Estimation method of the extreme wind pressure of cladding structures based on similarity law

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SUMMARY:
In this study, the method of calculating the extreme wind loads of the cladding structure on a limited area by a certain time-span moving average of the wind pressure time history is analyzed. And considering the similarity law of the Strouhal number and the similarity law of the flow scale, a more reasonable value of the moving average time is proposed. Due to the limitation of test equipment, the turbulence integral scale simulated by the wind tunnel test is usually smaller than the target value. This will lead to the unsatisfactory similarity law of incoming flow scales. The dissimilarity of the inflow scale will significantly affect the simulated gust front area and gust duration. This causes the time scale of the incoming flow to be inconsistent with that determined from the similarity law of the Strouhal number, thereby affecting the wind loads of the cladding structure as measured by wind tunnel tests. Therefore, it is an effective means to obtain a reasonable wind load on the cladding structure by considering the similarity law of the incoming flow scale to determine the moving average time.

Keywords: extreme wind pressure, cladding structure, similarity law, turbulent integral scale, wind tunnel tests

1. INTRODUCTION

In the pressure test of the rigid model, the full-scale tributary area of the pressure holes is usually required to be less than 120m^2 (Australia and Zealand, 2002; Lo, 2005) for ensuring the accuracy of measurement and avoiding the mutual influence of over-dense pressure holes. In order to ensure sufficient frequency domain resolution, the cut-off acquisition frequency of the measurement system is usually set to four times 1 Hz of the full-scale structure (Lo et al, 2005). The cut-off acquisition frequency reflects the range of eddy sizes that affect the safety of the structure. The range of different eddy sizes in the incoming flow affects the gust frontal area (Holmes and Allsop, 2012). The larger extreme wind pressure coefficient measured at a larger acquisition frequency corresponds to a smaller gust front area. However, the tributary area of the pressure holes in the wind tunnel test is relatively large, which will lead to a relatively large design wind load of the cladding structure obtained from the wind tunnel test. In current structural design codes, an area reduction factor is usually introduced to correct this effect so as to obtain a relatively good design load value. In some previous studies, the moving average time considering wind speed and the tributary area was also introduced to correct this effect (Holmes, 1997; Lawson, 1976). This correction method is based on the similarity law of the Strouhal number, and the reasonable value of the design wind load of the cladding structure is obtained by a certain time-span moving average of the wind pressure time history. On the other hand, due to the limitation of wind tunnel equipment, the turbulence integral scale simulated in wind tunnel is usually too small. The smaller turbulence integral scale, the obtained design wind load of the enclosure structure is smaller (Yang et al, 2022). The correction for the effect of this dissimilarity of flow scale on wind loads has been rarely addressed in previous studies. The dissimilarity of the incoming flow scale will make the gust simulated in the wind tunnel different from the gust in the actual atmospheric boundary layer, which will affect the gust front area and gust duration, making it impossible to obtain a reasonable wind load on the envelope. Based on the moving average method, this paper proposes a method of calculating the moving average time considering the similarity law of Strouhal number and the similarity law of flow scale to correct the influence of different flow scales on the design wind load of the cladding structure. This study can provide a valuable reference for obtaining a more reasonable wind load on the cladding structure.

1. EXPERIMENTAL SETUP

The pressure on the windward at the height of 2/3 of the CAARC model is collected in four flow fields with the same turbulence intensity and different turbulent integral scales. The collection duration is 180s and the collection frequency is 256Hz. The pressure measurement signals are all corrected. The parameters of the test cases are listed in Table 1.

Table 1. The parameters of cases.

Cases	λ_D	U(m/s)	I_u	L_u^x (m)	L_u^x / D
W1	1: 200	9.0	0.125	0.831	3.64
W2	1: 300	12.6	0.128	0.321	2.11
W3	1: 200	13.3	0.123	0.255	1.22
W4	1: 100	10.0	0.127	1.328	2.90

The full-scale tributary area of the pressure holes is 60m^2 (6m×10m)。The turbulence integral scale at the height of 2/3 of the prototype is 160m (Manwell et al, 2010). So W1 case is the standard case satisfying similarity law of incoming flow scale. W4 is the validation case of the method proposed in this paper.

