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Study on the influence of torsional eccentricity of section on bridge flutter stability

SUMMARY:

In wind tunnel tests of bridge sectional models, the torsion center is usually set at the centroid, but the actual torsion center may shift, which will affect the flutter stability of the structure. Due to the influence of structural system, torsional eccentricity will also appear in actual Bridges. In this paper, the effect of torsional eccentricity on the flutter response of box girder is studied by computational fluid dynamics method (CFD), and the internal mechanism is also explored. The research shows that the flutter stability of the box girder can be improved by the downward shift of the torsion center; however, the upward movement of the torsion center will have the opposite effect, which makes the wind tunnel test results potentially dangerous. The effect of torsional eccentricity on structural flutter stability does not work by changing the additional attack angle, and eccentricity has opposite effects on the aerostatic and aerodynamic moments of the structure.

Keywords: torsional eccentricity, bridge, fluent

1. GENERAL INSTRUCTIONS

Flutter is a kind of divergent vibration, which will cause great threat to the safety of the structure. In the wind tunnel test of sectional model, the centroid of section is usually taken as the torsional center, but there is a deviation between them in practice (Li et al., 2018). For the actual bridge, under the influence of torsional stiffness of cables and pylons, torsional eccentricity may also occur during flutter. The deviation of the torsion center will change the moment arm of the aerodynamic self-excitation force, which will affect the flutter stability of the bridge.

Previously, in the flutter study of airfoils, researchers found that moving the torsional center to the windward side can improve the flutter critical wind speed U_{cr} (Theodorsen, 1979). Later, the eccentric mass method was introduced into the bridge wind resistance design. Larsen (1997) studied the Humber Bridge with eccentric roller, and the results showed that the eccentric mass method can effectively improve the U_{cr}. Phongkumsing and Wilde (2001) used the time-domain analysis method to verify the effectiveness of the eccentric mass flutter control method. Gao (2006) found that the improvement effect of eccentric mass method on flutter stability increases with the increase of construction completion rate. In further study, it is found that in addition to the downwind shift mentioned above, the torsional center also has an obvious up-and-down shift. The study of Wu (2016) shows that the torsion center is offset up and down, and the U_{cr} always increases whether the torsion center moves up or down.

In this paper, the influence of the up and down offset of the torsion center on the box girder flutter stability is investigated by CFD, and further explore their internal mechanism.

2. NON-ECCENTRIC NUMERICAL SIMULATION

The size of the section is shown in Fig. 1, which is consistent with the model of Long (2010). The m and I_m are 12 kg/m and 0.44 kg*m^2/m. The f_h and f_a are 2.01 Hz and 3.79 Hz. When initial wind attack angle $a_{initial}$ = 0°, the section appeared divergent vibration, and soft flutter appeared when $a_{initial}$ = 5°. The mesh is shown in Fig. 2.

Figure 1. Section size diagram of box girder (m)

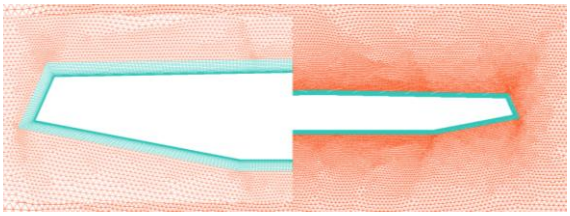

Figure 2. Diagram of mesh near the section

First, the flutter response of the section was calculated under the condition of no torsional eccentricity at $a_{initial}$ = 5°. The variation of vertical and torsional vibration amplitude with reduced wind speed U_{re} is shown in Fig. 3(a), while the curve of aerostatic displacement is shown in Fig. 3(b). Fig. 3 also shows previous results for this section (Ying et al., 2017), and the results in this paper are in good agreement with these.

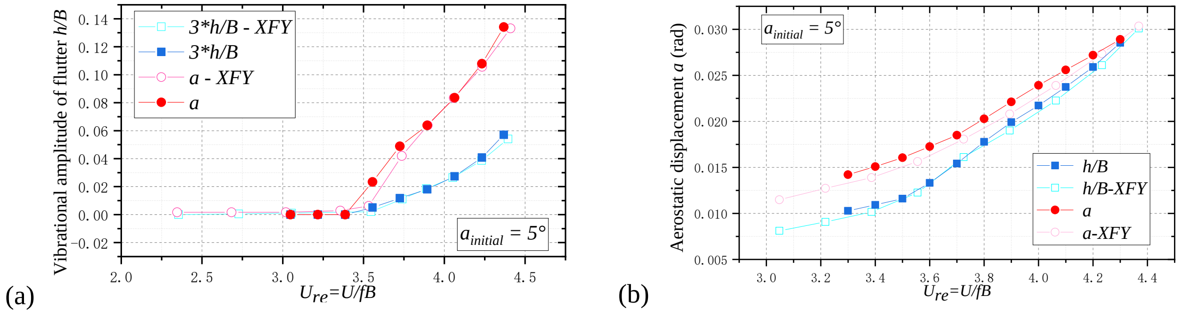

Figure 3. Flutter response under $a_{initial}$ = 5°: (a) flutter amplitude; (b) aerostatic displacement. (Ying et al., 2017)

