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Aerodynamic Measures for the Vortex-induced Vibration of π-shape Composite Girder in Cable-stayed Bridge

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ABSTRACT

Wind tunnel experiment for aerodynamic measures for the vortex-induced vibration of π-shape composite girder in cable-stayed bridge was carried out in Chang'an University in China. Several measures were investigated such as deflector, central stabilizer, sealed barrier, etc. Comparison was discussed among the measures. Effects of upper central stabilizer, sealed barrier, vertical deflector and lower central stabilizer on vertical amplitude and velocity pathlines were studied.

1. INTRODUCTION

Π-shape composite girders are used in cable-stayed bridges due to its small cross-section, light self-weight and convenient construction technology. However, π-shape composite girder is a bluff body which is more critical to wind actions comparing to streamlined box girder. Vortex-induced vibration (VIV) of long span bridge is an aerodynamic phenomenon which usually happens in low wind speed. It affects the driving comfort and may cause the fatigue failure of the main girder of the bridge. Suppression measures for VIV could be classified into two types: structure measure and aerodynamic measure. Structure measure includes increasing natural frequency of the bridge and using TMD, TLD and TLCD. Aerodynamic measure can change the aerodynamic characteristic of the bridge to suppress or eliminate the VIV, such as deflector, fairing, stabilizer, central barrier, etc. (Liu, Jianxin, 1995)

Many researchers have carried out investigations in wind tunnel experiments for different aerodynamic measures for the long span bridges (Sun, Yanguo, et al, 2012; Liu, Jun, et al, 2015). Numerical study on suppression of VIV of bridge section by aerodynamic countermeasures has been carried out and a method based on forced oscillations to identify the reduced velocity corresponding to the maximum amplitude of vibration was proposed. This study aims to compare the effects of some aerodynamic

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measures for the VIV of π-shape composite girder in cable-stayed bridge, wind tunnel experiment was carried out and numerical analysis was studied as well.

2. EXPERIMENT SETUP

Wind tunnel experiments were carried out in a Boundary Layer Wind Tunnel in Chang'an University, China. The test section was 3.0m wide and 2.5m high. The atmospheric boundary layer was simulated as a geometrical scale of 1:50. Uniform flow was generated were simulated and a velocity scale of 1:2.5 was adopted. The prototype in this experiment was a cable-stayed bridge with the π-shape composite girder, the main span was 565m, the overall width of the girder was 30.25m and the largest depth of the girder was 3.43m (4.03m including the barrier).

A rigid segmental model of the main girder was designed and the dynamic characteristics are as shown in Table 1.

Table 1 design parameters of the model

Parameter	Model	Full scale	Ratio
Equivalent mass $\boldsymbol{m}$/(kg/m)	19.39128	71573.5	1/502
Equivalent mass $\boldsymbol{J}/(\mathrm{kg}\cdot\mathrm{m}^2/\mathrm{m})$	0.582529	7549570	1/504
Vertical bending characteristic frequency $\boldsymbol{f_b}$/(Hz)	3.76564	0.134617	50/2.5
Torsion characteristic frequency $\boldsymbol{f_t}$/(Hz)	5.91236	0.231591	50/2.5

Totally 7 aerodynamic measures were considered in this study, the cross-section of the main girder and the measures are as shown in Fig. 1. The specific measures are as below:

① Horizontal deflector (deck), 1.65m in full scale;
② Horizontal deflector (girder), 1m in full scale;
③ Upper central stabilizer, 1.6m in full scale;
④ Sealed barrier (half sealed);
⑤ Sealed barrier (full sealed);
⑥ Vertical deflector, 1m in full scale;
⑦ Lower central stabilizer, 3.4m in full scale.

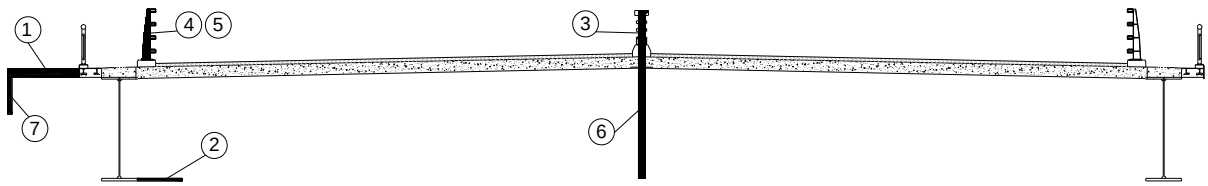


Fig. 1 Aerodynamic measures of Π-shape composite girder. (unit:cm)

Based on tentative test results, measures ①+②+③ were combined and arranged as the basic case. In measure ④, half sealed represents the half bottom of barrier was sealed as a non-porous panel. In measure ⑤, full sealed represents the entire barrier was sealed.

