Wind Barrier Effects on Aerodynamic Performance of Bluff Girder

Yokohama National University Student Member ○Anousit VILAIVONG
Yokohama National University Fellow Member Hiroshi KATSUCHI
Yokohama National University Regular Member Jiaqi WANG
Yokohama National University Ryoko MITSUHASHI

1. Introduction

With the growth of society and the economy, the demand for long-span bridges to support transportation infrastructure has increased. However, most of these bridges are constructed in locations exposed to strong crosswinds, which exert a large wind load on vehicles traveling on them and lead to wind-induced accidents, such as side slips and rollovers. Therefore, it is necessary to implement effective measures to prevent such accidents and to ensure driving safety. One such method is installation of wind barriers, which are popular for their effectiveness. However, the shielding efficiency of the wind barriers can be influenced by factors such as their height, and type, shape, and size of opening, etc. [1]. Moreover, the wind barriers may impair the aerodynamic performance of the bridge since they modify the flow pattern and generate significant additional wind loads. Hence, enhancing the shielding efficiency of the wind barriers while minimizing their negative effects on the aerodynamic stability of the bridge is crucial.

To clarify the effects of the wind barriers on the aerodynamic performance of the bridge, a series of two-degree-of-freedom free vibration tests and aerodynamic force tests on a stationary model were conducted in a wind tunnel. The employed model was a typical box-girder bridge model with a width-to-depth ratio of 3.44 and a scale of 1/100, as illustrated in Figure 1.

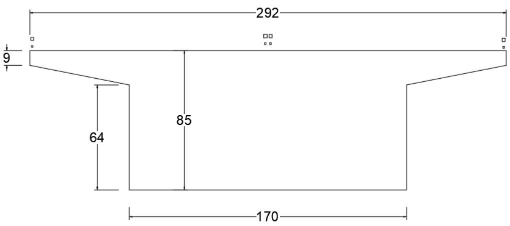


Figure 1 Bridge-model section (unit: mm)

In this research, the opening ratios of 25% and 50% (named 25 and 50) were selected for the wind barriers. Two methods for installing them on the girder were considered: installing in front of the handrail (named F) and installing above the handrail (named P). The total height of the prototype wind barriers for both installations methods was 3 m. The bare deck case was named BD.

Following the occurrence of a large amplitude of vertical vortex-induced vibrations, modifications were made to the full 50-percent opening ratio wind barrier by adjusting hole distances of horizontal bar members to be larger in the bottom part and smaller in the upper part (named DD). Additionally, a one-meter length with 30-degree angle flap was attached to this wind barrier (named DD+Flap), as summarized in Figure 2.

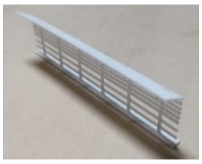
F-25

F-50

P-25

P-50

F-50-DD



F-50-DD+Flap

Figure 2 Wind barriers

2. Experimental Results and Discussions

Figure 3 presents the free vibration responses indicating that installing the wind barriers results in a large amplitude of vertical vortex-induced vibration. This may be caused by the enlarged windward area of the bridge when the wind barriers were attached. In particular, the F-25 case, which has the most closed area, causes the largest vibration amplitude compared to other cases, about 2.25 times the BD case, while the F-50 case is about 2.00 times the BD case.

However, with installing the wind barriers above the handrail, the vibration amplitude and response pattern for both opening ratios are insignificant, with an amplitude of only 1.50 higher than the BD case. The reasons for the lower amplitude compared to the F cases have not been clearly identified, but installing the wind barriers in front of the handrail increased the blockage effect and changed the flow pattern above the girder considerably compared to installing them above the handrail.

Although presence of the wind barriers leads to susceptible vertical vortex-induced vibration, it appears to be negligible for torsional mode. As in Figure 3 (b) which demonstrates that the critical wind speeds for torsional flutter are slightly higher than the BD case for both opening ratios, raising from approximately 70 m/s to 80 m/s for the 25% opening case and over 90 m/s for the 50% opening case.

Keywords: wind barrier, vehicle stability, wind-induced vibration, vortex-induced vibration, aerodynamic force coefficient
Contact address: 79-5 Tokiwadai, Hodogaya-ku, Yokohama 240-8501, Japan, Tel: 045-339-4041

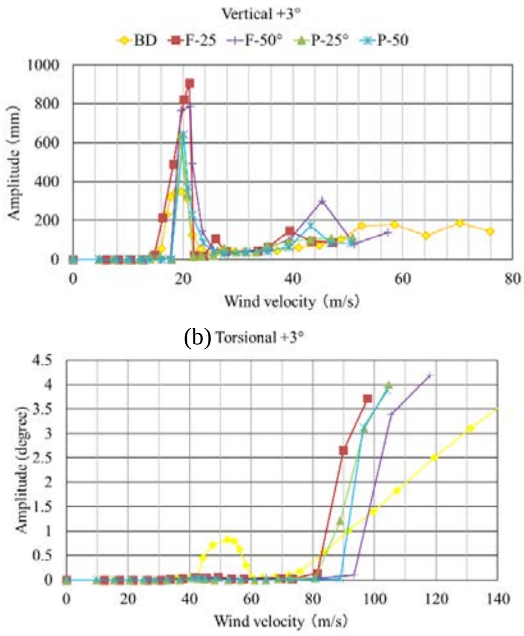


Figure 3 Aerodynamic responses at different openings and installations of the wind barriers

