

Study on gust coefficient of solar power tower heliostat based on wind tunnel experiment

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Abstract. Heliostat is an important part of the tower solar thermal power generation system. In order to ensure the safety of the heliostat glass panel under wind load, wind resistant design parameters of the heliostat glass panel must be accurately achieved. Through accurate simulation of wind characteristics with the full measurement, heliostat scale rigid model of multi-channel synchronous wind tunnel experiment was conducted and obtained the wind pressure of heliostat panel under various conditions. Based on the analysis results, the gust coefficient for china's specification to design this type of heliostat panel was obtained. The results also show that the actual wind characteristic parameters have a great influence on the value of gust coefficient, and the value of gust coefficient decreases with the increase of the heliostat's height.

1. Introduction

Concentrating solar power (CSP) tower plant is a promising technology to solve the energy crises, and heliostat is a major portion of the direct costs of CSP. Heliostat is composed of support, beam, column and mirror panels etc. Wind load is one of the main loads of heliostat, to ensure the safety of the structure, from 1970s onwards, a great effort about wind load and wind-induced response was made by some scholars and a fruitful results was achieved ^[1-5].

In order to effectively reflect the sun's light on the endothermic tower, glass panels are typically used in practical engineering. Glass panels are directly exposed to the atmosphere, due to the need for work, the location of the mirror panel varies with the height of the sun. So the safety of the mirror panel should be paid special attention for the incoming flow. The heliostat field measurement results have showed the mirror panel stiffness was high ^[6], in accordance with the provisions of China specification ^[7], to acquire the load of mirror panels, the design methods of enclosure structure were used, which only considering the gust coefficient multiplied by the average wind pressure ^[8].

Previous studies were focused on wind load and wind-induced response of heliostat, but the safety of mirror panel was rarely involved, ignoring it will bring great trouble to the maintenance and operation of CSP tower heliostat.

In this paper, a certain type of heliostat was used as the research object, a scale rigid model was manufactured, and a wind field comparable with the results of field measurements was simulated in the wind tunnel laboratory ^[9]. Under the conditions wind pressure distribution of heliostat was obtained.



Built on the test results, the recommended value of gust coefficient suitable for heliostat structural designers in China was obtained.

2. Heliostat wind tunnel experiment

2.1. The general situation of the experiment

The wind tunnel experiment was conducted in an open test section of the Boundary Layer Wind Tunnel III at the Hunan University. The wind tunnel has a test section length of 11m, with cross section dimensions of 3m wide by 2.5m high at the measurement location, the diameter of the turntable is 1.8m.

The heliostat rigid model was made of organic glass, scaled by 1:30. A 8×8 arrangements of the measuring points in the each face of mirror panels were adopted and a total of 128 test points arrangement was used, the arrangement of measuring points as showed in Figure 1.

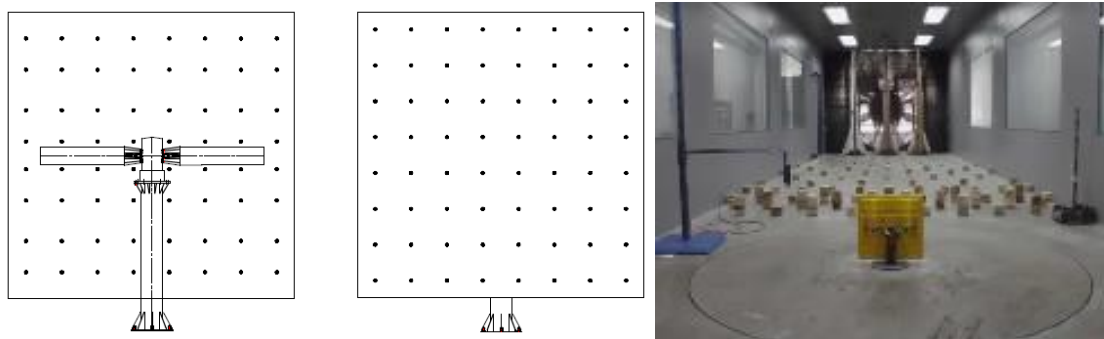


Fig. 1. Pressure tap layout on the heliostat model

In the wind tunnel test, the sampling frequency is 312.5Hz. According to the predetermined wind speed requirement of 14m/s, the corresponding sampling length for each working condition is determined to be 12000. After transforming the similarity criterion^[4], complies with the requirements of the 10 minute sampling time required for the prototype structure measured in China's specification. During the test, the azimuth angle adopted 0 degrees, 30 degrees, 45 degrees, 60 degrees, 90 degrees, 120 degrees, 135 degrees, 150 degrees, 180 degrees, and the elevation angles were 0 degrees, 30 degrees, 45 degrees, 60 degrees, and 90 degrees. In this paper, the working conditions are numbered by the way of alpha and beta. For example, 000-90 indicates that the azimuth angle is 0 degrees and the elevation angle is 90 degrees.

