Experimental and numerical studies of VIV performance of twin-box girder bridges with various L-shaped plates

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SUMMARY
With the development of the economy and the increase of traffic volume, the span of the bridge increases, and the flutter test wind speed of the girder also increases. Compared with other types of girders, the Twin-box girder has superior flutter performance. As a result, it has been applied in more and more sea-crossing bridge projects, but it's prone to vortex-induced vibration (VIV). As a new aerodynamic measure, the L-shaped plate can improve the VIV performance of the twin-box girder and save steel compared with the wind fairing. In this paper, the effects of the aspect ratio of the L-shaped plate on the VIV performance of twin-box girders with three different slotting ratios are studied. The results show that the torsional amplitude decrease and the vortex-induced force contribution coefficient decrease with the increase of aspect ratio. The L-shaped plate could weaken the flow separation and has the same effect as the wind fairing.

Keywords: twin-box girder, vortex-induced vibration, wind tunnel test, numerical simulation

1. ENGINEERING BACKGROUND

To meet the traffic demand brought by economic development, the bridge is developing in a longer and wider direction (Yongle Li et al., 2022). The twin-box girder has been applied widely because of its superior flutter performance, but it's prone to VIV (Yongxin Yang et al.,2016). As a new type of aerodynamic measure, the L-shaped plate can effectively suppress the VIV of the twin-box girder as a substitute for wind fairing using less steel.

In this paper, through the vibration-measuring wind tunnel test, the influence of different aspect ratios of the L-shaped plate on the VIV suppression effect of three twin-box girders with different slotting rates is studied. By means of numerical simulation and pressure measuring tests, the twin-box girder with a slotting rate of 24.4 % is taken as the research object. The mechanism of vortex vibration suppression by L-shaped plates is studied.

2. OVERVIEW OF THE WIND TUNNEL TEST

As shown in **Fig.1**, the geometric scale ratio of the model is 1:70. The model is 1.80m in length and 0.057m in height. The center slot width (CB) can be changed to 0.12m, 0.16m, and 0.20m, corresponding to the slotting rate of 19.5%, 24.4 %, and 28.8 %. The height (h) of the L-shaped plate is 0.5m, the width (b) varies between 1m-2m, and the corresponding aspect ratio varies between 2-4. The specific design parameters are shown in **Table 1**. The experiment is carried out in the CA-1 atmospheric boundary layer wind tunnel laboratory of Chang ' an University. The test section is 3m in width, 2.5m in height, and 15m in length. The experimental wind speed can vary between 0-53m/s.

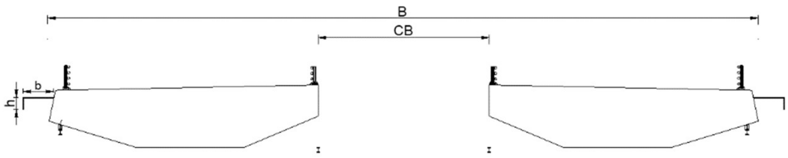

Figure 1. Wind tunnel test model

Table 1. Parameter of wind tunnel test model.

Parameter	Model A	Model B	Model C
Slotting rate	24.4%	19.5%	28.8%
Width	0.655m	0.615m	0.695m
Torsional frequency	8.667Hz	8.789Hz	8.301Hz
Torsional damping ratio	0.193%	0.172%	0.204%
Aspect ratio of L plate	2,2.5,3,3.5, 4	2,2.5,3.5	2,2.5,3.5

3. STUDY ON VIV PERFORMANCE

Fig.2 shows the curve of the reduced amplitude with the reduced wind speed, where *D* is the height of the model, U is the test wind speed, and *f* is the torsional frequency. It can be seen from the figure that when testing the original sections of the three slotting rates, the torsional VIV occurs in a low wind speed range and a high wind speed range.

