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Aerodynamic analysis and safety counter measures to ensure runnability of a 3-box girder super-long span bridge

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SUMMARY:
To ensure the runnability of a novel three-box girder bridge, wind tunnel tests involving the pressure distribution, VIV responses, and wake were performed to investigate the influence of additional structural elements on the aerodynamic characteristics. According to the results of experiments, indicating that unsteady shear flow separated from the wind barrier top acting on the middle and leeward girders, resulted in a large amplitude torsional VIVs. Moreover, because wind flow across the slot parts interacted with the girder and additional structural elements, stronger torque forces were generated. Consequently, correlation and contribution were enlarged, which corresponding to large-amplitude torsional VIVs. This provides a reasonable explanation for the considerable influence of wind barriers on highway decks on VIVs, regarding to the three-box girder (especially the upper surface of the windward girder, upper and lower surfaces of the leeward girder, and windward gaps (regions II to IV, VI, and X to XI, respectively)), the distributed wind pressures acting on the characteristic parts of bridge decks furtherly contributed to the generation of torsional VIVs. Furthermore, the use of a perforated cover plate with 30% porosity is considered a reasonable measure to suppress torsional VIVs and improve the aerodynamic characteristics of three-box girder bridge.

Keywords: three-box girder bridge, wind tunnel tests, a perforated cover plate

1. INTRODUCTION

An increasing number of bridges are constructed with complicated cross-section types to improve their aerodynamic characteristics, thus ensuring long-span bridge safety under extreme wind loads. For instance, a 3-box girder was adopted in the Messina Bridge to improve its flutter characteristics (Diana et al., 2013). The aerodynamic characteristics of long-span bridges, especially slotted box girder bridges are more sensitive to vortex-induced vibrations (VIVs) than to flutter instability. Moreover, the additional structural elements interfere with the wind flow around the girder, hence, the aerodynamic characteristics of a bridge with added structural elements are significantly differ from those of the bridge with a bare deck. Thus, to ensure runnability of a 3-box girder long-span bridge, analysing the effects of additional structural elements on bridge aerodynamic behaviour is necessary. The study presents the major contribution of gaining insight into the influence of different additional elements on the bridge deck on aerodynamic characteristics of a 3-box girder bridge. A counter measure with a perforated cover plate with 30% porosity was then suggested to improve the aerodynamic characteristics.

2. AERODYNAMIC PERFORMANCE OF THE 3-BOX GIRDER BRIDGE

The experiment was conducted on a 3-box girder installed with various additional components (wind barriers, balustrades, and maintenance rails). The section model scale was as 1:30, the length was 6.0 m, with a width of 2.267 m (considering the length of the wind tunnel, aspect ratio *L*/*B*=2.65) and a height of 0.1667 m, as shown in Fig. 1.

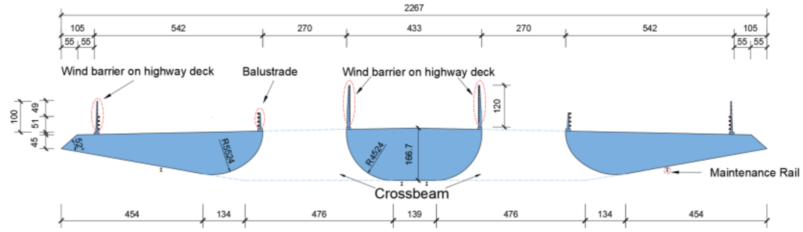


Figure 1 Scheme diagram of the 3-box girder cross-section in the 1:30 model (unit: mm)

2.1. VIV Performance

To analyse the effects of additional structural elements on the aerodynamic characteristics and VIV responses, four section types are used in the wind tunnel tests. Case A (equipped deck) is a 3-box girder with full additional structural elements. Case B considers a 3-box girder with balustrades, wind barriers on railway, and maintenance rails. Case C includes a 3-box girder with balustrade and maintenance rails. Case D involves a 3-box girder with maintenance rails. To improve the aerodynamic characteristics, a 3-box girder (with all additional structural elements and gaps covered with a 30% porosity plate) was studied and named Case E. To reveal the VIV mechanism of the 3-box girder bridge, wake flow tests as well as free vibration and pressure measurements are performed in the TJ-3 wind tunnel.

The torsional VIVs amplitude at 0°AOA of the 3-box girder with different additional structural elements is shown in Fig. 2. The torsional VIVs occurred at, *U**=7.17, *U**=7.96, and *U**=6.37 for models A, B, and C, respectively.

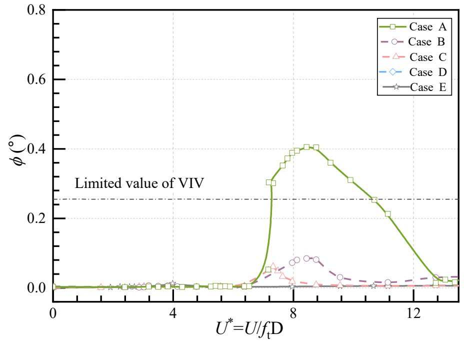


Figure 2 Torsional VIV displacement versus reduced wind speed of the 3-box girder (0° AOA)

2.2. Contributions of the distributed wind pressure

According the contribution results (Fig.3), the contribution values of the entire surface of models A and B were larger than those of the other models. Furthermore, the contribution values of model D were relatively small, indicating no evident influence on the torsional VIVs and that maintenance rails only weakly influenced the torsional VIVs as the small contribution values did not cause vibration in this case. According the contribution results, the local VEFs of upper surface of windward, upper, and lower surfaces of leeward girder dominated the torsional VIVs of a 3-box girder in a large extent. In summary, regions of II to IV, V to VI, and X to XI, are the key regions that local VEFs promoted torsional VIVs significantly for a 3-box girder. Wind barriers on the highway and railway deck surfaces were more sensitive to torsional VIVs.

