J6.9 TURBULENT ORGANIZED STRUCTURE OVER A REDUCED URBAN SCALE MODEL
- STABILITY EFFECT AND HORIZONTAL DISTRIBUTION -

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1. INTRODUCTION

It is known that the turbulent organized structure (TOS) accounts for the most of the turbulent momentum or scalar fluxes. Therefore, it is significant to understand the TOS over the building roughness to examine and modeling the turbulent transport processes of heat or momentum in urban region. We attempted to observe the coherent structure in the reduced urban scale model experiment using 16 sonic anemometers.

It is expected that the TOS have complex three-dimensionality, however, the observational studies in urban region are mostly conducted one-dimensionally in vertical extent because of the urban restriction. Furthermore, few studies have examined the effect of atmospheric stability on the TOS over urban region (i. e. Moriwaki and Kanda, 2005).

Thus the present study investigated the followings, focusing on the SL turbulence over the scale model site; (1) the effect of the atmospheric stability on the vertical distribution of the turbulent properties, and (2) the horizontal distribution of the coherent structures developed over the urban like roughness.

2. OUTDOOR SCALE MODEL EXPERIMENT

2.1 *Scale mode site*

The urban scale model was constructed in outdoor. The size of the model is 50 x 100 m horizontal extent and with 1.5 m (= H) cubic roughness blocks arranged uniformly (see Fig.1). The plan area index becomes 0.25. An 8 m tower is established at the center of the site, where the vertical distribution was measured. The displacement height is calculated using the equation in Macdonald et al. (1998) as $d = 0.46H$. The roughness length is estimated using the above d and the vertical profile of mean wind velocity in neutral stratification as $z_0 = 0.13H$.

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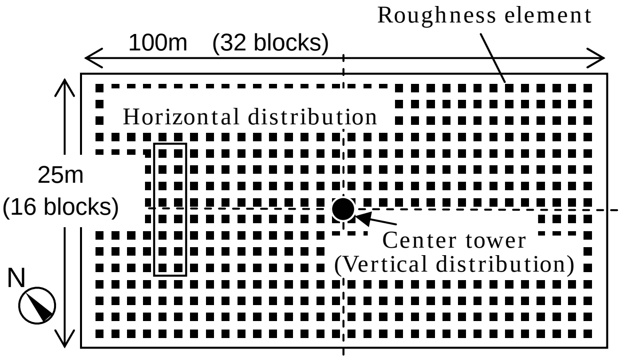

Fig.1 Urban scale mode site

2.2 *Instruments*

To observe the turbulent properties, we used totally 16 sonic anemometer-thermometers (8 are KAIJO DA-600 TR90AH, and the other 8 are YOUNG, model 81000). These are arranged in the model site and measured turbulence synchronously.

2.3 *Atmospheric stability*

One of the advantages of the outdoor experiment is that it is possible to examine the thermal effect. The present study evaluated the stability based on the following value,

$$\frac{z'}{L} = -\frac{(g/T)(\overline{w'T'})}{u_*^3/kz'} \quad (1)$$

where L is Obukhov length (m), z is height of an instrument (m) and $z' = z - d$, T is temperature (K), $\overline{w'T'}$ is sensible heat flux (K m s^{-1}), g is the gravity acceleration (m s^{-2}), u_* is friction velocity (m s^{-1}), k is von Karman constant ($k = 0.4$ is applied). Based on this value, the vertical profiles are classified into stable ($z'/L > 0.01$), neutral ($-0.0075 < z'/L < 0.01$), and unstable ($z'/L <$ -0.0075) conditions.

