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Research and analysis on response characteristics of bracket-line coupling system under wind load

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Abstract. In this paper, a three-dimensional finite element model of bracket-line coupling system is established based on ANSYS software. Using the wind velocity time series which is generated by MATLAB as a power input, by comparing and analyzing the influence of different wind speeds and different wind attack angles, it is found that when 0 degree wind acts on the structure, wires have a certain damping effect in the bracket-line coupling system and at the same wind speed, the 90 degree direction is the most unfavorable wind direction for the whole structure according to the three kinds of angle wind calculated at present. In the bracket-line coupling system, the bracket structure is more sensitive to the increase of wind speed while the conductors are more sensitive to the change of wind attack angle.

1. Introduction

In modern industry, composite materials are artificial, synthetic, two-phase or multiphase materials, usually one phase reinforced material, and the other as matrix. The most commonly used composite material in industry is the fiber reinforced plastic (FRP). Because this composite material can be combined with different materials to play a role, it has the advantages of fatigue resistance, corrosion resistance, electromagnetic shielding and long service life and widely used in aviation, aerospace and other fields which requiring light and high-strength structures [1].

FRP bracket-wire coupling system has the characteristics of high span and large span, its structure is complex, sensitive to the wind, very easy to cause vibration under the action of wind load, causing some damage and fatigue failure of components, and even cause the collapse of the whole structure, thus bring about serious consequence [2]. The wind-induced response of the FRP bracket-wire coupling system is mainly caused by the fluctuating wind, therefore, the accurate simulation of wind load, especially the simulation of random wind with random characteristics, is the key to ensure the safety and reliability of structural system under wind load. Domestic and foreign scholars have done a lot of research on the characteristics of fluctuating wind, and proposed two important characteristics of fluctuating wind—fluctuating wind velocity spectra and empirical formula of spatial correlation [3-4].

In this paper, firstly, using finite element software to establish the overall structure and using numerical simulation method to simulate the wind speed. Then, under the wind speed of 30m/s, the wind-induced response of the structure at three different angles (0 degrees, 60 degrees, 90 degrees) is analyzed by ANSYS. At last, the response of bracket-line coupling system is calculated under the action of 45m/s wind speed.

2. Finite element model

According to the design drawings, the largest span of brackets is 61.8m, the maximum height is 30.8m, four-span brackets connect with 300 wires and the ZJ-4 bracket is connected to the ground anchor through 30 FRP tie bars. The total length of the whole structure system is 198m, the span is 61.8m, and the height is 30.8m. The support beam is mainly made of Q345 steel pipe, and the support column is FRP pipe connected with steel joint.

Taking into account the actual force situation, the BEAM189 unit is selected in the ANSYS to simulate the main force components of the support structure and the LINK10 unit is used to simulate the traverse. Finally, the three span wires and the FRP tie rod are assembled and connected with the four brackets, and the finite element model is shown in figure 1.

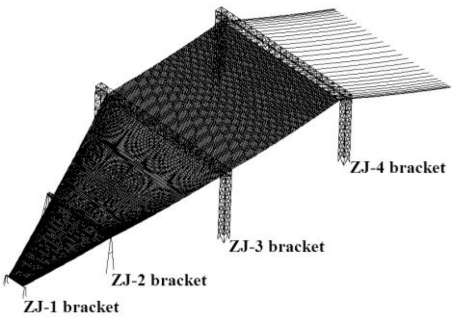
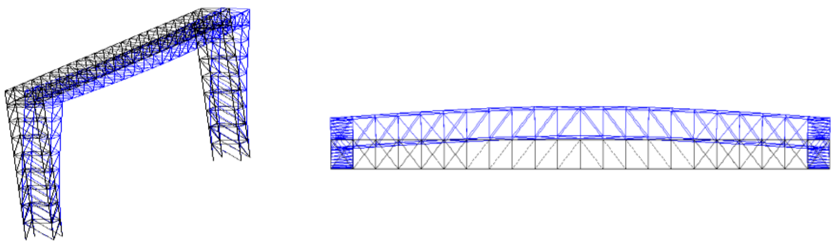


