Numerical Simulation of Pedestrian Level Winds around Tall Buildings*

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Abstract: A three-dimensional non-hydrostatic numerical model based on $k-\varepsilon$ turbulence closure has been used to simulate the pedestrian wind fields around the proposed tall buildings in Beijing. The model results are well agreed with those of the wind tunnel experiments. Since numerical model can provide the detailed flow field data, it has a great advantage compared with the wind tunnel experiment in accurately evaluating the wind effects on pedestrian. Furthermore, advance computational technology has made the numerical modeling become fast and cheap. It is believed that the numerical simulation will play an increasingly more important role in the coming years.

Key words: numerical model; pedestrian wind environment; wind tunnel
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1 Introduction

It is well known that the existence of one or a group of tall buildings may change the flow field, and it has adverse influence on the comfort of pedestrians. Production of corner vortex shedding, horseshoe vortex[1], and other wind effects are one of the important reasons for the occurrence of the areas of high wind velocity and turbulences. Pedestrian comfort ability is often an important design parameter to be considered by the building owner and architect.

It has developed rapidly in the latest decade that the method of calculating flow around blunt body in computational fluid dynamics (CFD) applied to simulation of flow around buildings in the atmospheric boundary layer[2-3]. Traditionally, the evaluation of wind environment relies heavily on wind tunnel experiment. However, CFD and the computer capability have been developed so fast in recent years that numerical simulation can now be made more economically and yield more complete and accurate results. For an example, where as wind tunnel experiment can only give wind velocity data at limited number of points, the numerical model can give complete contour lines of velocity and turbulence level[4].

In this paper, non-hydrostatic equations based on $k-\varepsilon$ turbulence closure are used for simulating the flow field around the proposed tall buildings in Beijing. Comparisons are examined between numerical simulations and the wind tunnel results.

2 Numerical models

2.1 Equations, boundary and initial conditions

In the numerical simulation, the atmosphere is assumed to be neutral without thermal effects, so the thermodynamic equation is neglected. The Navier-Stokes equation is Reynolds-averaged in which variables are split into mean and fluctuating components. The turbulent kinetic energy and its dissipation rate are the outputs of the modified model[5]. The properties are fixed constants at the inflow boundary, while in the open-ended boundaries the gradient continuity conditions are adopted. The initial wind profile is described by power law $u_{(z)} = u_{10}\,(z/10)^p$, where u_{10} is the wind speed at 10m above the ground, $p = 0.26$ under the neutral condition.

2.2 Computational domain

The proposed tall buildings in Beijing mainly are

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composed of Building A, B and C with the height of 71m, 71m, and 6m respectively. There are some existing buildings (D ~ I, heights 40 ~ 80m, see Fig. 1) surrounding A, B and C. The computational domain is 300 m × 500 m × 200 m with even grid mesh of 2 m. The total grid numbers is 151×251×101.

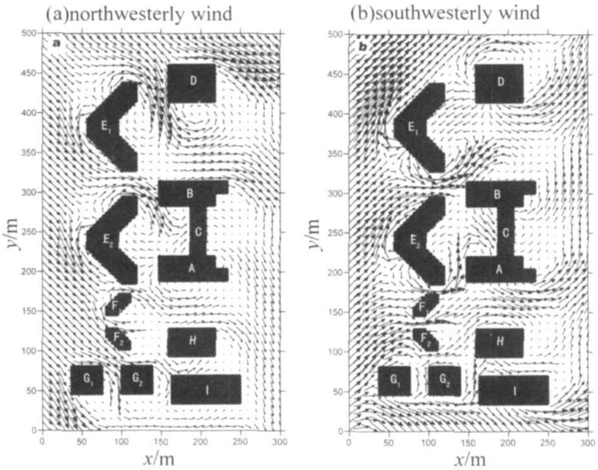

Fig. 1 Flow field at 2 m above ground.

