

Aerodynamic force and vortex flow evolution for a double-slotted box girder under vortex-induced vibration

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SUMMARY:

To investigate vertical vortex-induced vibration (VIV) performance of double-slotted box girder with three separated boxes, surface pressure and displacement measured wind tunnel tests were conducted and aerodynamic distribution characteristics were analysed. The results show that the aerodynamic forces on the upper and lower surfaces of upstream box, the upper surface of middle box and the rear regions of upper and lower surfaces of downstream box make positive contributions to VIV response, which is the main reason for the vertical VIVs. The regions with obvious contributions around double-slotted box girder increase significantly compared with streamlined closed-box girder and central-slotted box girder, which indicates that a double-slotted ventilating structure allows aerodynamic forces acting on larger areas of the girder surface to participate in the process of vortex-excited forces generation, and then potentially affects the VIV performance. A vortex-related flow pattern was described combined with the vortex drifting theory, which would deepen the understanding of vertical VIV mechanism: There is a vortex drifting on the upper surface of the downstream box periodically, and the aerodynamic forces from windward side to the front area of the lower surface of the middle box may be significantly affected by vortices generated in the windward slot.

Keywords: double-slotted box girder, vertical vortex-induced vibrations, distributed aerodynamic forces

1. BACKGROUND

Double-slotted box girder is a novel type of main girder with a potential engineering application prospect in super long-span bridges. The Messina bridge in Italy, with a main span of 3300 m, is one of the typical examples. In terms of wind-resistant performance, the complexity of the flow field around the double-slotted box girder may remarkably increase and lead to the potential risk of vortex-induced vibrations (VIVs) (Diana et al, 2006 and 2013). During the past decades, plenty of research has been done on the VIV of streamlined closed box girder and central-slotted box girder (Hu et al, 2018, 2021 and 2022; Liu et al, 2021). However, for double-slotted box girder, although some researches about the VIV performance and mechanism have been done, there is still a lack of investigation on the vertical VIV process, especially on aerodynamic forces distribution and evolution characteristics and flow pattern, which is essential to reveal vertical VIV mechanism, since this kind of VIVs have been repeatedly reported these years.

2. EXPERIMENTAL SETUP AND VORTEX-INDUCED VIBRATION RESPONSE

To study on vertical VIV of double-slotted box girder, a spring-suspended sectional model with a geometric scale ratio of 1:30 is used to conduct surface pressure and displacement measured wind tunnel tests. The cross-section of the model is shown in Fig. 1. The vertical and torsional frequency of the model is about 1.9 Hz and 3.7 Hz, respectively. There are two vertical VIV lock-in regions within the range of testing wind velocity. The first one was selected as the representation to analyze the aerodynamic force distribution and evolution characteristics during the vertical VIV process because of its larger amplitude.