Experimental wind velocity was ranging from 2m/s to 19m/s. In tests, a decomposable elastic suspension system was developed. In order to reduce aerodynamic end effects, two timber end plates were fixed to the both longitudinal ends of the segmental model. Restraining the lateral DOF, only the vertical and torsional DOFs were interested in the experiment. The model length was 1.5m and the model was elastically suspended by 8 springs, as shown in Fig. 2.

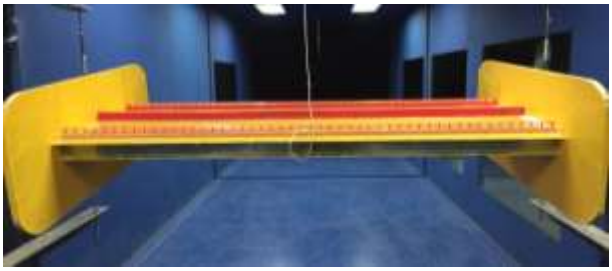


Fig. 2 Overview of experimental model

3. RESULTS

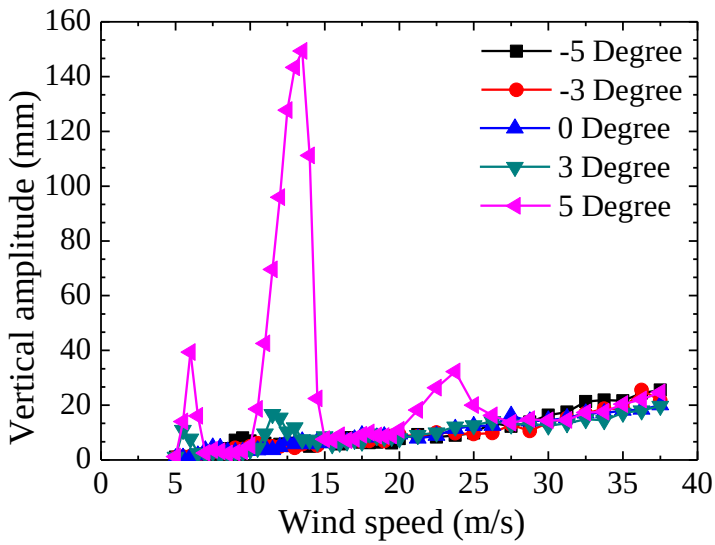


Fig. 3 Comparison on vertical amplitudes among different wind attack angles.

Fig. 3 shows the comparison on vertical amplitudes among different wind attack angles for the original designed cross-section. A remarkable VIV range can be found when the wind attach angle is 5 degree. The largest vertical amplitude is around 150mm (RMS) in full scale and the wind speed of the VIV range is from 10m/s to 15m/s. There is no VIV for the other wind attack angles. Fig. 4 shows the results of the torsion angles among different wind attack angles and there is no torsional VIV can be found.

Therefore, the aerodynamic measures to suppress the vertical VIV of this bridge are investigated in this study and all the experiments and numerical analysis are only focusing on case when the wind attack angle 5 degree.

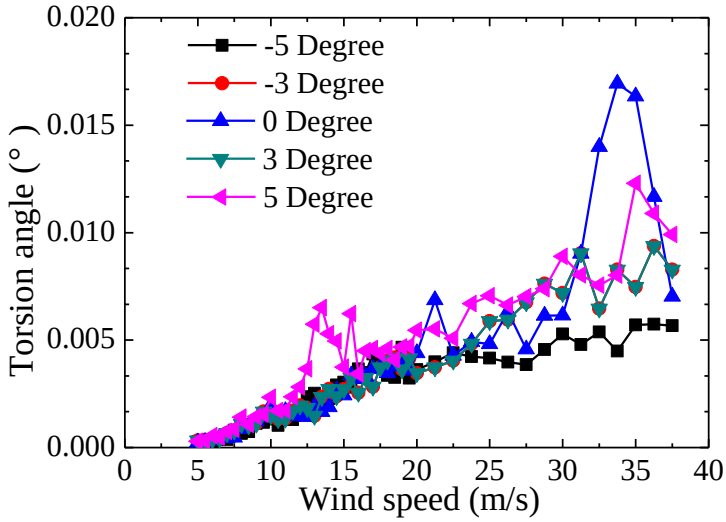


Fig. 4 Comparison on torsion angles among different wind attack angles.

