Wind loads investigation on angle steel columns in lattice structures via force measurement method on members

Zhou Qi [1], Gao Yakun [2], Zhu Ledong [3]

[1] *Shantou University, Shantou, China, zhouqi@stu.edu.cn*
[2] *Shantou University, Shantou, China, 18ykgao@stu.edu.cn*
[3]*Tongji University, Shanghai, China, ledong65@tongji.edu.cn*

SUMMARY: It is hard to obtain the wind loads on the members in lattice angle steel structure in a traditional wind tunnel test. Due to some insurmountable defects, like the wings of angle steel aren't thick enough, although the pressure measurement method was once employed in rare cases, the results aren't worthy of trust. A novel wind tunnel test method–force measurement method on members, which directly measures the wind loads on members in a lattice structure , is proposed in this article. A column member in a lattice angle steel structure was investigated while a single angle steel column with a same shape as the member was also studied. Aerodynamic forces on both the member and the column were obtained under different conditions, such as flow field, wind speed, wind direction and solidity ratios. An effective skewed wind load factor and wind load proportion factors of members in lattice structure were proposed in this article, based on which the calculation of wind loads on members were also recommended.

Keywords: lattice angle steel structure, drag coefficient, skewed wind load factor

1. GENERAL INSTRUCTIONS

With the increasing demand for stress hierarchy analysis of lattice structures, the traditional method of evenly distributing the wind loads of the whole segment no longer meets the analysis requirements. Therefore, it is increasingly urgent to accurately obtain the wind loads of single member in lattice structures(Lou, 2013; Prud'homme, 2014 and Yang, 2019). In this article, the aerodynamic coefficients of an angle steel column in a typical lattice structure were experimentally studied by force measurement method on members via multiple mini balances, and the skewed wind load factors and wind load proportion factors of the column in the lattice structure were obtained. Moreover, the calculation method of related wind loads was established.

2. DESCRIPTION OF WIND TUNNEL TESTS

The experimental program consisted of two parts, the first dealing with the force measurement on a single angle steel column under different flow conditions and the second, with the force measurement of an angle steel member in a lattice structure under different wind directions. In the case of a single angle column, an equilateral angle steel with a shape of 50×2 was selected in the tests. In the case of the member in the lattice structure, a tower body with a rectangle section in a lattice transmission tower was investigated. The transmission tower is 85.5 m in nominal height and the selected tower body is 9.4 m high. Both models consisted of three parts, the upper and lower compensation sections, and the testing section in the middle. Models were all installed vertically at the mid-width of the test section, normal to the flow in the wind tunnel. Figure 1 shows two models in the wind tunnel and the installing detail of testing member. All the tests were conducted in three kinds of wind flow field, a smooth flow field and two kinds of grid turbulent flow fields which are with turbulence intensities of 5% and 10%. As for the lattice structure model, the testing member is 0.58 m with a scale ratio of 1:4, and the solidity ratio could change in a range from 0.32 to 0.52 with a gap of 0.03. As for the single angle member model, the testing section is 0.6 m with a scale ratio of 1:1. The wind direction in the all wind tunnel tests ranges from 45° to 225° with a gap of 5°, while the wind direction of 0° is along the positive X-axis of the lattice structure while the measuring member is on the windward.

Figure 1. Models in the wind tunnel: a) the lattice structure model; b) details of testing member; c) ways of change solidity ratio; d) the single angle member model**.**

3. AERODYNAMIC COEFFICIENTS AND SKEWED WIND LOAD FACTORS

3.1. Calculation of aerodynamic coefficients

In two kinds of wind tunnel tests, two mini-balances were installed on the top/bottom of the angle steel member/column. Therefore, the dimensionless mean aerodynamic force coefficients of the single column and the member in structure can be calculated using the following formula:

$$\mathbf{F}_{\mathrm{W}} = \mathbf{T}_{\mathrm{bw}}\mathbf{C}_{\mathrm{F}}\mathbf{F}_{b} = \mathbf{T}_{\mathrm{bw}}\mathbf{C}_{\mathrm{F}}\sum_{i=1}^{2}\mathbf{D}(i)\mathbf{f}_{\mathrm{b}}(i) \quad (1)$$

