

P03

PIV Analysis of Turbulent flow and Momentum transfer around Regularly Arranged Urban like Building Models

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Abstract

Recent studies proved turbulent flow properties in high-rise building models differ from those in low-rise building models by comparing turbulent statistics. Although it is important to understand the flow characteristics within and above high-rise building models in the study of urban environment, it is still unknown and under investigation. For this reason, we performed wind tunnel experiment using Particle Image Velocimetry (PIV) to investigate and identify the turbulent flow properties and characteristic flow patterns in both low-rise and high-rise building models. In particular, we focus on instantaneous flow field near the building models and extracted flow field when homogeneous flow field were observed.

1. Introduction

The characteristics of turbulent boundary layer have been investigated from more than 100 years ago. In a primary stage of study, turbulent flow property was researched based on only spacial-temporal averaged parameters⁽¹⁾ or time-averaged turbulent statistics⁽²⁾ due to the limitation of experimental equipment. On the other hand, in recent years, researchers start to focus on instantaneous turbulent flow field structure with the development of research devices and computers, and some such studies indicate instantaneous turbulent flow field is not completely messed and contains coherent structure⁽³⁾⁽⁴⁾ (Fig.1(a)(b)) (fluid body, having specific motion or mode).

At first, the existence of coherent structure was proved in boundary layer over smooth surface, and some latest studies pointed out that similar structure

arise over rough surface. Moreover, it is pointed out that coherent structure in atmospheric boundary layer strongly related to the dispersion of momentum, heat and mass transfer⁽⁵⁾. This fact is extremely important for improving urban ventilation ability and livability of a city, so many researchers have investigated coherent structure in urban boundary layer.

However, the character of spatio-temporal structures of coherent structure in urban boundary layer has not been still understood very well. Especially, there are very few data how building shapes affects the property of coherent structure. From this background, in this study, we investigate the instantaneous turbulent flow field around regularly arranged building models by using PIV (Particle Image Velocimetry) and try to extract typical turbulent flow patterns.

2. Experimental condition

2.1 Experimental set up

The experiment was conducted with same wind tunnel and setting of previous study (Sato et al. (2013)⁽⁶⁾). Only the laser generator(Coherent) is different and target area is almost twice as large as previous one.

2.2 Model arrangement

Two types of uniform staggered block arrays with different block shape were adopted for the

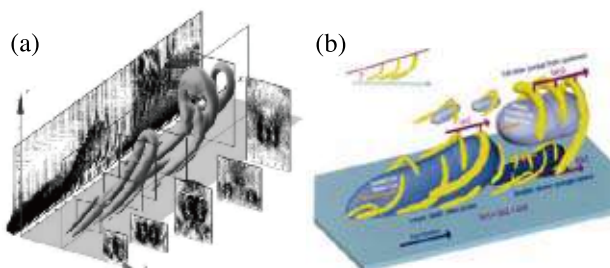
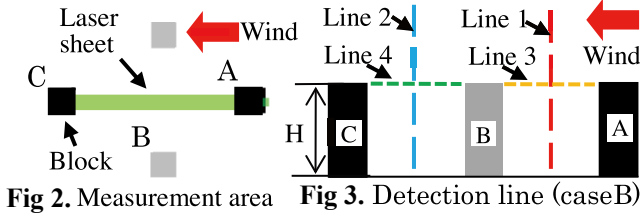


Fig 1. Perspective view of horse shoe vortex (Zhou et al. 1999)

Conceptual view of Hairpin packet structure (Adrian et al. 2000)



measurement as shown in Table 1. Cases A and B imitate to an array of high-rise buildings and low-rise buildings, respectively. The block covering ratio (λ_p) is set to the similar value for comparing. Fig.2 and fig.3 shows position relation of laser sheet and models.

3. Temporary-averaged flow field

Previous to instantaneous flow field, temporary-averaged flow field structure is investigated. Fig.4(a) and (b) shows the vector maps of temporary-averaged flow field in two cases. In both cases, wind velocity is almost uniform horizontally and direction is parallel to mean wind direction. On the other hand, larger spatial spatial distribution appears within the canopy. In case A, inverse flow arises behind block A, and a small vortex is observed on the windward of block B. These tendencies are consist with the result of well-resolved DNS calculation⁽⁷⁾ and low-time resolution PIV experiments⁽⁸⁾. Meanwhile, inverse flow also arises in case B, but it is uncertain whether a small eddy present nor not in front of downstream block due to the short of spacial resolution.