3.FLUTTER RESPONSE UNDER TORSION ECCENTRICITY

In this paper, four eccentric positions were set, which were ±0.03 and ±0.3 m. Where positive represents the upward shift of the torsion center. Among them, 0.03m is equivalent to 43% of the beam height. Considering that the height of the main beam is small, the offset is increased to 0.3m to highlight the influence of eccentricity on flutter response.

Fig. 4 shows flutter responses under four eccentric conditions with $a_{initial}$ = 5°. It can be seen from Fig. 4(a) that the downward shift of the torsional center will improve the flutter stability, while the upward deflection has the opposite effect. When the torsional center is shifted downward by 0.3 m, the U_s is increased by 15% compared with that without eccentricity; and when it moves up 0.3 m, the U_s is decreased by 5%. This indicates that the downward shift of the torsion center has a more obvious effect on flutter response. When it moves down 0.03 m, the U_s only increased by about 3%, while the flutter response almost did not change when it moves up 0.03 m. In general, the flutter response of the box girder is not sensitive to the up-and-down deviation of the torsion center. However, it should be noted that eccentricity is not always beneficial. When the actual torsion center is located on the upper side of the centroid, the result without eccentricity is dangerous. On the other hand, the flutter stability can be improved by lowering the torsional center position in the wind resistance design. Although previous studies have shown that the deflection of the torsion center to the windward side can improve the flutter stability, the wind direction at the bridge site may vary seasonally. The downwind eccentricity will become invalid when the wind direction changes greatly. The vertical eccentricity can avoid this defect.

According to Fig. 4(b), it can be found that the torsional eccentricity has an influence on the angle of wind attack (AOA), so it is initially suspected that the change of AOA is the internal cause of flutter response affected by torsional eccentricity. Further comparison shows that the lower eccentricity will increase the AOA, and the flutter stability should have decreased with the increase of the AOA, but the U_s of this working condition has increased. This phenomenon also exists when the torsion center moves up. Therefore, the real internal mechanism needs further exploration.

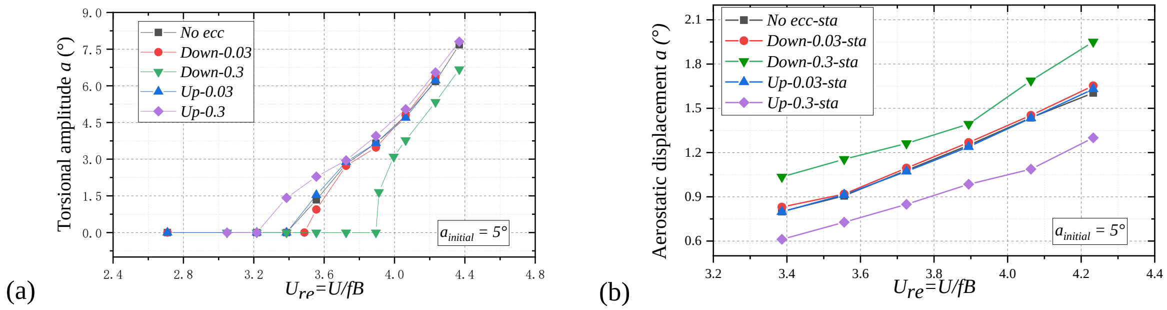

Figure 4. Effect of eccentricity on flutter response: (a) torsional amplitude; (b) aerostatic displacement

Table 1 shows the flutter response under $a_{initial}$ = 0°, where a_{cr} represents the AOA under flutter critical condition. The results show that the effect of eccentricity on hard flutter is consistent with that of soft flutter: the downward shift of the torsion center will decrease the a_{cr} and reduce the flutter stability; it moves up will increase the a_{cr}, but improve the U_{cr}.

