

Investigation on wind tunnel blockage effect of super high-rise building

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ABSTRACT: As the significant difference in wind tunnel data between two scaled models of a practical engineering, the cause of this difference, which was regarded as blockage effect, was analyzed in this paper. Research shows that, for wind tunnel test with more surrounding buildings, blockage effect may result in serious data distortion, especially for lateral wind pressure, and existing correction method does not possess universality. Moreover, blockage ratio, as a global concept, is not appropriate to evaluate blockage effect of wind tunnel pressure data at different parts of building models. This study has reference value for blockage effect of wind tunnel pressure data in practical engineering.

KEYWORDS: blockage effect rectangular high-rise building wind pressure coefficient wind tunnel test

1 INTRODUCTION

Wind field of models in wind tunnel has wall boundary, while the wind field of actual structure in the atmosphere is unbounded. Simulation of unbounded atmospheric flow field in the bounded wind tunnel **will** bring the wall interference. Lateral constraint of flow field around the model by the wind tunnel boundary is known as the body obstruction, and the lateral constraint of the wake flow field is known as the wake blocking, namely, which are blocking effect.

Blocking effect seriously affected the accuracy of test data in some cases. Taking an example that blocking ratio is 15% in the wing - body combination model wind tunnel test, when the attack angle is 90° , the correction value of the drag coefficient reaches 88% of the measured values^[1]. Saathoff and Melbourne found through the study on rectangular building blocking effect that when the blocking ratio is 5%, the mean lateral wind pressure near the corner increased by 15%, the root variance of wind pressure increased by 20%^[2], which shows the blocking effect of test data cannot be ignored. However, building wind tunnel tests, even when the obstruction is relatively large, its effects are often ignored^[3].

The blocking effects correction of aviation and automotive wind tunnel tests have been effectively developed. The correction methods used commonly are mirror method, the vortex lattice method, the wall pressure of Information Act^[4] and the Mercker semi-empirical method^[5]. However, due to the differences between the shape of the rectangular buildings and aircraft, as well as cars, the above methods cannot be applied to wind tunnel blocking effect correction of rectangular building models.

Wind engineering researchers have investigated on wind tunnel blocking effects of rectangular building models for several decades. As early as 1978, Awbi proposed blocking effect correction method for two-dimensional rectangular section^[6] on the basis of the Maskell theory, he believed that the difference of the aspect ratio of rectangular cross section should be taken into account for the blocking effect correction, the blocking effect of the long side windward without reattachment, is more obvious than the shorter side windward^[7]. Cherry, Melbourne, et al also pointed out that the

average length of the bluff body surface reattachment will decrease with blockage ratio increasing. Cherry's test results showed that 5% of the blockage ratio makes reattachment length reduce by 20% [8]. According to these theory results, blocking will not only affect the size of the surface pressure, but also affect the pressure distribution. Therefore, the blocking effect mechanism and correction formula based on the Maskell assumption, that the blocking effect affects only the size of wind speed and doesn't affect the pressure distribution, has not been widely accepted. After that, Saathoff [2], Hunt [9], Noda, [10], Atsushi Okajima [11] et researchers also researched on the blocking effect with special wind tunnel tests or numerical simulation. While a large number of scholars are concerned about and studied on the blocking effect of the rectangular cylinder, but so far there is still no generally accepted blocking effect theory and correction method of wind tunnel test for practical rectangular tall building models.

The research objects of above-mentioned studies are single rectangular buildings, the results of these studies can be summarized as follows: 1、 blocking effect of the along wind pressure on a rectangular cylinder is very small, makes the lateral pressure increase, change the lateral pressure distribution as the result. 2、 most of the blocking effect correction methods focus on the correction of dynamic pressure, however these methods did not jump out of the stereotype of Maskell assumptions. This study found that the above conclusion cannot be applied to the wind tunnel test of an actual building project with group effects.

