Wind Engineering Joint Usage/Research Center
FY2015 Research Result Report

Research Field: Wind disaster and wind resistant design
Research Period: FY2014～ FY2015
Research Number: 152003
Research Theme: Study on aerodynamic environmental effects on pedestrians and medium- and low-rise buildings around super-tall buildings
Representative Researcher: Prof. Qingshan Yang

Budget [FY2014]: 444000

1. Research Aim

There were some past studies on pedestrian level winds in Japan, Australia, Canada, and so on, but they were basically considering tall buildings with a height up to around 200m high; and these studies were focusing on basically conventional rectangular plan buildings. However, with the development of the technology, there are more and more untraditional super-tall buildings had been built in the world. Compared with the traditional buildings, the design of these super-tall buildings were not limit to be symmetric rectangular, in plan; they were been designed to be the novel and unconventional expressions. A series of wind tunnel tests have been carried out to determine pedestrian level winds around 38 super tall building models with various configurations: square plan, rectangular plan, elliptic plan, with corner chamfered, tilted, tapered, inverse tapered, with setbacks, helical, openings and so on. The results of these tests have led to comprehensive discussions on the pedestrian-level wind environment characteristics of various tall building configurations, and studies on corresponding optimal structural systems.

2. Research Method

For this research, using the thermistor sensors and hot-wire sensor to test wind speed around the super tall buildings and the inflow wind speed, calculate the mean speed-up 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.

The **Fig. 1** shows the variation of speed-up ratio distribution of the square buildings models with the building height (Kami and CBS) ; **Fig. 2** is the experiment result of the square model. Roughly compared with the past studies, the pattern of the high speed zone is almost same, but the area of the high speed zone is much larger, and it increases with the building height. The measurement method in this experiment and past studies is all the Multi-point measurement: the wind velocity information can be acquired just at the measurement point, and the information of the all wind field is not continuous. As mentioned before, thermistor anemometers were used in the experiments, and the fluctuating component cannot be discussed. **Table 1** shows the max speed-up ratio in some past studies and this experiment result. It can be seen that as the height of the building increasing, the max speed-up ratio becomes larger.

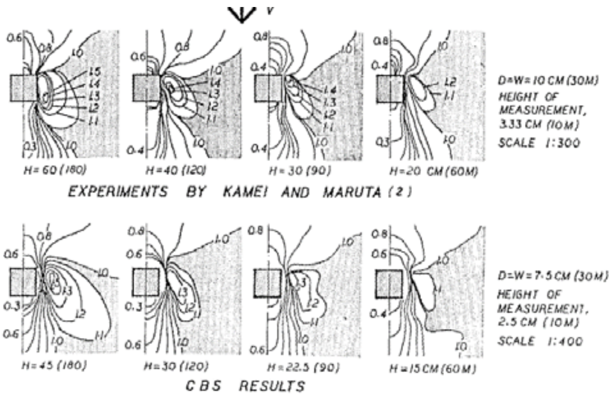

Figure 1. Speed-up Ratio Distributions in Past studies

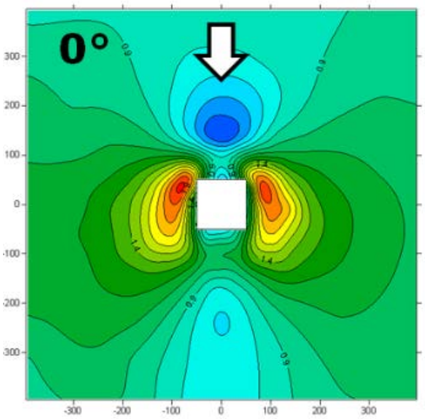

Figure 2. Speed-up Ratio Distributions in current result

Table 1 Compared with the Maximum area

Model	Width	Height	Aspect ratio	Maximum speed-up ratio	Researcher
Square	30m	60m	2	1.2	**KAMEI And MARUTA**
Square	30m	60m	2	1.1	**CBS**
Square	30m	90m	3	1.4	**KAMEI And MARUTA**
Square	30m	90m	3	1.3	**CBS**
Square	30m	120m	4	1.4	**KAMEI And MARUTA**
Square	30m	120m	4	1.3	**CBS**
Square	30m	180m	6	1.5	**T. Stathopoulos**
Square	30m	180m	6	1.5	**KAMEI And MARUTA**
Square	30m	180m	6	1.5	**CBS**
Square	50m	400m	8	2	**Present result**