3.2. Characteristics of aerodynamic coefficients

As shown in Figure 2a, both the drag coefficients and lift coefficients under different wind speeds are relatively close to each other in all wind directions, likewise the resultant force coefficients which are SRSS of drag and lift coefficients. Figure 2b shows that in some wind directions, both drag and lift coefficients have obvious deviations, thus the remarkable differences of the resultant force coefficients are represent under different flow field. InFigure 3 , it could be found that, drag coefficients in the range of $45^{\circ} \le \theta \le 135^{\circ}$ are almost overlap each other while descend with the solidity ratio decrease in the rest range. The lift coefficients with different solidity ratios remain a similar change law except the range of $155^{\circ} \le \theta \le 195^{\circ}$, and keep dramatical variances under all wind directions. As shown in Figure 4 for the case of a single angle steel member, the effect of wind speeds on drag and lift coefficients is slight enough to ignore, while the effect of turbulence is dramatic especially on the lift coefficients.

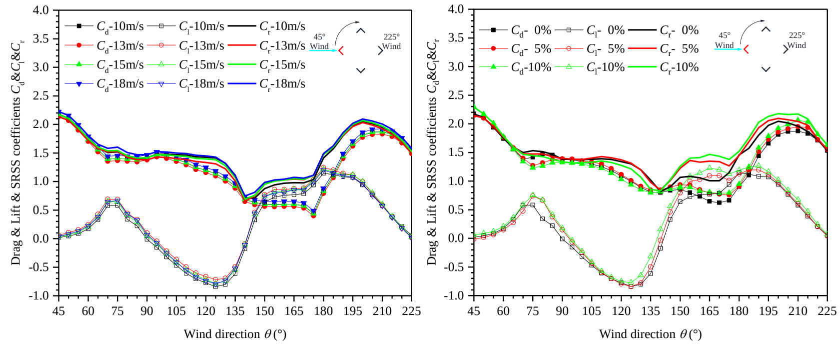

Figure 2. Aerodynamic coefficients of the member in the structure vs. wind directions: a) under different wind speeds; b)under different turbulent flow fields

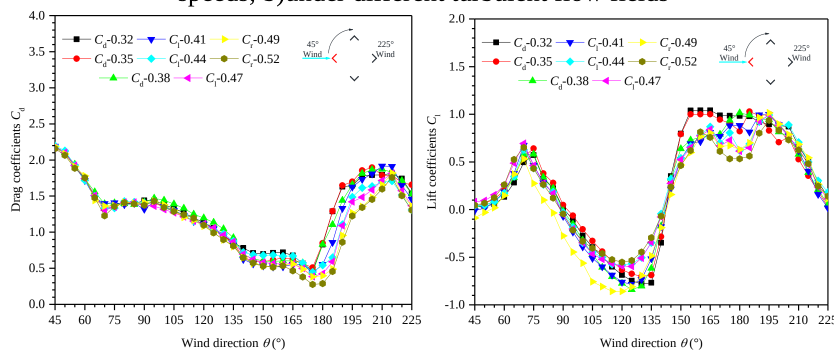

Figure 3. Aerodynamic coefficients of the member in the structure with different solidity ratios vs. wind directions: a) drag coefficients; b)lift coefficients

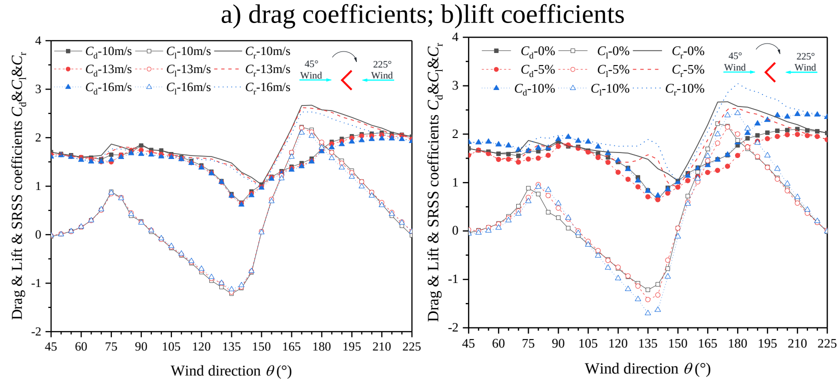

Figure 4. Aerodynamic coefficients of the single column vs. wind directions: a) under different wind speeds; b)under different turbulent flow fields