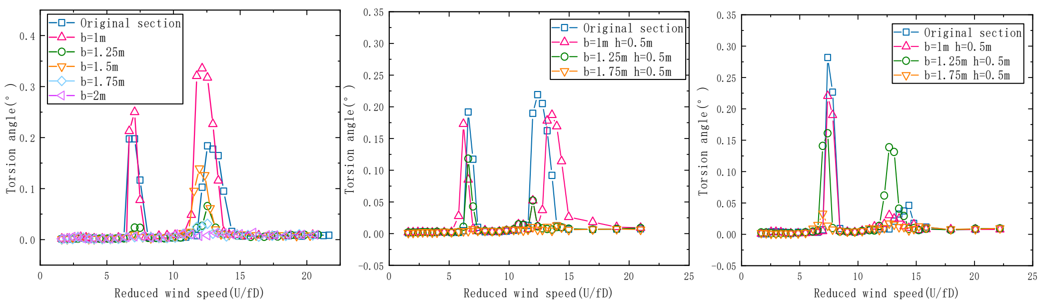

Figure 2. Reduced amplitude of model with a slotting rate of 24.4%, 19.5%, and 28.8%

For the model with a slotting rate of 24.4%, when the aspect ratio of the L-shaped plate is not less than 2.5, the torsional VIV at low wind speed can be effectively suppressed. When the aspect ratio is 2.5 or not less than 3.5, the torsional VIV at high wind speed can be effectively suppressed. For the model with a slotting ratio of 19.5%, when the aspect ratio reaches 2.5, the peak amplitude at low wind speed reduces by 50%. When the aspect ratio is not less than 3, the torsional VIV is completely suppressed. As for the torsional VIV at high wind speed, except for the L-shaped plate with an aspect ratio of 2, the others can effectively suppress the VIV. For the model with a slotting ratio of 28.8%, the L-shaped plate with an aspect ratio of 2 cannot effectively suppress the torsional VIV at low wind speed. When the aspect ratio increases to 2.5, the torsional VIV at low wind speed is effectively controlled. **Fig.3** shows the curves of the peak value ratio between the original section and sections with L-shaped plates at low and high wind speeds. The overall trend is: when the height of the vertical plate is constant, with the increase of the aspect ratio, the maximum value of torsional VIV at low wind speed and high wind speed shows a downward trend.

4. STUDY ON PRESSURE CHARACTERISTIC DISTRIBUTION OF GIRDER

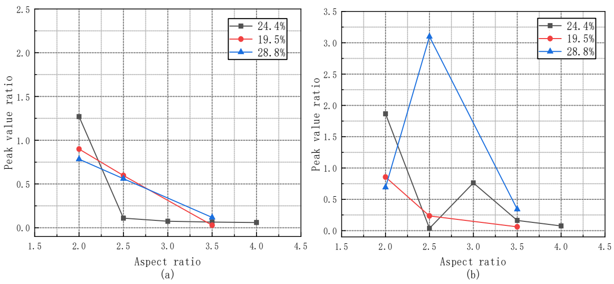

Figure 3. Peak value ratio at low wind speed (a) and high wind speed (b)

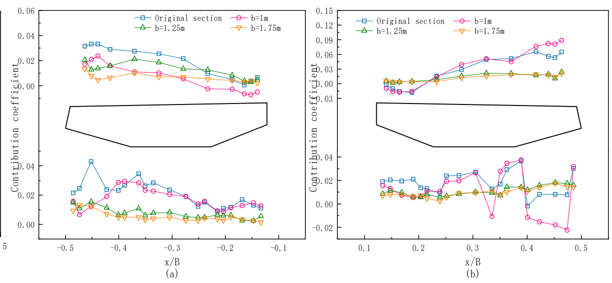

Figure 4. Contribution coefficient of the upper and lower face of upstream(a) and downstream(b) girder

