Numerical Simulation on Wind Environment of the Square with High-Rises

Hong XIAO
College of Civil Engineering
Hunan City University
Yiyang, 413000, China
e-mail: 305860083@qq.com

Na WANG
Wind Tunnel Laboratory,
No. 203 Research Institute of China Ordnance Industries,
Xi'an, 710065, China
e-mail: 119944934@qq.com

Liang SUN
College of Mechanical and Electrical Engineering
Hunan City University
Yiyang, 413000, China
e-mail: 17597238@qq.com

Abstract: A SST turbulence model is applied to solve the Reynolds Averaged Navier-Stokes Equations in numerically simulating the 3D steady wind flow field around the square with high-rise buildings in atmospheric boundary layer. The aerodynamic prediction was supported by velocity data collected in field measurement of 240 points from an campus square. Then a detailed parametric study is performed on velocity distribution. The parameters include wind attack angle, green belt length and the distance between green belts. The analysis results show that numerical simulation is a feasible way to study the wind environment around square and the distributing of velocity. The green belts accelerates the air flow parallel to it. The effect of acceleration depends mainly on the distance between the green belts rather than the length of the green belts. When the wind is southeast or northwest, the maximums velocity in pedestrian height are between buildings. The curved green belts can improve the wind environment rather than linear green belts. The research provides a foundation for the wind resistance design of squares.

Key words: computational fluid dynamics, square, numerical simulation, high-rise, turbulence model

I. INTRODUCTION

With the development of the cities, the quantity of square increase rapidly. These squares have become the main sites of entertainment, communication and exercise for public. Squares always keep the densely populated state. City square, park square and campus square are generally arranged around a lot of high-rise buildings which change local flow field greatly. The strong wind causes the pedestrian level wind environment problem which makes the pedestrians very uncomfortable even blown down[1]-[3]. Moreover, strong winds may cause billboards and curtain wall damage. Thus ensuring the safety and comfort of the pedestrian become one of the major concerns for square designing and urban planning.

Field measurement is an basic and important method to study building wind environment. Although there have been many advances in wind tunnel testing, many critical phenomena can still only be investigated by full-scale experiments[4]-[6]. In recent years, computational methods have become more popular because they are less expensive and much faster compared to the field and wind tunnel experiments in most cases and they predict the parameters of interest with reasonable accuracy[7]-[10].These studies focus on the wind environment of individual buildings and buildings. However, the study of square wind environment is still very limited[11][12].

We carried out CFD method of estimating velocity in and around the square building. The results are compared with field measurement.

II. COMPUTATIONAL MODELS

A. *Geometry Model*

The study focuses on the square, high-rise building and green belts on the central axis considering other buildings and hills in the range of 300m (see Fig. 1). Fig. 1 also illustrates the wind attack angle and the serial number of the building. The height of the high-rise building is 28m. The area of the square is 60000m^2, including central garden (16900m^2). The south green belts appear to be 450 meters long and 5 meters wide. The distance between the south green belts is 18 meters. The north green belts are 250 meters long by 5 meters wide. The distance between the north green belts is 10 meters. Shrub green belts height are all 2 meters.The distance between the building and far field is 10L (L is the diameter of the garden square).

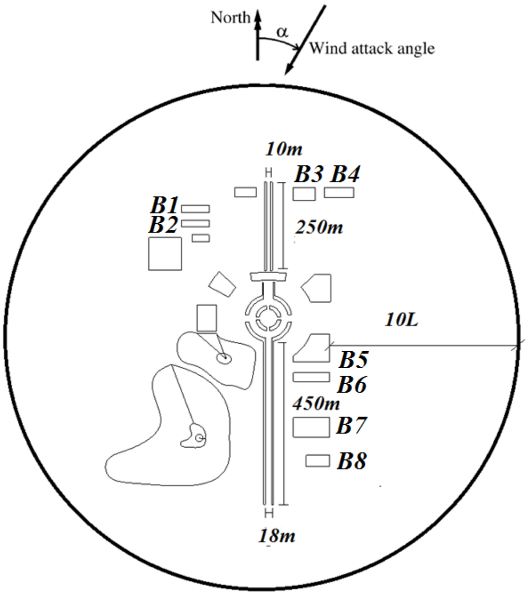
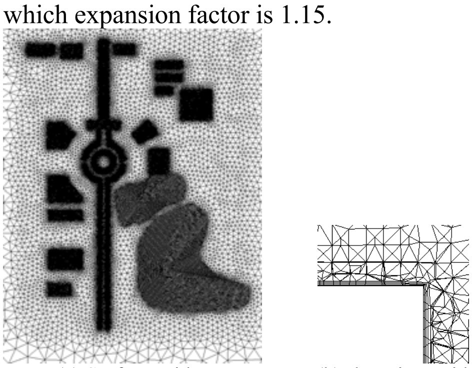


Figure 1. Geometry model

B. Computational Grids

The geometrically complex buildings are decomposed into 2.7 million of hybrid prism/tetrahedral elements by Octree method. Unstructured mesh triangles are used on the body surface, such as shown in Fig. 2(a). The forfeiture of orthogonality will influence the simulation accuracy of boundary layer. Therefore, the prism grids is a good choice in the boundary layer. The close-up views near buildings are shown in Fig. 2(b). There are 4 layer prism grids in which expansion factor is 1.15.