3. VERTICAL PROFILE

Vertical profile of turbulent statistics was observed using 5 sonic anemometers (KAIJO DA600). The instruments were aligned vertically at 4H , 3H , 2H , 1.5H , H on the center tower. The averaging time to calculate the profile is 30 minutes. Furthermore, the members of the temporal mean

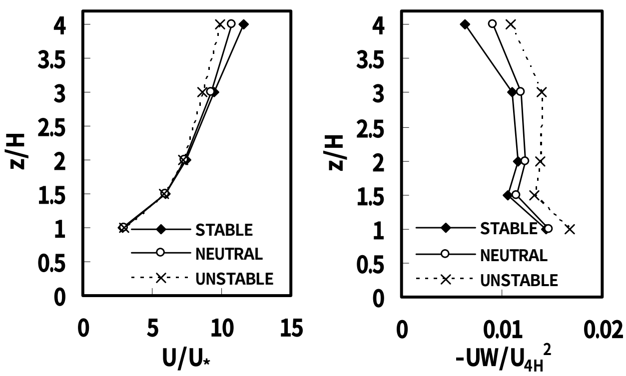

Fig.2 Vertical profile of mean velocity and momentum

statistics are ensemble-averaged according to the above category of stability at the respective heights. The stability measured at $2H$ was used. The data, when the deviation of the horizontal wind direction is less than 45 degree from the northwest-southeast axis, is used for the ensemble-average. Then the fetch becomes more than 50 m.

3.1 *Mean velocity and momentum flux*

Fig. 2 shows the vertical profiles of the horizontal mean wind and momentum flux. It is clearly shown that the vertical gradient of the stream wise velocity becomes steep and the momentum flux is larger in unstable condition. This is because of the thermal effect, which enhances the vertical mixing then the vertical change of the horizontal wind speed is reduced. In contrast, the flow is more stratified in stable condition where the vertical change of mean wind speed becomes large.

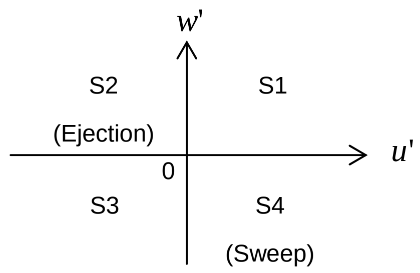

Fig.3 Quadrant analysis

3.2 *Quadrant analysis*

The quadrant analysis has often been used to characterize the turbulent structure (e.g. Shaw et al., 1983). We used this method to analyze the momentum flux. The analysis classifies atmospheric turbulence events into four quadrants based on the sign of the fluctuations of horizontal velocity (u') and of vertical velocity (w') as depicted in Fig. 3. The second quadrant (S2) accounts for the sweep event and the fourth quadrant (S4) corresponds the occurrence of the ejection event.

Fig. 4 shows the vertical change of the fractions of momentum flux due to each quadrant, which are also ensemble-averaged values in respective stabilities. Overall, the sweep mode (S2) is dominant in the SL over the building roughness. However, the more unstable the stability, the more close the fraction of the ejection mode (S4) and that of sweep (S2). In unstable condition, the ejection mode crossed over the sweep mode higher than 3H.

Field observations in vegetation canopy have reported that the fraction of sweep mode is much larger than that of ejection (e.g. Shaw et al., 1983). The mixing layer analogy (Raupach et al., 1996) explains the reason, slower flow in vegetation canopy and faster flow above the canopy creates an inflection point of horizontal mean velocity. Then the shear instability occurs and generates turbulence where the sweep mode is dominant. The other hands, the ejection mode is dominant in flat wall turbulence (Krogstad et al., 1992) where there is no inflection point in the mean velocity profile.

The urban roughness has just intermediate characteristics between flat wall boundary and vegetation roughness. The rigid surface on the building top acts as flat wall. The other hands, since the wind speed within a street canyon is slower than the flow above the canopy, an inflection point is created in the vertical profile of the mean wind velocity as similar to the vegetation canopy. Therefore the dominance of the sweep mode is thought to be attributed to the turbulence due to the shear instability.

As explained in the previous sub-section, thermal enhances the vertical mixing and it reduces the vertical gradient of mean wind velocity. This makes the inflection point of the mean wind becomes weaker.

