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Experimental investigation on effects of wind barrier on aerodynamic stability of the bridge and the wind velocity on the bridge

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SUMMARY
The objective of this research is to experimentally investigate the effects of the wind barrier on the aerodynamic response of the bridge and the wind velocity on the bridge. The wind barrier is with a section of Straight-line Type (ST) and Curved-line Type (CT), and the Opening-area Ratio (*OR*) of the wind barrier, the ratio of the area of its total openings to its windward-surface area, is 0%, 20%, and 50%. A streamlined box girder model (scale:1/60; width-to-height ratio: 9) installed with different wind barriers were tested by the vertical and torsional one-degree-of-freedom (1DOF) free vibration tests and the wind-velocity measurement on the girder. The wind barrier of *OR* = 0% and 20% made the girder show vortex-induced vibration and torsional flutter while increasing *OR* from 0% to 50% made the girder show increasingly better aerodynamic response. The girder with the wind barrier of 50% was more aerodynamic stable than the bare girder. Additionally, decreasing *OR* significantly decreased the wind velocity below the vehicle height on the girder, while the wind velocity on the bare girder was reduced to half its value due to the wind barrier of *OR* = 50%.

Keywords: torsional flutter, wind barrier, streamlined box girder

1. INSTRUCTION

The wind-induced vehicle accident on a bridge has been a main concern in Japan. The wind barrier is effective to reduce the wind velocity on the bridge and protect the vehicle. However, according to past research (Honshu-shikoku Bridge Authority, 1994), the adverse effects of the wind barrier on the aerodynamic stability of the already-built and in-plan long-span bridges in Japan were observed. The aerodynamic performance of the bridge installed with the wind barrier is significantly affected by its Opening-area Ratio (*OR*), the ratio of the area of its total openings to its windward-surface area. Meanwhile, the wind barrier is growingly applied in bridges around the world (Yang et al., 2016; Martin et al., 2004). The wind barriers in these bridges have different section configurations such as Curved-line Type and Straight-line Type. To provide wind barriers for long-span bridges in Japan, further research is necessary to clarify the relationship between the aerodynamic performance and the wind-barrier parameter. Therefore, this research intends to clarify the effects of the wind barrier on the aerodynamic performance of the girder and the wind velocity on the girder through wind tunnel tests.

2. SET-UP FOR WIND TUNNEL TESTS

A series of wind tunnel tests, i.e., aerodynamic force measurement, free vibration tests, and wind-velocity measurement, was carried out on a B/D =9.4 streamlined box girder model (Fig. 1 (a)) with four traffic lanes in the wind tunnel at Yokohama National University. Regarding the wind barrier, two types of section configuration were considered in this research: Straight-line Type (ST) and Curved-line Type (CT) (Fig. 2). The Opening-area Ratio (*OR*) was defined as L2/(L1+L2), where L2 is the opening height and L1 is the plate height. The distance between the plates of the wind barrier was adjusted to set the Opening-area Ratio to 0%, 20%, and 50%. The vertical and torsional aerodynamic responses of the model with different wind barriers were measured by one-degree-of-freedom (1DOF) free vibration tests at the angle of attack α = 0° and +3° in the smooth flow. The distribution of the wind velocity on the girder was measured by an 'X' hotwire anemometer at α = 0° in the smooth flow (U = 9m/s) with a sampling frequency of 1000Hz. The measurement points are distributed along the vertical lines at the boundary and center of traffic lanes, the handrails, and the median of the girder below 200cm height from the girder. The aerodynamic forces were measured in the smooth flow at U = 10m/s. The coefficients of drag force (Cd), lift (Cl), and moment (Cm) on the wind axis are defined in Fig. 1 (b) below:

$$Cd = D/(0.5\rho U^2 Hl) \tag{1}$$

$$Cl = L/(0.5\rho U^2 Bl) \tag{2}$$

$$Cm = M/(0.5\rho U^2 B^2 l) \tag{3}$$

where, D, L, and M are the drag force (N), lift force (N), and pitching moment (N·m) on the wind axis, ρ is the air density (kg/m^3), l is the model length (1.25m).

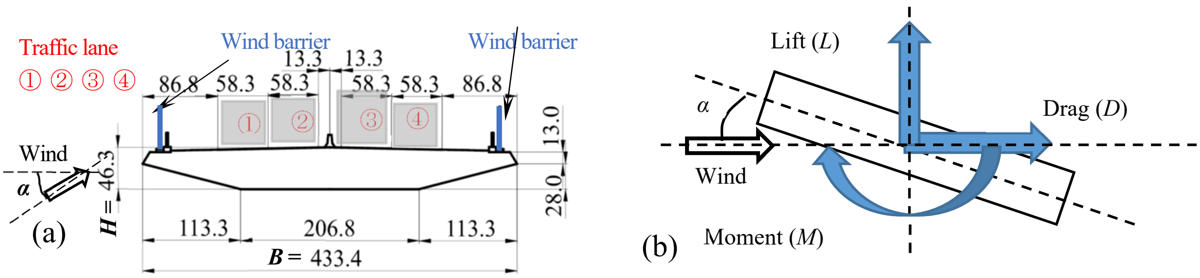

Figure 1 (a) Section of the model for the wind tunnel test (unit: mm; 1/60), (b) aerodynamic forces on wind axis