(a) Surface grids (b)The prism grids of boundary layer

Figure 2. Computational grid

C. Governing Equations and Numerical Algorithm

The three-dimensional compressible form of the Navier-Stokes equations can be written in generalized coordinates and conservation form:

$$\frac{\partial}{\partial t}\iiint_V \mathbf{Q}dV + \iint_{\partial V}(\mathbf{\Phi}(\hat{n}) - \mathbf{V}(\hat{n}))dS = 0 \quad (1)$$

where the vector **Q** represents the conserved variables; where the vectors **Φ** and **V** are the directed inviscid and viscous fluxes.

Using the implicit, finite-volume, upwind algorithm described in [13]. The no-slip, impermeable, and adiabatic wall boundary conditions were imposed in the present calculations.

The SST turbulence model is Standard k-ω near-wall region with the Standard k-ε in the far field.The SST turbulence model is more accurate and reliable for a wider class of flows than Standard k-ω, including adverse pressure gradient flows.

III. RESULTS AND DISCUSSION

A. Experimental Verification

Field measurement was carried out to study the velocity distribution of the square. There were 240 measuring points in and around the square. Fig. 3 provides the velocity comparable to field measurement and numerical simulation at freestream velocity 6m/s. A relatively good agreement between this SST numerical simulation and field measurement, furthermore, the differences are within 8%. It can be drawn the conclusion that the numerical model and simulation results are both reliable.

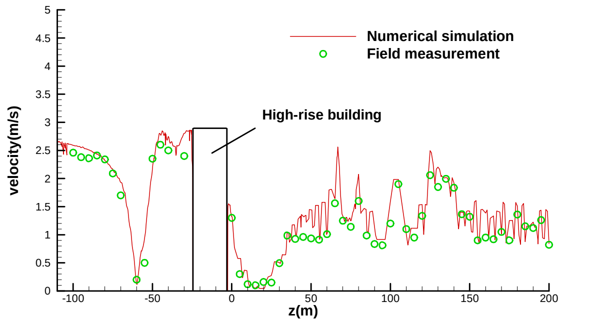


Figure 3. Wind profile at central axis at V_∞=6m/s

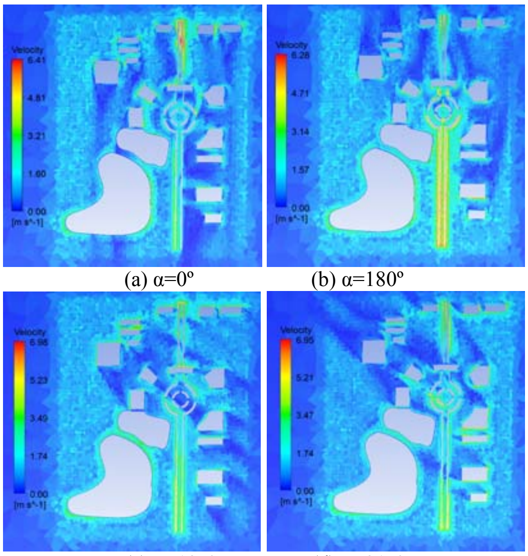
B. Parametric Analysis

In southern China the winds in winter are mainly from the Northwest and in summer mainly from the Southeast.Computations were carried out for wind attack angle α at 0, 135º, 180º and 315º. The freestream velocity was range from 6m/s (4 Beaufort scale) to 12m/s (6 Beaufort scale).

The simulation result demonstrates the influence of the length of green belts and the distance between green belts, and is illustrated in Table 1 and Fig. 4. It can be seen that the maximum velocity of pedestrian level greater than freestreem velocity. The green belts accelerates the air flow parallel to it. At α=0 (North wind), V_{max} appears between north green belts. Relatively, V_{max} appears between south green belts at α=180º (South wind). The effect of acceleration depends mainly on the distance between the green belts D rather than the length of the green belts L. The distance between the north green belts D_n is 10m, accordingly, the speed increase about 7%. However, speed only increase by 5% in the south green belts with D_S=18m. When the wind is southeast or the northwest, southeast or the northwest, V_{max} appears in narrow channel between the buildings such as B1-B2, B3-B4, B5-B6 and B7-B8. The pressure difference between the windward side and the leeside induces strong pressure gradient which make the flow speedup.