3.3. Wind load factors

An effective skewed wind load factor, described wind forces on members accurately under different wind directions, was recommended in this article and could be calculated by the Eq. (2). Took ratio to the resultant force of the single column, a wind load proportion factor was also proposed to consider the aerodynamic interference of other members on the concerned member in lattice structure, which can be calculated in the following Eq. (3). As shown in Figure 5, the curve of effective skewed wind load factors could be depicted as a Pentacle and approaches close under different solidity ratios. The wind load proportion factors remain approximate under the windward wind direction, and represent drastic discrepancies in the others.

$$K_{\theta}^{pe}=C_r^p\left(\theta\right)/C_d^p\left(45^{\circ}\right)\left(p=m,s\right) \tag{2}$$

$$\eta_k=C_r^m\left(\theta\right)/C_r^s\left(\theta\right) \tag{3}$$

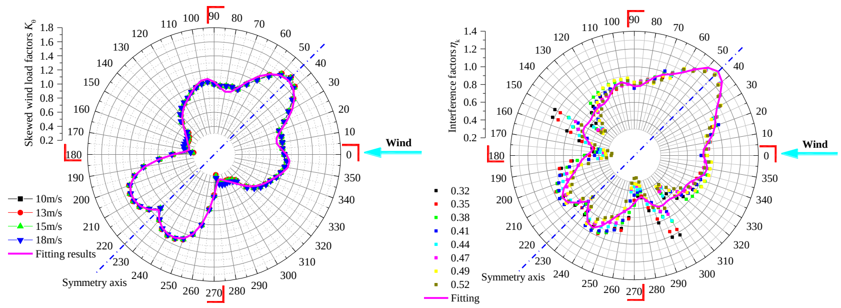

Figure 5. Wind load factors: a) Effective skewed wind load factors; b) wind load proportion factors

4. CALCULATION OF WIND LOADS

Based on the effective skewed wind load factor and wind load proportion factor, the characteristic values of wind loads on column members and diagonal bracing members in lattice structures can be calculated by the Eq. (4) and Eq. (5).

$$W_s^m\left(\theta\right)=W_0\left(0^{\circ}\right)\mu_z\beta_z A_s B_2 A_s^m\left(0^{\circ}\right)C_r^m\left(\theta\right)\approx W_0\left(0^{\circ}\right)\mu_z\beta_z A_s B_2 A_s^s\left(45^{\circ}\right)C_d^s\left(45^{\circ}\right)K_{\theta}^{se}\eta_k \tag{4}$$

$$W_s^b\left(\theta\right)=W_s\left(\theta\right)-\left[W_s^m\left(\theta\right)+W_s^m\left(\frac{\pi}{2}+\theta\right)+W_s^m\left(\pi+\theta\right)+W_s^m\left(\frac{3\pi}{2}+\theta\right)\right] \tag{5}$$

5. CONCLUSION

The main conclusions that can be drawn from research are as following:

(1) Effect of wind speed on the single column and members in lattice structures is slight enough to ignore, while the effect of turbulence cannot.

(2) Drag coefficients under the windward angle almost overlap each other with different solidity ratios, while lift coefficients represent a distinct differences under all the wind directions.

(3) The characteristic values of wind loads on members in lattice structures were proposed based on the effective skewed wind load factor and the wind load proportion factor.

ACKNOWLEDGEMENTS

This work is partially supported by State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji University (Grant No. SLDRCE18-01), National Science Foundation, China (Grant No. 52278508) and Guangdong Science and Technology Program, China (Grant No. STKJ202209084), which are gratefully acknowledged.

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