Wind Engineering Joint Usage/Research Center
FY2014 Research Result Report

Research Field: Wind disaster and wind resistant design

Research Period: FY2013～ FY2014

Research Number: 133007

Research Theme: Study on wind flow characteristics around super tall buildings with various cross section

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Budget [FY2014]: 41000Yen

*If the research was not continuous, this will be the Final Result Report, so the contents of the report has to be detailed.
*There is no limitation of the number of pages of this report.
*Figures can be included to the report and they can also be colored.
*Submitted reports will be uploaded to the JURC Homepage.

1. Research Aim

   This project mainly focuses on the wind flow characteristics around super tall buildings with various cross sections. Study on the influence of the super tall buildings with various cross sections to the pedestrian wind environment. Compare with the different shape of the super tall building; find the maximum wind speed area. About the research on pedestrian wind environment, it can be divided into three parts, mean wind velocity analyze, fluctuation wind velocity analyze and the wind direction. In February, FY 2014, it is already finished the experiment on mean wind velocity analyze.

2. Research Method

   For this research, using the thermistor sensors and hot-wire sensor to test wind speed around the super tall building and the inflow wind speed, calculate the mean wind speed ratio. Use each point's wind speed ratio to draw the contours; and then compare different models' contours to find difference of the high wind speed ratio area.

3. Research Result

Speed up ratio *R*

Pedestrian level winds around buildings have been mostly investigated, either by wind tunnel or CFD, for a small near-field area or along the centreline of separation between buildings. Stathopoulos et al. studied the wind flow around a building in a boundary layer wind tunnel. They described the variation of wind speeds by a speed up ratio R defined as:

$$R = \frac{U_i}{U_{i0}} \tag{1}$$

Where U_i is the measured wind speed at pedestrian level at point i and U_{i0} is the measured wind speed without the buildings at the same point

As the Fig.4 shows, considering the direction of 0 degree, it can be seen that there are three different types of wind speed zones: 1) upstream low wind speed (UL) zone. 2) Side stream high wind speed (SH) zone. 3) Down steam low wind speed (DL) zone. UL zone in front of the model is a low velocity zone. Effected by the resistance, flow forms a low velocity zone which emerges a roundness in the front of the structure.

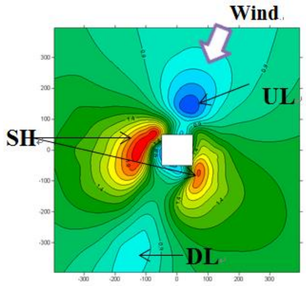
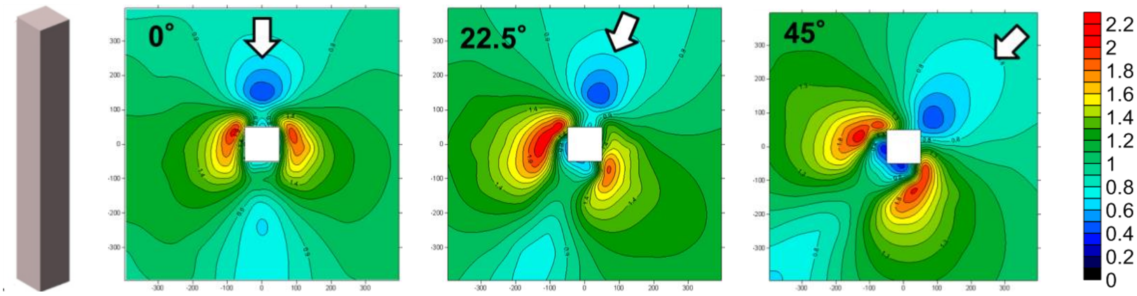
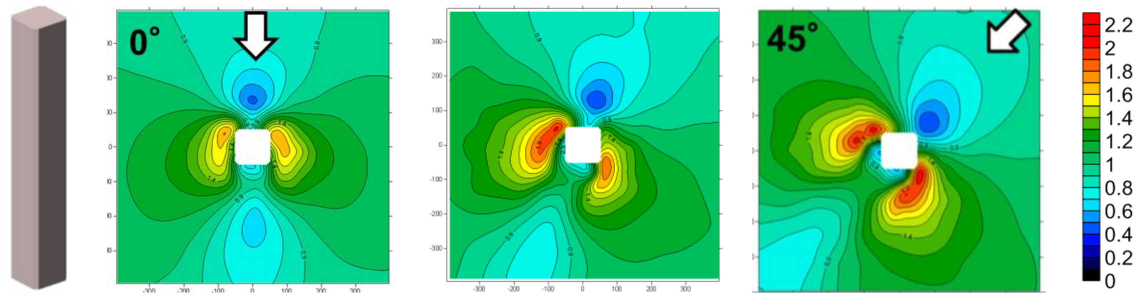