2. WIND TUNNEL TEST

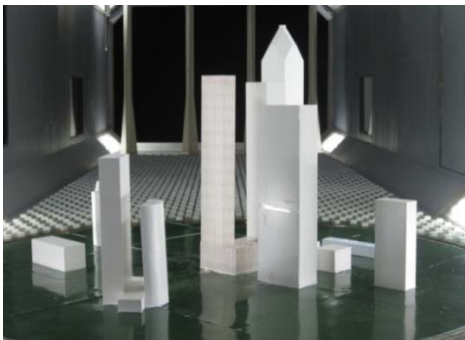


Fig. 1 1/300 model

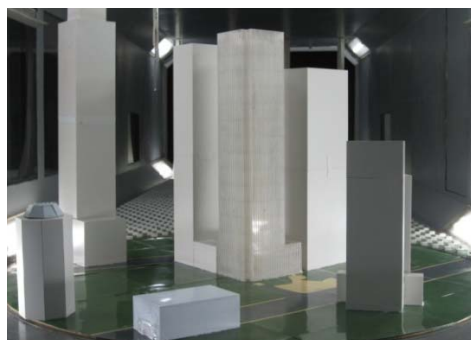


Fig. 2 1/200 model

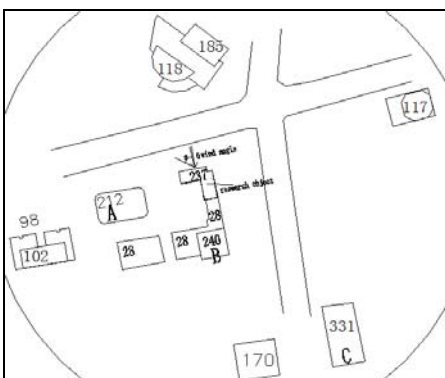


Fig. 3 layout of surroundings

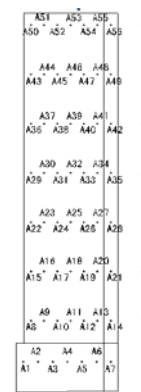


Fig. 3 layout of test points

The layout of manometrical model and surrounding buildings with 1/300 geometrical scale in wind tunnel is shown in Figure 1, the layout of those with 1/200 geometrical scale in wind tunnel is in Figure 2, and two sets of models are same except the geometry sizes. The general layout of the

building surrounding is shown in Figure 3. Among the models, the manometrical model is simulating a 237m-highrise building with rectangular cross section. In actual wind field, there are 9 surrounding buildings whose heights are above one hundred meters, where Building A is 212m, Building B is 240m, and Building C is 331m. The wind tunnel test was carried out in low-speed test section (3m x 2m) of the CGB-1 wind tunnel in Guangdong Provincial Academy of Building Research, and the test wind field is the C category, according to China's code. Under the wind azimuths of 0°, the blocking ratio, the ratio of effective frontal area S to wind tunnel cross-sectional area, reaches the maximum, which were 8.9% for the 1/200 models and 4.1% for 1/300 models, respectively.

3. ANALYSIS OF EXPERIMENTAL DATA

3.1 mean wind pressure coefficients

The mean wind pressure coefficients of the test points on the along wind side, leeward side and the lateral side are illustrated in Figure 5, 6 and 7 respectively, where the abscissa is the point number. The pressure coefficients of 1/300 model are relatively close to those of National Building Codes, To facilitate the analysis here, the difference between the pressure coefficient of 1/200 and 1/300 models is called the absolute difference, the ratio of absolute difference to the pressure coefficient 1/300 model is called the relative difference (seen in Equ. 1 to 4). Figure 8 illustrate the pressure coefficient relative difference on the along wind side, leeward side and the lateral side.

Mean pressure of test points:

$$\bar{w} = (\sum_{i=1}^N w_i) / N \quad (1)$$

Mean wind pressure coefficient:

$$\mu_s = \frac{\bar{w}}{w_{h_{ref}}} \left(\frac{h_{ref}}{h} \right)^{2\alpha} \quad (2)$$

Absolute difference between the mean wind pressure coefficients:

$$\Delta_1 = |\mu_{s200} - \mu_{s300}| \quad (3)$$

Relative difference between the mean wind pressure coefficients:

$$\Delta_2 = |\mu_{s200} - \mu_{s300}| / |\mu_{s300}| \quad (4)$$

Where the mean wind pressure $\bar{w}$ of 1/200 model is corresponding to the pressure coefficient μ_{s200} of 1/200 model and the mean wind pressure $\bar{w}$ of 1/300 model is corresponding to the pressure coefficient μ_{s300} of 1/300 model. h_{ref} is the height of the reference point, and $\bar{w}_{h_{ref}}$ is the wind pressure of the reference point. N is the number of the wind pressure time history sample data, and w_i is the wind pressure at i th time.