Based on tentative test results, measures ①+②+③ were combined arranged and the suppression effect is significant that the VIV range shifted into lower wind speed range and the largest vertical amplitude reduced from 150mm to 40mm. Thus, the basic case was the combination of measures ①+②+③. The effects of the other measures are studied through experimental data and numerical analysis results.

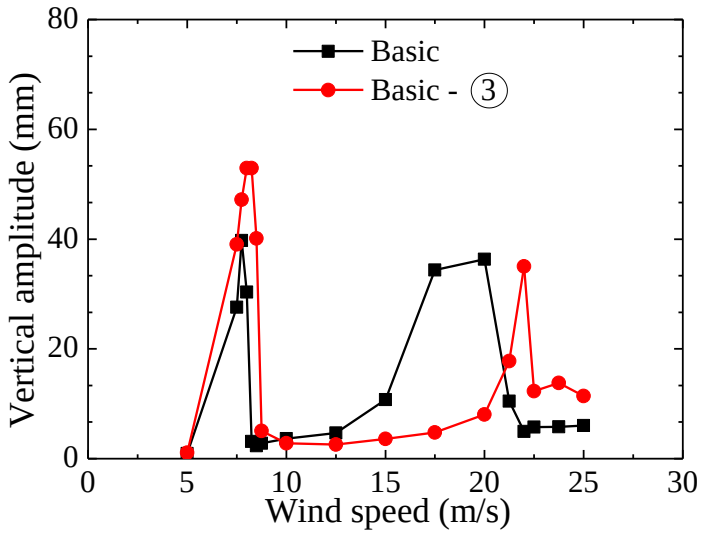
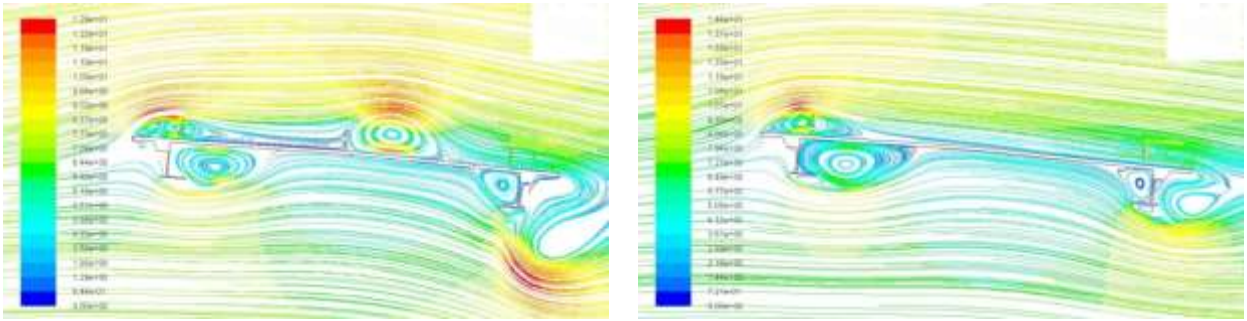


Fig. 5 Effects of upper central stabilizer on vertical amplitudes.

Upper central barrier may affect the vortex distribution around the surface of the girder. Fig. 5 shows the comparison of vertical amplitude between the basic case and the case that the upper central barrier (measure ③) is removed. VIV can be found in both the

two cases and the VIV ranges are quite close. The largest vertical amplitude increases from 40mm to 53mm when the upper central barrier is removed. The result shows that the upper central barrier may not eliminate the VIV but could reduce the largest vertical amplitude.

Commercial computational fluid dynamics (CFD) software FLUENT was used in this study to analyze the velocity pathlines around the bridge girder. Calculation region was 600m wide and 400m high, the total meshing grids was 571054. A 2-D transient numerical analysis was carried out with the consideration of the lateral wind. Fig. 6 shows the effects of upper central stabilizer on velocity pathlines. A remarkable vortex is generated on the upper surface of the girder and the location is right behind the upper central barrier. This vortex may suppress the vertical VIV that leads to a reduction of the largest vertical amplitude value.



(a) Basic case (v=7.5m/s) (b) Upper central stabilizer is removed (v=7.5m/s)

Fig. 6 Effects of upper central stabilizer on velocity pathlines.

