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Effects of surface roughness on the local pressure of high-rise building

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Abstract

Wind load is sensitive to the shape of high-rise buildings. In this study, the effects of building's surface roughness is studied in details based on wind tunnel experiment. 5 different building roughness types are adopted. It is found that the arrangement of roughness can strongly affect the local wind load on building. Results show that these roughness plate shows adverse effects on the positive pressure on windward face, which means the positive pressure is increased due to the presence of roughness. But the extreme negative pressure coefficient with roughness can be 36% lower than the smooth surface building.

Introduction

High-rise buildings become more and more popular in large cities in recent years. While high-rise buildings are wind sensitive structures. Therefore, the wind resistance design of claddings becomes one of the major issues for high-rise building design.

It is known that many factors can affect the effects of wind on structure, such as the shape, incident wind direction, ground roughness, and surface roughness of structure et. al. Cheung et al.[1] studied the mean, maximum and minimum pressure distribution of windward and leeward face of a building with Height to breadth ratio 2:1. Many researchers have tried to improve the structure's property for wind resistance design. Tanaka et al.[2] studied the wind effects on various shapes of building and different helical shaped high-rise buildings. Bandi et al.[3] studied several triangular cross section type building, found out the unfavorable wind direction and cross section type. Lin et al.[4] checked wind load characteristics of buildings with different height ratios.

Although modifying the cross-section or vertical section of high-rise buildings can effectively reduce the wind effects on structure, such measures will also affect the space for human activities, and thus increase the cost of the building. Tse, et al.[5] studied several high-rise buildings with different cross sections，and discussed their affections on the economic cost of building. Stathopoulos, et al.[6] quantitatively studied the balcony's effects on the wind pressure of building. They also made suggestions on the design of balcony based on their study. Maruta, et al.[7] studied the effects of structure's surface roughness on the wind effects，analyzed different arrangements of balconies. However, their studies only considered very limited types of arrangements of surface roughness, studies on many more arrangements are still needed.

This study will check several different roughness arrangements' effects on local wind pressures based on wind tunnel experiment, analyze the mean, standard deviation(STD), and extreme pressure coefficients, and try to find out the best arrangements for cladding design, that will help engineers for their future work on high-rise building design.

Experiment arrangement

The wind tunnel experiment was carried out in HD-2 boundary layer wind tunnel of Hunan University, China. The cross section of wind tunnel is 3m in width, and 2.5m in height. City terrain was simulated for the incident wind profile, with roughness exponent α=0.3. The geometrical scale ratio of building model is 1:300, wind speed ratio is 1:5, and the time scale is 1:60. The mean incident wind speed at top of model is 12m/s, corresponding to 60m/s in prototype. The size of model is depth: breadth: height 100mm: 100mm: 500mm. 420 pressure taps are set on the model surface at 15 levels, with each level 28 taps, as shown in Fig. 2. Since the wind load acting at upper part of the building contribute more to the overall wind load, the more taps were set at the upper part for detailed checking of wind load.

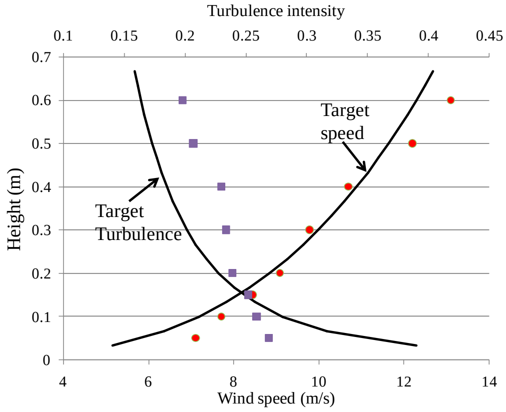

Fig. 1 Wind profile of the wind tunnel test

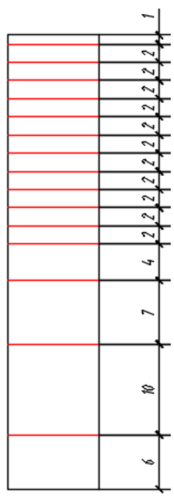

Fig.2 Layout of pressure taps in height (cm)

Five different roughness arrangements were adopted in this study, as shown in Fig. 1 and described in Table 1. The width of the roughness plate is 12.5mm. And the distance between each level is 20mm. Type 1 is smooth surface for comparison; continuous plate with the same breadth of building was set at each level in type 2. In type 3-5, the plates are not continuously mounted on at each level. For type 3, 30mm long plates are arranged at the two end of each face on each level. While type 4 three 20mm long plates are set two ends and middle at each level for each face. And type 5 is similar as type 3 with only difference replacing the 30mm long plates in Type 3 by 20mm long plates.

