The aerodynamic stability of a new type of Multi-tower cable-stayed bridge with rhombic stiffening cables

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Abstract. Aerodynamic stability is an important problem in the design and research of long-span multi-tower cable-stayed bridges. The three-dimensional nonlinear aerodynamic stability analysis method is used to qualitatively analyze the aerodynamic stability of a new type of rhombic stiffened cable-stayed bridge in this paper, and compared with conventional cable-stayed bridges. The results show that the new rhombus stiffener can greatly increase the longitudinal stiffness of the structure and reduce the vibration period of the structure. The maximum lateral displacement, vertical displacement and torsion Angle of the structure under wind load are reduced, and the critical unstable wind speed of the structure is increased. It can be seen that the aerodynamic stability of the new type of rhombus cable-stayed bridge is better than conventional cable-stayed bridge.

1. Introduction

Long-span multi-tower cable-stayed bridge is a flexible structure [1], which is easy to vibrate and deform under wind load. In history, the damage accidents of cable-stayed Bridges due to wind vibration often occur, so the influence of wind load on cable-stayed Bridges should be paid attention to.

It is of great significance to study the strength, stiffness and carrying capacity of long-span multi-tower cable-stayed bridge under natural wind load so that it can still play the role of transportation in the process of high wind. Because of the difficulty in anchorage of the middle tower, the longitudinal stiffness of the long-span multi-tower cable-stayed bridge is low and vibration and deformation are more likely to occur under wind load. A new type of rhombic stiffener cable-stayed bridge which can increase the directional stiffness of a multi-tower cable-stayed bridge was proposed in this paper. The aerodynamic stability of the new type of rhombic stiffener cable-stayed bridge and the conventional cable-stayed bridge under the wind load was compared and analyzed by considering the wind attack Angle, vertical wind load and cross wind load in this paper. It is a reference for the application of the new cable-stayed bridge in practical engineering.

2. Dynamic characteristics of a new type of rhombus cable-stayed bridge

The stiffness control of multi-tower cable-stayed bridge is very important in design. Through reasonable layout of stiffening cables can improve the overall stiffness of multi-tower cable-stayed
bridge [2]. But the conventional methods of stiffening cables have many deficiencies, the new stiffening cables system (rhombic Cables) was performed in this paper (as shown in Figure 1):

![Figure 1. Multi-tower Cable bridge with rhombic cables]

As shown in Figure 1, because one end of Tie-down cables was anchored on the top and root of tower and the other end is anchored on the girder, it causes that tower and girder are validly connected to become a balanced system and increase the overall stiffness of the structure.

The actual bridge design parameters were used in this paper, and diamond stiffeners were set on each tower. Compared with the conventional cable-stayed bridge, the influence of rhombic stiffening cables on the wind resistance of the bridge was analyzed.

The total length of Bridge is 1327.6m. This bridge has three towers and four spans whose midspan is 460m, side span is 203.8m and height of tower is 247.5m. The calculation model is shown in figure 2.

![Figure 2. Calculation model]

The above models were analysed by using the finite element software Ansys, and the first 6 order natural vibration frequencies and formations obtained were shown in table 1

| Num | Frequency (Hz) Model a | Frequency (Hz) Model b | The vibration shape Model a | The vibration shape Model b |
|-----|-----------------------|------------------------|----------------------------|----------------------------|
| 1   | 0.0645                | 0.1841                 | Longitudinal floating     | Longitudinal floating     |
| 2   | 0.1851                | 0.1968                 | The main tower bends in the same direction | The main tower bends in the same direction |
| 3   | 0.1972                | 0.2404                 | The side tower bends in the same direction | The middle tower bends in the opposite direction |
| 4   | 0.2011                | 0.2736                 | The main beam bends in a symmetrical vertical direction | The main beam bends in a symmetrical vertical direction |
| 5   | 0.2433                | 0.2991                 | The middle tower bends in the opposite direction | The main beam is opposed to vertical bending |
| 6   | 0.3084                | 0.3188                 | Main girder torsion       | Main girder torsion       |

(*Attention : Model a is calculation model of conventional cable-stayed bridge. Model b is calculation model of cable-stayed bridge with rhombus cable)
As shown in table 1, the self-vibration period of rhombus cable-stayed bridge decreases from 15 seconds to 9 seconds, and the frequency increases from 0.1045 to 0.1841, indicating that the rhombus greatly increases the stiffness of the structure along the bridge. Moreover, the vertical bending formation of the main girder is relatively late compared with the traditional cable-stayed bridge, so the vertical rigidity of the main girder can be increased.

3. The aerodynamic stability of the new rhombus stiffening cable-stayed bridge
In -3°, 0° and 3° initial wind Angle of attack, the conventional cable-stayed bridge and rhombus stiffening cable-stayed bridge had carried on the aerodynamic stability analysis by three dimensional nonlinear analysis method [3]. The bridge model was simplified to the bar model. The bridge deck main beam and bridge tower were simulated by spatial beam element. The cable-stayed cable was simulated by spatial rod element. The calculation model is shown in figure 2. The main beam takes into account the action of three components of static force. Because the main girder size of the bridge in this paper was similar to that of Taizhou Changjiang river bridge, static three-component force [4] of Taizhou Changjiang river bridge was adopted in this analysis.

![Figure 3. Static three-component force coefficient of Taizhou bridge](image)

(*Attention: CH- Lateral component coefficient, CV- Vertical component coefficient, CM- Torque component coefficient)

The cable and the bridge tower only consider the role of the resistance component. The drag coefficient of the cable is 0.8 and the drag coefficient of the bridge tower is 2.0. The maximum horizontal, vertical and torsional displacement of the main beam under initial wind attack Angle changes with the increase of wind speed [5] ~ [8], as shown in figure 4.
Under 3° and +3° angle of attack wind, the displacement changing law of different wind speeds is similar. In the same wind speed, the vertical and horizontal displacement and torsion angle of the rhombic stiffening cable-stayed bridge are smaller than conventional cable-stayed bridge. As the wind speed is higher, the displacement of the rhombic stiffening cable-stayed bridge in all directions is reduced obviously. It further states that in the same case, the structure stiffness of rhombic stiffening cable-stayed bridge is larger than that of conventional cable-stayed bridge, and the aerodynamic stability of rhombus stiffening cable-stayed bridge is better than that of conventional cable-stayed bridge [10].
4. Conclusion
The three-dimensional nonlinear aerodynamic stability analysis method is used to qualitatively analyze the aerodynamic stability of a new type of rhombic stiffened cable-stayed bridge in this paper, and compared with conventional cable-stayed bridges.

The results show that the new rhombus stiffening can greatly increase the longitudinal stiffness of the structure and reduce the vibration period of the structure. The maximum lateral displacement, vertical displacement and torsion Angle of the structure under wind load are reduced, and the critical unstable wind speed of the structure is increased. It can be seen that the aerodynamic stability of the new type of rhombus cable-stayed bridge is better than conventional cable-stayed bridge.

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