3 Wind effects on pedestrian

In general, the evaluation of wind effects on pedestrian is based on two factors: wind speed and frequency. The wind speed directly affects the comfort level of pedestrian. The Beaufort Scale[6] gives a classification of the wind speed effect on pedestrian, and the wind speed is averaged over 10 min at 10m above the ground. Recently, wind tunnel experiments show that the wind speed should include the effect of wind gust. The effective peak gust u_{pk} can be expressed as $u_{pk} = u_m + g u_{ms}$, where u_m is the time averaged wind speed, u_{ms} the wind turbulence intensity, the gust factor $g \in [1, 3]$. The dimensionless form of u_{pk} is defined as $R = u_{pk}/u_{10} = u_m/u_{10} + g u_{ms}/u_{10}$.

The other factor of the wind effect on pedestrian is the occurrence frequency of such wind. The criterion of wind frequency effect on the pedestrian comport level may vary with different person in different regions. However, many researchers proposed similarly general criteria, which can be used as a standard. In this study, according to the situation considered, Davenport's criteria are adopted[7]. It is also different for the criteria of the wind effect on different pedestrian activities (such as sitting, standing and walking) in the region.

4 Numerical simulation results

We calculate the flow fields and compare the results with those of the wind tunnel experiments under northwesterly and southwesterly wind.

When the wind is northwesterly, flow field (Fig. 1a) can be divided into three flow patterns: wind channeling flow, corner flow and lee side vortices. Increased velocity due to the wind channel effect between two large buildings (such as Building D and E_1, E_2 and B) is clearly seen. Corner flow mainly occurs at the upper corners of the buildings, namely Building D′s and B′s northeastern corners. The buildings result in a higher mean wind velocity. Vortices are usually located behind buildings. Two clear vortices and a weak vortex appear behind Building D and B respectively. In the vortex area the wind velocity is lower, while the turbulence intensity is usually higher due to vortex shedding from the corner. An interesting phenomenon should be noted. Because northwesterly wind blows against the broad side of Building E_1 and E_2, it generates a strong vortex. This is the reason why the wind in front of Building E_1 and E_2 at the pedestrian level is blowing downward and away from the buildings, contrary to common expectation. These detailed flow field information are difficult to obtain with wind tunnel experiments because they require measurements at many points for long time periods.

Although the above flow characteristics for northwesterly wind also occurs for southwesterly wind (Fig. 1b), the locations of corner flow, wind channel effect flow, lee side vortices and the strength of velocity are clearly changed.

Dimensionless peak gusts are shown in Fig. 2. According to Cocharan et al (1993)[8], the value displayed in Fig. 2 should not exceed 1.15 ~ 1.20 for pedestrian comfort. This value is only slightly exceeded in a small location near the proposed new buildings A, B and C, but in many locations around the existing buildings the dimensionless peak gust exceed this value. Therefore, some improvements should be considered in the future development.

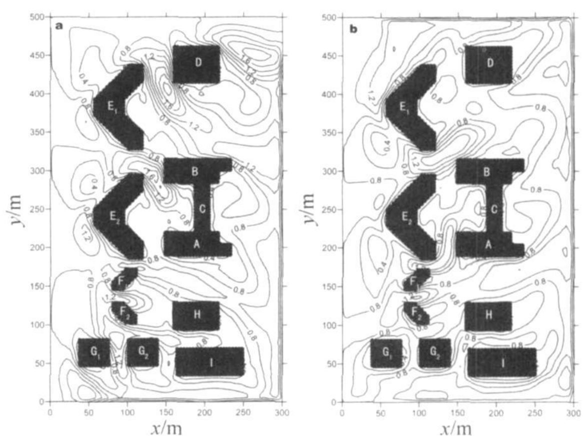

Fig. 2 Wind speed ratio at 2m above ground.
a: northwesterly wind; b: southwesterly wind

5 Comparison with the results of the wind tunnel experiments

The wind tunnel experiments were carried out in the boundary layer wind tunnel in Peking University. Pedestrian wind conditions were measured by thermal anemometer. The diagrammatic sketch is shown in Fig. 3. The sampling points are located at the level of 10mm above the ground or roof of Building C. A good agreement between computed and wind tunnel results can be identified (Fig. 4). The correlation coefficients are 0.75 for northwesterly wind and 0.84 for southwesterly wind. This reveals that this model is capable of simulating flow field in urban area.

