Numerical Simulations of Wind-induced Mean Interference Effects between Two Low-rise Buildings with Gable Roof

Shi Gan, Gang Li and Yongxin Li

ABSTRACT

In this study, numerical computations for wind pressure of low-rise buildings were conducted in order to investigate wind-induced mean interference effects between the buildings. The primary purpose is to make clear the characteristics of wind pressure distribution on low-rise gable roof building considering interference effects, so as to put forward practical wind-resistant design method and measures. Various ranges of arrangement modes, arrangement distances and wind direction angles were considered based on the numerical simulation method which was verified by wind tunnel test. Results showed that there are the most obvious wind-induced mean interference effects on cornice of interfered building for two same low-rise building. As for the arrangement of low-rise buildings, the tandem arrangement is largest, followed by staggered arrangement and less is parallel arrangement.¹

INTRODUCTION

Wind-induced interference effect refers to the engineering structures probably acts to changing forces or surface pressure due to surrounding structures under winds. The pressure distribution is associated with the flow patterns, building outside shapes, surrounding environments and structures, and so on. Most researches have focused on isolated low-rise buildings and there is a well understanding of the mechanism of the distribution of pressure on them. The resurrection of interference effect studies occurred in 1970s due to eight

¹Gan Shi, Gang Li, Yong-xin Li, Dalian University of Technology, Dalian, Liaoning, China 116023
natural draft cooling towers in England affected by wind-induced interference effects[1].

In this study, a Reynolds Stress Model (RSM turbulent model) as a numerical simulation method is selected and validated to be an feasible method by comparing with results of wind tunnel test of TJ-2. Then, the numerical simulation method was selected to analyze the interference effects between two low-rise buildings considering full effective factors including arrangement modes, arrangement distances and wind direction angles. Finally, the quantitative interference coefficient of wind pressure is presented for actual engineering design.

NUMERICAL SIMULATION AND VERIFICATION

This study uses CFD software FLUENT and several user-defined functions (UFD) to calculate the pressure on buildings. The turbulent wind flow around buildings is modeled by employing the Reynolds Averaged Navier-Stokes (RANS) equations of motion, in which the Reynolds stresses turbulent model[2] is adopted.

The area mean pressure coefficient is defined as $C_{p,\text{mean}} = \frac{1}{A} \frac{1}{\rho_g V_r^2} \int_A p dA$, where $p$ is the area mean pressure calculated by software, $\rho_g$ is the density of air, and $V_r$ is the speed of the reference elevation. Worst pressure coefficient is minimal mean wind pressure coefficient under seven different wind directions, defined as $C_{p,\text{min}} = \min(C_{p,\text{mean}})$. Interference factors (IF) of worst pressure coefficient was induced to evaluate the interference effects, defined as $IF = \frac{C_{p,\text{min}}}{C_{p,\text{isolated}}}$, where $C_{p,\text{min}}$ is the worst pressure coefficient of building affected by interference effect, and $C_{p,\text{isolated}}$ is the worst pressure coefficient of isolated building. The interference factor (IF) reflect the influence on interfered building from interfering building, when $IF>1$ the wind pressure on the roof of interfered building is amplified and $0<IF<1$ indicates that the wind pressure on the roof is reduced.

Wind pressure coefficient on the isolated building calculated by numerical simulation is compared with the wind tunnel experiment (TJ-2) results completed by Gu[3], of which the model with length scale of 1/30 has a same dimensions with the model in numerical simulation as shown in Fig. 1. The low-rise building model with roof pitch of 30° and 1m long eave has dimensions of 7m wide, 10.5m long, the eave height of which is 7m.

The mean wind pressures coefficients of divided partitions under three wind directions of TJ-2 building are compared with which of numerical simulation, as shown in Fig. 2. Although there are some error between numerical simulation results and TJ2 results in some zones, the pressure coefficients in most zones between the two results are approximate. From the plot, it can be concluded that there is a reasonable match between results from the numerical simulation and TJ2 wind tunnel.
INTERFERENCE EFFECT ON TWO LOW-RISE BUILDINGS

Arrangement of Two Low-rise Buildings

This paper study the interference effects between two buildings with dimension as shown in Fig. 1 by changing the relative position between the buildings. The roof of the building is partitioned in different zone to express the change of pressure of roof corner caused by interference effect, shown in Fig. 3. The arrangements of buildings are shown in Fig. 4. $L_x$ is defined as $L_x = \frac{D_x}{D}$, where $D_x$ is the distance between centers of each building in x direction and $D$ is the width of the buildings, and $L_y$ is defined as $L_y = \frac{D_y}{B}$, where $D_y$ is the distance between centers of each buildings in y direction and $B$ is the length of the building. In this study three kinds of arrangement of two buildings are analyzed, including tandem arrangement ($L_x=0$), parallel arrangement ($L_y=0$), and staggered arrangement ($L_x=\frac{L_y}{2}$). For each arrangement, the interference effect of two buildings is studied in four different spacing ratios (1.5, 2.0, 2.5, 3.0) for seven different wind directions, $\theta = 0^\circ, 15^\circ, 30^\circ, 45^\circ, 60^\circ, 75^\circ, 90^\circ$. 
Analysis of Wind-induced Interference Effects Between Two Low-rise Buildings

Figure 3. The partition of the roof.  
Figure 4. Arrangement of building model.