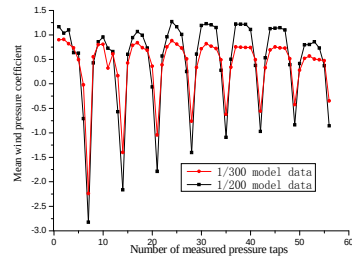


Fig. 5 mean along wind pressure coefficient

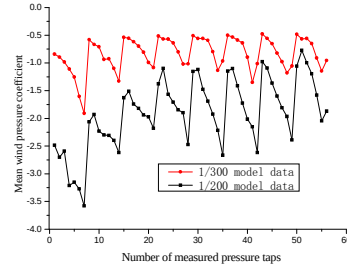


Fig. 6 mean lateral wind pressure coefficient

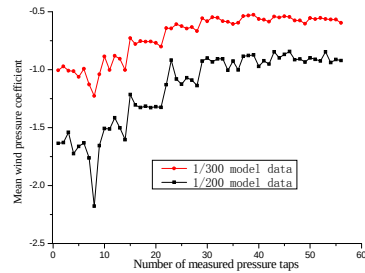


Fig. 7 mean leeward wind pressure coefficient

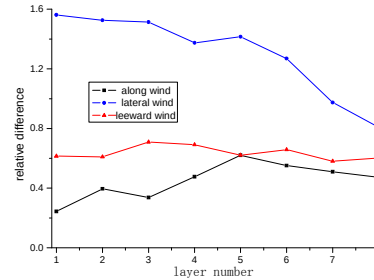


Fig. 8 relative difference of mean wind pressure coefficient

It can be seen from the figures:

a. The absolute value of mean wind pressure coefficients of 1/200 model is much larger than those of 1/300 of load cell model. b. In Figure 5, the mean wind pressure coefficient curves of two model change consistent, along wind pressure distribution doesn't change much with different blocking ratios. In Figure 6, the trend of the two curves is very different, and the peak position is not the same. c. As the height increases, the difference between the two curves is decreasing. It should be noted that the along wind pressure of some points is negative, due to the edges of the building and the surroundings. In fact, the blocking ratio of 1/300 model is still 6.7%, blocking effect exists, thus, the difference between the test data of 1/200 model test data and the correct values should be greater.

It can be seen in Figure 8, the relative difference on the lateral side is more significant than those on the along wind side and leeward side; furthermore, the relative difference of lateral side decreases along the height and the along wind relative differences increase at the beginning, and then decrease along the height. The reason can be explained as follow: the lateral wind pressure is influenced by the blocking effects caused by the manometrical model itself and the surrounding model, and the accelerated air would inevitably lead to the increased pressure coefficient. On the along wind side, in a certain height range from the bottom the blocking effect is the most serious, according to the basic characteristics of the boundary layer of fluid motion, the bottom blockage which has a most serious blockage ratio, will not significantly cause flow velocity changes, but it will only affect on the stream lines high away badly. In the middle of the pressure measurement model, the wind velocity changes most serious; the relative difference near the tor of the mean wind pressure coefficients is small because this effect there is weak, together with the blocking effect of the height decreasing. It is made that the along wind relative differences increase at the beginning, and then decrease along the height. Ultimately that makes the relative difference on the along wind side trend with height first increases and then decreases. Generally, the blocking ratio is definite as an overall concept, but in fact, the degree of blockage along the high greatly affects the quantitative analysis of the blocking effect in wind tunnel tests with surrounding buildings, which is one reason why correction method is not applied to the actual engineering of wind tunnel test.

3.2 RMS wind pressure coefficients

RMS pressure coefficients and differences can be obtained as follow:

RMS wind pressure of test points:

$$w_{\sigma} = \left(\frac{\sum_{i=1}^N w_i^2 - N \bar{w}^2}{N} \right)^{0.5} \quad (5)$$

RMS pressure coefficients:

$$\mu_{\sigma} = \frac{w_{\sigma}}{w_{h_{ref}}} \left(\frac{h_{ref}}{h} \right)^{2\alpha} \quad (6)$$

Absolute difference between the RMS wind pressure coefficients:

$$\Delta_{\sigma 1} = |\mu_{s\sigma 200} - \mu_{s\sigma 300}| \quad (7)$$

Relative difference between the mean wind pressure coefficients:

$$\Delta_{\sigma 2} = \frac{|\mu_{s\sigma 200} - \mu_{s\sigma 300}|}{|\mu_{s\sigma 300}|} \quad (8)$$

Where the RMS wind pressure w_{σ} of 1/200 model is corresponding to the pressure coefficient

$\mu_{s\sigma 200}$ of 1/200 model and the RMS wind pressure w_{σ} of 1/300 model is corresponding to the

pressure coefficient $\mu_{s\sigma 300}$ of 1/300 model.

The comparison charts of the RMS coefficients of the points on the along wind side, leeward side are illustrated respectively in Figure 9, 10 and 11, and in Figure 12 is for the pressure coefficient relative difference on the along wind side, leeward side. It can be seen: the lateral and the along wind and leeward relative differences are small, the lateral relative difference is significant. The RMS wind pressure of 1/200 has been severely distorted, thus, extreme pressure cannot be for engineering wind assessment. It can also be seen from Figure 12, the relative difference of the RMS coefficients on three sides significantly changes along the height, the curve trends are consistent with those of the mean pressure coefficients.