The maximum wind speed-up ratios of all wind directions for each model are shown in **Fig 3**. The maximum speed-up ratio ranges from 1.9-2.3. Referring to the square model, the rectangular model, elliptic model, tapered models, helical models, tilted models, and triangular models show hither value and the circular model, octagon models and dodecagon models shows the lower values.

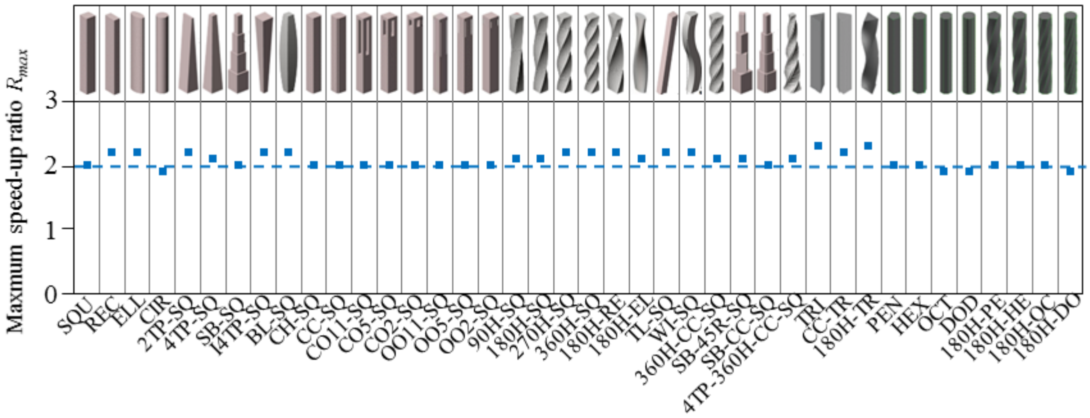

Figure 3 Maximum Wind Speed-up Ratio

Normalized Speed-up Area $A^*_{1.3}$

Normalize speed-up area is defined as follow:

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

where A^*_R is the area ratio, and B^2 is the base area of the square model, A^*_R is the speed-up area. In this paper, we will discuss the normalized speed-up area corresponding to speed-up ratios: 1.3, 1.5, 1.8 and 2.0.