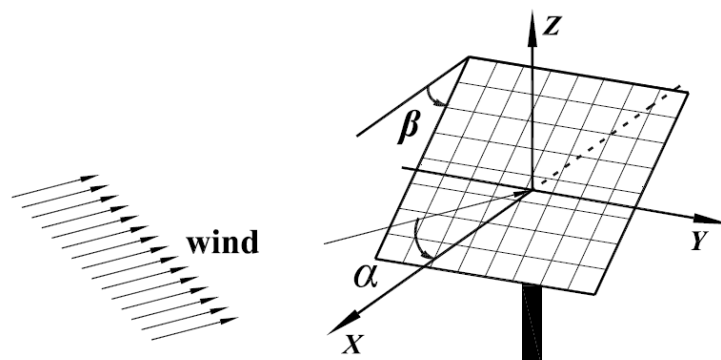


Fig. 2. Azimuth angle (a) and elevation angle (b)

The spires, baffle and roughness element was utilized to reproduce the mean velocity and turbulence intensity variation with height. Figure 3 presents the measured and target results of the mean wind profile and longitudinal wind velocity profile in 15m height range. Figure 3 shows the simulated wind profile

and turbulence profile in the wind tunnel are in good agreement with the results of field measured described in the literature ^[9], which is belongs to the class B ground roughness category in China specification. Note the mean wind speed profiles in the figure are normalized to the mean wind speed recorded at a height of 10m.

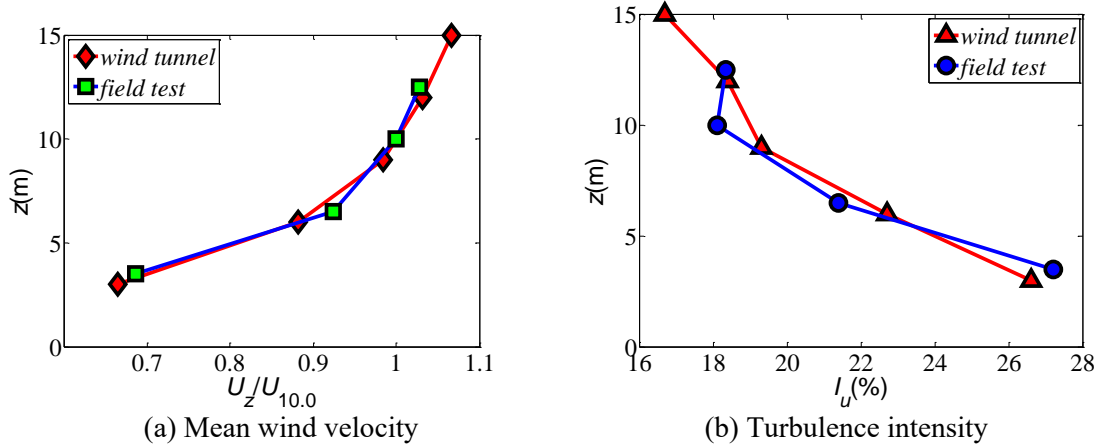


Fig. 3. Flow profiles compared with wind tunnel and field test

2.2. Data processing

Time history of wind pressure coefficient $C_{p,i}(t)$ is the ratio between the wind pressure of a measuring point on the surface of the structure and the pressure of remote flow. It can be defined as:

$$C_{p,i}(t) = \frac{P_i(t)}{0.5\rho U(z)^2} \quad (1)$$

Where $P_i(t)$ is the value of the pressure measured at the tap i and t is the time. ρ is air density, $U(z)$ is the average wind speed in wind tunnel at the reference height z . Because of the maximum height of heliostat not more than 10m in most conditions, therefore, $U(z)$ adopted to the height of 10.0m average wind speed in the process of data.