Figure 1. Finite element model of the structure

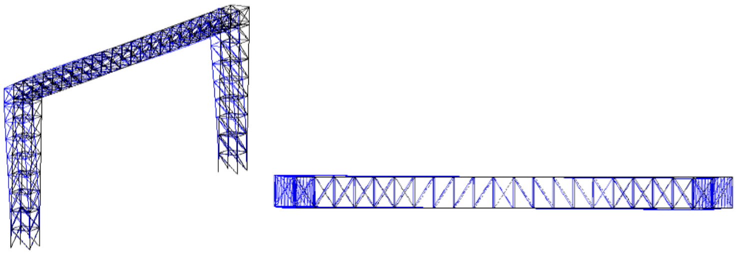
After the finite element model is established, modal analysis of the four supports is carried out respectively, and the natural frequencies of the structures are shown in Table 1. Figure 2 shows the first three modes of the ZJ-3 bracket.

Table 1. The first five modal frequencies of each bracket

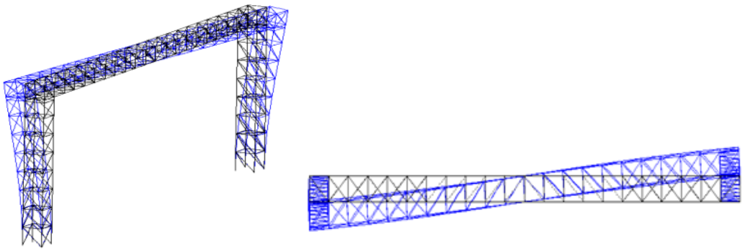
Order of modes	No.ZJ-1 bracket	No.ZJ-2 bracket	No.ZJ-3 bracket	No.ZJ-4 bracket
1	10.221 Hz	1.7428 Hz	1.1624 Hz	1.1308 Hz
2	12.002 Hz	2.1605 Hz	1.6530 Hz	1.6043 Hz
3	19.088 Hz	3.5025 Hz	1.7416 Hz	1.7467 Hz
4	25.846 Hz	4.2863 Hz	2.9711 Hz	2.8905 Hz
5	42.090 Hz	4.5686 Hz	3.3161 Hz	3.8207 Hz



(a) First order vibration mode of ZJ-3 bracket



(b) Second order vibration mode of ZJ-3 bracket



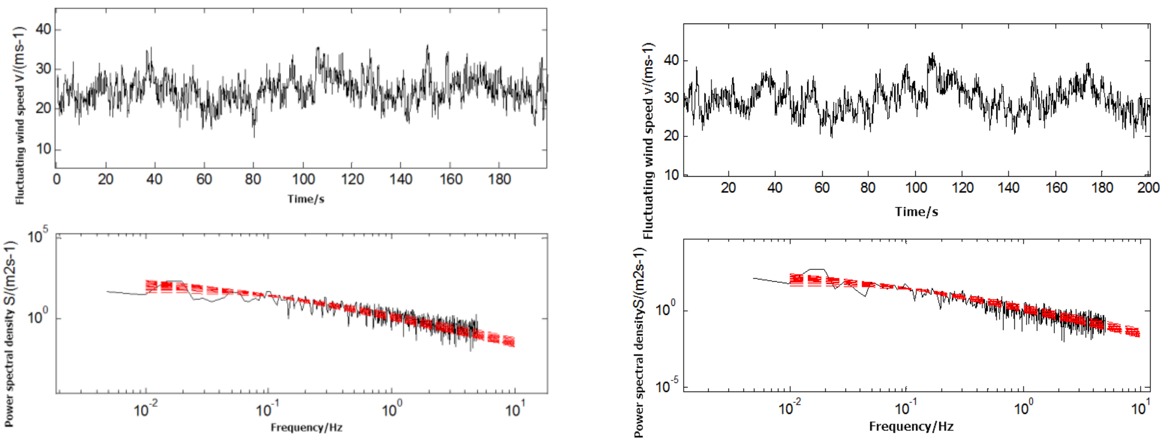
(c) Third order vibration mode of ZJ-3 bracket