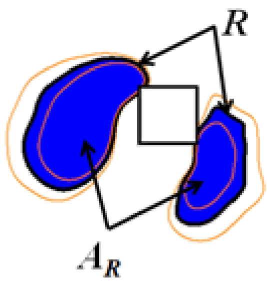

Figure 4 Normalized Speed-up Area

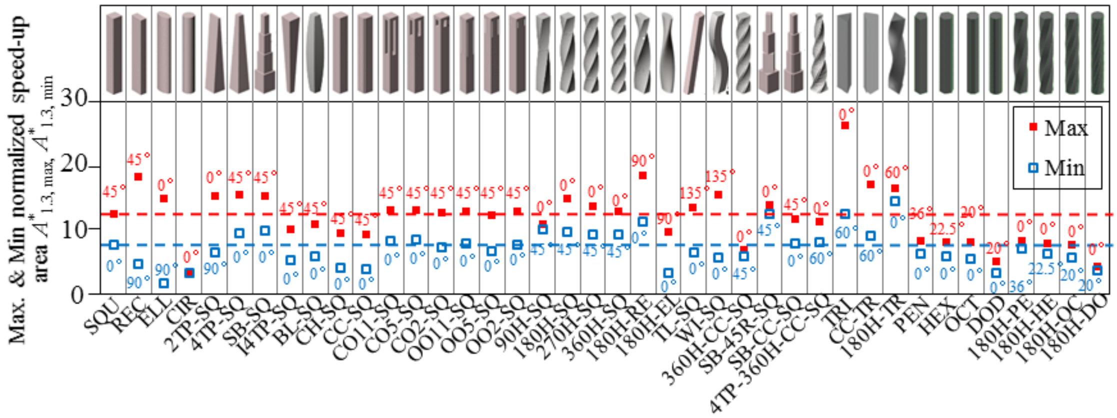

Fig. 5. Maximum and minimum values of normalized speed-up area $A^*_{1.3}$

Fig. 5 shows overall comparisons of maximum and minimum values of normalized speed-up area $A^*_{1.3}$ for all wind directions, $A^*_{1.3,\,max}$ and $A^*_{1.3,\,min}$. The left end of **Fig. 5** is for model square, and the two dash lines indicate $A^*_{1.3,\,max}$ and $A^*_{1.3,\,min}$. From this figure, the following facts are clearly found. For maximum normalized speed-up area $A^*_{1.3,\,max}$, models rectangular, elliptic, 2-tapered, setback, 180°helical, 180°helical-rectangular, triangular, and 180°helical & triangular show higher values than model Square. In particular, model Triangular shows the highest and is almost double that for model Square. However, models circular model, inversely 4-tapered, bugler , corner chamfered, corner cut, 90°helical, 180°helical, 360°helical & cut, setback & cut, 4-tapered &360°helical & Cut, and polygonal show lower values and better characteristics than model Square. For minimum normalized speed-up area $A^{*}_{1.3,\,min}$, models rectangular, elliptic, corner chamfered, corner cut, 180helical & elliptic, and Polygon show smaller values than model square.

In addition, it is noteworthy that models circular, corner cut, 90°helical, 180°helical, 360°helical & cut, setback & 45° rotated, 180°helical & triangular and polygonal show smaller differences between $A^{*}_{1.3,\,max}$ and $A^{*}_{1.3,\,min}$, thus suggesting less directionality in pedestrian-level wind characteristics of those configurations. Those models, except for model 180°helical & triangular, show better wind environmental conditions. However, the situation is opposite for models rectangular, elliptic, 2-tapered and titled model, which show large differences between $A^{*}_{1.3,\,max}$ and $A^{*}_{1.3,\,min}$ suggesting significant effects of wind direction.

It is also noteworthy that the opening models show almost the same results as model square, suggesting that openings in the upper parts of buildings cause less effects on the pedestrian wind characteristics.

Intergraded-normalized speed-up area

To evaluate the general effect of different wind directions of a model, the integrated normalized speed-up area $A^{*}_{R\text{-}int}$ is defined as

$$A^{*}_{R-\mathrm{int}} = \frac{\sum_{\theta_j=1}^{N} A_{R,\theta_j}}{N} \tag{3}$$

where N is the number of the tested wind directions. $A^{*}_{R\text{-}int}$ is the averaged normalized speed-up area considering all wind directions, and can be a representative index showing the speed-up nature of pedestrian-level wind for individual building models.