2. EXTREME WIND PRESSURE BASED ON AREA REDUCTION FACTOR

The design wind load of cladding structure can usually be calculated by the following formula (Australia and Zealand, 2002):

$$P = K_a K_o \beta \mu q \tag{1}$$

where K_a is the area reduction factor，K_o is other influence factors (e.g. wind direction, structural importance, etc.)，β is the gust factor，μ is the local shape coefficient，q is the basic wind pressure. Among them, the gust factor and local shape coefficient need to be obtained through wind tunnel tests. For the tributary area of the pressure hole with a size of 60m^2, K_a is usually taken as 0.85 (Australia and Zealand, 2002). The extreme wind pressure coefficient after corrected by the area reduction factor can be calculated by the following formula:

$$C_{\text{peak}} = K_a \beta \mu \tag{2}$$

The above equation can be calculated by extreme value theory (Davenport, 1964).

Fig. 1 shows the extreme wind pressure coefficients at the stagnation point area on the windward of the three test cases W1, W2, and W3. It can be seen that with the decrease of the turbulence integral scale, the extreme wind pressure coefficients obtained from the wind tunnel test gradually decreases. Among them, the extreme wind pressure coefficient of standard case W1 is the correct result.

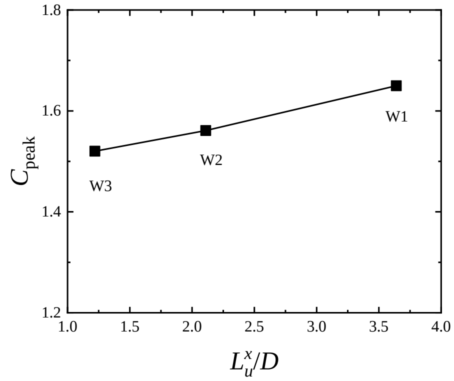

Figure 1. The extreme value wind pressure coefficient corrected by the area reduction factor.

3. EXTREME WIND PRESSURE BASED ON MOVING AVERAGE

In the frequency domain, the τ-second moving average is a transfer function as the form:

$$|H_2(f)|^2 = \left(\frac{\sin(f\pi\tau)}{f\pi\tau} \right)^2 \tag{3}$$

The widely accepted method based on similarity law of Strouhal number for determining the moving average time is $4.5L/U$， L is the maximum side length of the tributary area (Lawson, 1976). Then the moving average time in this study should be 1.25s. Fig. 2 shows the extreme wind pressure coefficients of W1, W2, and W3 under different moving average times (the observation duration is 600s). It can be seen from the Fig. 2 that for the standard case W1, the moving average time can be well determined according to $4.5L/U$, so as to obtain a suitable extreme wind pressure coefficient of the cladding structure. However, for W2 and W3 with dissimilarity of flow scales, this method of calculating the moving average time underestimate the extreme wind pressure coefficient.

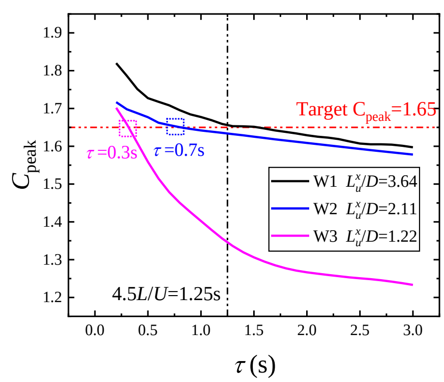

Figure 2. The extreme value wind pressure coefficient corrected by the area reduction factor.

According to the reasonable moving average times of the three cases, this study introduces the similarity law condition (L_u^x / D) of the incoming flow scale to modify the moving average time value method:

$$\tau = (1.4 L_u^x / D - 0.5) L / U \tag{4}$$

According to formula (4), the reasonable moving average time of W4 case should be 0.99s. The extreme wind pressure coefficient in the stagnation point area of W4 case is calculated as 1.64 after 0.99s moving average, which is similarity law of to the result of standard case W1. This proves the reliability of the conclusions of this study.

4. CONCLUSIONS

In this study, a method of calculating the moving average time considering the similarity law of Strouhal number and the similarity law of flow scale to correct the influence of different flow scales on the design wind load of the cladding structure. This method can effectively eliminate the influence of dissimilarity of flow scales on the design wind loads of the cladding structure obtained from wind tunnel tests. Although this study only analyzes the wind pressure on the windward that satisfies the Gaussian distribution. However, this result still has valuable reference significance for calculating the design wind loads of cladding structure on the side, leeward, or separation area of the large-span space structure.

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