Study on aerodynamic stability and anti-vibration measures of streamlined box girder

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Abstract: To study the vortex induced vibration and flutter stability of streamlined box girder and the relevant anti-vibration measures, a large-scale segment model, which has a scale ratio of 1:40, of a large-span steel box girder suspension bridge was tested in a wind tunnel. In the test, some measures, such as changing the position of track of the overhaul vehicle and adding a central stabilizer, were taken to check the anti-vibration effect. The test results show that: when the central stabilizer is added, the flutter suppression effect is remarkable, and there is no obvious vortex anti-vibration effect; when the track of the overhaul vehicle is located in the middle of the main girder oblique web plate, suppression for vortex induced vibration is obvious, as for flutter, there is no inhibition effect, but excitation effect; when the track of the overhaul vehicle is located in the middle of the main girder oblique web plate and the central stabilizer is added at the bottom of the girder, the flutter and vortex induced vibration stability are effectively improved.

1. Introduction
Long-span bridges, especially streamlined steel box girder suspension bridges, always have structural features such as light weight, low stiffness, and low damping, then their wind-induced vibration problems often become control factors in design[1]. The Tacoma Bridge was destroyed due to flutter under wind. Vortex-induced vibration is a self-limiting wind-induced vibration between forced vibration and self-excited vibration. Although it does not cause catastrophic damage to the structure like flutter, its vibration velocity is lower and the probability of occurrence is higher. Large amplitude vortex-induced resonance will not only affect the safety and comfort of the bridge, but also may cause structural fatigue damaged or even destroyed[2]. Various famous long-span bridges had been found to have different degrees of vortex-induced vibration, such as the Xihoumen Bridge in Zhoushan[1], the Tokyo Bay Channel Bridge[3], the Rio-Rotello Bridge in Brazil, and the Danish Big Belt East Bridge[4], etc. For different bridges, although the difference in the shape of the streamlined steel box girder is small, the aerodynamic stability may vary greatly. The reason is generally attributed to the influence of pneumatically sensitive components such as railings and inspection vehicle tracks.

Research on anti-vibration measures for various forms of wind-induced vibration has always accompanied the development of long-span bridges. The anti-vibration measures are mainly divided into structural measures and pneumatic measures. Improving the structural stiffness, increasing the structural quality and structural damping are some common structural measures. Pneumatic measures include setting the wind fairing, deflector, stabilizer, airflow-depressing board and central stabilizer on the main beam[5-6]. Pneumatic measures have the advantages of economical and practical, simple structure and good anti-vibration effect compared with structural measures. They are the first choice for wind-suppression measures for long-span bridges. Larsen[7] studied in detail the effects of...
pneumatic components such as railings, tuyere deflectors and tuyere configuration on critical wind speed of flutter by wind tunnel test of the Danish Big Belt East Bridge. Yang[8] reviewed the aerodynamic measures such as central stabilizer to improve the critical wind speed of flutter of long-span bridge based on wind tunnel test results and practical engineering applications. Li Yongle[9] found that optimizing the position of the track of the overhaul vehicle can significantly reduce the torsional vortex vibration of the steel box girder and the distributor plate at the tuyere can significantly reduce the vertical vortex response of the main girder by wind tunnel test. Zhu Siyu[10] confirmed by wind tunnel test that the deflector on the inside of the inspection vehicle track can effectively reduce the vortex-induced vibration amplitude of flat steel box girder. Most of the above studies only discuss the anti-vibration effect of the anti-vibration measures on the single vibration mode, ignoring the effect of the same vibration suppression measure on other vibration modes. For example, adding a central stabilizer to the bottom of the box girder has a certain anti-vibration effect on the flutter, but it may have no obvious inhibitory effect on the vortex induced vibration, and may even increase the vortex response. Therefore, it is necessary to study the influence of the same anti-vibration measures on the vortex induced vibration and flutter stability of the box girder.

Based on the above research background, in this paper, some researches on a long-span steel box girder suspension bridge were studied by the test of segment model in wind tunnel, to show the influence of the position of track of the overhaul vehicle and the central stabilizer on the vortex induced vibration and flutter performance.

2. Wind tunnel test of segment model

2.1. Test overview

The main span of the long-span steel box girder suspension bridge is 1160 m, and the bridge deck is arranged in two-way six lanes, with a width of 34.7 m and a height of 2.8 m, the track of the overhaul vehicle is 0.8 m away from the lower edge of the main beam. The flutter test speed is 59.5 m/s and the standard cross section of the main girder is shown in Figure 1. The scale ratio of the segment model is 1:40, site photo of the wind tunnel test is shown in Figure 2.