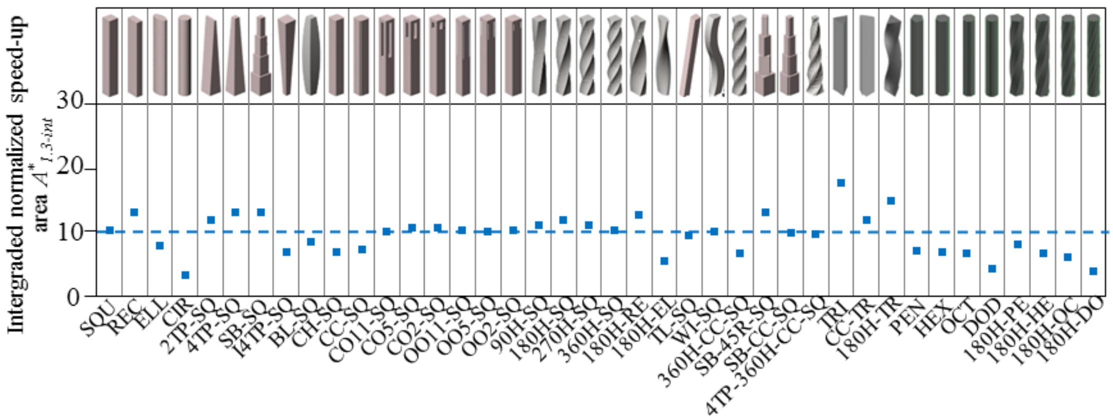

Fig. 6. Intergraded normalized speed-up area $A^{*}_{1.3\text{-}int}$

Fig.6 presents the intergraded normalized speed-up area $A^{*}_{1.3\text{-}int}$ of all the measured models. Synthesizes each kind of situation of wind direction, it can be seen that 1) For basic models, elliptic model and circular model show good behavior to reduce the pedestrian level height wind speed, while the speed-up area is large around rectangular model to cause terrible pedestrian wind environment. 2) Because the section areas of the lower part of 2-tapered, 4-tapered and setback models are larger than square model, the speed-up areas increase. Similarly, it reduces for inversely 4-tapered and bulged models. 3) There is a 30-persent reduction in the speed-up area if modifying the corner. 4) Opening in the upper of models has little or no effect on the speed-up area. 5) Compared with the straight models, rotating the models makes the area of the minimum speed-up larger than the square model, on the contrary, makes the area of the maximum speed-up smaller than the square model. The impact on the speed-up radio distribution of rotating the model is obvious, but small on speed-up area. 6) Triangular models show the worst behavior to pedestrian level height wind speed in the all measured models. 7) As the edge number increasing, the polygon models trend to circular, so the speed-up area decreases around the models.

Conclusions

1) High wind speed at pedestrian level height around the rectangular model, elliptic model, tapered models, helical models, tilted models, and triangular models and cause danger for pedestrians; but the maximum wind speed-up ratio around the circular model, octagon models and dodecagon models is small, hence these models are in favor of reducing the maximum wind speed at pedestrian level height.

2) Compared with the square model, the wind speed at the corner stream area of the corner modification models is significantly reduced.

3) The maximum Normalized Speed-up Area $A^{*}_{1.3}$ of the helical models is lower than the straight models, however, the minimum value is opposite. And the difference of the maximum area and minimum area become reduce. That's means the helical modified of the buildings can reduce the difference of the wind speed among each wind directions.

4) Under the same volume and height, the normalized speed-up area of the models decreases with the increase of the number of the sides. The wind speed around the triangular model is much higher than the other types of models. The decagon and the circle models show good behavior on the pedestrian level environment. The difference between straight models and helical models also decrease as the sides increase.

4.Published Paper etc.

［Presentations at academic societies］

Report in" 東京工芸大学・風工学共同研究拠点・研究集会（ 2016 年 2 月 27 日）のご案内--高層建物周辺の風環境と不整形高層建築物および地上設置構造物の風荷重に関する研究集会".

Pedestrian-level wind speed distributions around super-tall buildings with various configurations；Xu Xiaoda (Beijing Jiaotong University)

Wind loads acting on solar panels mounted on flat roofs of buildings； Wang Jingxue (Beijing Jiaotong University)

5. Research Organization

1. Representative Researcher

Qingshan Yang Beijing jiaotong University, China, Professor

2. Collaborate Researchers

Akihito Yoshida Tokyo Polytechnic University, Japan, Professor

Yukio Tamura Tokyo Polytechnic University, Japan, Professor

Xu Xiaoda Beijing jiaotong University, China, PHD

Wang Jingxue Beijing jiaotong University, China, PHD