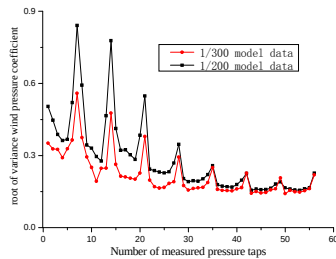


Fig. 9 RMS along wind pressure coefficient

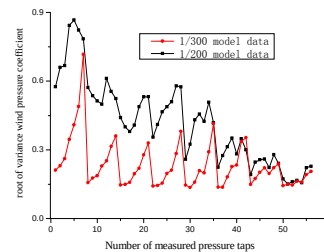


Fig. 10 RMS lateral wind pressure coefficient

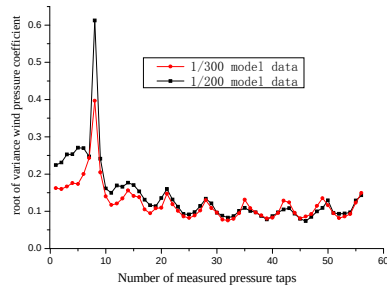


Fig. 11 RMS leeward wind pressure coefficient

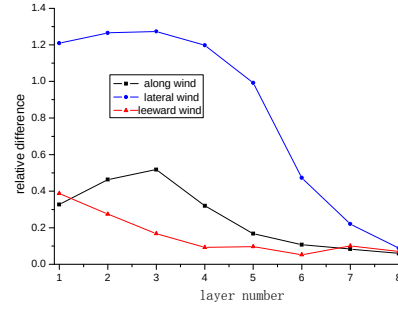


Fig. 12 relative difference of RMS wind pressure coefficient

3.3 data results with correction of reference pressure

There are many blocking effect correction methods, but the pressure data are corrected on the overall proportion according to them. Literature 14 considered that the model blockage makes the wind through the model at wind speed slightly higher than the calibration of no-load wind tunnel, when the air flows through the model, the dynamic pressure at the place in the calculation of the pressure coefficient correction method: $q = q_0(1 + 1.25\varepsilon)$. where, when the air flows through the empty wind

tunnel model, q_0 is dynamic pressure, ε is blockage ratio. In fact, this correction method is actually that the pressure coefficient is multiplied by the adjustment factor which is less than 1. This correction method extends to be applied to the wind tunnel tests of the building structures. In fact, it is equivalent to the correction of wind speed of the reference point. In this paper, the experimental data were corrected by the correction method in the literature 14.

Figure 13 and Figure 14 shows after the correction of the pressure at the reference point the relative differences of the mean wind pressure coefficient and RMS wind pressure coefficient difference. It can be seen that the relative difference has increased after the correction, but the reduction is only about 10%. And correction of the reference point wind speed is just changing the whole pressure measurement data on the scale, regardless of the differences and other factors among the three sides. This means that the pressure errors of the reference point affect of on the data distortion only a little, or the impact of the blocking effect cannot be eliminated fundamentally, solely by the amendment of the reference point pressure.

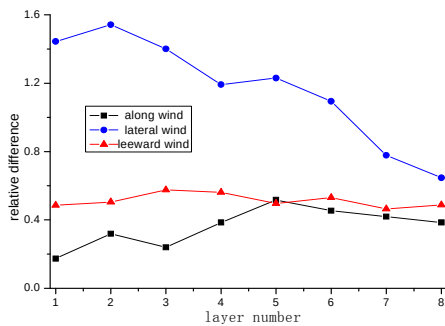


Fig.13 relative difference of the mean wind pressure correcting reference pressure

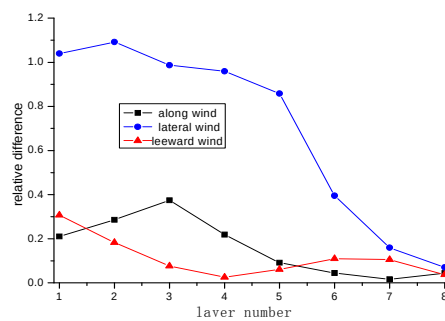


Fig.14 relative difference of the RMS wind pressure coefficient with correcting reference pressure

4. CONCLUSIONS

In this paper, the blocking effect on rectangular high-rise buildings with surroundings is studied; the conclusion can be summarized as follows:

- (1) Blocking effect on the pressure data cannot be ignored. When the blocking ratio is big, the change of pressure coefficient caused by obstruction is even more than double of the due pressure value without interference
- (2) Blocking effect influences the lateral wind pressure greatly, and also changes the lateral wind pressure distribution to some extent; the change on pressure data of windward and leeward caused by blocking effect is relatively small.
- (3) For wind tunnel data of high-rise building model with many low surrounding buildings, the influences of blocking effect on its pressure coefficient change along the height significant. In the amendment to blocking effects, blocking effect influenced by the degree of obstruction at different heights should be considered.
- (4) For wind tunnel data of rectangular building model with surroundings, blocking mechanism is very complex, so far, there is no universal theory and proper correction method to solve this problem, thus reasonable proportion of the model to control the blocking effect is particularly important.

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