Figure 1. Schematic diagram of the cross section of the main beam (unit: m)

Figure 2. Photo of wind tunnel test

2.2. Optimization of vortex vibration performance

In order to investigate the influence of track location on vortex vibration performance of the main girder, three sets of optimization conditions were set up in the test including 0.4 m and 1.2 m apart from the lower edge of the main girder, middle of the main girder inclined web, and another set of optimization conditions, that is, central stability plates are arranged on the basis of the original scheme.
The test flow is a lateral uniform flow with a wind attack angle of 0°. Results of vortex induced vibration response of the main girder under completed bridge condition are shown in Figure 3.

![Figure 3. Torsional vortex response](image)

It can be seen from Figure 3 that torsional vortex-excited vibration occurs when the track of the overhaul vehicle is 0.4 m, 0.8 m (original scheme) and 1.2 m away from the lower edge of the main beam, and the maximum amplitude has reached or even far exceeded the allowable value of the specification. The vortex-locked wind speed range is basically the same. Among them, when the track of the overhaul vehicle is 0.4 m away from the lower edge of the main beam, amplitude of the torsional vortex-induced vibration is the largest, up to 0.585°, and the vibration-starting wind speed is slightly ahead of the other two conditions. When the track of the overhaul vehicle is located in the middle of the inclined web, no obvious torsional vortex-induced vibration is found and the anti-vibration effect is significant. Central stabilizer is arranged on the basis of the original scheme, but vortex-induced vibration is not effectively suppressed.

The track of the overhaul vehicle has a significant influence on vortex-induced vibration response of the main beam. The reason is the track of the overhaul vehicle which was located at the middle of the inclined web changed the separation and reattachment of the incoming flow through the wind nozzle at the lower edge of the main girder. That affects the formation and detachment of the vortex behind the lower edge of the main beam, and destroys the specific flow field required for the vortex-induced vibration of the main beam.

2.3. Optimization of flutter performance

Same as the vortex-induced vibration, flutter stability of the main beam is also extremely sensitive to the position of the bridge affiliated facilities such as the track of the overhaul vehicle. In order to study position of the track of the overhaul vehicle and the influence of the central stabilizing plate on flutter performance of the main beam, four sets of optimal operating conditions are set up same as the vortex vibration test. Results are shown in Table 1.

| Position of the track of the overhaul vehicle | Flutter test wind speed (m/s) | Flutter critical wind speed (m/s) | Flutter form |
|-----------------------------------------------|-------------------------------|-----------------------------------|-------------|

Table 1. Main beam flutter response
As shown in Table 1, the flutter critical wind speed of the original scheme is lower than that of the test wind speed, and flutter stability problem is involved. The minimum value of flutter critical wind speed occurs in the condition that the track of the overhaul vehicle is 0.4 m below the lower edge of the main girder, which is 50.2 m/s, lower than the test wind speed.

The flutter critical wind speed increases with distance increase of the track of the overhaul vehicle from the lower edge of the main beam. When the distance is 1.2 m, flutter critical wind speed is higher than the test wind speed, and flutter stability meets the requirement. When the track of the overhaul vehicle is located in the middle of the inclined web of the main beam, it not only fails to suppress the vibration effectively, but reduces the flutter stability. Adding a central stabilizing plate to the bottom of the main beam can increases the flutter critical wind speed significantly, and the scheme is feasible.

### 2.4. Combination optimization

According to the content shown in content 2.2 and 2.3, the optimum scheme of the vortex performance is to locate the track of the overhaul vehicle in the middle of the inclined web of the main beam. However, this measure can’t effectively suppress flutter, in the opposite, its stability was reduced. So it is necessary to seek a combined optimization scheme that can simultaneously improve the stability of flutter and vortex. After many experiments, it was found that suppression effect of vortex and flutter is obvious when the track of the overhaul vehicle is located at the middle of the inclined web of the main beam and a central stability plate is set. The maximum amplitude of vortex is significantly reduced, and flutter critical wind speed is significantly increased to 75.5 m/s. Results of vortex test are shown in Figure 4.
3. Conclusions
Based on the wind tunnel test of segment model, the influence of track of the overhaul vehicle position and central stability plate on the aerodynamic performance of the main beam is studied. The same vibration suppression measure has a suppression effect on a certain vibration mode, but may have an inhibitory effect on another vibration form, or may have no effect or even a side effect that increases the vibration response of the structure. This issue cannot be ignored but be taken seriously.

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