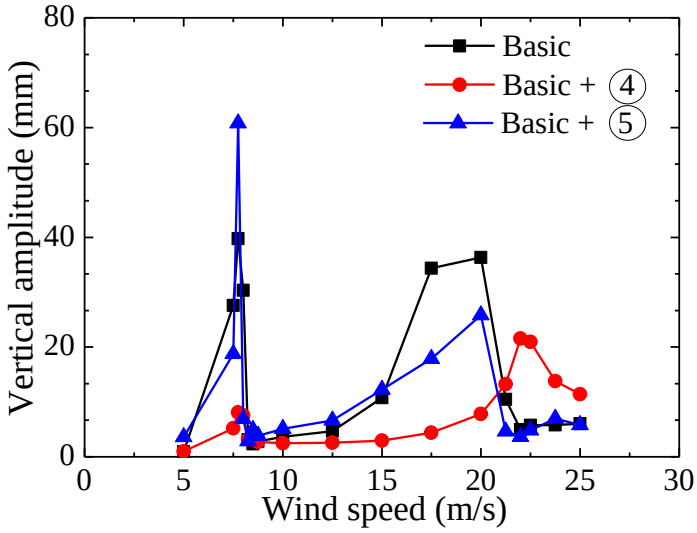
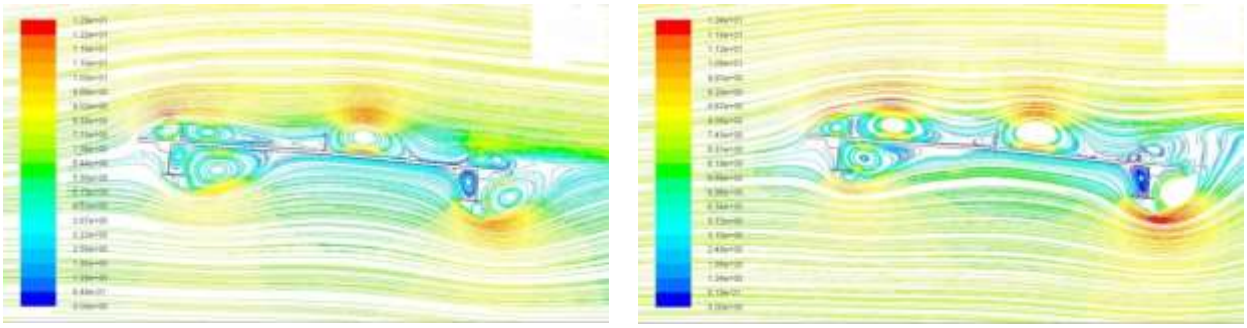


Fig. 7 Effects of sealed barrier on vertical amplitudes.

Beside the measures ①+②+③, two types of sealed barrier were considered and arranged in this study, which are half sealed and full sealed, respectively. Fig. 7 shows the comparison among the half sealed, full sealed and basic cases. The results show

the full sealed barrier could increase the largest vertical amplitude but the half sealed barrier could reduce the value. However, the VIV range doesn't shift significantly. Fig. 8 shows the velocity pathlines of the measure combinations which including the measures of half sealed barrier and full sealed barrier. The results show a large re-attaching vortex in the wake of the girder, as shown in Fig. 8(b). A remarkable upward tilting of the vortex may increase the vertical vortex-induced force.



(a) Basic case+ half sealed barrier (v=7.5m/s)

(b) Basic case+ full sealed barrier (v=7.5m/s)

Fig. 8 Effects of sealed barrier on velocity pathlines.

Fig. 9 shows the comparison among the basic case, full sealed barrier, vertical deflector and lower central stabilizer. Except the basic case, all the other three combinations can eliminate the VIV which the wind speed range is from 15m/s to 21m/s, but a VIV range at lower wind speed appears around 5.5m/s. The full sealed barrier reduces the largest vertical amplitude from 58mm to 44mm. The last measures combination which including the vertical deflector eliminates all the vertical VIV phenomena. From the results of velocity pathlines, vortex shedding and vortex re-attaching can be found in Fig. 10 (a), (b) and (c). The most significant difference is that there is a pair of vortexes can be found in the wake in Fig. 10 (c) which may suppress the VIV. For Fig. 10 (a) and (b), there is only one big vortex can be found and which tilts upward.

