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Experimental study on dynamic response influence factors of flexible photovoltaic support structure

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SUMMARY: (10 pt)
The wind-induced response and vibration modes of the flexible photovoltaic (PV) modules support structures with different parameters were investigated by using wind tunnel based on elastic test model. The results show that 180° is the most unfavourable wind direction for the flexible PV support structure. For double-cable flexible PV supports, vortex-induced vibration (VIV) will occur at 15° and 20° inclinations, and flutter will occur in almost any cases. At 180° wind direction, the critical flutter wind velocity decreases firstly and then increases with the increase of inclination. 25° is the most unfavourable inclination, and the critical flutter wind speed is 25.1 m/s. Under 0° wind direction, flutter occurred only at 20° and 25° inclinations. After increasing the spacing of PV modules, the VIV of the structure is controlled. With the increase of component spacing, the structure flutter critical wind speed is increased. At 180° wind direction, the critical flutter wind velocity is increased with the increase of initial tension.

Keywords: Flexible photovoltaic modules, Wind-induced responses, Wind tunnel tests, dynamic response

1. INTRODUCTION

Baumgartner et al. (2009, 2010) first proposed the concept of flexible PV modules support structure, in which the PV modules were mounted on the cables. Ma et al. (2021) investigated the effects of wind direction, inclination angle, spacing ratio and installation position on the wind loads of the flexible PV modules support structures. He et al. (2021) investigated the mechanical properties of a new flexible PV modules support structure with a span of 30 meters, and discussed the effects of row spacing, inclination angle, initial cable force and cable diameter on the structural properties. There are little attentions were paid on the dynamic response of the flexible PV modules support structures.

2. OUTLINE OF WIND TUNNEL TESTS

2.1. Test model

The prototype structure of the flexible PV support adopted in this study is shown in Fig.1. The height of the columns is 6 m. The span of the flexible PV support is 33 m, which is consisted of 28 PV modules. The inclination angle of the PV modules in the north-south direction is 15°, and the PV modules are mounted on two steel cables C1 and C2 (along the ease-west direction). The length, width and thickness of the PV module are respectively 2256 mm, 1133 mm and 35 mm, and the weight for each PV module is 32.3 kg.

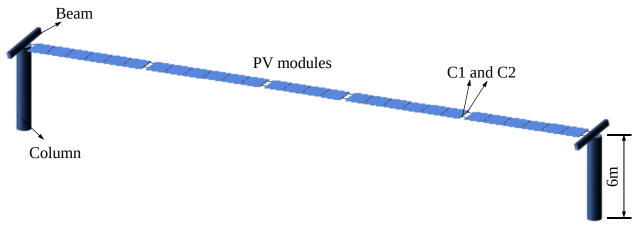


Figure 1. Structure of the flexible PV support

Considering the geometrical size and maximum wind velocity of the test section of wind tunnel used in this study, the length scale of the test model is λ_L=1:20, and the maximum blockage ratio is about 3.4%. According to Strouhal and Froude numbers, other scales, including velocity, frequency and force (λ_V, λ_f and λ_F), can be determined. The photo of the assembled elastic test model of the flexible PV support is shown in Fig.2. Because the interference between PV modules is not considered, the test models adopt the form of single row and single span. In order to ensure the stability of the test model, the base of the model is connected the ground with bolts.

Figure 2. Photo of the test model

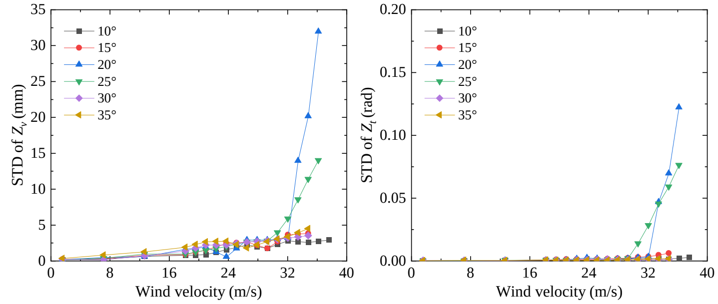
2.2. Test cases

The aeroelastic model tests of flexible PV support were conducted in uniform flow. The wind velocity increased form 0 m/s and the test was stopped when a large amplitude of average displacement or dynamic response was observed. The flexible PV support structure is prone to large deformation and wind-induced vibration under wind load. It is necessary to reduce the wind-induced vibration of the PV modules by changing structural parameters. In this study, three influencing factors including the module inclination, module spacing and initial tension of steel cable and are considered.