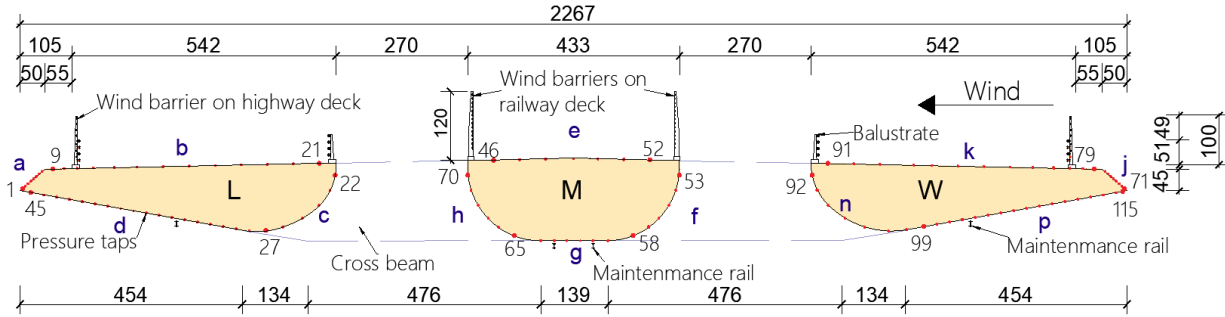


Figure 1. The dimension of model cross-section

3. AERODYNAMIC FORCE CHARACTERISTICS

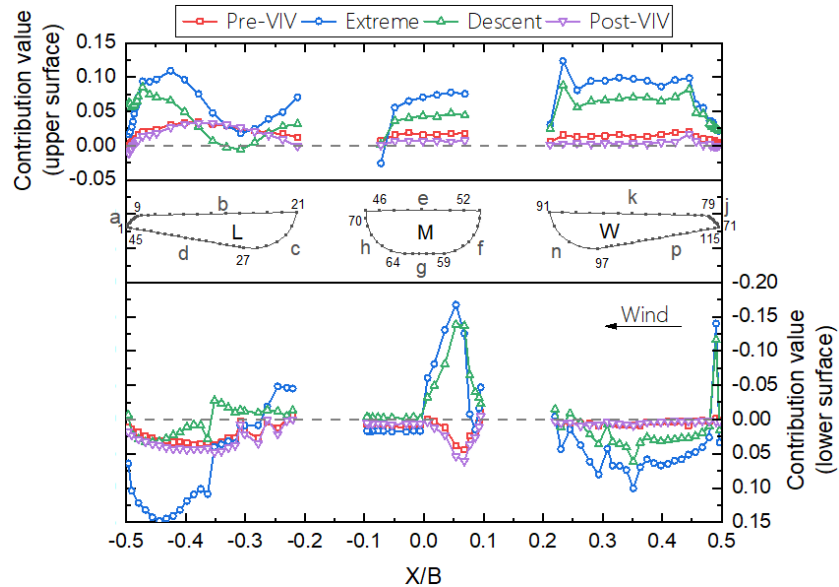


Figure 2. Distribution of contribution value around double-slotted box girder

The aerodynamic force distribution and evolution characteristics around the double-slotted box girder was analysed on the aspect of mean pressure, fluctuating pressure, correlation between distributed aerodynamic forces and general VEF, and contribution value, which is a quantitative description of the influence of the distributed aerodynamic force on the general VEF. The spatial

distribution of contribution value during the vertical VIV is shown in Fig. 2. The positive contribution values of zone a, b, d, e, j, k, n, p all increase obviously when the VIV occurs, which indicates that the distributed aerodynamic forces on these zones all play a significant role in promoting the occurrence of vertical VIV. The contribution values of zone c and the part from zone f to the front area of zone g are negative, where the distributed aerodynamic forces have an inhibitory effect on the VIV. Only the contribution values from the downstream of zone g to zone h are close to 0, the effect of distributed aerodynamic force is relatively small.

For streamlined closed-box girder (Hu et al, 2018) and central-slotted box girder (Liu et al, 2021), when VIV occurs, the distributed aerodynamic forces on the downstream surfaces and the front area of the upper surface contribute much more than those of the other areas. However, for double-slotted box girder, the contribution values of almost the whole model surface are significant. It can be inferred that the existence of the double slots may make the aerodynamic forces acting on more zones of the girder surface more fully participate in the VIV process, then the VEF effect of the double-slotted box girder is inevitably strengthened over the other two.