According to the formula (2) and (3), the statistical parameters, such as the mean wind pressure coefficients $C_{p,\text{mean}}$ and fluctuating wind pressure coefficients $C_{p,\text{rms}}$ of the test taps, can be obtained.

$$C_{p,\text{mean}} = \frac{\sum_{i=1}^n C_{p,i}(t)}{n} \quad (2)$$

$$C_{p,\text{rms}} = \frac{1}{n} \sqrt{\sum_{i=1}^n (C_{p,i}(t) - C_{p,\text{mean}})^2} \quad (3)$$

Where n is the data's length of the pressure time history.

Due to convenient to process and product, the mirror plate is often composed of many small plates. In order to ensure the safety of the mirror plate, the total pressure coefficients of each small plate can be defined as follows:

$$C_{p,i}(t) = \frac{P_i^f(t) - P_i^b(t)}{0.5\rho U(z)^2} \quad (4)$$

Where $P_i^f(t)$ and $P_i^b(t)$ are front and back surface pressures at the tap i respectively.

According to the formula (2) and (3), the total mean wind pressure coefficient and the total fluctuating wind pressure coefficient of each small plate can be obtained. The gust coefficient of each small plate can be used as follows:

$$\beta_{gz} = \max \left(\frac{C_{p,\max}}{C_{p,\text{mean}}}, \frac{C_{p,\min}}{C_{p,\text{mean}}} \right) \quad (5)$$

Where $C_{p,\max}$ and $C_{p,\min}$ are peak positive and peak negative pressure coefficients respectively. These coefficients is obtained by the peak factor method according to the standard of China ^[7].

3. Gust coefficient

3.1. The mean wind pressure under typical working conditions

The operating condition of Heliostat is numerous and limitations of space. It's unrealistic to describe all of the working condition. Research results of many scholar have showed that the force coefficient of heliostat is different under the most unfavorable operating conditions ^[3, 5]. Only 000-90 is taken as an example to show distribution of the mean wind pressure. The results are presented in figure 4. It can see that the whole facade is positive, the maximum value in the mirror panel is located at the height of about 3/4 and the corresponding value is more than 0.7. It is radially decreasing distribution from middle to four sides. The mean wind pressure coefficient of back facade were all negative and the distribution is almost uniform, and the value of it is -0.5 or so. The distribution shape of mean wind pressure after superposition is similar with the façade's, but its value is more than 0.5.

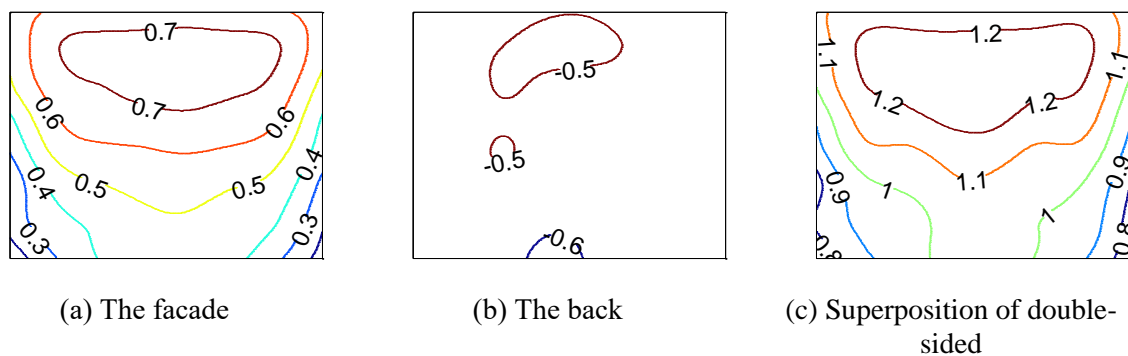


Fig. 4. The mean wind pressure coefficient contour of the mirror surface at 000-90

3.2. The fluctuating wind pressure under typical working conditions

To illustrate the distribution of fluctuating wind pressure, the 000-90 working condition is also selected for the same reasons, as shown in Figure 5. It can be seen from the diagram that the value of the façade is that the upper is larger than the lower, but the value of the back is almost uniform, and the superposition is still similar to the distribution of the vertical facade.

