can be explained by the fact that when the wind was channeled to flow through the space between the two buildings, high local peak minimum wind pressures are induced on the wall of the principal building, which may be due to channeling effect, as shown Figures 4 (e) and (f).

### Local Wind Pressure Coefficients

Figure 7 shows notations for minimum wind pressure coefficient on line \((z/H)\) with distance \((x/D)\) from the corner of the windward wall of the principal building. The distances from the windward wall were \(x/D = 0.07, 0.21, 0.36, 0.5, 0.64, 0.79\) and \(0.93\), and the distances from a line on the side wall perpendicular to the wind direction were \(z/H = 0.06, 0.19, 0.31, 0.44, 0.56, 0.69, 0.81, 0.92\) and \(0.98\), where \(D\) and \(H\) are the depth and height of the principal building. The result for the local wind pressure coefficient was given by the minimum wind pressure coefficient, \(C_{p,\text{min}}\).

![Diagram showing wind pressure coefficients](image)

Figure 7: Notations for minimum wind pressure coefficients on a line with distance from surface of principal building

Figure 8 shows the variations of \(C_{p,\text{min}}\) on a line with distance \((x/D)\) from the corner of the windward wall of two tandem arranged buildings for wind direction 0°. In Figure 8 (a), \(C_{p,\text{min}}\) on line \((z/H)\) of the side wall increases significantly between \(S_y/B = 2\) and \(S_y/B = 6\). It can be explained that for larger separation distances of upwind interfering building, the vortices have enough time and space to become well organized before they hit the principal building, thus increasing the vertical correlation of wind loading, which is responsible for higher negative wind pressure [5]. It is also noted that the largest \(C_{p,\text{min}}\) on the side wall occurred near its top while the largest \(C_{p,\text{min}}\) on side wall of the isolated building occurred near its base. However, when the interfering building was located at \((S_x, S_y) = (1.5B, 0)\), \(C_{p,\text{min}}\) on the side wall greatly decreased. For smaller separation distance, \((S_x, S_y) = (1.5B, 0)\), the principal building interferes with the
steady vortex shedding and disrupts its frequency, thus destroying the vortex shedding mechanism and resulting in a small $C_{p,\text{min}}$ value [5]. Another notable observation was that $C_{p,\text{min}}$ on the side wall dramatically decreased far away from the edge of the windward wall rather than that on the side wall of the isolated building, as shown in Figures 8 (b), (c) and (d). From these figures we can be seen that $C_{p,\text{min}}$ on the side wall decreased as the interfering building was close to the principal building.

Figure 9 shows the variations of $C_{p,\text{min}}$ on a line ($x/D$) from the corner of the windward wall of two adjacent buildings for wind direction 0°. For this configuration, $C_{p,\text{min}}$ on the leading edge ($x/D = 0.07$) of the inner side wall (right side wall) greatly increases, and the largest $C_{p,\text{min}}$ of -4.88 occurred at the top of the side wall at $(S_x, S_y) = (0, 1.5B)$, as shown in Figure 9 (a). Another notable observation was that at closer distances, $C_{p,\text{min}}$ is generated because the velocity of flow through the channel between the two buildings increases, thus generating a larger $C_{p,\text{min}}$ on the entire inner side than on the outer side. Even when the interfering building was located at $(S_x, S_y) = (0, 4B)$, $C_{p,\text{min}}$ on the side wall still increases. It is interesting that when the interfering building was located at $(S_x, S_y) = (0, 1.5B)$, for $C_{p,\text{min}}$ between $x/D = 0.5$ and $x/D = 0.98$ of the side wall deceased while it increased for other locations of the interfering building. This may be due to the flow that separated flow from the windward wall of the interfering building the disturbs velocity increase from the principal building.