4. VORTEX DRIFTING PATTERN AND SIMPLIFIED VORTEX MODEL

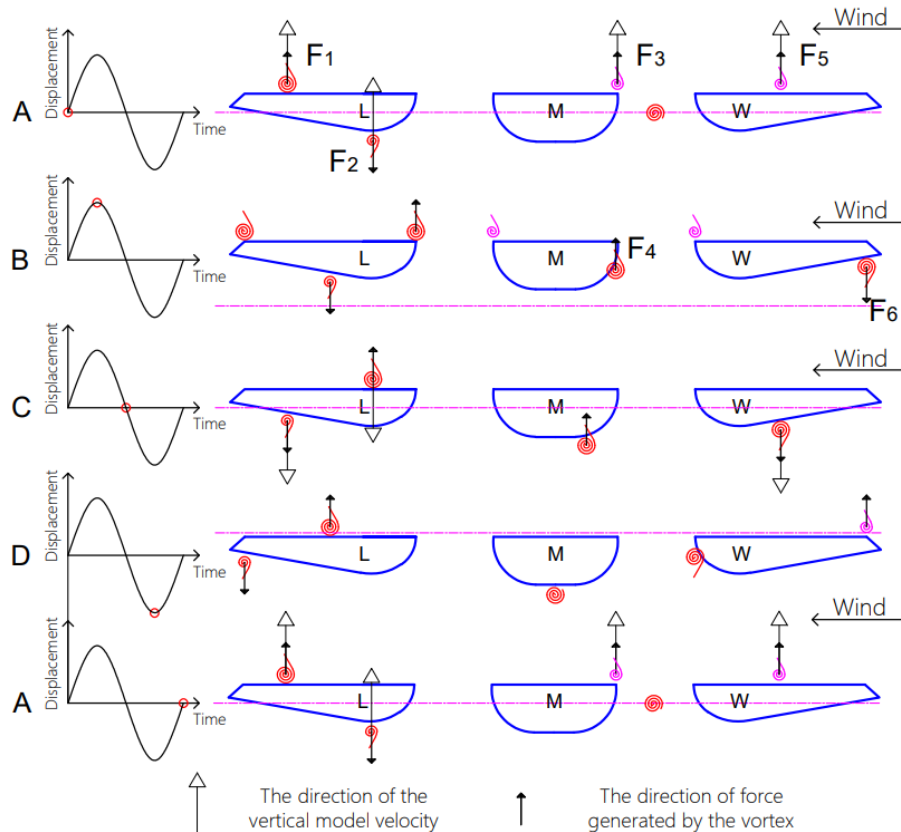


Figure 3. Schematic diagram of simplified vortex flow pattern during vertical VIV

The variation of phase lag between the distributed aerodynamic force and the general VEF along the model surfaces was analysed, whose monotonic trend is closely related to the concept of

vortex drifting. A vortex-related flow pattern around the double-slotted box girder during the vertical VIV was described combined with the vortex drifting theory and simplified vortex model (Hu et al, 2021 and 2022), as shown in Fig. 3. A linear variation trend of phase lag is observed on the upper surface of the downstream box, especially in descent stage, which implies that there may be a vortex drifting on this zone, and the drifting time is one period under a certain oncoming wind velocity in the lock-in region (F_1 in Fig. 3). The phase lags on the part from windward side to the front area of the lower surface of the middle box show a negative correlation between the distributed aerodynamic force of these zones and general VEF, which may be the result of the vortices in the windward slot (F_4) interacting with the middle box and controlling the distributed aerodynamic forces of this part. The phase lags on the upper surfaces of the upstream box and the middle box do not show an obviously monotonous distribution trend, which may indicate that there are different contribution mechanisms existing on these zones instead of regular drifting of large-scale vortices, and these mechanisms are simplified as the purple vortex F_3 and F_5 so that their contribution can be taken into consideration.

5. CONCLUSION

Through pressure and displacement measured wind tunnel tests, the vertical VIV performance of double-slotted box girder was explored and the aerodynamic characteristics on the model surface were analysed. Almost the whole model surface shows obvious contribution values during VIV, which increase significantly compared with streamlined closed-box girder and central-slotted box girder, and potentially weakens its VIV performance. A simplified assumption of the flow field around the double-slotted box girder was made: There is a vortex drifting on the surface of the downstream box periodically, and the aerodynamic forces from windward side to the front area of the lower surface of the middle box may be significantly affected by vortices generated in the windward slot. Besides this, different aerodynamic contribution mechanism instead of vortex drifting pattern may also exist on the upper surface of the double-slotted box girder.

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