As the building model is symmetric, so incident wind direction in this study was 0°-45°, with 5°interval. The sampling frequency is 330Hz. Eight 10s long samples were collected for each wind direction, with each sample corresponding to 10min long sample in full scale.

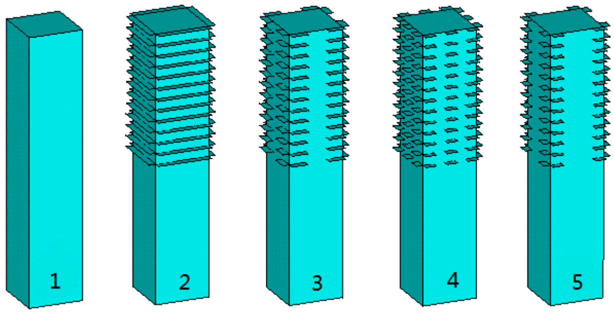

Fig. 3 Models used in the experiment

Table 1 Plate arrangement

Type	Arrangement	Overall length L（mm）
1	/	0
2	Full	100
3	30__30	60
4	20__20__20	60
5	20__20	40

Results and discussion

Mean and STD of local pressure

When wind direction is 0°, which means it is normal to one face of the model. The mean and STD pressure coefficients on the windward face of the five models are examined and shown in Figs. 4 and 5. It can be checked mean pressure coefficients of all five models are very similar. The largest difference of the largest mean pressure coefficients of them is about 5%. However, the largest $C_{p,std,0}$ of the model with roughness plate can reach 0.3, the largest $C_{p,std,0}$ of the smooth surface model is just 0.21. That means when the roughness plates are mounted, the STD of the pressure coefficients become larger than the smooth surface case. Such results indicate that the roughness plate or balcony on the windward face may enlarge the positive local wind load.

Since the negative pressures are critical for cladding design, the mean and STD wind pressure coefficients at wind direction θ=0° is shown in Figs. 6 and 7. It is clear that when roughness is mounted on the building surface, the mean and STD pressure coefficients are all reduce compared with the smooth model of Type 1. Comparing the results for Type 2-5, it can be seen that, values of Type 2 and 3 are lower than that of Type 4 and 5, no matter the mean or STD pressure coefficient. Such results indicate that both the length and the position of plates is very important in affecting the local wind load. When the plates are placed at the upwind corner of the side face, they effectively reduce wind load at the upwind direction of side face. One more results can be noticed that, comparing the smooth model, the STD pressure coefficients of roughness model have larger values at the upwind corner of the side face, such results can be observed in all wind directions.