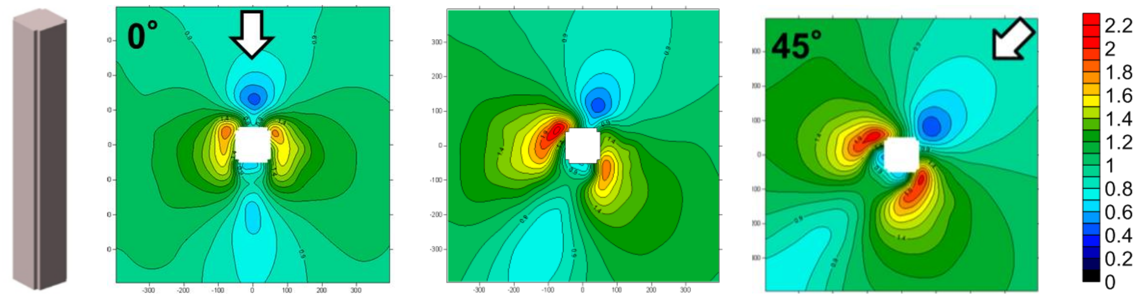
Figure 4 wind speed up ratio



a) distribution of wind speed up ratio around the square model



b) distribution of wind speed up ratio around the corner chamfered model



c) distribution of wind speed up ratio around the corner cut model

Figure 5 Effect of the corner modified model

As it shown in Fig.5 square model are the axisymmetric model. It means that when we consider about the wind directions, 3 directions are enough to describe the pedestrian wind environment around the square model, 0 degrees, 22.5degree and

45degree. The result of these 3 directions can represent the other directions' results.

The partition for the direction of 22.5 degrees is approximately the same as the one for the direction of 0 degree, which is the UL zone, SH zone and DL. It's different in the SH zone. The right and left sides of the model is not symmetrical when using the direction of 22.5 degrees as the axis of symmetry. Under the influence of the shape of the model, the flow is separated to the left and right sides of the model from the corner. And the flow to the left area is more, so the figure reveals that the area of accelerating region on the left is large than the right. For the square model, the angles of the wind directions have a great influence on mean wind velocity distribution. It can be seen in Fig.5, the mean wind speed up ratio distribution around the square model from 0 degree to 45 degree at 22.5° intervals, the wind distribution as the figure shows, when the wind direction change from 0degree to 45 degree, the mean wind velocity and the area of the speed increased region become larger.

The corner modified building but only shows the good behavior on the building's aerodynamic (Tanaka 2012), but also improve the wind field at the pedestrian height, reduce the area of the corner stream zone, and decrease the wind speed.