Figure 2. First three modes of the ZJ-3 bracket

3. Numerical simulation of wind field

According to the basic properties of fluctuating wind, Simiu spectrum and linear autoregressive filter method [5-7], a program of Simiu spectrum-time curve has been compiled in the MATLAB, and the fluctuating wind speed at different heights has been obtained. In this paper, the fitting curves of the simulated spectrum and the target spectrum at two different heights are given.

It can be seen from Fig.3 that the simulated wind spectrum of each layer agrees well with the target spectrum, so the simulated wind can be used to analyze the wind-induced response.



（a）Fluctuating wind speed-time curve at hight of 3.75m （b）Fluctuating wind speed-time curve at height of 11.25m

Figure 3. Fluctuating wind speed-time curve

4. Wind-induced response analysis of bracket-line coupling system

4.1. Loaning mode

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The structure is layered according to the height and applied with corresponding wind loads，take the No.ZJ-3 bracket as an example. The column is divided into 5 layers and the wind load of each layer is added to the 4 nodes and the beam is divided into 11 sections to apply wind load. The loading mode is shown in figure 4, where the arrow refers to the position of the loading point.

The application of wind load on conductors：Along the longitudinal direction of the structure, the first-span conductors are divided into 5m sections to be loaded, the second-span conductors are divided into 5m sections to be loaded, the third-span conductors are divided into 15m sections to be loaded and the fourth-span conductors are divided into 5m sections to be loaded. The details are shown in figure 5.

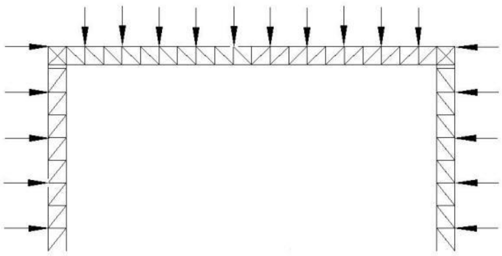

Figure 4. Loading mode of brackets

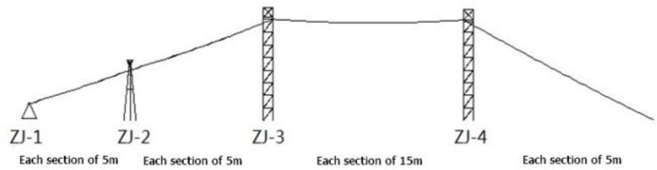

Figure 5. Loading mode of wires

4.2. Time response curve under wind load excitation (the wind speed is 30m/s)

Considering the damping ratio (0.03), the wind-induced vibration response of the structure is analyzed. Figure 6 is the displacement-time curve of the top of No.ZJ-3 bracket, figure 7 is Displacement-time curve of third span conductors along vertical direction of the wire, figure 8 is the Vertical displacement-time curve of third span conductors and figure 9 is the axial force-time curve of third span conductors.

