CFD Prediction of Wind Environment around a High-rise Building Located in an Urban Area

Ryuichiro Yoshie\textsuperscript{a} Akashi Mochida\textsuperscript{b} Yoshihide Tominaga\textsuperscript{c}
Hiroto Kataoka\textsuperscript{d} Masaru Yoshikawa\textsuperscript{e}

\textsuperscript{a} Tokyo Polytechnic University, Iiyama 1583, Atsugi-City, Kanagawa, Japan
\textsuperscript{b} Tohoku University, Aoba 06, Aramaki, Aoba-ku, Sendai-City, Miyagi, Japan
\textsuperscript{c} Niigata Institute of Technology, Fujihashi 1719, Kashiwazaki-City, Niigata, Japan
\textsuperscript{d} Technical Research Institute, Obayashi Corp., Shimokiyoto 4-640, Kiyose-City, Tokyo, Japan
\textsuperscript{e} Niigata Institute of Technology, Fujihashi 1719, Kashiwazaki-City, Niigata, Japan

ABSTRACT: Flow-field around a high-rise building surrounded by low-rise urban blocks in a turbulent boundary layer was calculated, and the results were compared with those of the wind tunnel experiments conducted by the present authors. In the strong wind region, the calculated wind speeds with standard k-\(\varepsilon\) model were somewhat lower than the experimental results, while this was improved by using revised k-\(\varepsilon\) models. Influence of various calculation conditions on CFD results was also investigated. This paper focuses on the influence of reproduction range of the surrounding urban blocks on the flow-field around the high-rise building and the profile of the turbulent boundary layer.

KEYWORDS: Pedestrian wind environment, CFD, Urban block,

1 INTRODUCTION
Progress in high-speed processing by personal computer and rapid propagation of software for numerical analysis of fluid dynamics in recent years have enabled prediction of the pedestrian wind environment around high-rise buildings based on CFD (Computational Fluid Dynamics). However, prediction accuracy of CFD simulations and influence of various calculation conditions on the CFD results have not yet been thoroughly understood.

Thus, a working group named “Working Group for Preparation of Wind Environment Evaluation Guideline based on CFD” was organized by the Architectural Institute of Japan. Since its inception, this group has been working continuously to prepare a guideline for proper use of CFD for calculation of the wind environment. Comparative and parametric studies have been carried out on several building configurations to elucidate the problems on setting or selecting calculation conditions and turbulence models. [1-4].

The present article introduces one of the results (flow-field around a high-rise building located in a city) and discusses influence of reproduction range of the surrounding urban blocks on the flow-field around the high-rise building and the profile of the turbulent boundary layer.

2 OUTLINES OF WIND TUNNEL EXPERIMENT
The flow-field analyzed here is that around a high-rise building in a simple urban area, for which the wind tunnel experiment was carried at the Niigata Institute of Technology. The low-rise urban block was assumed to be 40m square and 10m high as shown in Figure 1 (simulating a condition where low-rise houses are densely jammed), with a high-rise building 25m square and 100m high (1:1:4) in a block at the center of this area. One urban block is assumed to be enclosed by two roads (each 10m wide) and roads 20m and 30m wide.
The wind velocity measuring points are shown in Figure 2. The scale of the experimental model was 1/400 and the measuring height was 5mm above the floor of the wind tunnel (2m above ground in real scale). Wind speed was measured using a split film probe.

Figure 1. Outline of wind tunnel experiment

Figure 2. Measuring points

3 OUTLINES OF CFD CALCULATION
In the working group, the conditions shown in Table 1 and Figures 3 were given as the standard calculation conditions for the comparative studies. In addition to the standard calculation conditions, we investigated the influence on the calculation results of changing the boundary conditions, the computational domain, the grid resolution, and the turbulence models, etc.

<table>
<thead>
<tr>
<th>Table 1. Standard Calculation conditions  (Calculation was carried out in experimental scale.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computational Domain</td>
</tr>
<tr>
<td>Grid resolution</td>
</tr>
<tr>
<td>Scheme for advection term</td>
</tr>
<tr>
<td>Building wall and ground surface</td>
</tr>
<tr>
<td>Upper and side surface of computational domain</td>
</tr>
<tr>
<td>Turbulence model</td>
</tr>
<tr>
<td>Inflow boundary condition</td>
</tr>
<tr>
<td>Outflow boundary condition</td>
</tr>
</tbody>
</table>

※High-rise building was divided into $12(x) \times 12(y) \times 27(z)$

Figure 3. Computational domain and grid resolution for standard calculation conditions
4 RESULTS OF EXPERIMENT AND CALCULATION

4.1 Comparison of experimental results with CFD results

The calculation results based on the standard calculation conditions and the experimental results are compared in Figure 4. The wind speed ratio between the scalar wind velocity at each measuring point and \( U_H \) (inflow wind speed at the height of the central high-rise building) is represented on the ordinate. In strong wind region such as measuring points 35, 38, 44, the calculation results were ten or so % lower than the experimental results. However this was improved by using modified \( k-\varepsilon \) models [4].

Figure 4. Comparison between CFD and experiment (Wind direction = 0°)

4.2 Influence of reproduction range of surrounding urban blocks

Figure 6 shows the results of calculation with two rows and three rows each deleted from the peripheral region of the surrounding urban blocks, as shown in Figure 5. The difference from the standard case was very small except at measuring points 1, 2, 3 and 4 on the roads on the windward side. Figure 7 shows the vertical profiles of wind velocity \( U \) for the three cases. The inflow velocity profiles upper than the high-rise building (the height of the high-rise building is 0.25m) are maintained from the inflow boundary (point A in Fig.7) to the outflow boundary (point J in Fig.7) regardless of the reproduction range of surrounding urban blocks. And there are almost no differences in the three cases of the wind velocities higher than twice the height of the low-rise surrounding urban blocks (the height of the low-rise urban block is 0.025m). At the point D which is behind the urban block the vertical profiles of the wind velocities for the standard case and for the case of deleting two rows are almost the same even in the region near the floor. Also, at the point E, F and G which are behind the urban blocks or the high-rise building, much difference can not be seen among the three cases regardless of the reproduction range of surrounding urban blocks. Therefore it is concluded that pedestrian wind in urban blocks is almost determined by the blocks near the target area. Two or more surrounding urban blocks each of several tens of meters around the region to be evaluated would be satisfactory for practical application.
5 CONCLUSIONS
According to the results of the present study, the influence on the calculation results of the computational domain, the grid resolution, and the reproduction range of the surrounding urban block is relatively low. In the strong wind region, the wind speed ratios of modified k-ε models agreed well with the experimental results compared with the standard k-ε model. Two or more urban blocks each of several tens of meters should be reproduced in the area surrounding the region to be evaluated.

6 REFERENCES

2 Tominaga, Y., Mochida, A., Murakami, S. (2003), Large Eddy Simulation of Flowfield around a High-rise Building, 11th International Conference on Wind engineering, B10-5.