Research on interference effects of wind loads on tall buildings in staggered arrangement

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ABSTRACT: To research the interference effects of wind loads on a real project with three similar-shaped staggered arranged tall buildings, wind tunnel tests about the three tall buildings and one isolated tower were conducted respectively. By comparison of the measured results, effects of wind directions and building positions on the design wind forces for main wind-force resisting system, i.e., along-wind, cross-wind and torsion wind loads, were discussed. Interference mechanisms were analyzed by integrating CFD simulated results and experiment measured data. It indicates that wind loads of the middle tower, named tower 2, are greatly increased compared to isolated cases and in the unfavorable wind direction of 110 degree, the static interference factor of torsion load, dynamic interference factor of wind load in Y and torsion directions are 1.53, 1.32 and 1.37 respectively.

Keywords : tall buildings, synchronization pressure wind tunnel test, staggered arrangement, static interference, dynamic interference

1 INTRODUCTION

Research shows that, wind loads of the tall buildings in the real environment and that of the isolated buildings are not same. In the early 1930s, people have realized the interference effects for a cluster of high-rise building\textsuperscript{[1]}. In 1965, cooling tower collapse in the ferry bridge power plant aroused great research interest in wind interference\textsuperscript{[2]}, which marked the beginning of the wind-induced interference effects research. Hereafter, more and more wind tunnel tests were conducted in order to obtain general results\textsuperscript{[3-6]}. In the late 1980s, some research results were applied to the wind load codes, such as the Australian standard. In China, interference research began at the end of 1980s\textsuperscript{[7]}. Recently, interference effects of two and three tandem rectangular buildings models were tested in literature\textsuperscript{[8, 9]} and\textsuperscript{[10]} respectively. These research were mainly about tandem rectangular buildings and focused on the along and across wind results. But in realities, most unfavorable wind direction are not necessarily perpendicular to the facade, and under interfered conditions torsion wind loads are often not negligible\textsuperscript{[11,12]}. In this paper, wind pressure of a real project including three staggered high-rise buildings was test in wind tunnel. A CFD numerical calculation was conducted to figure out the mechanism of interference. Comparison between three grouped buildings and one isolated building indicates the wind direction have great effects on the interfered wind loads.

2 WIND TUNNEL TEST

The project consists of three high-rise buildings, named tower 1, 2 and 3. These buildings are approximately 190m height and have consistent section size. To investigate the interference effect, wind pressure of additional isolated tower was measured after three tower group test. Both experiments were conducted in the $4m \times 3m$ test section of the China Academy of Building Research wind tunnel. Wind field of type A was simulated according to the Chinese load code. Rigid pres-
sure model scale ratio is 1:250. In each model, 162 ports are measured using Scanivalve electronic scanning pressure measurement system. Test wind speed is 14m/s at 1m height in wind tunnel. For each port, 4200 pressure signals were recorded in time domain with sampling frequency 312.5Hz.

3 RESULTS AND ANALYSIS
In this paper, maximum bending moments or torque are selected to evaluate the interference effects. Static interference factor can be calculated by

\[
\text{IF}_{s} = \frac{\text{SIGN} \left( M_s(\alpha) \right) \times \text{MAX} \left( \left| M_s(\alpha) \right| \right)}{\text{SIGN} \left( M_0(\alpha) \right) \times \text{MAX} \left( \left| M_0(\alpha) \right| \right)}
\]

(1)

where \( M_s(\alpha) \) and \( M_0(\alpha) \) is mean values of base moment or torque in \( \alpha \) wind direction for interfered and isolated building respectively; '| |' denotes absolute value calculation; 'MAX' denotes maximum value calculation; ‘SIGN’ is to obtain number sign; \( \alpha_M \) is wind angle where the maximum value occurs.

Dynamic interference factor can be evaluated as

\[
\text{IF}_{D} = \frac{\text{MAX} \left( \sigma_M'(\alpha) \right)}{\text{MAX} \left( \sigma_M^0(\alpha) \right)}
\]

(2)

Where \( \sigma_M'(\alpha) \) and \( \sigma_M^0(\alpha) \) is RMS value of base moment or torque for interfered and isolated building respectively.

3.1 Static interference effects
Fig. 3 (a) ~ (c) show mean base moment and torque in different wind direction. Table 1 gives the static interference factor. It’s notable that mean base torque of tower 2 reaches a maximum value in the direction of 110 degree, where the corresponding static interference factor is 1.53, which means that interfered by tower 1 and 3 the maximum static torsion of tower 2 increase by more than 50%. From the CFD simulation results shown in Fig.5, it can be seen that, unlike isolated buildings, wind pressure in the windward face of tower 2 is partially negative, which may result in large unsymmetrical torsional force.

3.2 Dynamic interference effects
Dynamic base moments are calculated by stochastic method. It can be seen from Figure 6 although the geometric and structural parameters are exactly the same, maximum responses of tower 2 are larger than that of tower 3.

Table 2 gives the dynamic interference factors. It can be seen from the table that all dynamic interference factors are greater than 1. It indicates that the interfered dynamic responses are to some extent amplified. Especially, in the wind direction of 110 degree, the dynamic interference factor of tower 2 in Y and torsion direction is 1.32 and 1.37 respectively. The pressure power spectra on each facade of tower 2 show obvious vortex peaks. Vortex excitation may result in larger dynamic interference factor as compared with tower 3.
Figure 7 shows the power spectrum of wind pressure in 110 degrees. It’s evident that for the tower 2 wind pressure spectrum on each facade show distinguished spectral peak corresponding to vortex shedding and for tower 3 and isolated building the vortex shedding effects are weaken and spectrum peak are relatively not obvious.

![Figure 7](image)

**Fig.3 Mean value of base moments and torque**

**Tab.1 Static interference factor**

<table>
<thead>
<tr>
<th>Base moments or torque</th>
<th>Isolated building</th>
<th>Tower 3</th>
<th>Tower 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum value(KN.m)</td>
<td>Azimuth</td>
<td>Maximum value(KN.m)</td>
</tr>
<tr>
<td>$M_x$</td>
<td>$-2.5 \times 10^8$</td>
<td>300°</td>
<td>$-2.32 \times 10^8$</td>
</tr>
<tr>
<td>$M_y$</td>
<td>$-8.0 \times 10^7$</td>
<td>210°</td>
<td>$-9.6 \times 10^7$</td>
</tr>
<tr>
<td>$M_t$</td>
<td>$-8.8 \times 10^4$</td>
<td>0°</td>
<td>$-8.36 \times 10^4$</td>
</tr>
</tbody>
</table>

![Fig.4 Mean value of wind pressure coefficient on typical floor (110° wind degree)](image)

![Fig.5 CFD simulated wind field (110° wind degree)](image)
4 CONCLUSION

Based on wind tunnel experiment, along-wind, across-wind and torsional load interference effects are discussed in this paper. CFD analysis method is used to figure out interference mechanism. The results show that wind direction and tower location are important factors that influence the interference effect. Tower 2, located in the middle of the staggered group, have much larger interference factor than that of tower 3. In the most unfavorable interference angle of 110 degree, the torsion static interference factor reached 1.53, the dynamic interference factor in weak lateral axis and torsional direction is 1.32 and 1.37 respectively.
5 ACKNOWLEDGEMENTS
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