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Experimental studies on suppression of vertical vortex-induced vibrations of an edge girder bridge by mechanical and aerodynamic countermeasures

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SUMMARY:

The edge girder bridge is prone to vertical vortex-induced vibration (VIV) at low wind speeds. In order to control the VIV response of an edge girder bridge, this paper used sectional model wind tunnel tests to study the influence of mechanical and aerodynamic countermeasures on the VIV response of an edge girder bridge. First, an eddy current damper was developed to finely adjust the damping of the spring-suspended sectional model (SSSM) system; then, the effect of mechanical countermeasures on the VIV response of the edge girder bridge was investigated by using the eddy current damper; finally, the effect of combined mechanical and aerodynamic countermeasures on the VIV response of the edge girder bridge was investigated. The results show that the maximum VIV amplitude and the lock-in region of the edge girder bridge become smaller with the increase of structural damping, but the decline curve varies with the wind angle of attack; the vertical VIV of the edge girder bridge is more sensitive to structural damping after the addition of aerodynamic countermeasures, and the VIV response can be completely controlled by adding smaller damping.

Keywords: edge girder bridges, vortex-induced vibration, mechanical and aerodynamic countermeasures

1. INTRODUCTION

The edge girder bridge has many advantages in engineering application, such as simple appearance, light weight, easy construction, and low engineering cost. It has been widely used in long-span cable-stayed bridges, and has also been used in long-span suspension bridges in recent years. Due to its typically blunt body, the long-span cable-bearing bridges, especially the long-span suspension bridges, with the edge girder is more prone to vertical VIV at low wind speed than the streamlined steel box girder. Therefore, it is essential to accurately predict the VIV response of a long-span cable-stayed bridge with the edge girder in order to ensure its operation safety. Though the VIV of a long-span bridge is highly sensitive to structural damping, the influence of structural damping on the VIV response of the edge girder bridge is yet not clear, which hinders the accurate prediction of VIV response of the cable-stayed bridge with the edge girder.

2. THE EDDY CURRENT DAMPER FOR SECTION MODEL WIND TUNNEL TESTS

The basic construction of the developed eddy current damper has been given in Figure 1. The eddy current damper mainly consists of a connecting plate, a conductor plate, a permanent magnet, a magnet back iron, a spacing adjustment device and a base. One end of the connecting plate is rigidly connected to the end of the sectional model, and the other end is rotatably connected to the conductor plate, so that the conductor plate can be adjusted to the vertical direction; the conductor plate moves along the vertical direction between the permanent magnets on both sides; the permanent magnets are mounted on the back iron on both sides; the magnet back iron is fixed to the spacing adjustment device, and the size of the air gap between the conductor plate and the permanent magnets can be adjusted by the spacing adjustment device; the spacing adjustment device is placed on the base, and the base can realize the height adjustment. Install the eddy current damper to the SSSM system, as shown in Figure 2.

