WIND RESPONSE OF INTERFERENCE EFFECT ON TALL BUILDING

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ABSTRACT

The construction of a tall building in close proximity to an existing building may affect the response to wind load of the latter. Therefore, wind loads on buildings in realistic environments may differ considerably from those on isolated buildings. Neighboring buildings may alter the flow-induced forces on a structure and this is particularly dependent on the geometry and layout of the buildings and their orientation with respect to the direction of flow and upstream terrain conditions. The main aim of this paper is to investigate the differences between two prismatic building models for two types of boundary layer (BL) flow: suburban (BL1) and urban (BL2). To investigate the interference effects on dynamic responses of tall buildings, a high-frequency force-balance test was conducted.

Keywords: Suburban, urban, interference effects, displacement.


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1. INTRODUCTION

In recent years, mixed-use residential and commercial buildings in Korea have consisted of several, rather than a single, building. The interference effect of the arrangement of buildings in a group has not been evaluated. The current wind load has been investigated only for a single building and no standards have been set for the siting of a group of buildings. The interference effect on wind load for a group of buildings was highlighted when three out of eight cooling towers collapsed in Ferrybridge, England in 1965. Blessmann and Riera [1] and Ruscheweyh [3] reported that the most significant factor in the maximum torsional moment of...

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the interference effect was the addition of surrounding buildings. This effect was three times larger with multiple structures compared with a single building.

Blessmann [2], and Kareem [7] compared the interference effects seen in larger urban areas with those occurring in smaller suburban areas, based on the boundary layer (BL) effect. Holmes and Best [7] and Bailey and Kwork [4] presented the interference effect for various buildings as a buffeting map in the Australian standard for minimum design loads on structures (SAA, 1989). Studies in the early 1990s on the interference effect were also conducted to reveal the mechanism of the interference effect and its applications, and various contributing factors were identified. Further studies have built on previous work, such as that on the shielding effects of upstream buildings [5], aerodynamic interference due to tall buildings, and interference effects arising from groups of buildings [6,8,20]. Furthermore, flow visualizations have been used to explain the interference effect caused by groups of buildings. Tanike [16] investigated the mutual interference between neighboring tall buildings in highly turbulent flow over an urban area. Interference effects decreased exponentially with increased turbulence and were reduced to zero when turbulence intensities increased by up to 17–18%. Sakamoto [12,13] produced a flow visualization around a pair of square buildings to study the flow pattern generated due to interaction effects. Kareem [8] studied the interference effect between two and three circular cylinders, in various arrangements, at high subcritical Reynolds numbers. Sun [20] investigated the aerodynamic characteristics of the interference effect between two circular and rectangular cylinders for different slenderness ratios of cooling towers. The development of a new analysis method has rendered it possible to study the effect of the eccentricity of structures [14,18], to employ the K-e model of turbulence for numeric calculations [19], and to generalize test results by application of artificial neural networks [9,10].

This paper investigates the interference effect by other buildings. The variables used in the wind tunnel test were the interference distance (0.5, 1.0, 1.5, or 2.0 B), wind angle (0°, 15°, 30°, or 45°), and BLs (BL1, \( \alpha = 0.15 \); BL2, \( \alpha = 0.30 \)). The results of this test were analyzed in terms of wind spectrum and root mean square (rms) displacement response based on the distribution of wind factors in the along-wind and across-wind directions.

2. WIND TUNNEL TEST

The wind tunnel test was performed at a large-scale wind tunnel, which was built in the wind tunnel laboratory in Chonbuk University. The specifications of the measurement section were as follows: length of 12 m; height of 1.2 m; open-type; and wind speed in the range 0.5–20 m/s. Figure 1, which illustrates the BL produced inside the wind tunnel, shows the vertical distribution of the mean wind speed and turbulence intensities of BL1 (suburban area) and BL2 (urban area). The turbulence intensity at the highest floor of the model was 10% for BL1 and 17% for BL2. The dimensions of the upwind side model (interference model) and the downwind side model (analysis model) were equal, and a square model with a side ratio of 1 and aspect ratio of 4 was used in this test. Table 1 shows the specifications of the model. The wind model used in this test was made of balsa, and the natural frequency in the along- and across-wind direction was 55 Hz. The blocking ratio of the model installed in the wind tunnel was 2.2%. Figure 2 shows the wind angle and interference distance of the upwind and downwind side models, where the interference distance, \( S_x \), has values of 0.5, 1.0, 1.5 and 2.0 B, based on model section B. The wind angles applied ranged from 0–45°, with an interval of 15°, and were configured such that the values were the same for both the upwind and downwind side models, to account for changes in the interference distance. Table 2 shows the
dynamic characteristics of the analyzed buildings, and the test wind speeds for the BL and the geometric similitude.