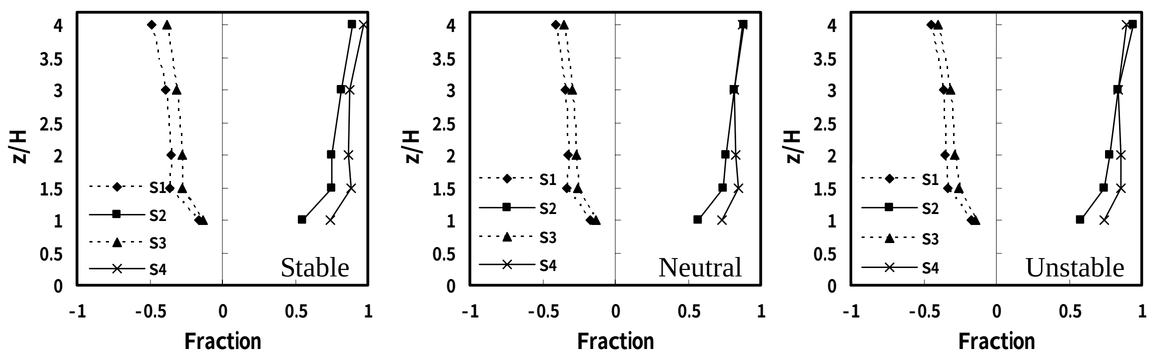

Fig.4 Vertical distribution of quadrant fraction of momentum

Then the turbulence, invoked by shear instability, is weakened and the fraction of the sweep event is also decreased.

4. HORIZONTAL DISTRIBUTION

The horizontal distribution of TOS is detected using 16 sonic anemometers (both DA600 and Model 81000). The instruments are aligned in the span wise direction to the horizontal mean wind as shown in Fig.5. The height of the measurement is $2H$. The range of the horizontal distribution of instruments is $16H$. A succeeded 1 minute data in daytime was analyzed. During the selected term for the analysis, the horizontal mean wind velocity was 2.7 m s^{-1}, and the wind direction was 2.2 degree decline perpendicular to the alignment of the instruments.

4.1 *Horizontal distribution of coherent structure*

Fig.6 shows the horizontal distribution and time series of the fluctuation of stream wise velocity, vertical velocity and temperature. The fluctuations were calculated from the average during the selected 1 minute. 1 second moving average is conducted in time to make comparable the resolution of the span wise scale and stream wise scale in the figure. The depicted time duration is 60 second, which is corresponds to $54H$ in stream wise direction if Taylor's hypothesis is assured.

From these figures, streaky coherent structure is found. The span wise scale of the structure is much larger than the individual roughness blocks (about 5~6 times larger). The stream wise scale is succeeded more than 1 minute. LES also simulated the similar low speed streaks (Kanda et al. 2004, Kanda 2005).

The streak structure consists of a low speed, updraft, and relatively high temperature region. Therefore, this low speed streak accounts for main part of the ejection event. Meanwhile, a clear sweep event appears in the short event at 48 second in time