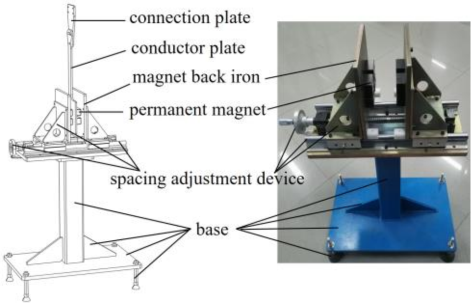

Figure 1. Basic structure diagram of eddy current damper

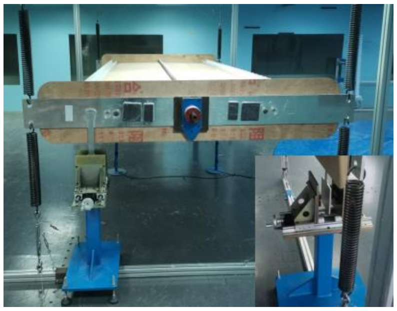

Figure 2. Installation photo of eddy current dampers

3. VIV MITIGATION BY MECHANICAL COUNTERMEASURES

The +3° and 0° wind attack angles were selected to study the effect of mechanical measures on the vertical VIV response of the edge girder bridge, and the results are shown in Figure 3. From Figure 3(a), it can be seen that the maximum VIV amplitude and lock-in region of vertical VIV are becoming smaller with the increase of structural damping for the edge girder bridge. Although there are two lock-in regions, but the VIV amplitude is small, and is particularly sensitive to the damping ratio in the first lock-in region. The VIV amplitude is larger in the second lock-in region, and its starting wind speed basically does not change with the structure damping ratio, but the VIV termination wind speed with the structure damping ratio increases and gradually decreases. The second vortex vibration locking wind speed interval is larger, and its starting wind speed does not change with the damping ratio of the structure, but the vortex vibration termination wind speed gradually decreases with the increase of the damping ratio. From Figure 3(b), the maximum VIV amplitude and lock-in region of vertical VIV become smaller with the increase of structural damping for the edge girder bridge, and the change law is basically the same as the +3° wind attack angle. In general, the VIV is more sensitive to the structural damping ratio at 0° wind attack angle. In addition, it is found that the second vertical lock-in region under different wind attack angles shows different profiles. Among them, the dimensionless VIV amplitude-wind speed curve at +3° wind attack angle shows a steep increase and slow decrease, and the symmetry axis is tilted to the left; the dimensionless VIV amplitude-wind speed curve at 0° wind attack angle shows a slow increase and slow decrease, and is basically symmetric about the plumb line.

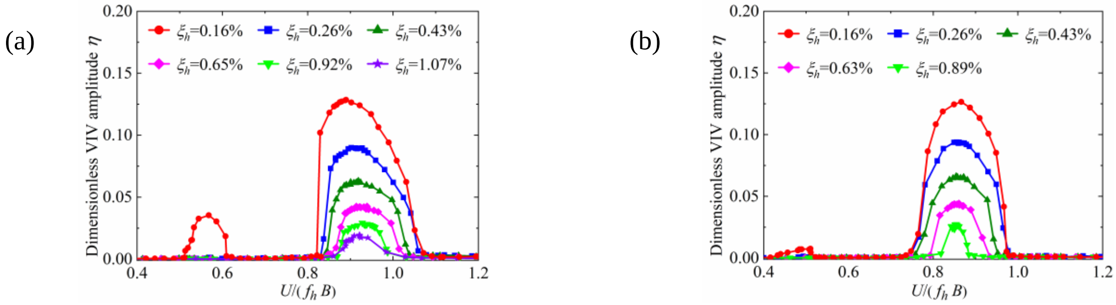

Figure 3. VIV response versus wind speeds of the edge girder bridge with different structural damping (a) +3° wind attack angle and (b) 0° wind attack angle

Figure 4 shows the variation of the maximum VIV amplitude with Sc number for the edge girder bridge at +3° and 0° wind attack angles. It can be seen that the maximum VIV amplitude of the edge girder bridge at different wind attack angles decreases gradually with the increase of the Sc number, and the decreasing speed becomes slower. The effect of the wind attack angle on the maximum VIV amplitude of the edge girder bridge with the change of the Sc number is basically negligible. Figure 5 shows the variation of the maximum VIV amplitude with Sc number for the edge girder bridge at +3° wind attack angle with different model scaling ratios. It can be seen that the effect of the model scaling ratio on the variation of the maximum VIV amplitude with Sc number of the edge girder bridge at +3° wind angle of attack is basically negligible.