Fig.5 indicates vertical profiles of normalized streamwise velocity measured on windward and leeward (Red and blue line in fig.3) in two cases.

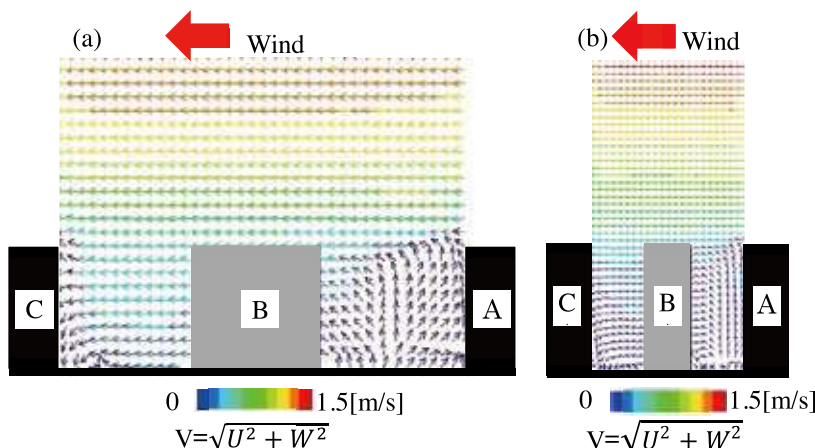


Fig 4. Vector map of Temporary-averaged flow field (a)CaseA (b)CaseB

Table 1. Model Arrangement

| | L×W×H(mm) | λ_p | Arrangements |
|--------|-----------|-------------|--------------|
| Case A | 25×25×25 | 17% | Staggered |
| Case B | 8×8×25 | 16% | Staggered |

Reference velocity (U_{ref}) was measured at $20H$ above wind tunnel floor. Velocity rapidly decreases within the canopy and under 0.05 of reference wind speed under $0.9H$ on line A in both model arrangements. On the other hand, in case A, deceleration rate becomes small in downstream region and U/U_{ref} moderately decrease with height within canopy. However, in case B, U/U_{ref} is still under 0.1 under $0.8H$. It is assumed that the distance from upstream block is small in this case and blockage effect is still large on line 2.

4. Typical instantaneous flow patterns

Although existence of specific flow patterns is known, it is still under discussion how to extract them. According to some past studies (i.e. Takimoto et al.(2012)⁽⁵⁾), these typical flow patterns stimulate momentum transfer near the canopy roof height. Thus, in this study, we specified the moments when ventilation between inside and outside of a canopy efficiently proceeds by an averaged value of instantaneous Reynolds stress (normalized by friction velocity) measured on line 3(upwind) and line 4(downwind) shown in fig.3, and then extracted specific turbulent flow fields at these moments

Fig.6 shows time series fluctuation of Reynolds stress

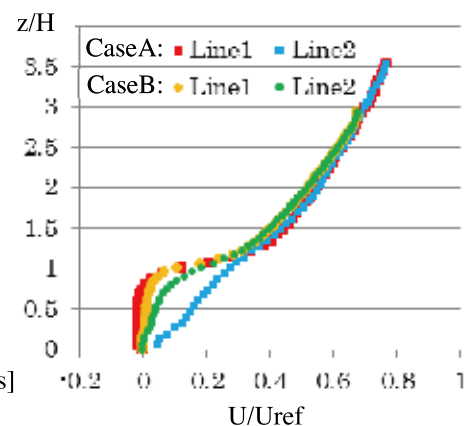


Fig 5. Vertical profile of temporary-averaged mean wind speed in two cases

on line 3 of case B during a period of 1.5 seconds. A strong positive spike with a value of about 10 times of the average can be seen from 0.64s to 0.73s, which clearly indicates large downward momentum transfer arises.

Fig.7(a) shows instantaneous flow field at 0.64s in case B. Strong downward flow is observed above the canopy and a part of it penetrates into the canopy. This downward flow continued from 0.64s to 0.74s, thus combined to fig.6, this result indicates the large momentum transfer during the period was triggered by this specific flow.