**Figure 1** Vertical distributions of the mean wind speed and turbulence intensities.

**Table 1** Specification of the model

<table>
<thead>
<tr>
<th>Height(H)</th>
<th>Breadth(B)</th>
<th>Depth(D)</th>
<th>Aspect Ratio (H/B)</th>
<th>Side Ratio (B/D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40cm</td>
<td>10cm</td>
<td>10cm</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table 2** Dynamic characteristics and geometrical similitude law for the objective building

<table>
<thead>
<tr>
<th>Natural Frequency (Hz)</th>
<th>Generalized Mass (kg)</th>
<th>Damping ratio</th>
<th>Experiment velocity(m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>16384000</td>
<td>0.02</td>
<td>BL1 ((\alpha = 0.15))</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>BL2 ((\alpha = 0.30))</td>
</tr>
<tr>
<td>7.4</td>
<td>6.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Model scale: 1/400
Velocity scale: 1/5.67, 1/5.07
Time scale: 1/70.54, 1/78.89
Sampling frequency (Hz): 200Hz

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2.1. Interaction Mechanism for the Surrounding Building
To understand the interaction mechanism of the main buildings and the surrounding buildings, a test of the wind stream pattern must first be completed for a single building. After the surrounding buildings have been positioned, the dynamic response of the main building is affected because the wake, which is generated from the rear of the upwind buildings (surrounding buildings), suppressed the vortex-shedding of the downwind buildings (main buildings). Figure 3 shows the wind stream pattern for the surrounding buildings.

![Wind stream pattern](image)

**Figure 3** Wind stream patterns of the surrounding buildings.

3. ANALYSIS OF THE WIND TUNNEL TEST
The wind tunnel test measured the effect of wind angle, BL, and interference distance using a 6-component force balance. Wind spectrum, and rms displacement response were analyzed using the wind data, which were measured in the downwind model according to the change in the upwind model.

3.1. Interference Excitation Spectra
3.1.1. Along-Wind Direction
Figures 4 and 5 show the wind force spectrum according to the BL1 and BL2 in the along-wind direction. The force spectrum produced by changing the interference distance was different from the wide band produced by the single model. For the secondary peak, between 0.5 B and 2.0 B and at a wind angle of 0°, the wake generated in the upwind model affected the downwind model. The force spectrum produced the smallest value at 0.5 B, due to a large shielding effect, and there were no differences from the single model for 2.0 B. It seems that the effect of the wake was greater than that of shielding between 0.5 B and 2.0 B. The secondary peak in the high frequency region decreased in width as the wind angle increased. This was because the wake, generated at the rear due to stream reattachment at the side of the upwind model as wind angle increased, affected the downwind model.

The scale of the spectrum according to the boundary layer produced large values in BL2, which showed high turbulence intensity, but the secondary peak in the high frequency region in BL1 produced larger values than in BL2. This was due to the periodic property of the wake generated at the rear of the upwind model in BL1. The shape of the force spectrum was near-constant regardless of the turbulence intensity, and the scale of the spectrum increased as the interference distance increased from 0.5–2.0 B. This seems to be a result of the shielding effect caused by the upwind model.
Wind Response of Interference Effect on Tall Building

Figure 4 Wind force in for the along-wind direction (BL1).
3.1.2. Across-Wind Direction

Figures 6 and 7 show the wind force spectrum of the interference distance according to the BL in the across-wind direction. In the force spectrum at a wind angle of 0°, a narrow band occurred around the dimensionless frequency of 0.1 Hz in the single model. The narrow band peak disappeared at an interference distance of 0.5 B due to the shielding effect of the upwind model, but the narrow band peak produced a larger value at 2.0 B than the single building. The shielding effect increased from 0.5–1.5 B, and then decreased at 2.0 B turbulence intensity increases, shown by the increase in the narrow band peak. The scale of the spectrum increased as the wind angle decreased from 45–15°, with the largest value seen at 15° because the stream reattachment that occurred at the side edge of the upwind model significantly affected the wake. A wide band was produced at a wind angle of 45°, and the wind spectrum was similar to that for the single building, irrespective of the interference distance. The scale of the spectrum was larger for the BL1 versus BL2 because of the influence of the wake. As with the along-wind direction, the scale of the spectrum increased with interference distance as a result of shielding. The single building showed a secondary peak in the high frequency region as the wind angle increased, but no secondary peaks with respect to interference distance in the interference model test. This was because a large vortex, generated at the rear of the upwind model, affected the side of the downwind model.
Wind Response of Interference Effect on Tall Building

Figure 6 Wind force spectrum in the across-wind direction (BL1).