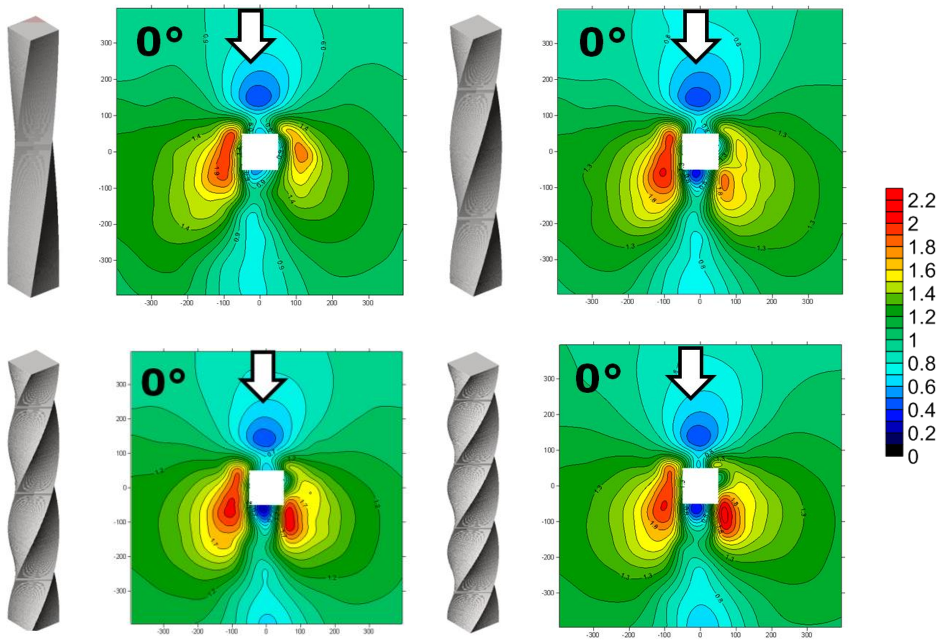


Figure 6 Effect by Helical type model

As the Fig 6 shown, for the square type helical Model, when to the flow comes from the direction of 0 degree, due to the windward side of the bottom of the model have a tilt Angle to the left, so a part of the coming flow can flow to the left of the building along the inclined plane, which results in the increase of the area of the accelerating region on the left of the building and also increase the wind speed.

The windward side changes in the upper position of the model due to rotating. The right side begins to be the windward surface and forms a downward sloping angle. When the air blowing the model, forming a part of down drafts. This makes the area of the wind speed increasing on the right of the model, not same as the square building, changes back, and forms the increasing area beginning from the corner of the building.

The mean wind speed up ratio distribution around the square type helical buildings, the twisting angle is change from 0 degree to 360 degree at 90 degree intervals. Compare with the square building, at the pedestrian height, the windward width of the helical buildings are almost same as the square buildings, but the mean wind speed ratio distribution are totally different. In 0 degree of the wind direction, the SH zones of the helical buildings are not symmetric. For the left side, the maximum mean wind speed up area is not start from the corner of the upstream. It appeared on almost the centre of the speed up area. For the right side, as the twisting angle increased, the centre of the maximum area moves to be near the right side of downstream corner, and the maximum speed up ratio become larger, but the area of the high speed up zone become smaller. In 45 degree of the wind direction, same as the 0degree, on the right side of the wind direction, the maximum value of the speed up ratio become larger, and the high speed up zone become smaller.

Normalized Speed up Area

Using the each measurement point's speed up ratio and its coordinate, the mean wind speed contour can be draw. According to the contour of mean wind velocity around the models, the area of each speed up ratio can be calculated.

R- Mean wind speed-up ratio

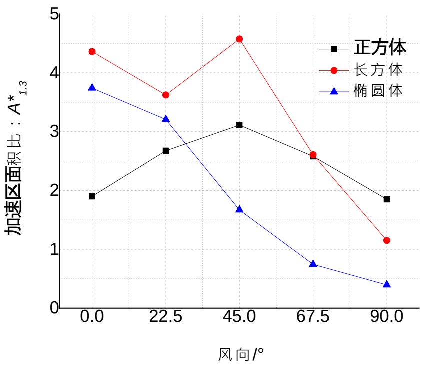
A_R -Area of the $R > 1.3, 1.5, 1.8, 2.0$

Normalize the area of the wind speed up ratio according to the equation:

$$A_R^* = \frac{A_R}{B^2}$$

which A_R^* is the area ratio, and B^2 is the base area of the cube model.

Normalized speed up area can easily show which wind direction of the building will conducive to improve the pedestrian environment, and which direction show bad effects. This parameter is suit for analyse area which has the domain wind direction. But for the other kind of area which does not have the significant domain wind direction, it needs to define the other parameters.



As the figure.7 shown, in the basic

three axisymmetric models, the pedestrian wind environment surrounding the square building is better than that of the rectangular buildings and elliptic building in 0 degree, and in 45 degree, the situation is opposite, the rectangular building and the elliptic building show good behaviour to decrease the mean wind speed. From Figure We can see that with the change of wind direction, the shape of the windward side and the windward width also have change, which leads to the mean wind speed up ratio distribution around the building difference. It can be used for some area which has the domain wind direction, construct the rectangular building or elliptic buildings which the long symmetric centre line parallel to the domain wind direction can effectively improve the surrounding pedestrian wind environment.