![Figure 8](image)

**Figure 8:** Variations of minimum wind pressure coefficients on a line with distance ($x/D$) from corner of windward wall of two tandem arranged buildings for wind direction 0°
Figure 9: Variations of minimum wind pressure coefficients on line with distance \((x/D)\) from corner of windward wall in side-by-side configuration for wind direction \(0^\circ\)

**LOCAL INTERFERENCE EFFECTS**

The minimum wind pressure coefficients above represented in Figures 8 and 9 are just a local description of \(C_{p,\text{min}}\) on the side walls for two arranged buildings and does not give the complete information of the interference effects for all configurations. Statistical analysis for a thorough description of the interference effects for higher negative pressure values generated in the side wall is therefore needed and the results of the interference effects due to the distance \((x/D)\) from leading edges of side walls are shown in Figure 10, where \(p\) represents the percentage of the positions of the corresponding local interference factor for all configurations. From Figure 10, Local Interference Factor \((LIF_{\text{min}})\) is expressed by:

\[
LIF_{\text{min}} = \frac{\text{Smallest } C_{p,\text{min}} \text{ on a line of side wall surface with an interfering building}}{\text{Smallest } C_{p,\text{min}} \text{ on a line of side wall surface without an interfering building}}
\]

(1)

where the smallest \(C_{p,\text{min}}\) is the smallest minimum wind pressure coefficient on line \((z/H)\) with distance \((x/D)\) from the corner of each wall of the principal building with and without an interfering building.
From Figure 10 (a), one can see that \( p \) is 40% when \( LIF_{\text{min}} \) for \( x/D = 0.07 \) is equal to 1.0 for the right side wall of the two buildings. As discussed above, since the smallest \( C_{p,\text{min}} \) occurred at the leading edge part of the right side wall of the principal building, the focus should be \( LIF_{\text{min}} \) at \( x/D = 0.07 \). \( LIF_{\text{min}} \geq 1.1 \) was 40% at the leading edge \( (x/D = 0.07) \) of the right side wall for the complete set of interfering building arrangements, and the largest \( LIF_{\text{min}} = 1.5 \) was recorded as shown in Figure 10 (a).

From Figure 10 (b), one can see that \( p \) was 30% when \( LIF_{\text{min}} \) for \( x/D = 0.07 \) is equal to 1.0 for the left side wall of the two buildings. \( LIF_{\text{min}} \geq 1.1 \) was 41% at the leading edge \( (x/D = 0.07) \) of the left side wall for the complete set of interfering building arrangements, and the largest \( LIF_{\text{min}} = 1.3 \) was recorded as shown in Figure 10 (b). At \( x/D = 0.93 \) in Figure 10 (b), \( LIF_{\text{min}} \) increased to 1.3 for 10% and 1.4 for 4%, but it is negligible because the smallest \( C_{p,\text{min}} \) is much smaller than that of the leading edge \( (x/D = 0.07) \) of the left side wall.

![Diagram](attachment:image.png)

(a) Distribution of local interference effects right side wall

![Diagram](attachment:image.png)

(b) Distribution of local interference effects for left side wall

Figure 10: Distribution of local interference effects for smallest minimum wind pressure coefficient on line with distance \( (x/D) \) from corner of windward wall for two buildings at wind direction 0°
CONCLUSIONS

Wind tunnel experiments were performed to investigate the interference effects of an interfering building on the wind-induced local wind pressures on walls of a principal building. The interfering building was placed at 100 different locations upstream and downstream of the principal building at wind direction $0^\circ$.

1. When the interfering building was located upstream, the largest $C_{p,\text{max}}$ on the windward wall of the principal building slightly increases compared to that on the windward wall of the isolated building, while along wind load decreases due to the interfering effects.

2. For tandem configuration, $C_{p,\text{min}}$ on the side wall of the principal building dramatically decreased with distance from the edge of the windward wall rather than that on side wall of the isolated building.

3. For side-by-side configuration, $C_{p,\text{min}}$ on the leading edge ($x/D = 0.07$) of the inner side wall of the principal building greatly increases, and the largest $C_{p,\text{min}}$ of -4.88 occurred at the top of the side wall at $(S_x, S_y) = (0, 1.5B)$. At closer distances of side-by-side configuration, $C_{p,\text{min}}$ is generated because the velocity of flow through the channel between the two buildings increases, thus generating a larger $C_{p,\text{min}}$ on the inner side wall than on the outer, and even when the interfering building was located at $(S_x, S_y) = (0, 4B)$, $C_{p,\text{min}}$ on the side wall still increases.

4. $LIF_{\text{min}} \geq 1.1$ was 44% at the leading edge ($x/D = 0.07$) of the right side wall for the complete set of interfering building arrangements, and the largest $LIF_{\text{min}} = 1.5$ was recorded. Also, $LIF_{\text{min}} \geq 1.1$ was 41% at the leading edge of the left side wall for the complete set of interfering building arrangements and the largest $LIF_{\text{min}} = 1.3$ was recorded.

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REFERENCES