Figure 7 Wind force spectrum in the across-wind direction (BL2).
3.2. Dynamic Response
The dynamic response was analyzed according to the rms displacement of the main building, calculated using equations 1.

3.2.1. Rms Displacement

\[
\sigma_x = (A_n + A_k)^{1/2} = \left[ \frac{\sigma_M^2}{((2m_0)^2 M_1)^2 H^2} + \frac{m_0 S_M (n_0)}{4 \eta_1 ((2m_0)^2 M_1)^2 H^2} \right]^{1/2}
\]

\[
= \frac{\sigma_M}{(2m_0)^2 M_1 H} \left[ 1 + \frac{\pi}{4 \eta_1} \frac{n_0 S_M (n_0)}{\sigma_M^2} \right]^{1/2}
\]

Where \( n_0 \): natural frequency , \( \eta \): damping ratio, 

\( M_1 \): generalized mass

The designed wind velocity for a 100-year return period was used to evaluate the rms displacement, with the values in BL1 and BL2 set at 42 m/s and 32 m/s, respectively. Seoul (Korea) was the area used for evaluating the dynamic response, and the basic wind velocity used in the designed wind velocity was a type of gradient wind velocity. The natural frequency assumed in the analysis was 0.3 Hz, and the damping ratio was 2%. Figure 12 shows the rms displacement response according to the BL for each wind direction. In the along-wind direction, the rms displacement response increased by up to 47%, at a wind angle of 0° and interference distance of 1.0 B. However, the rms displacement response at wind angles between 15° and 45° decreased by up to 30% for interference values ranging from 0.5 B to 2.0 B. Notably, the rms displacement response at 2.0 B was similar to that for the single building because of the effect of shielding and wake. The secondary peak in the high frequency region, seen in the spectrum in the along-wind direction, was in the region of the displacement response and showed large values at a wind angle of 0°. A decrease in the secondary peak as wind angle increased produced a decrease in the displacement response. The displacement response decreased in BL2 irrespective of the interference distance and wind angle compared with the single building. In the across-wind direction, the value in BL1 increased by up to 30% at a wind angle of 0° and interference distance of 0.5 B, and decreased above a wind angle of 15°. BL2 showed a near-constant distribution, similar to that of the single building.

(a) Displacement for r.m.s. of alongwind-direction(BL1)(unit:m)
Wind Response of Interference Effect on Tall Building

(b) Displacement for r.m.s. of alongwind-direction (BL2) (unit: m)

(c) Displacement for r.m.s. of acrosswind-direction (BL1) (unit: m)

(d) Displacement for r.m.s. of acrosswind-direction (BL2) (unit: m)

Figure 12 r.m.s displacement for each direction

4. CONCLUSIONS
During the interference effect test in this study, a tall building surrounded by interference buildings was exposed to varying wind loads. Three variables (wind angle, interference
distance and turbulence intensity) were manipulated in upwind and downwind models. The results can be summarized as follows:

(a) Interference excitation spectra
Although the force spectrum of the single model in the along-wind direction showed a wide band peak at a wind angle of 0°, the secondary narrow peak in the high frequency region produced in the interference test decreased with interference distance and wind angle. It is evident that this result was due to the wake generated at the rear of the upwind model and to the shielding effect. Although the force spectrum of the single model in the across-wind direction showed a narrow band peak at a wind angle of 0°, there was no secondary peak in the high frequency region, like that produced in the along-wind direction, with increasing interference distance and wind angle in the interference model. However, a peak in the region of the dimensionless frequency of 0.1 Hz showed an increase or decrease in the value because of the periodic wake (generated at the rear of the upwind model), with larger values seen in BL1 than in BL2.

(b) Dynamic response
The rms displacement response increased by up to 47% at an interference distance of 1.0 B and wind angle of 0° in the along-wind direction, because the secondary peak in the high frequency region (produced according to the change in the interference distance) was in the region of the displacement analysis. The value in BL1 was larger than that in BL2, as the secondary peak in the high frequency region of BL2 was smaller than in previous cases. In the across-wind direction, the wind angle of 0° produced the largest value, and the value increased by up to 30% due to the decrease in the secondary peak in the high frequency region.

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Wind Response of Interference Effect on Tall Building