This theory is supported by the turbulent flow field shown in fig.7(b), observed 0.16s after fig.7(a). Strong downward flow in fig.7(a) moved to downward and portion of this flow penetrates into the canopy as like as fig.7(a). The value of summation of Reynolds stress on line B at that time becomes 7 or 8 times of the averaged value and rapidly becomes small after downward flow vanished.

Same tendency is confirmed in case A. Fig.7(c) and (d) demonstrate two snapshots of continuous flow field from 2.2s to 2.3s. Downward flow moved to downstream and momentum transfer become large during the downward flow dominates. From this result, it is concluded same flow pattern stimulates momentum transfer near the canopy in both cases.

5. Conclusion

Relation between momentum transfer and turbulent flow field is revealed and a common point of turbulent flow field structure in two experimental cases is discovered.

6. Reference

- 1] Jackson, P. S. (1981) "On the displacement height in the logarithmic velocity profile", J. Fluid Mech. 111, 15-25
- 2] Cheng, H. and Castro, I. P. (2002) "Near wall flow over urban-like roughness" Boundary-Layer Meteorol., 104, 229-259
- 3] Adrian, R. J., Meinhardt, C. D., Tomkins, C. D. (2000) "Vortex organization in the outer region of the

turbulent boundary layer" J. Fluid Mech. 422, 1-54

4] Zhou, J., Adrian, R. J., Balachandar, S., Kendall, T. M. (1999) "Mechanisms for generating coherent packets of hairpin vortices in channel flow" J. Fluid Mech. 387, 353-396

5] Michioka, T., Sato, A., Takimoto, H. and Kanda, M. (2010) "Large-eddy simulation for the mechanism of pollutant removal from a two-dimensional street canyon", Boundary-layer Meteorol., 138, 195-213

6] Sato, T., Hagishima, A., Ikegaya, N. Tanimoto, J. (2013) "Particle image velocimetry measurement of unsteady turbulent flow around regularly arranged high-rise building models", International journal of high-rise buildings, 2, 105-113

7] Coceal, O., Thomas, T. G., Castro, I. P., Belcher, S. E. (2006) "Mean flow and turbulence statistics over groups of urban-like cubical obstacles", Boundary-layer Meteorol., 121, 491-519

8] Reynolds, R. T., Castro, I. P. (2008) "Measurements in an urban-type boundary layer" Experiments in Fluids, 45, 141-156

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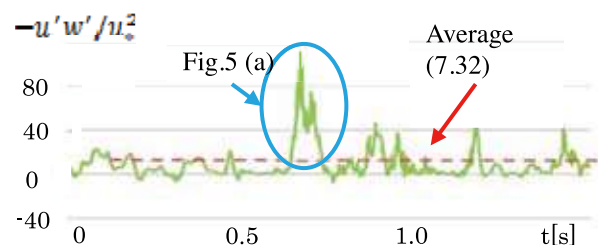


Fig 6. Time fluctuation of Re stress on line 3

← Mean flow

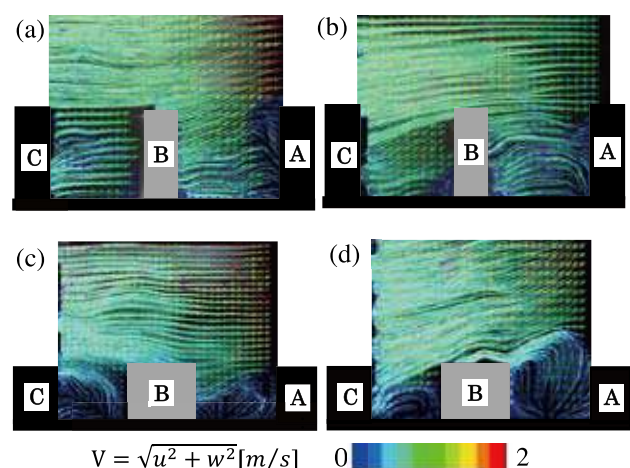


Fig 7. (a)-(d) Instantaneous turbulent flow patterns with large momentum transfer