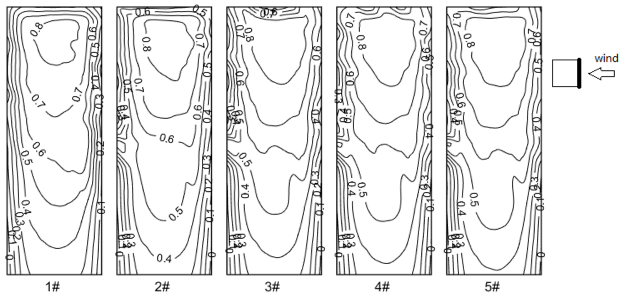

Fig. 4 Contour of $C_{p,mean,0}$ of windward face for 5 models

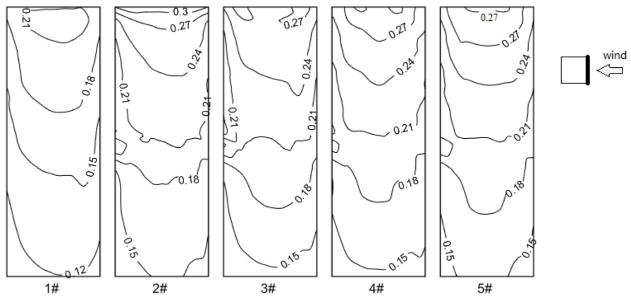

Fig. 5 Contour of $C_{p,std,0}$ of windward face for 5 models

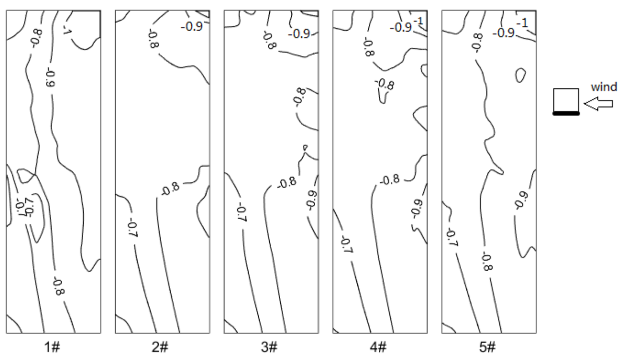

Fig. 6 Contour of $C_{p,mean,0}$ of side face for 5 models

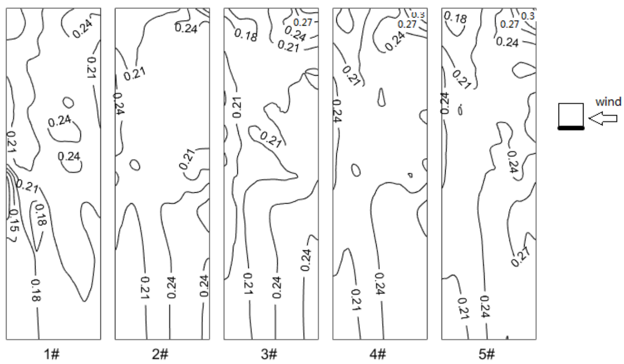

Fig. 7 Contour of $C_{p,std,0}$ of side face for 5 models

Extreme wind pressures

Extreme pressure coefficients are crucial for cladding design. In this study, the widely used Cook-Mayne method is adopted for estimation of extreme local wind load. The mean recurrence interval(MRI) of 50 year is used as design target. Cook-Mayne method for positive or negative extreme peak wind pressure coefficient is estimated as follows:

$$\hat{C}_p = C_p + 1.4 / a_c \quad (1)$$

where C_p and $1/a_c$ are the mode and scale parameter of the extreme distribution of pressure coefficients, and 1.4 is the coefficient corresponding to the 50-year MRI design.

Under 0° wind direction, the extreme positive peak pressure coefficients of the five models are 2.2, 2.1, 2.3, 2.4, and 2.5 respectively. The differences of the extreme values are about 10%-15%. Although the differences of extreme positive peak pressure coefficients of all five models are not quite large, it can be checked in Fig. 8 that the distribution of the extreme pressure distribution with roughness plates are very different with the smooth surface model. Especially for Type 2, the area of large positive peak pressure is clearly bigger than the results of Type 1. That means more claddings need to be designed for higher largest positive peak pressures when the roughness plates or balcony are going through the whole windward face. The results of Type 3 to 5 seem not as unfavorable as the Type 2, which means the discontinuous plates are better for the positive local wind load.

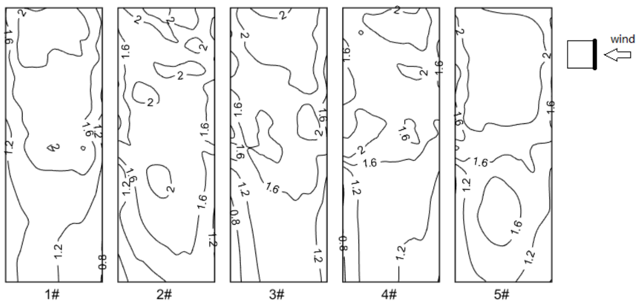

Fig. 8 Contour of $C_{p,max,0}$ of windward face for 5 models

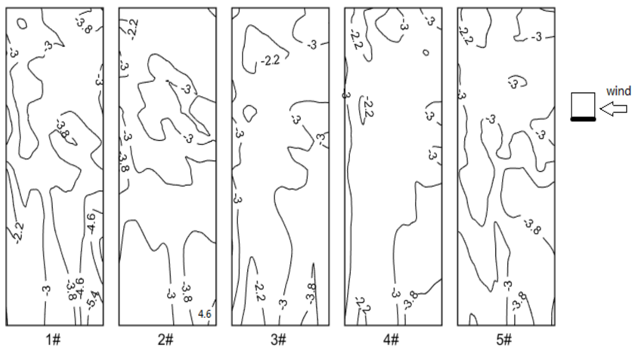

Fig. 9 Contour of $C_{p,min,0}$ of side face for 5 arrangements.

The negative extreme pressure coefficients of the five models are -6.1, -4.0, -3.9, -4.4, and -4.5 respectively. The largest difference of the five conditions is about 36%, which clearly indicates the effects of surface roughness on the extreme local wind load. As shown in Fig. 9. It can be checked that the largest negative extreme pressure coefficients of all five model appear at the upwind lower corner of side face. The differences of the results from Type 2-5 also suggest that the arrangement of roughness plate can also strongly affect the local wind effect. The results shows that Type 2 and 3 has the lowest negative extreme peak pressure coefficient, which means the longer plats at the two ends of the side face can reduce the extreme local wind pressure. However, the similar values of Type 2 and 3 indicate that length of roughness plate has its limit on the affections of local extreme wind load.

