Aerodynamic Investigation on a Long-Span Suspension Bridge with Central-Slotted Box Girder

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Summary

The aerodynamic investigation including flutter and vortex-induced vibration performance of long-span suspension bridge with central-slotted box girder was carried out based on Xihoumen Bridge with the main span of 1650m, which will be the longest box girder suspension bridge in the world. The flutter performance was investigated through sectional model wind tunnel tests and theoretical analysis. It is found that slot width has the most significant influence, and the variation of local aerodynamic configuration inside and outside the box girder section will also change the structural flutter performance in some comprehensive way. Central stabilizers can further improve the aerodynamic stability of slotted box girder section, and the “combined types” of stabilizers are recommended. Since heaving and torsional vortex-induced vibrations were observed when wind speed is relatively low, vibration control measure was investigated through wind tunnel tests.
Keywords: aerodynamic investigation; flutter instability; vortex-induced vibration; long span bridge; box girder section; central slotting; vent width; central stabilizer; guide vane.

1. Introduction

Theoretical and experimental investigations reported in the literature support the conclusion that the application of central slotting in the box section can improve aerodynamic stability of suspension bridges. The feasibility study of Gibraltar Bridge shows that not only there is a clear trend for the slotted-box section to become increasingly aeroelastically stable for increasing deck vent width but also this increase ratio of critical wind speeds with vent width can be fitted to the Power-law expressions by means of the least squares method. While previous investigations carried out by the authors indicate that the relationship between structural aerodynamic stability and vent width is not mono increase even for some kind of box girder section. As another important problem in the research of aeroelastic stability of bridge structure, the vortex-induced vibration performance of long-span suspension bridge with central-slotted box girder should also be paid significant attention to, since the existence of central vent will make the vortex shedding process and its effect on bridge girder more complicated.

2. Flutter performance

2.1 Relationship between flutter performance and vent width

According to previous research results, vent width is a key parameter in determining the aerodynamic performance of a slotted box girder section. Therefore the relationship between structural aerodynamic performance and vent width was investigated first of all. In order to establish the experimental evidence linking vent width to aerodynamic stability, the ratio of vent width b to the solid box width B was respectively set to b/B=0, 0.2, 0.4, 0.6, 0.8, and 1.0 in wind tunnel tests with simplified cross sections based on Xihoumen Bridge. The flutter stabilizing effectiveness of slotted box girders generally depends upon two important characteristics including

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width of central vent and angle of attack. The values of critical wind speeds vary with angle of attack for all cases with various widths of central vent. For each angle of attack, the relationship between flutter performance and vent width is not mono increase, and the evolution trend of flutter critical speed comprises two different regions: the critical wind speed first increases with the relative width of central vent until an optimal point is reached, then decreases.

2.2 Effects of outboard and inboard configurations

As vent width is the most decisive factor in determining the general aerodynamic stability of a bridge structure with a central-slotted box girder, the detailed aerodynamic configuration especially the outboard and inboard edge configuration of a central-slotted box girder section may also has a considerable effect on the structural flutter performance. So some quantitive evaluations about the effects of these aerodynamic configuration modifications are conducted based on the evolution of the central-slotted box girder cross sections of Xihoumen Bridge.

2.3 Aerodynamic improvement for slotted box girder

In some cases we need to search for additional improvement on slotted box girder sections. Therefore, we conducted a series of wind tunnel tests to investigate the flutter controlling effects of central stabilizers installed on S4 Section. The tested results show that all types of central stabilizers can improve aerodynamic stability of central-slotted box girder section. For three basic types of central stabilizers, Type C where the stabilizer is under the central slot has the best flutter-controlling effect. It should also be noted that the combination types of stabilizers are more effective, which can increase flutter critical speed up to 15%.

3. Vortex-induced vibration

For vortex-induced vibration testing, a combination of geometrical, mass, stiffness and Reynolds number considerations resulted in the selection of a 1:20 geometrical scale for the sectional model. Vortex-induced vibration in heaving degree of freedom of the model were observed at all three wind angle of attack, and the maximum amplitude of heaving response is 17.5 cm for the prototype bridge structure. Torsional vortex-induced vibration was observed only at 0˚ wind angle of attack with the maximum amplitude of 0.5˚ for the prototype bridge structure.

In order to mitigate the oscillations induced by vortex shedding, guide vanes were installed at the bottom slab near central vent. The torsional vortex-induced vibration of the original central-slotted box girder can be nearly eliminated by the installation of guide vanes. No heaving vortex-induced vibrations of the girder with guide vanes were observed except for the case with 0˚ wind angle of attack. In this case the peak amplitude of heaving vortex-induced vibration was reduced from 17.5cm to 13.5cm for the prototype bridge structure.

4. Conclusion

Slot width has the most significant influence on the flutter performance of central-slotted box section, and the variation of inboard and outboard aerodynamic configuration will also affect the structural flutter performance in some comprehensive way. Central stabilizers can further improve the aerodynamic stability of slotted box girder section, and the “combined types” of stabilizers are recommended. Vortex-induced vibrations in both heaving and torsional degrees of freedom were observed in the 1:20 sectional model wind tunnel test. The mitigating effect of guide vane installed at the bottom slab near the central vent is quite good, especially for torsional vortex-induced vibration.

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