3. EXPERIMMENTAL RESULTS

3.1. Influence of module inclinations

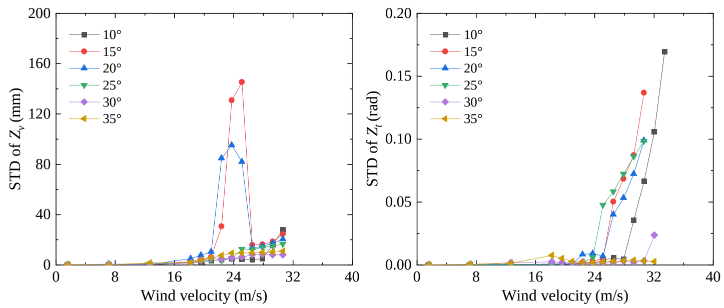
Fig.3 shows the variations of STD of vertical and torsional displacements with wind velocity under wind direction of 0° in different inclinations. It can be found from Fig.3 that the flutter phenomenon of flexible PV modules occurs at the inclinations of 25° and 20°.



(a) STD of vertical displacement (b) STD of torsional displacement

Figure 3. Variations of STD of vertical and torsional displacements with wind velocity under wind direction of 0°

Fig.4 shows the variations of STD of vertical and torsional displacements with wind velocity under wind direction of 180° in different inclinations. When the module inclinations are 15° and 20°, the vortex-induced vibration (VIV) occurs at the wind velocity of 20.9 ~ 26.5 m/s, as shown in Fig.4 (a). It can be found in Fig.4 (b) that the flutter phenomenon of PV modules occurs at the inclinations of 10° to 30°.

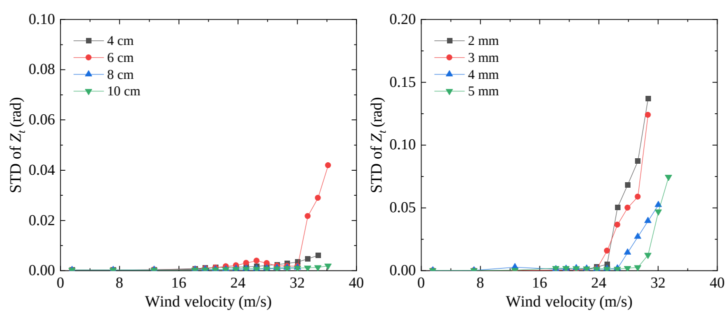


(a) STD of vertical displacement (b) STD of torsional displacement

Figure 4. Variations of STD of vertical and torsional displacements with wind velocity under wind direction of 180°

3.2. Influence of module spacings

Fig.5 shows the variations of STD of torsional displacements with wind velocity under wind direction of 0° and 180° in different module spacings. The flutter occurs only when the module spacing is 6 cm, which the wind velocity is 33.4 m/s. Before reaching the flutter critical wind velocity, the vibration amplitude of the flexible PV support increases steadily, which is safe for the structure. It can be found from Fig.5(b) that when the module spacing is greater than 6 cm, the flutter critical wind velocity increases with the increasing module spacing.

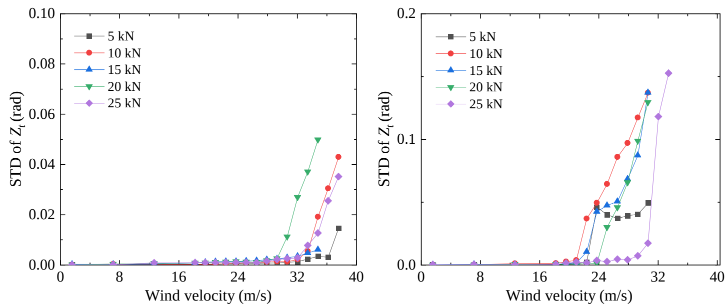


(a) STD of torsional displacement of 0° (b) STD of torsional displacement of 180°

Figure 5. Variations of STD of torsional displacements with wind velocity under wind direction of 0° and 180°

3.3. Influence of initial tension

Fig.6 shows the variations of STD of torsional displacements with wind velocity under wind direction of 0° and 180° in different initial tension. It can be found from Fig.6 that when the wind direction is 0°, the initial tension of 130kN is the most unfavourable condition, and the critical wind velocity is 30.6m/s. When the wind direction is 180°, with the increase of initial tension, the critical flutter wind speed increases. When the initial tension is 100kN, the flutter critical wind velocity is 22.3m /s.



(a) STD of torsional displacement of 0° (b) STD of torsional displacement of 180°

Figure 6. Variations of STD of torsional displacements with wind velocity under wind direction of 0° and 180°

4. CONCLUSIONS

The wind-induced response and vibration modes of the flexible PV modules support structures with different parameters were investigated by using wind tunnel based on elastic test model. The results show that 180° is the most unfavorable wind direction for the flexible PV support structure. For double-cable flexible PV supports, VIV will occur at 15° and 20° inclinations, and flutter will occur in almost any cases. At 180° wind direction, the critical flutter wind velocity decreases firstly and then increases with the increase of inclination. 25° is the most unfavorable inclination, and the critical flutter wind speed is 25.1 m/s. Under 0° wind direction, flutter occurred only at 20° and 25° inclinations. After increasing the spacing of PV modules, the VIV of the structure is controlled. With the increase of component spacing, the structure flutter critical wind speed is increased. At 180° wind direction, the critical flutter wind velocity is increased with the increase of initial tension.

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