In earlier period, it is generally considered that the shape of building's lower structure is the domain factor which effect the wind field at the pedestrian level height; and with the height of the buildings increased, the effect of the up structure play less role on pedestrian wind environment. In this experiment, There are two type of buildings, the setback building and the setback & 45°rotate building. The Fig.8 shows the windward side of the two buildings in 0 degree and 45 degree. It can be seen that, below the 100 meter, the shape of the windward

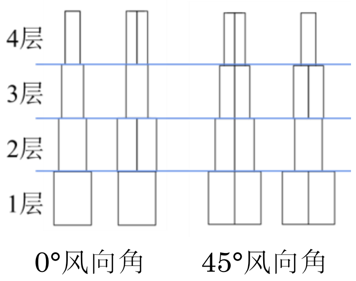


Figure 8 Windward Width

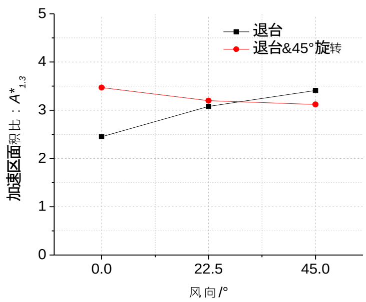


Figure 9 Wind speed up area

section are the totally same. But in the section of 100 meter to the 200 meter, the windward side are different because of the second section was been rotated by 45 degree. Fig.9 shows the mean speed up ratio distribution around these two kinds of the buildings. It can be observed that, compare with the setback building, the SH zone of the setback & 45 R building was increased almost 30% in 0 degree; and in 45 degree, it decreased almost 10%. It can be conclude that for super tall buildings, even in 200 meter height, the section of the building also affect the pedestrian level height wind speed.

For the square model, the angles of the wind directions have a great influence on mean wind velocity distribution. the mean wind speed up ratio distribution around the square model from 0 degree to 45 degree at 22.5° intervals, the wind distribution as the figure shows, when the wind direction change from 0degree to 45 degree, the mean wind velocity and the area of the speed increased region become larger. It can be seen in Fig.10 Fig. 11, i) The corner modified can be significant decreased the wind speed at the pedestrian height around the buildings. ii) The twisting angle is an important factor affecting the mean wind speed distribution around the buildings Fig.10shows the relationship between Normalized Speed up Area $A^{*}_{1.3}$ and the twisting angle of wind direction in 0 degree and 45 degree. It can observed that when the wind direction in 0 degree, the Normalized Speed up Area $A^{*}_{1.3}$ of the helical buildings are larger than the square building. iii) Compare with the setback building, the SH zone of the setback & 45 R building was increased almost 30% in 0 degree; and in 45 degree, it decreased almost 10%. It can be conclude that for super tall buildings, even in 200 meter height, the section of the building also affect the pedestrian level height wind speed.