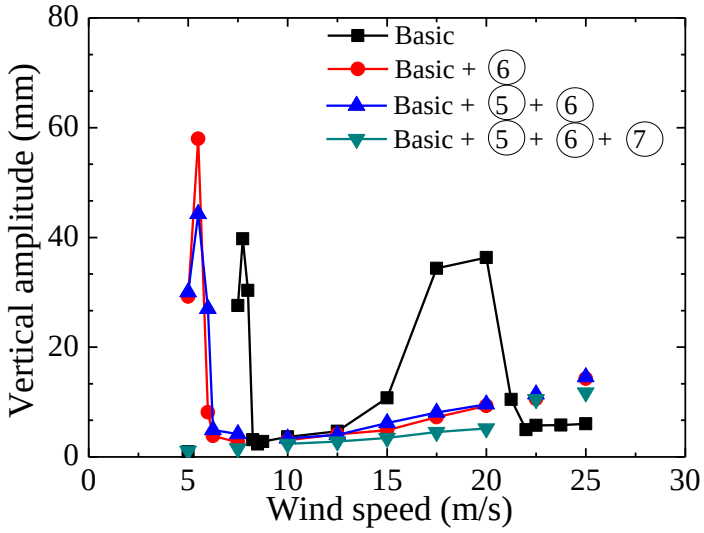
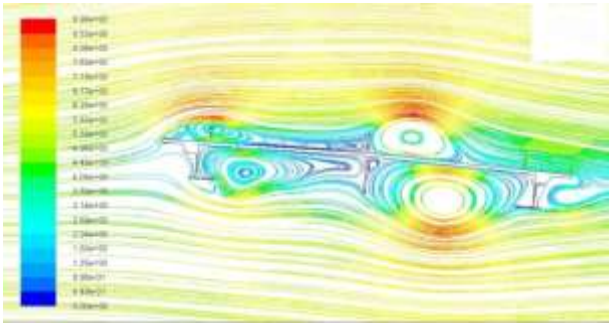
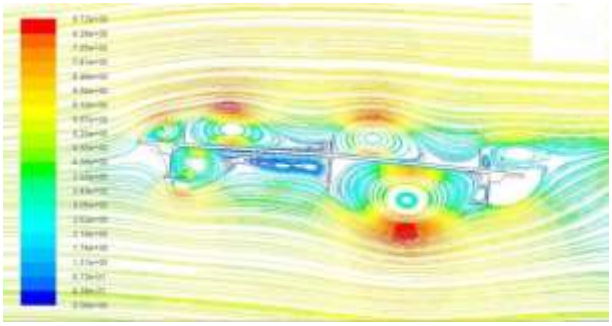


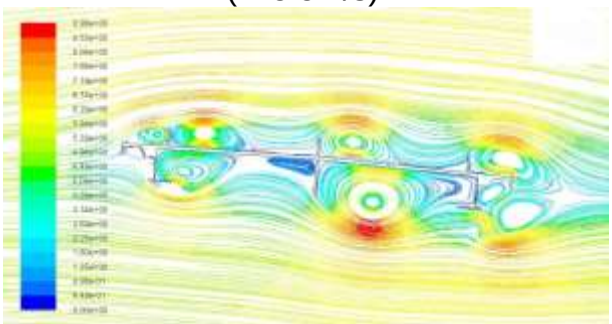
Fig. 9 Effects of combined measures on vertical amplitudes.



(a) Basic case + lower central stabilizer (v=5.5m/s)



(b) Basic case + full sealed barrier + lower central stabilizer (v=5.5m/s)



(c) Basic case + full sealed barrier + vertical deflector + lower central stabilizer (v=5.5m/s)

Fig. 10 Effects of combined measures on velocity pathlines.

4. CONCLUSIONS

Wind tunnel experiment for aerodynamic measures for the vortex-induced vibration of π-shape composite girder in cable-stayed bridge and numerical analysis were carried out. Totally 7 aerodynamic measures, Horizontal deflector (deck)，horizontal deflector (girder)，upper central stabilizer, sealed barrier (half sealed)，sealed barrier (full sealed), vertical deflector and lower central stabilizer, were considered in this study. Effects of upper central stabilizer, sealed barrier, vertical deflector and lower central stabilizer on vertical amplitude and velocity pathlines were discussed.

The result shows that the upper central barrier may not eliminate the VIV but could reduce the largest vertical amplitude. Full sealed barrier may cause more critical VIV compared with half sealed barrier in some cases. A vertical deflector may eliminate VIV successfully, the vertical deflector is arranged in the windward which still affects the leeward flow. Different aerodynamic measures have different effects on the flow pathlines. However, π-shape composite girder is a complex cross section of bluff body, it is not easy to determine an optimized aerodynamic measure or a measures combination. Some measures may counteract the effect for each other. Different effects may be found with the same measure and the opposite effects could happen in particular cases. More experimental studies need to be done in the future work.

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