The model with a slotting rate of 24.4% was selected as the research object for the pressure measuring test. The wind pressure coefficient of the surface of the original section and the girder with different aspect ratios of the L-shaped plate was measured, and the variation of the vortex-induce force contribution coefficient of each point on the model surface with L-shaped plates was analyzed. The aerodynamic contribution coefficient C of each measuring point is defined according to Eq. (1), where Cp_{std} is the fluctuating wind pressure coefficient of each measuring point, and r_i is the correlation coefficient between the aerodynamic force of each measuring point and the vortex-induced force of the girder.

$$C = C_{P_{std}} r_i \quad (1)$$

Fig. 4 shows the distribution of the vortex-induced force contribution coefficient of each measuring point on the surface of the girder with L-shaped plates. It can be seen that the distribution of the contribution coefficient of the girder with different L-shaped plates is similar. The contribution coefficient at each point of the girder is basically positive. In the range of-0.5<x/B<-0.4, the contribution coefficient of the upper and lower surfaces of the upstream box girder is larger, and in the range of 0.35<x/B<0.5, the contribution coefficient of the upper surface of the downstream box girder is larger, which indicates that the aerodynamic force here contributes more to the vortex-induce force.

Compared with the original section, it is found that the L-shaped plate can effectively reduce the contribution coefficient of each point. With the increase of the aspect ratio of the L-shaped plate, the contribution coefficient decreases. When the aspect ratio is small, the variation of each point is similar to the original section. When the aspect ratio is large, the contribution value of each point fluctuates around 0. Combined with the comparison of the VIV response, it can be speculated the reason why the VIV amplitude is small when the aspect ratio is large.

5. FLOW SIMULATION OF THE GIRDER SECTION

The flow (A.J.Alvarez et al., 2021) around the original section with a slotting rate of 24.4% and the section with an L-shaped plate with an aspect ratio of 2.5 is simulated by fluent.**Fig.5** shows the flow line of the original section: there is a large-scale vortex (V1) on the upper surface of the upstream girder, which is almost the same as its width, and there are two large-scale vortices (V2 and V3) at the central slot. There is a small-scale vortex (V4) on the upper surface of the downstream girder, which is a relatively stable vortex. Two vortices (V5) at the end of the box girder fall off alternately.

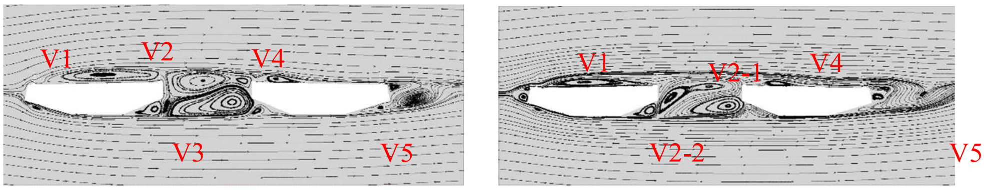

Figure 5. Flow line of the original section and section with an L-shaped plate

After adding the L-shaped plate, the size of the vortex on the upper surface of the upstream box girder decreases and moves upstream. The size of the vortex V2-1 at the central slot decreases, and V2-2 approaches upstream. The size and influence range of V3 decrease. It shows that L-plate has the effect of weakening flow separation, similar to the effect of wind fairing, which shows that an L-shaped plate as a new aerodynamic measure can effectively suppress vortex-induced vibration.

6. CONCLUSIONS

(1) Twin-box girder is prone to vortex-induced vibration. In this paper, there are obvious VIV phenomena in the girders with three different slotting rates. (2) Through the vibration test of twin-box girders with different slotting ratios, it is found that the L-shaped plate can suppress the torsional VIV of twin-box girders, and the suppressing effect increases with the increase of the aspect ratio of the L-shaped plate. (3) Through the pressure measuring test, it is found that the vortex-induced force contribution coefficient of each point decreases with the increase of the aspect ratio of the L-shaped plate. (4) The results of numerical simulation show that the L-shaped plate can weaken the airflow separation phenomenon on the upper surface of the upstream box girder, reduce the vortex size and move upstream.

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