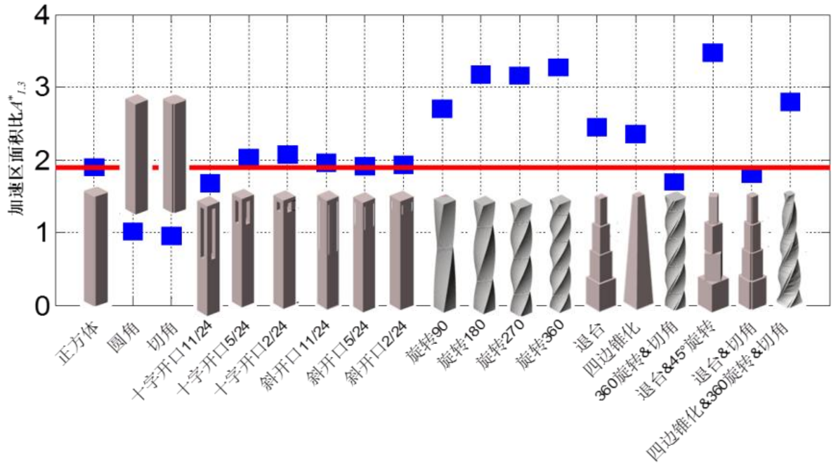


Figure 10 Wind speed up area ratio of the square type building in 0 degree

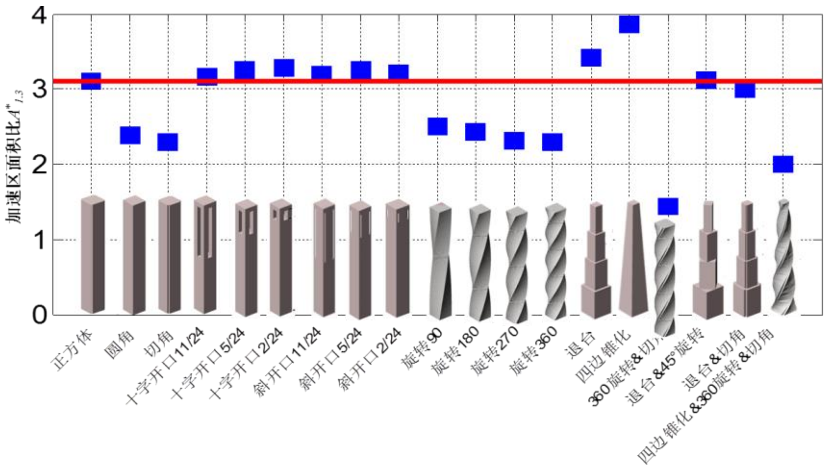


Figure 11 Wind speed up area ratio of the square type building in 45 degree

Mean Normalized Speed up Area A^{*}_{R-mean}

Considered the area which doesn't have the significant domain wind directions, in order to analyse the mean wind speed distribution around the buildings, the new parameter should be defined. Mean Normalized Speed up Area is the average of the all wind direction's wind speed up area, defined as:

$$A^{*}_{R-mean} = \frac{\sum_{\theta_j=1}^{N} A_{R,\theta_j}}{N}$$

Where $\sum_{\theta_j=1}^{N} A_{R,\theta_j}$ is the sum of the Normalized Speed up Area in all Wind Directions, N *is* Number of Wind Directions.

To consider the each wind direction respectively, it hard to say which type of the basic buildings is better to improve the pedestrian wind environment. Synthesizes each wind directions, as it shown in Fig.12, the elliptic building show good behaviour on improves the surrounding pedestrian wind environment.

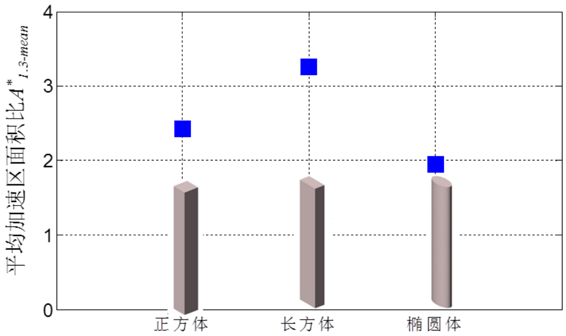


Figure 12 Normalized speed up area of the basic model

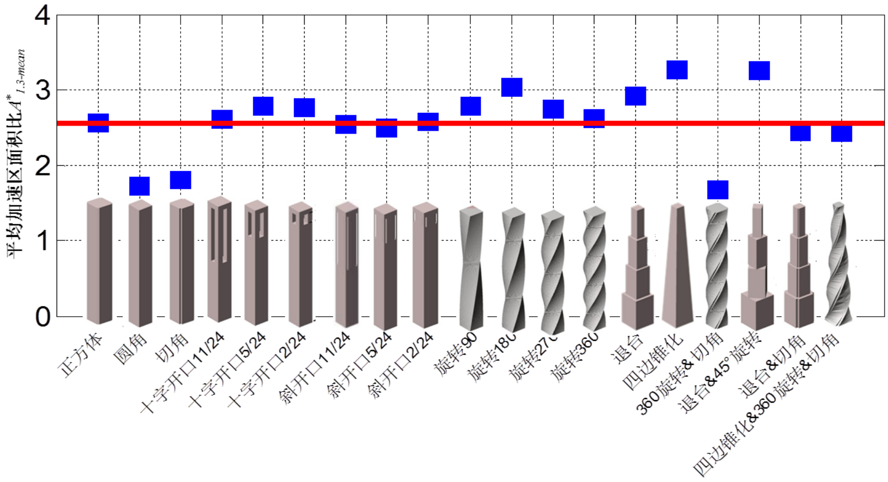


Figure 13 Normalized speed up area of the Square type model

Conclusions

1. There are a lot of parameters effect the pedestrian wind environment, the Wind ward width, the shape of the windward side, the wind direction and so on, they

combine together to effect the pedestrian-level wind speed around the super tall building.
3. The up structure of the building is an important factor for influence the pedestrian wind environment around the building.
4.The Conner modified model show good behavior to reduce the mean wind speed around the models, and improve pedestrian wind environment.

4.Published Paper etc.
[Underline the representative researcher and collaborate researchers]
[Published papers]
[Presentations at academic societies]
[Published books]
[Other]
Intellectual property rights, Homepage etc.

5. Research Organization
1. Representative Researcher
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2. Collaborate Researchers
Akihito Yoshida Tokyo Polytechnic University, Japan, Associate Professor
Yukio Tamura Tokyo Polytechnic University, Japan, Professor
Xu Xiaoda Beijing jiaotong University, China, Professor