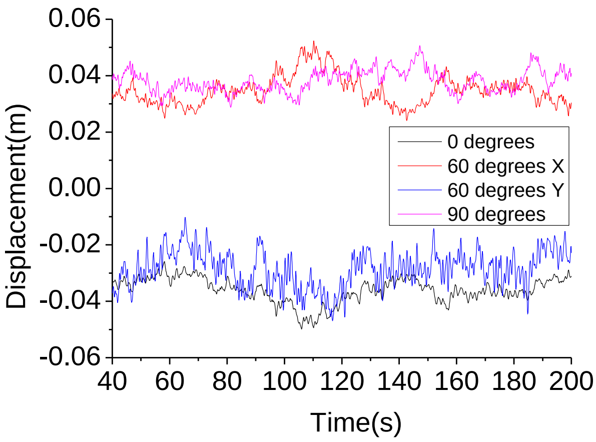

Figure 6. Displacement-time curve of the top of No.ZJ-3 bracket

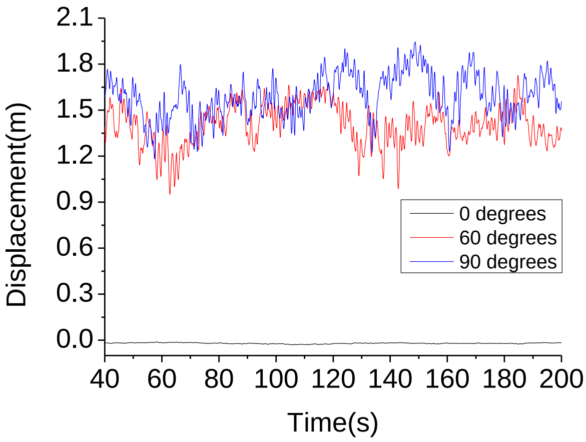

Figure 7. Displacement-time curve of third span conductors along vertical direction of the wire

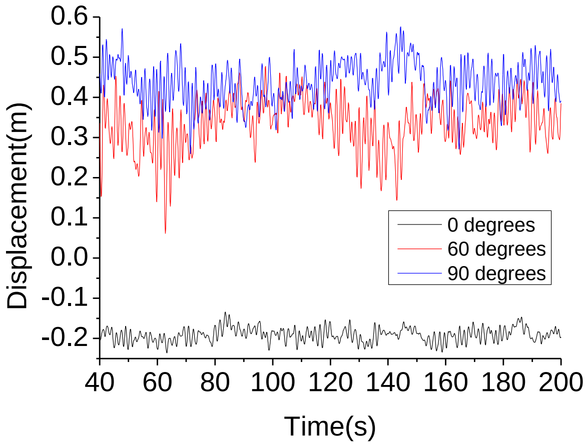

Figure 8. Vertical displacement-time curve of third span conductors

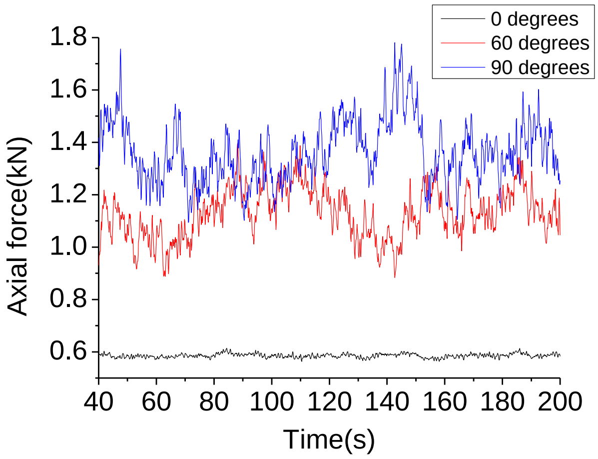

Figure 9. Axial force-time curve of third span wires

It is not difficult to see from the diagram that the effect of wind at different angles on the structure is different. When the 90 degree wind acts, the brackets have the largest displacement response, while the 0 degree wind has the least influence on the brackets. This is mainly because: In the bracket-line coupling system, When the 0 degree wind acts on the structure， Wind-shield area of the wire is small，as a result, it is less affected by wind load. What is more, the wire itself has a certain weight，therefore, wires have a certain damping effect in the whole structure.

Table 2 is the maximum displacement of the top of each bracket along the wind direction under the influence of wind at different angles. (When 60 degrees wind acts, there are two directions of displacement).