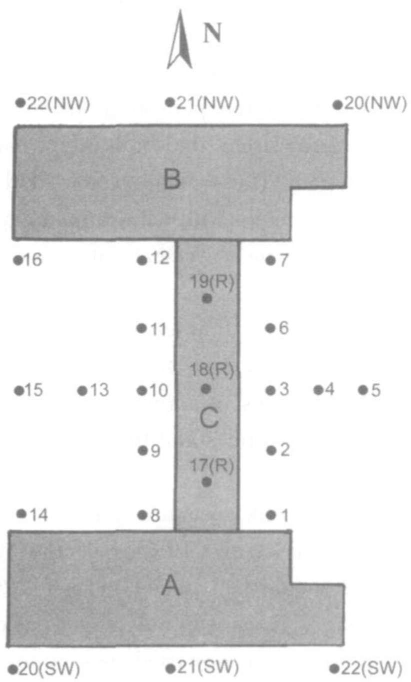

Fig. 3 Diagrammatic sketch of pedestrian level wind conditions measurement in the wind tunnel

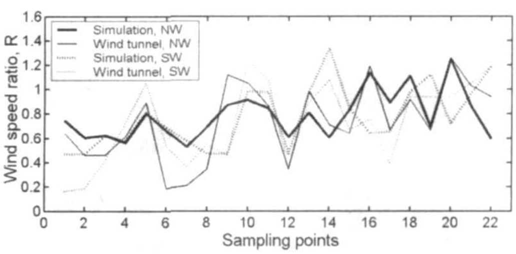

Fig. 4 Comparison of wind speed ratio R between numerical simulation and the wind tunnel experiments

6 Conclusions

The pedestrian wind environment around proposed tall buildings in Beijing for the northwesterly wind and the southwesterly wind has been carefully investigated using numerical model based on incompressible equations. The results of this model are well agreed with those of the wind tunnel experiments. Numerical model has a great advantage over wind tunnel test to accurately evaluate the wind effects on pedestrian and other environmental issues since it can provide the detailed flow field data at every location. Furthermore, advanced computing technology has made the numerical modeling become fast and cheap. It is believed that numerical model is a more economical and fast tool to evaluate urban wind environment.

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Dynamic Analysis of the Wetland Resource Changes in the Estuary of the Pearl River Delta Using Remote Sensing

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Abstract: The Pearl River Estuary wetland in the developed region was selected as the studying object in this thesis. The integrated approach including the remote sensing and geography information system (GIS), the field survey and collecting history data was adopted to analyze the spatio-temporal evolution in recent twenty years. In the wetland classification of east and west shore of inner Lingding ocean, taking ERDAS software as the flat roof, gradation and classification method based-on knowledge were adopted. The main conclusions were summed up as following: (1) It is a great advantage to study the wetland landscape evolution using remote sensing and GIS in the regional scale of the Pearl River Estuary. The gradation and classification method based-on knowledge can overcome the shortage of human-computer alternation translation with eyes, realize the goal of classification for great region and the more temporal images, and also fulfill the landscape mapping. In this paper, the total classification resolution reaches 85 percent, the coefficient of kappa exceeds 0.8. (2) The results indicated that the areas of wetlands reduced 12270 hm^2 during the period of 1988 to 2004. The proportion of wetland accounting for the research area descended from 43.4 percent in 1988 to 40 percent in 2004. The land use conversion matrix analysis indicated that 91.92 percent tidal flat, 80.43 percent dike-pond, 62.21 percent mangrove forest, 54.63 percent reservoir, and 13.06 percent river transferred into other land utilization from 1988 to 2004.

Key words: wetland landscape; estuary wetland; remote sensing; Pearl River estuary

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高层建筑周围行人风环境数值模拟

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摘 要：采用基于 $k-\varepsilon$ 湍流闭合方法的数值模式对高层建筑周围行人风场进行模拟，与风洞实验结果吻合。数值模式能够在每一个计算格点和每一个时间段提供流场的详细信息，因而，在准确评价行人风环境或者其他风环境问题上比风洞实验更具优势。随着计算技术的提高，数值模拟已变得更为快速经济，并成为研究城市风环境的有效手段。

关键词：数值模式；行人风环境；风洞
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