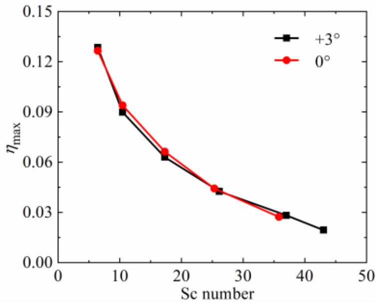

Figure 4. Maximum VIV amplitude versus Sc number for the edge girder bridge with different wind attack angles

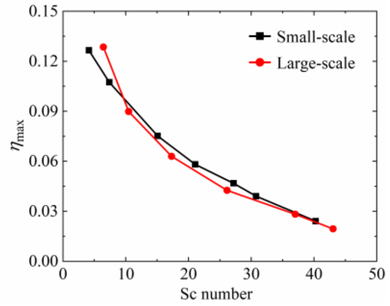

Figure 5. Maximum VIV amplitude versus Sc number for the edge girder bridge with different scales

4. VIV MITIGATION BY BOTH MECHANICAL AND AERODYNAMIC COUNTERMEASURES

The effect law of mechanical measures on vertical VIV response may be changed by the change of aerodynamic shape of the edge girder bridge. Two lower stabilizer plates were installed to the edge girder bridge to study the effect of combining mechanical and aerodynamic countermeasures on the VIV response of the edge girder bridge with test wind attack angles of +3° and 0°. As can be seen from Figure 6, the maximum VIV amplitude and the lock-in region wind of the edge girder bridge are significantly reduced after the adoption of aerodynamic countermeasure, and they are also more sensitive to damping. In addition, it can be found that the sensitivity of vertical VIV of the edge girder bridge to damping varies with the wind attack angle after adding aerodynamic countermeasures.

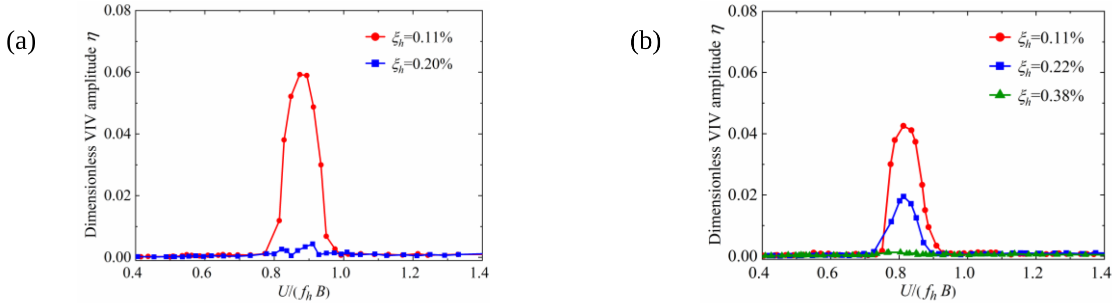

Figure 6. VIV response versus wind speeds of the edge girder bridge with different structural damping and aerodynamic countermeasures (a) +3° wind attack angle and (b) 0° wind attack angle

5. CONCLUDING REMARK

In the present study, eddy current dampers are used to finely adjust the structural damping of the SSSM system, and the effect law of mechanical measures on the vertical VIV response of the edge girder bridge is investigated in detail. The sensitivity of the edge girder bridge to mechanical countermeasures under different aerodynamic countermeasures is also investigated. The main ideas are concluded as follows:

(1) The maximum vertical VIV amplitude and the lock-in region of the edge girder bridge both become smaller continuously with the increase of structural damping, but the decline curve varies with the wind angle of attack.

(2) The vertical VIV of the edge girder bridge is more sensitive to structural damping after the addition of aerodynamic countermeasures, but the degree of sensitivity varies with the wind angle of attack.

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REFERENCES

Xu, K., Ge, Y., Zhao, L., 2018. Calculating Vortex-Induced Vibration of Bridge Decks at Different Mass-Damping Conditions. J. Journal of Bridge Engineering, 23(3): 04017149.

Hua, X., Ma, W., Huang, Z., 2022. Effect of Sc Number on Vertical Vortex-induced Vibration of Bridges Based on Precise Damping Adjustment. J. Journal of Hunan University(Natural Sciences), 49(5): 17-25.

Marra, A. M., Mannini, C., Bartoli, G., 2015. Measurements and improved model of vortex-induced vibration for an elongated rectangular cylinder. J. Journal of Wind Engineering and Industrial Aerodynamics, 147: 358-367.