Table 2 Maximum displacement of each bracket

	No.ZJ-1 bracket	No.ZJ-2 bracket	No.ZJ-3 bracket	No.ZJ-4 bracket
0 degrees of wind	0.017m	0.028m	0.050m	0.025m
90 degrees of wind	0.002m	0.087m	0.052m	0.035m
60 degrees of wind	0.009m 0.017m	0.011m 0.074m	0.047m 0.052m	0.020m 0.035m

From the table we can find that under the influence of 30m/s wind speed, different angles of the wind on each bracket will have a certain impact, but at any angle of the wind, the top displacement response of the ZJ-2 and ZJ-3 brackets is the largest in the four supports. This is mainly due to the fact that the two supports are in adjacent positions, and the height difference is large. Therefore, when the wind load is applied, a large unbalance force is produced between the two supports, which make the displacement response more obvious.

Table 3 shows the maximum tension at the mid-span of conductors under the influence of wind at different angles

Table 3.Maximum tension at the mid-span of conductors

	First-span wires	Second-span wires	Third-span wires	Fourth-span wires
0 degrees of wind	1.023 kN	0.872 kN	0.611 kN	4.432 kN
90 degrees of wind	1.591 kN	1.646 kN	1.781 kN	16.720 kN
60 degrees of wind	1.467 kN	1.434 kN	1.387 kN	12.373 kN

Comparative analysis of wire tension in the maximum value under the effect of different wind angle, we can see that no matter what kind of wind angle acts in the structure, the fourth wire has the largest value of tension. This is mainly due to the fourth wire compared to other wires, has the characteristics of large diameter and the end is directly connected with the anchor. This allows it to play a stabilizing role in the overall structure and therefore bears greater power.

4.3. Spectral response under wind excitation (the wind speed is 30m/s, 90 degrees of wind)

In this paper, the displacement spectrum and acceleration spectrum of the support and the displacement spectrum of the wire are obtained by the Fast Fourier Transform (FFT). They are shown in figure 10, figure 11 and figure 12. Figure 13 also gives the amplitude-frequency curve of the wind load.