TABLE I. MAXIMUM VELOCITY OF PEDESTRIAN LEVEL AT DIFFERENT WIND ATTACK ANGLE

V_∞(m/s) V_∞ V_{max}(m/s) Y=1.5m	α=0	α=180º
6	6.41	6.28
10	10.66	10.49
12	12.98	12.61

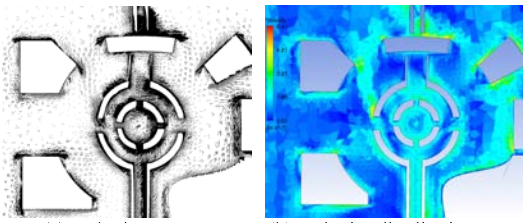


(a) α=0º (b) α=180º

(c) α=135º (d) α=315º

Figure 4. Velocity distributions in the cross section for y=1.5m

Fig. 5 shows the simulation result of velocity vector and velocity distribution in the square at y=1.5m. There are numerous and small scale eddies in the central garden. In 80% of the area, The velocity is between 1.5m/s and 4m/s which make pedestrian comfortable. On the contrary, the velocity distribution is not uniform out side the garden. The flow is stagnant in the most area. The strong wind on the boundary of the square are mainly caused by the corner flow. The curved green belts can improve the wind environment rather than linear green belts by comparing the velocity distribution at different wind attack angle in Fig. 4.



(a) Velocity vector (b) Velocity distributions

Figure 5. Wind environment of the square, V_∞=6m/s

IV. CONCLUSIONS

A good agreement is observed between experimental result and numerical value. The numerical model and simulation result are both reliable. Numerical simulation results indicate that the green belts accelerates the air flow parallel to it. The effect of acceleration depends mainly on the distance between the green belts rather than the length of the green belts. The wind environment of central garden is more comfortable for pedestrian. The curved green belts can improve the wind environment of square rather than linear green belts.

ACKNOWLEDGMENT

The study is supported by Hunan Province Education Department Research Program (No. 14C0223) and 2015 Hunnan City University Program.

REFERENCES

[1] Isyumov, N., A Study of pedestrain level Winds for the Canary Wharf Project[R], London, England: Engineering Science Research Report, BLWT-SS16, 1986.

[2] HOLMES J D.Wind loading of structures [M]. London: Spon Press, 2001:68-95.

[3] LI Biao, LUO Zhiwen, LIU Jing, SHUI Taotao, Wind Environmental Conditions in Passages between Two Long Narrow Buildings with Different Directions[J], Building Science, 2014, 30(8):85-89.

[4] Liang Shuguo;Peng Xiaohui;Wang Lei;Tang Huaiqiang;Wen Siqing; Comparative study between field measurement and wind tunnel test for wind pressure on Wuhan International Stock Building[J], China Civil Engineering Jounal, 2015, 48(5): 35-42.

[5] Shen Jianhong Li Chunxiang.Full-scale Measurement Investigation on wind field characteristics of based Tall buildings under strong wind gusts super[J], Journal of vibration and shock, 2010, 29 (5): 62-68.

[6] Zhengnong, Luo Diefeng, Shi Wenhai, et al. A comparative study of wind tunnel test and field measurements of wind pressure characteristics of super-tall building on coast of the Xiamen City during passage of typhoon Megi ［J］. Journal of Building Structures, 2012, 33 (1) : 10-17.

[7] AL ZOUBI Feras, LI Zheng-liang, WEI Qi-ke, SUN Yi. Wind tunnel testing and numerical simulation of wind pressure on a high-rise building [J]. Chongqing Univ: Eng Ed, 2010, 9(1): 47-53.

[8] Huang SH, Li QS, Xu SL. Numerical evaluation of wind effects on a tall steel building by CFD [J]. Journal of Constructional Steel Research, 2007, 63(5): 612-627.

[9] Tamura T, Nozawa K, Kondo K. AIJ guide for numerical prediction of wind loads on buildings [J]. Journal of Wind Engineering and Industrial Aerodynamics , 2008, 96(10-11): 1974-1984.

[10] Tominaga Y, Mochida A, Yoshie R, et al. AIJ Guidelines for practical applications of CFD to pedestrian wind environment around buildings [J].Journal of Wind engineering and Industrial Aerodynamics , 2008, 96(10-11: 1749-1761.

[11] Xin-Yu Zhang, Hong Jin, Study on the Improvement Strategies of Physical Environment for Square in Severe Cold Regions'Rural Areas,Journal of Harbin Institute of Technology (New Series), 2014 21(4):18-23.

[12] Hu Xiaojun, Tang Xiaomin, Xie Minggang, et al, Research on outdoor thermal environment of residential area[J]. Building Science, 2012, 28(2): 260-265.

[13] Roe, P. L., "Approximate Riemann Solvers, Parameter Vectors and Difference Schemes," Journal of Computational Physics, Vol. 43, 1983, pp. 357-372.