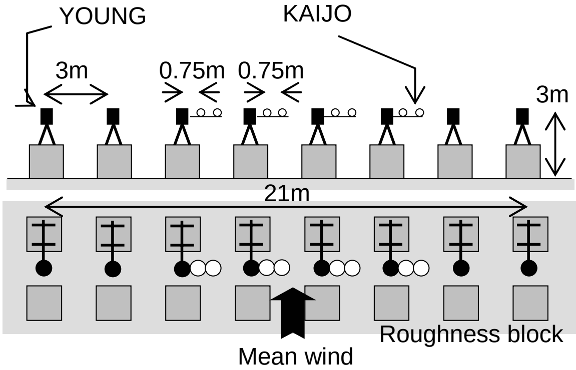

Fig.5 Arrangement of instruments

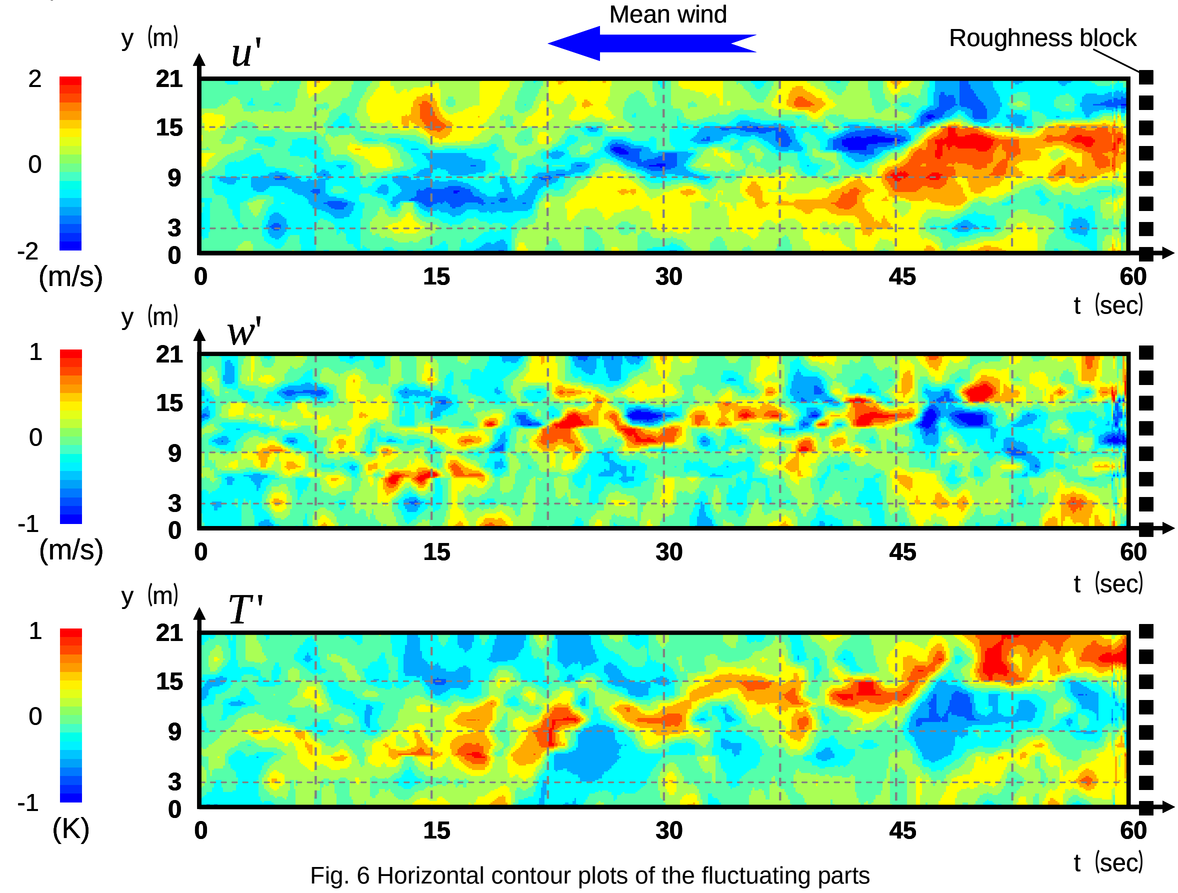

Fig. 6 Horizontal contour plots of the fluctuating parts

(top: horizontal wind, middle: vertical velocity, bottom: temperature) axis, which is not in the streak.

5. CONCLUSION

The turbulent properties were observed in the SL over the outdoor urban scale model site using 16 sonic anemometers. The concluding remarks are follows;

(1) The stability effect appeared clearly in the vertical profiles of mean wind velocity and momentum flux. The momentum flux is examined by the quadrant analysis. Overall, the sweep mode was dominant. However, the fraction of the ejection becomes comparable to that of the sweep when the stability becomes unstable.

(2) 16 sonic anemometers were aligned to the span wise direction of the horizontal mean wind. Based on the Taylor's hypothesis, the streaky pattern was found in the horizontal distribution of the fluctuations of horizontal wind velocity, vertical velocity and temperature. The low speed streak mainly accounts for the ejection mode. The span wise scale of this streaky structure was about 3 times larger than the roughness scale.

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