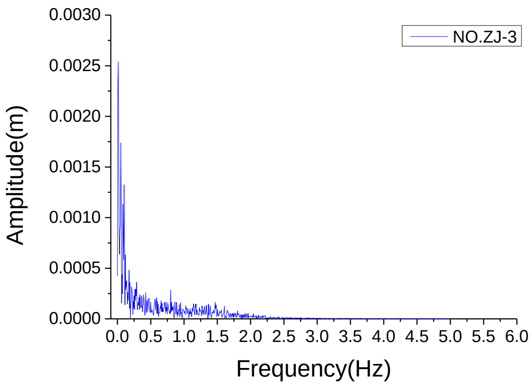

Figure 10. Displacement spectrum of support

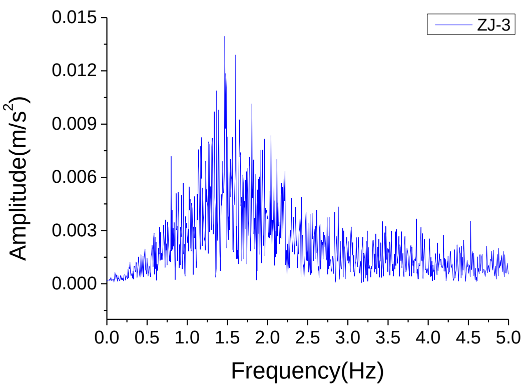

Figure 11. Acceleration spectrum of support

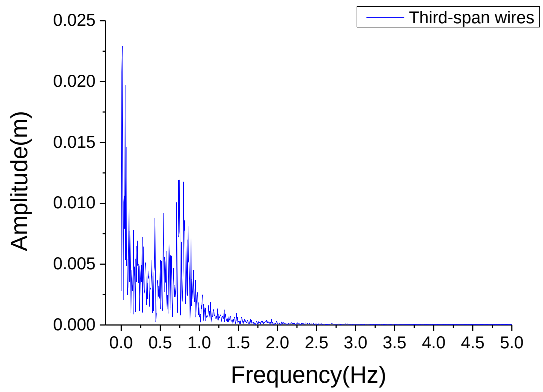

Figure 12. Displacement spectrum of wires

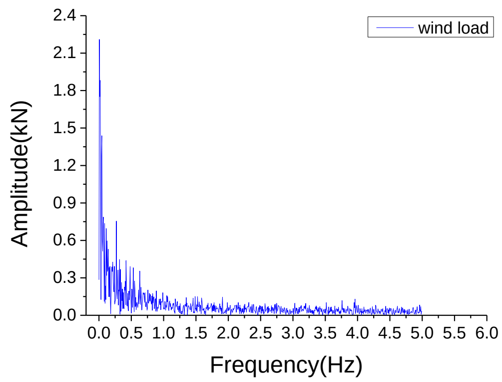

Figure 13. Amplitude-frequency curve of wind load

From above figures, it can be found that the displacement and acceleration spectrum of the top of bracket are mainly concentrated in the low frequency region and in the top displacement response of the brackets, the displacement response at low frequency is similar to that of wires. This shows that the influence of the conductors on the top displacement of bracket is obvious in the bracket-line coupling system. Comparing the spectrum curves of wind load and the displacement of support, it is easy to see that the two curves have great similarity, and all of them are mainly concentrated in the low frequency region. This shows that the displacement response of the support is greatly affected by wind load.

4.4. Comparison of structure response at different wind speeds (the wind speeds are 30m/s and 45m/s)

In the 90 degree wind condition, structural response in 30m/s wind and 45m/s wind speed are calculated respectively. Figure14, 15, 16 and 17 show the displacement-time curve of the top of No.ZJ-3 bracket, the acceleration-time curve of No.ZJ-3 bracket, the displacement-time curve and the axial force-time curve of third span wires.