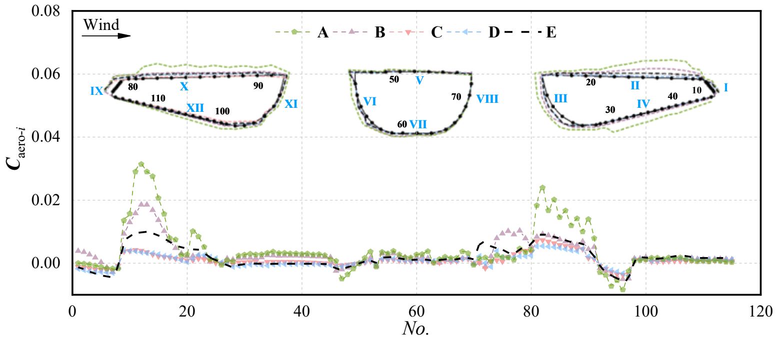


Figure 3 Comparison of contribution values of pressure coefficient

2.3. Wake characteristics

According to the vortex shedding results (Fig.4), torsional VIVs occurred at the critical wind speed in which the vortex shedding frequencies, for a 3-box girder, are obtained according to $S_t=f_tD/U=0.14$(Mastsumoto et al., 1993). Notably, the vortex-shedding frequency in the wind barrier wake on the highway deck was closer to the vortex-shedding frequency in the bridge wake under the stationary state and Case A, while torsional VIV occurred. It should be stated that for models A, B, and C, which exhibited VIVs, wind barriers on the highway deck significantly promoted the torsional VIVs of 3-box girders.

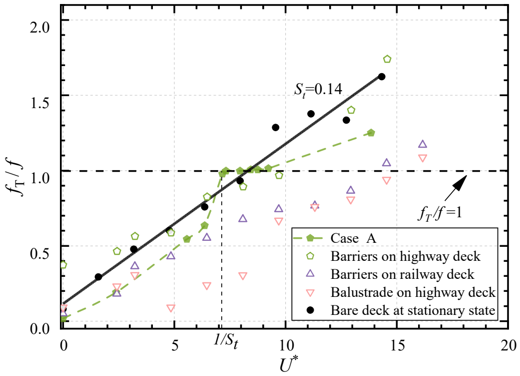
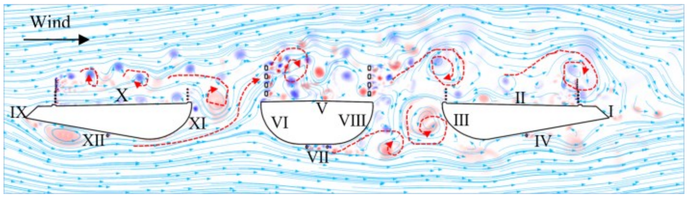


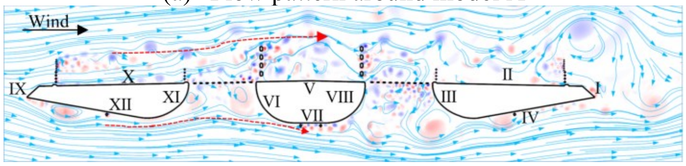
Figure 4 Vortex shedding frequency variation

2.4. Flow field around deck surface

The flow characteristics and vortex generation around the 3-box girder bridge with different additional structural elements obtained from the computational fluid dynamics (CFD) simulation A comparison between the flow pattern around the girder with different additional structural elements and the 3-box girder covered by a perforated plate with 30% porosity is shown in Fig. 5. It is noted that the torque moment effects were enlarged to a large extent while the wind flowed across the slot parts, after the barriers were installed. This was, because the wind impact area was larger, as shown in Fig. 5 (a). It can be seen that the abundant vortex generated behind the wind barrier, resulting in a stronger contribution of distributed pressures at upper surfaces of three girders to VIV responses, especially for wind pressures at V to VII region and upper surface of upper and leeward girder, from II to IV, and X regions. The VIV response was significantly promoted when the wind barriers were installed on the highway deck, which not only promoted vortex shedding from the leading edge of the windward barrier but also increased the correlation between the distributed aerodynamic force on the upper and lower deck surfaces and the overall aerodynamic forces. However, the stronger correlation and contribution are then broken after the slotted part is covered by a plate with 30% porosity.



(a) Flow pattern around model A



(b) Flow pattern around model E

Figure 5 Flow pattern around the 3-box girder

3. CONCLUSIONS

Maintenance rails have limited effects on the aerodynamic characteristics of a 3-box girder bridge. In contrast, the contributions and correlations indicated that the local vortex-induced forces at regions II to IV, VI, and X to XI considerably contributed to the overall vortex-induced forces, while the wind barrier and balustrades installed. In particular, the wind barriers on the highway deck are the generation source of vortices for torsional VIVs. Furthermore, a perforated cover plate with 30% porosity was considered as a reasonable counter measure to suppress torsional VIVs.

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REFERENCES

Diana G., Fiammenghi G., Belloli M., et al. 2013. Wind tunnel tests and numerical approach for long span bridges: The Messina bridge. Journal of Wind Engineering and Industrial Aerodynamics 122: 38-49.

Mastsumoto M., Shiraishi N., Shirato H., et al. 1993. Mechanism of, and turbulence effect on vortex-induced oscillations for bridge box girders. Journal of Wind Engineering and Industrial Aerodynamics 49: 467-476.