Interference effects of wind loads on a row of tall buildings

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ABSTRACT: We apply CFD to visualize wind flow around a row of three square-plan tall buildings closely arranged in a row. Increase in wind load on the upwind building is observed when wind blows to the row at 30°. CFD results show that the interference mechanism is mainly due by strong channeling of wind flow through the building gaps. This leads to highly negative pressures on building walls facing a gap.

KEYWORDS: High-rise buildings, wind forces, wind pressure, interference, CFD.

1 INTRODUCTION

When two or more buildings are placed in close proximity, flow interference occurs and wind loads on each building are modified from its isolated single building situation. Interference effects on two tall buildings in proximity have been reported extensively in the literature [1] but there are few studied on interference in a group of closely-spaced tall buildings. The authors’ group has been investigating wind loading of a row of identical tall buildings [2]. We found that when wind blows at an oblique angle to the building row, the upwind building experiences increased wind loads in direction along the row as compared to the isolated single building case. Some other interference effects are found for other building members as well. In this paper, we use computational fluid dynamics (CFD) to compute wind flow around a row of three buildings at wind angle θ = 30°. Wind flow pattern around the buildings closely spaced at separation S/B = 1/4 is visualized to explore mechanism of interference effects.

2 NUMERICAL SCHEME

Flow computation was carried using the finite volume code FLUENT (Fluent, Inc.). We chose the SIMPLEC algorithm for pressure-velocity coupling and the QUICK scheme for modelling convective transport. Steady solution on full three-dimensional turbulent wind flow was sought. Re-Normalization Group (RNG) k-ε model was used for turbulence scheme due to its better ability to model flows with sharply curving streamlines [3]. The computational domain was 6 m long, 3 m wide and 1.8 m tall. This corresponded to a section of our wind tunnel [2]. Along-wind, across-wind and vertical edges of the domain were divided into 136, 96 and 80 grid points, respectively. Three buildings, square in plan with breadth B = 0.1 m and height H = 0.5 m, was placed in a row with a clear spacing between buildings at S = B/4. An upwind fetch of 1.5 m from center of the building row was used. Each building wall was modelled by 40×20 meshes and there were 12 grid points across the width of each building gap. To model wind flow at 30° to the row, the buildings were obliquely placed in the computational domain. There was a region surrounding the buildings meshed with fine rectangular elements. The mesh then transformed to the edges of the domain with trapezoidal elements. Fig. 1 shows the mesh
on a horizontal plane in region around the buildings. The computational domain was digitized into \(2.1 \times 10^6\) finite volumes.

![Figure 1. Computational mesh on typical horizontal plane.](image)

For the boundary conditions, the top and two vertical sides of the computation domain were made symmetry boundary condition. The ground and all building walls were modelled as a solid wall with aerodynamic roughness length, respectively at \(z_o = 0.125\) cm and 0.05 cm (in wind tunnel scale). At the inlet face to the computational domain, both mean wind velocity and turbulence intensity varied with height following the power-law profile. The power exponent was 0.15 and \(-0.15\), respectively. We chose these characteristics of wind over a sub-urban terrain because rows of tall buildings are commonly found in sub-urban residential areas as well as along a coastline or harbor front in rather exposed sites. Gradient height was set at 1.5 m, above which wind speed stayed constant at 14.7 m/s and turbulence intensity constant at \(\sigma_u/U = 0.095\). Wind speed at roof height was \(U_H = 12.5\) m/s and Reynolds number was \(U_B/\nu = 8.3 \times 10^4\). For turbulence boundary conditions, turbulent kinetic energy, \(k = 0.5(\sigma_u^2 + \sigma_v^2 + \sigma_w^2)\), was obtained from the along-wind turbulence intensity and assuming \(\sigma_v, \sigma_w\) respectively at 0.7 and 0.5 times the along-wind \(\sigma_u\) value (\(\sigma\) being standard deviation of velocity fluctuations). Turbulence dissipation rate \(\varepsilon\) was calculated from \(\varepsilon = C_\mu 3/4k^{3/2}/0.4z\) with model constant \(C_\mu = 0.0845\).