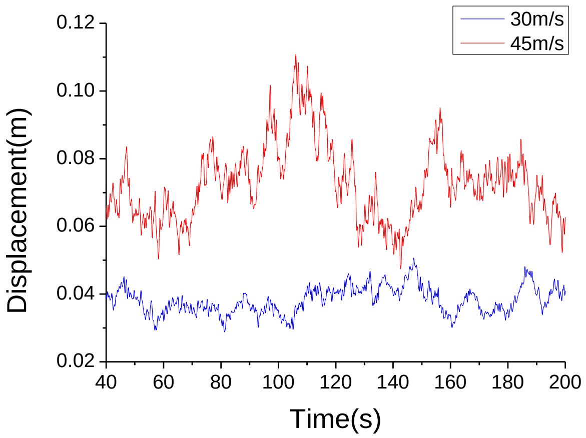

Figure 14. Displacement-time curve of the top of No.ZJ-3 bracket

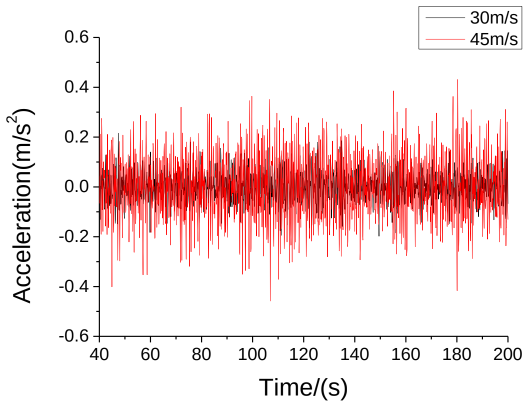

Figure 15. Acceleration-time curve of No.ZJ-3 bracket

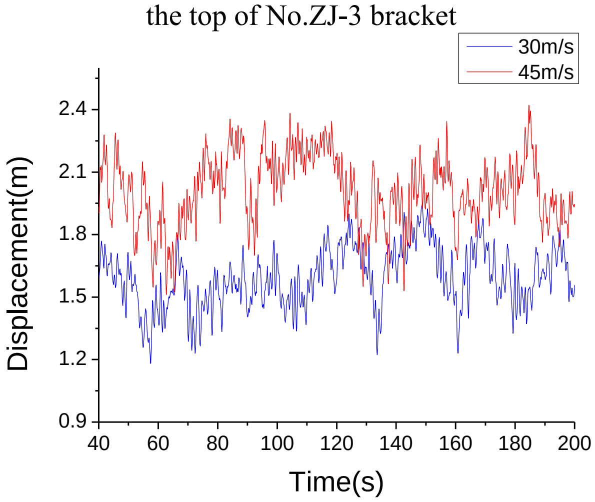

Figure 16. Displacement-time curve of third span wires

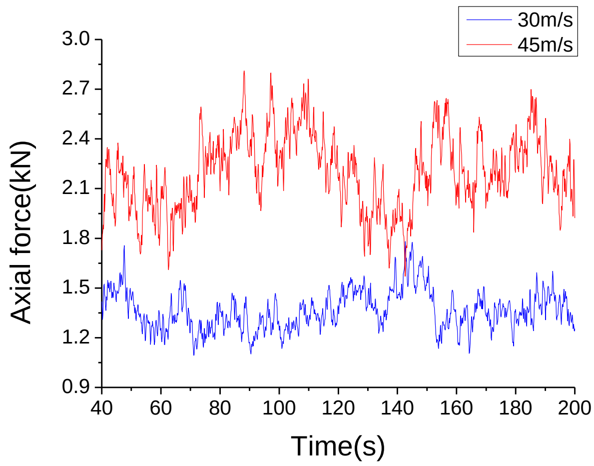

Figure 17.Axial force-time curve of third span wires

As we can see from the picture above：At the same angle of wind（90 degree wind），after the wind speed increased by 1.5 times，both the response of brackets and wires have increased obviously. According to the displacement-time curve of No.ZJ-3 bracket，the displacement-time curve of 45m/s wind is completely above the curve of the 30m/s wind and its maximum value is about 2 times than that of 30m/s wind acts, what is more, the acceleration of the top is generally larger than that of the 30m/s wind. For the wires, the displacement response is also increased when the 45m/s wind acts，but its displacement-time curve partly overlaps with the curve of 30m/s wind. The maximum displacement is about 1.3 times than that of 30m/s wind acts and the maximum tension is about 1.3 times than that of 30m/s wind acts.

5. Conclusions

In this paper, the following conclusions are obtained by simulating the fluctuating wind speed time series and analyzing the wind-induced vibration response of the FRP bracket-line coupling system:

(1) In the bracket-line coupling system，When the 0 degree wind acts on the structure，Windshield area of the wire is small，as a result, wires have a certain damping effect in the whole structure, so in the case of 30m/s wind, When the 90 degree wind acts, the brackets have the largest displacement response, while the 0 degree wind has the least influence on the brackets.

(2) Under the same wind speed, the influence of the 0 degree wind on the conductors is relatively small, and the displacement and tension response of the conductor is more obvious when the 90 degree wind acts.

(3) Considering the effects of wind on the brackets and the conductors at three different angles, we can see that in the case of 30m/s wind, the wind in the 90 degree direction is the most unfavorable wind direction for the whole structure according to the three kinds of angle wind calculated at present.
(4) The displacement and acceleration spectrum of the top of brackets are mainly concentrated in the low frequency region and the displacement response of brackets at low frequency is similar to that of wires. This shows that the influence of the conductors on the top displacement of brackets is obvious in the bracket-line coupling system.
(5) By comparing and analyzing the influence of different wind speeds and different wind attack angles, it is found that in the bracket-line coupling system, the bracket structure is more sensitive to the increase of wind speed while the conductors are more sensitive to the change of wind attack angle.

6. References

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