Table 1. Flutter response at $a_{initial}$ = 0°

a_{initial}=0°	*No ecc*	*Down-0.3*	*Up-0.3*
U_{cr}	17.02	16.74	17.52
a_{cr}	0.06	-1.05	1.21

4. INTERNAL MECHANISM EXPLORATION

Fig. 5 shows flutter responses with $a_{initial}$ = 4.8° and 5.2°. Fig. 5(a) shows that when $a_{initial}$ = 5.2°, the curve of AOA with U_{re} is consistent with the condition of 0.3 m lower eccentric, while Fig. 5(b) shows that the two have opposite effects on flutter stability. The same result can be obtained by comparing the $a_{initial}$ = 4.8° and the upper eccentricity of 0.3 m. The results further prove that the effect of torsional eccentricity on flutter is not induced by the AOA, and the change of torsional center position has opposite effects on aerostatic and aerodynamic moments. On the other hand, it can be concluded that the soft flutter is not only affected by the mass, stiffness, and actual AOA, but also different flutter responses can be obtained even when these factors are consistent.

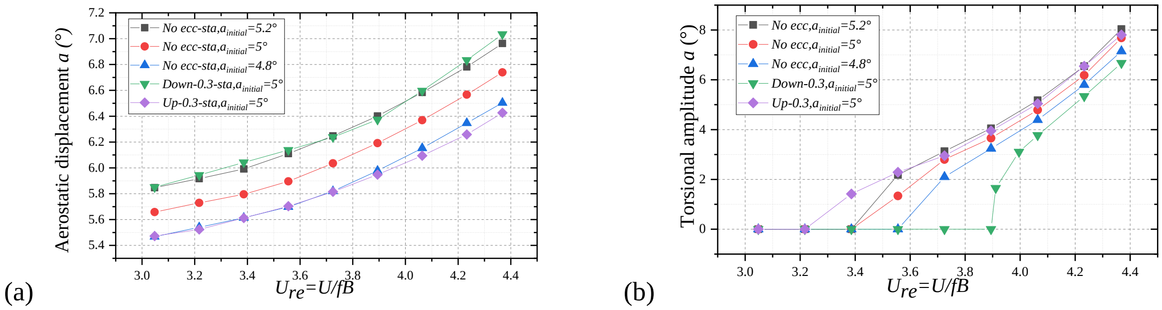

Figure 5. Flutter response with reduced wind speed :(a) aerostatic displacement; (b) torsion amplitude

5. CONCLUSIONS

In this paper, the flutter response of box girder under torsional eccentricity is obtained by CFD and compared with the results without eccentricity, the following conclusions are obtained:

The influence of torsional eccentricity on the flutter stability is not all favorable, and the eccentricity of different directions will produce opposite effects. This conclusion holds for both divergent flutter and soft flutter. Proper vertical eccentricity can improve flutter stability, and the method is not affected by wind direction change. The effect of torsional eccentricity on the flutter of box girder is not caused by the change of additional AOA. Torsional eccentricity has opposite effects on aerostatic moment and aerodynamic moment. The effects of torsional eccentricity may be amplified for main beam types such as truss beams or double beams

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REFERENCES

Li, Y. L., Wu, B., Wang, B., and Tang, P., 2018. Tests for effects of torsional center offset on flutter critical wind velocity of a truss bridge "JOURNAL OF VIBRATION AND SHOCK", 37(21), 165-170.

Theodorsen, T., 1979. General theory of aerodynamic instability and the mechanism of "NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS REPORT No. 496", 1050, 291.

Larsen, A., 1997. Prediction of aeroelastic stability of suspension bridges during erection "Journal of Wind Engineering Industrial Aerodynamics", 72, 265-274.

Phongkumsing, S., and Wilde, K., 2001. Analytical study on flutter suppression by eccentric mass method on FEM model of long-span suspension bridge "Journal of Wind Engineering Industrial Aerodynamics", 89(6), 515-534.

Gao, F., 2006. Study on improvement of flutter stability of long-span suspension bridge during erection by eccentric mass method. M.D, Southwest Jiaotong University, Chendu, Sichuan, China

Wu, B., 2016. The Eccentric Torsion Effect of the Long Span Truss Girder Bridge and its Influence on Flutter Performance. M.D, Southwest Jiaotong University, Chendu, Sichuan, China

Long, F., 2010. Wind-resistant Performance Analysis and Experimental Investigation on Long-span Self-anchored Suspension Bridges. M.D, Dalian University of Technology, Dalian, Liaoning, China

Ying, X. Y., Xu, F. Y., Zhang, M. J., and Zhang, Z., 2017. Numerical explorations of the limit cycle flutter characteristics of a bridge deck "Journal of Wind Engineering Industrial Aerodynamics", 169, 30-38.