3 RESULTS AND DISCUSSIONS

Fig. 2 shows the computed wind flow pattern around the buildings on the horizontal plane at building mid-height. Mean pressure on the building walls is shown in Fig. 3 as pressure coefficients, \(C_p = p/(\frac{1}{2}\rho U_H^2)\). With the buildings so close together, wind flows around the buildings as if they were a single body and the wake behind the row is like a single body wake. Wind hits mostly on the front wall of the first building leading to large positive wind pressure at \(C_p \approx 0.5\) to 0.9 over large parts of the wall. Along the windward side of the row, wind blows mainly parallel to \(y\)-walls of all three buildings. Low-level positive pressure is induced on these walls at \(C_p \approx 0.3\) to 0.4. On
the other side of the row, all \( y^+ \) walls and the rear wall of the last building are in the single-body wake. These walls are all under low-level negative pressure \( C_p \approx -0.3 \). The most important interference effect in Fig. 2 is the high-speed wind flow sweeping through the two building gaps. The flow is driven by the pressure difference between the windward side of the building row and the leeward side. Building walls facing the gaps are under highly negative pressure at \( C_p \approx -0.9 \) to \(-0.5\) over large parts of the walls.

Figure 2. Computed velocity vectors on horizontal plane at \( z = H/2 \).

Figure 3. Computed pressure coefficients on building walls.
Table 1 compares the wall-averaged mean pressure coefficients on building walls among the
three buildings and an isolated single building. We have not completed CFD study on the later
case \( \theta = 30^\circ \) and the values in Table 1 are estimated from relevant building walls of the first and
last building. Force coefficients on the body forces, \( F_x, F_y \), are shown and the values agree rea-
sonably well with base-balance measurements on a row of five buildings in Lam & To [2].

Table 1. Wall-averaged pressure coefficients and force coefficients

<table>
<thead>
<tr>
<th>Building</th>
<th>Average ( C_p ) on wall</th>
<th>( C_{px} )</th>
<th>Average ( C_p ) on wall</th>
<th>( C_{py} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Front</td>
<td>Rear</td>
<td>CFD</td>
<td>[2]</td>
</tr>
<tr>
<td>1st</td>
<td>0.61</td>
<td>-0.67</td>
<td>1.27</td>
<td>1.22</td>
</tr>
<tr>
<td>2nd</td>
<td>-0.50</td>
<td>-0.61</td>
<td>0.11</td>
<td>0.17</td>
</tr>
<tr>
<td>last</td>
<td>-0.46</td>
<td>-0.32</td>
<td>0.14</td>
<td>-0.07</td>
</tr>
<tr>
<td>(single)</td>
<td>0.61</td>
<td>-0.32</td>
<td>0.93</td>
<td>0.95</td>
</tr>
</tbody>
</table>

For the last building, shear force \( F_y \) is negative, that is acting upwind. This is because its up-
wind wall is facing a building gap and is under highly negative pressure. Its downwind wall is in
the wake and is under less negative pressure (Table 1).

The other shear force \( F_y \) acts in direction perpendicular to the building row and lower levels
of wind load modification occurs when compared to \( F_x \). The second and last buildings are under
slightly smaller \( F_y \) than the first building. Their \( y^- \) walls are under lower positive pressure because
wind flow almost parallel to them. Their \( y^+ \) walls are in the wake and are under less negative pressure
that the wall of the first building which is under suction from flow separation from the corner
of the building row.

4 CONCLUSIONS

This paper reports CFD results of wind flow patterns around a row of buildings at wind angle \( \theta \)
= 30\(^\circ\). They show that strong channeling of wind flow through the building gaps occurs as a re-
result of the close proximity of buildings. This leads to highly negative pressures on building
walls facing a gap. For the upwind edge building in the row, this much higher suction on its
leeward wall leads to increase in wind load components acting along direction of the row. The
CFD results serve to explain interference phenomena observed in wind tunnel tests.

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