Figure 5. $C_{p,min}$ and interference factor on each partition in staggered arrangement.
Fig. 5 shows the comparison of the worst wind pressure coefficients $C_{p, \text{min}}$ and interference factors (IF) on each partition in different arrangements. For the tandem arrangement, the worst pressure coefficients of most partitions of interfered building are less than that of the isolated buildings, and only the pressure coefficients of minority partitions of interfered building increase around 20%, which means shielding effect is dominant performance of interference effect of interfering building. In parallel arrangement, the interference effect of A partitions show the amplification effect, which is induced by the ‘slot effect’ act most significantly when the spacing ratio is 1.5. The wind pressure of B5 and B3 partitions decreased significantly, both of which reduce to about 70% of pressure of isolated building, so the interference effect of area B act in the reduce effect. From the figure of the variation range of the interference factor, the interference effect of roof A is greater than the roof B in the staggered arrangement, and it is still significant when spacing is small between two buildings, and the interference effect will be weaker with the spacing ratio greater.

Contrast of Interference Effects in Different Arrangements

Fig. 6 shows the comparison of interference factors (IF) of each partition of interfered building in staggered, tandem and parallel arrangements when the spacing ratio is 1.5. In tandem arrangement, the interfered building is mainly affected by the ‘shielding effect’, and the wind pressures in most partitions have suffered different degrees of decrease, especially in the windward roof edge (A1, A4, B1 and B4 partitions), of which largest reduction is more than 70%. However the wind pressure of A2 and A3 partitions comparing with isolated building increase by 14.7% and 25.8%, as shown in Fig. 6(a). For the parallel arrangement, the interfered building is mainly affected by the "slot effect", as Fig. 6(b) shown, the wind pressures of all
TABLE I. THE VALUE OF INTERFERENCE COEFFICIENT.

<table>
<thead>
<tr>
<th>Arrangement</th>
<th>Partitions</th>
<th>Spacing ratio</th>
<th>IF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tandem arrangement (&lt;i&gt;Lx&lt;/i&gt;=0)</td>
<td>A2, A3, B2, B3</td>
<td>Ly=1.5</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ly=2.0</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ly=2.5</td>
<td>1.1</td>
</tr>
<tr>
<td>Parallel arrangement (&lt;i&gt;Ly&lt;/i&gt;=0)</td>
<td>All Partitions</td>
<td>Lx=1.5</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lx=2.0</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lx=2.5</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lx=3.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Staggered arrangement (&lt;i&gt;Lx&lt;/i&gt;=&lt;i&gt;Ly&lt;/i&gt;)</td>
<td>A2, A5, B2, B5</td>
<td>Lx= Ly=1.5</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lx= Ly=2.0</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lx= Ly=2.5</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lx= Ly=3.0</td>
<td>1.1</td>
</tr>
</tbody>
</table>

(Linear interpolation can be used in the middle value)

partitions appear overall growth on roof A, where the pressure of A2 partition have increased by 73.9%. According to Fig. 6(c), for the staggered arrangement, influenced by clearance flow and wake flow, only the wind pressure of the central windward roof has a large growth, and the maximal growth of pressure could be reached 35.7% on the edge of roof (A2). Thus, for the three kinds of arrangement, the windward eave is most vulnerable to interference effect, and the amplification effect on the roof of interfered building is most obvious in tandem arrangement, followed by staggered arrangement, and less obvious in parallel arrangement.

According the prior results, to correct the pressure coefficients of isolated building which underestimate the pressure on the roof under interference effect, the interference factors (IF) of partitions where the amplification effect shows at three arrangement are given, in order to provide a reference of designing similar building. The values are shown in TABLE I.
CONCLUSIONS

Systematic wind pressure numerical simulations were conducted in order to investigate wind-induced mean interference effects between low-rise buildings. Conclusions of the results of the numerical simulation can be summarized as follows:

(1) For two low-rise gable roof buildings with same shape, interference effects on the roof of interfered building in tandem arrangement increase and are most obvious, followed by staggered arrangement, and less obvious in parallel arrangement. When spacing ratio is small, amplification of interference effects is the most obvious, and gradually decreases with the increase of the spacing ratio.

(2) In three arrangements, there are the most obvious wind-induced mean interference effects on corner of interfered building, and wind pressure of the parts of parallel arrangement can increase to 73.9%. Therefore, in order to consider the amplification of the interference effect, quantitative interference factors are given for wind-resistant design of same building.

ACKNOWLEDGEMENT

This work was financially supported by the National Key Technology R&D Program (2014BAL05B03).

REFERENCES