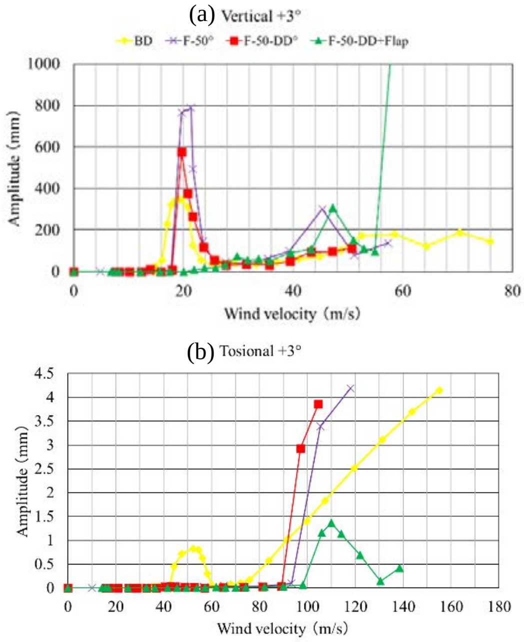


Figure 4 Aerodynamic responses of vortex-induced vibration suppression countermeasures

Figure 4 shows results of the countermeasures proposed to suppress the large vortex-induced vibration. Regardless the DD case reduces the amplitude to 0.75 compared to the F-50 case, it is still larger than the BD case. However, when combined with the flap, they suppress such vibrations potentially. Even though galloping may occur, it is still within the design wind speed ranges. Moreover, these countermeasures not only improve the vertical vibration performance, but they also increase the critical wind speeds for torsional flutter from 70 m/s to over 90 m/s.

Figure 5 presents the aerodynamic force coefficients, including C_d, C_l, and C_m, corresponding to drag, lift, and pitching moment coefficients at a 0-degree angle of attack for different wind barriers. The findings of Figure 5 (a) prove that installing the wind barriers increases the drag coefficient due to the enlarged windward area. However, the lift coefficient remains relatively constant for the wind barriers with different openings and installation methods.

Figure 5 (b) shows that the wind barriers have a minor effect on moment coefficients. Moreover, it is notable that the wind barrier combined with the flap (F-50-DD+Flap) exhibits slightly larger values of drag, lift, and moment coefficients compared to the other wind barrier cases.

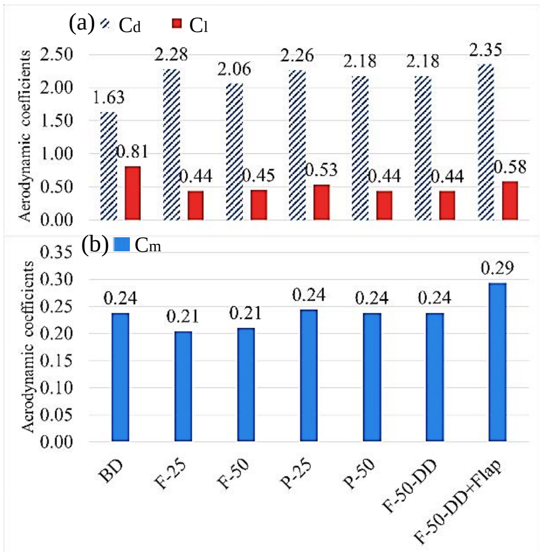


Figure 5 Aerodynamic coefficients at different wind barriers (a) drag and lift coefficient (b) Moment coefficient

3. Conclusions

This research aimed to investigate the effects of different wind barriers on aerodynamic performance of a bridge girder, and the suppression of vertical vortex-induced vibration, by employing free vibration test and aerodynamic force test. Based on the results obtained, the following conclusions can be drawn:

- Installing the wind barriers resulted in a large amplitude of the vertical vortex-induced vibration which was 2.00 to 2.25 times as of the BD case.
- The opening ratios played a limited role in reducing the vertical vortex-induced vibration. While for the same opening ratios, installing the wind barriers above the handrail resulted in a smaller amplitude of that vibration than installing them in front of the handrail.
- By amplifying the distance between the downside horizontal bars of the wind barrier and installing the flap on it, the vertical vortex-induced vibration was successfully stabilized, and the critical wind velocity of torsional flutter increased from 70 m/s to 90 m/s.
- The drag force coefficient of the girder with the wind barriers was 1.34 to 1.44 times that of the BD case. While the lift force coefficient was reduced to almost 60% as of the BD case but the moment coefficient was barely affected by the wind barriers.

4. References

1) Zou, Y., Xue, F., Shi, K., He, X., Han, Y., Liu, Q., Li, L. (2022). Analysis of the effects of wind barrier on driving safety and comfort of vehicles on long-span bridges under Crosswinds. *Structures*, 42, 367–385.