It can be seen in Fig. 9 that, the largest negative peak pressure is most likely to occur at the upper and lower upwind corner of side face, as shown in the region 1 and 2 of Fig. 10. While the value in Region 2 is usually higher than that in Region 1.

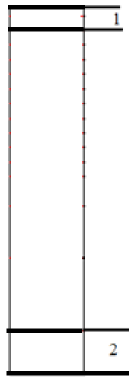

Fig. 10 Region of large negative peak pressure

The largest extreme negative wind pressure coefficient in Region 2 under different wind directions are shown in Fig. 11. It can be seen that although Type 2 model has very small local extreme negative wind load at 0°, it has quite similar value with smooth model at 5°. It means that the effects of Type 2 arrangement are not versatile for all incident wind direction. While model 3 shows the smallest negative extreme local wind pressure in all five models, which suggest the most favourable roughness arrangement. These results also shows a interesting phenomenon that although the roughness plates are all arranged at the upper half of the building, the largest value at the lower corner can still be strongly reduced.

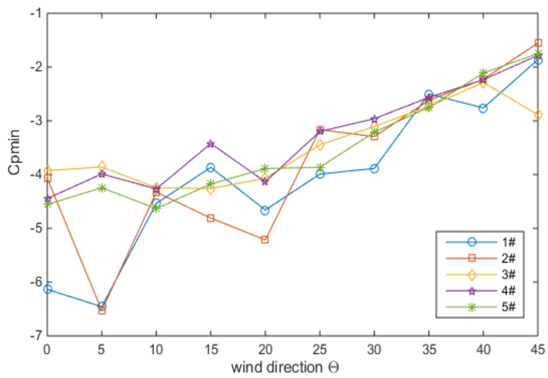

Fig. 11 Largest negative extreme local wind pressure coefficients in Region 2 under different wind directions

The largest extreme negative wind pressure coefficient in Region 1 under different wind directions of all five models are shown in Fig. 12. It can be seen that the Type 1 model is still the worst in all five models. The largest negative peak pressure coefficient can lower than -5.5. While the largest value of Type 2-4 are all about close or higher -4.0. And Type 2 shows the best results among all five model in this case, which means that the continuously arrange plate can have the most significant effects on the largest negative peak pressure at the upper corner of side face. While Type 3 and 4 have similar effects on it based on the results, and the effect of Type 5 is the weakest. These results indicates that the length of roughness plate shows clearly effects on the negative peak pressure at the upper corner, the longer the plate, the lower the peak value.

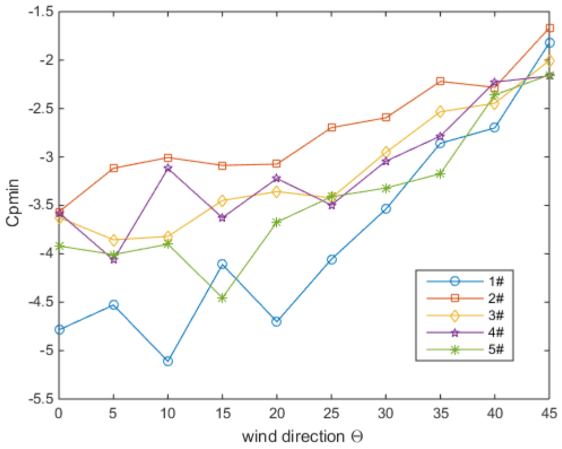

Fig. 12 Largest negative extreme local wind pressure coefficients in Region 1 under different wind directions

Conclusions

The wind pressure of high-rise buildings with and without surface roughness is studied based on the wind tunnel experiment. The thin plate is adopted as the surface roughness source in this study which simulate the balcony of buildings. The mean, STD, and extreme pressure coefficients are examined for 5 different models which have same building size but different roughness arrangements.

Based on the experiment results, it is found that the roughness plates show adverse effects on the positive pressure on the windward face. The maximum peak pressure with roughness can be 15% higher than the smooth model. And depends on the arrange of plate, the distributions of pressure in windward face are quite different.

The roughness shows more prominent effects on the negative pressures. Both large negative pressure at upper and lower corner of the side face can be significantly reduced by the plates. The largest negative peak pressure on the side face with roughness can be 36%. Results also suggest that the very closely spaced roughness such as long continuous plate that runs through the entire face is not necessarily the best arrangement for reducing the local wind load, although the length of plate clearly shows its effects on it.

Acknowledgments

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