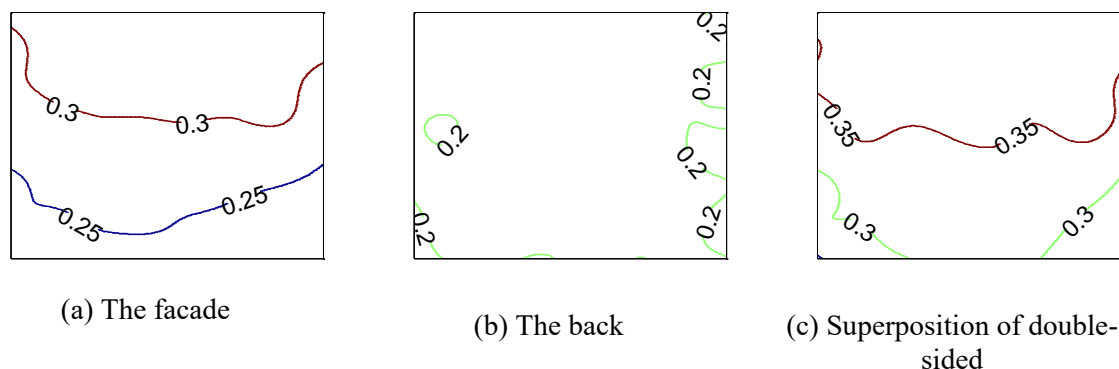


Fig. 5. The fluctuating wind pressure coefficient contour of the mirror surface at 000-90

3.3. Gust coefficient under typical working conditions

Similar to the previous reasons, the working conditions of 000-90 and 120-60 are selected as an example to show the distribution of gust coefficient, the results are shown in Figure 6. According to figure 4 and 5: the average wind pressure coefficient is generally larger and the change of fluctuating wind pressure coefficient is smaller at 000-90 working conditions, so the change of the gust coefficient is smaller, its value is about 1.8. The 120-60 cases has significantly different results, the minimum value is less than 2, but the maximum value is more than 100. The reason is that the mean wind pressure coefficient is quite small but the fluctuating wind pressure coefficient is relatively larger at the right side, and the difference is not so large at the left part.

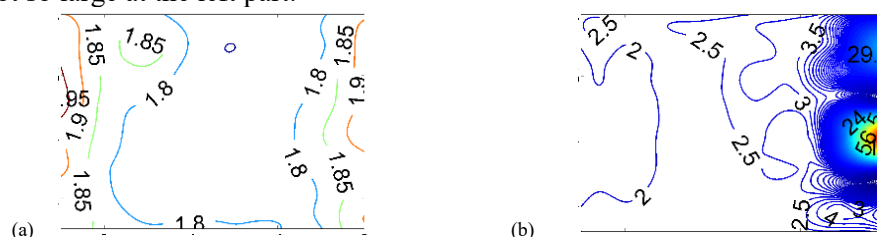


Fig. 6. The gust coefficient contour of the mirror surface at different working condition.
 (a)000-90; (b) 120-60

The working condition of heliostat is numerous, the results of same location under different working conditions have great changes. In order to convenient the designer and builder, the maximum and minimum values of mean wind coefficient at all measuring points under different working conditions are calculated based on the formula (4), and the envelope results of gust coefficients are obtained as shown in Figure 7. It can be seen that the gust coefficient is decreases with the height's increasing, the maximum value is 1.96, the recommendation value of gust coefficient is 1.96 comprehensively taking into account the production facilities and design.

The gust coefficient at B site was 1.70 within the scope of 10m height according to Chinese specification, which can be seen compared with the test results that the heliostat value is larger than the specification's value. The main reason is that the turbulence intensity of the actual wind field is larger than that of china code. For the maximum height of the heliostat is about 10m, it can be obtained that accurately acquire the actual parameters of wind characteristics is very important to ensure the safety of heliostat's mirror panel.

1.62	1.47	1.32	1.26	1.26	1.34	1.47	1.61
1.70	1.55	1.48	1.39	1.40	1.45	1.51	1.68
1.64	1.55	1.46	1.31	1.34	1.44	1.57	1.60
1.69	1.56	1.48	1.34	1.37	1.48	1.55	1.66
1.71	1.55	1.47	1.34	1.37	1.46	1.53	1.70
1.78	1.67	1.56	1.47	1.44	1.51	1.65	1.77
1.96	1.79	1.69	1.62	1.61	1.67	1.81	1.95
1.95	1.92	1.86	1.72	1.72	1.87	1.90	1.96



Fig. 7. Envelope diagram of gust coefficient

4. Conclusion

In this paper we have studied the gust coefficient of heliostat's mirror panel through pressure model testing in a boundary layer wind tunnel. The recommended value of gust coefficient for design in China code was obtained based on the heliostat wind tunnel experiment. The experimental results also showed that the wind characteristics near the ground have a greater impact on the gust coefficient. So the wind characteristic parameters of the actual wind field are very important to obtain accurate wind-resistant design parameters for heliostat.

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