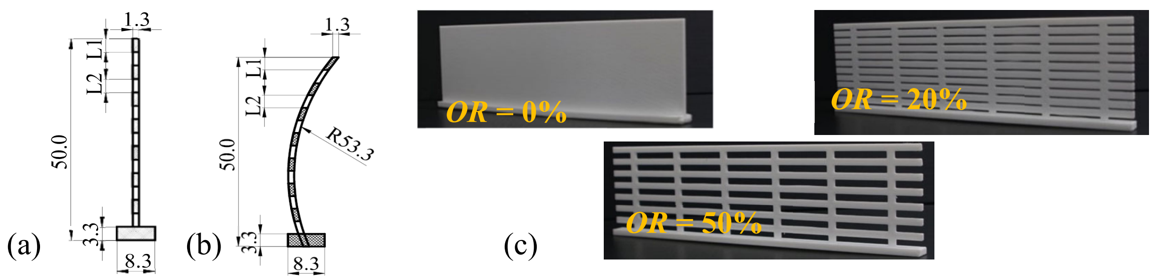

Figure 2 Section of the model barrier of (a) Straight-line Type (ST); (b) Curved-line Type (CT); and (c) side view of the wind barrier (unit: mm; 1/60; the height of the plate (L1) is 200/60mm.)

3. EFFECTS OF WIND BARRIER ON AERODYNAMIC PERFORMANCE OF THE GIRDER AND WIND VELOCITY ON THE GIRDER

Fig. 3 shows the vibration amplitude of the girder in the vertical and torsional direction for the wind barrier of Straight-line Type (ST) at $\alpha = 3°$. According to Fig. 3 (a), the bare girder was stable with no vertical Vortex-Induced Vibration (VIV) and galloping. The wind barrier of *OR* = 0% and 20% resulted in VIV at *Ubr* =13.6m/s~17.4m/s, while for *OR* = 50%, the girder showed no vibration until *Ubr* = 86m/s. Increasing *OR* from 0% to 50% decreased the maximum amplitude of VIV from 293mm to almost 0mm. According to Fig. 3 (b), the bare girder showed the torsional VIV with a maximum amplitude of less than 0.5°. For *OR* = 0% and 20%, the girder showed VIV at *Ubr* = 26m/s ~ 43m/s and the torsional flutter. With the increase of *OR* from 0% to 50%, the maximum amplitude of VIV decreased from 1.2° to 0.17° and the onset wind velocity of torsional flutter increased from 60m/s for *OR* = 0% to 80m/s for *OR* = 20% and over 120m/s for *OR*=50%. The torsional response of the girder with the ST and CT wind barrier at $\alpha = 3°$ is compared in Fig. 4. The girder with the ST and CT wind barrier showed almost the same vibration amplitude, for both *OR* = 0% and 50% (Fig. 4 (a) and (c)). For *OR* = 20%, the ST and CT wind barrier resulted in VIV both at *Ubr* = 28~40m/s, while the maximum amplitude (0.94°) for CT was slightly larger than that (0.82°) for ST. Additionally, the ST wind barrier resulted in the torsional flutter from 87m/s, while the CT wind barrier showed no torsional flutter until 120m/s. Therefore, the aerodynamic response was not significantly affected by the section configuration of the wind barrier.

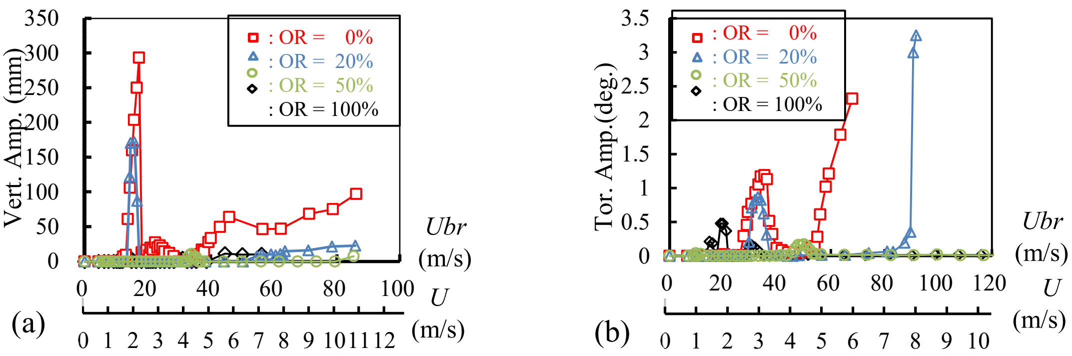

Figure 3 Aerodynamic response of girder with the Straight-line Type (ST) wind barrier in (a) vertical direction, (b) torsional direction. ($\alpha = +3°$, smooth flow, *U* and *Ubr* are the wind velocity in the wind tunnel and at the bridge site)

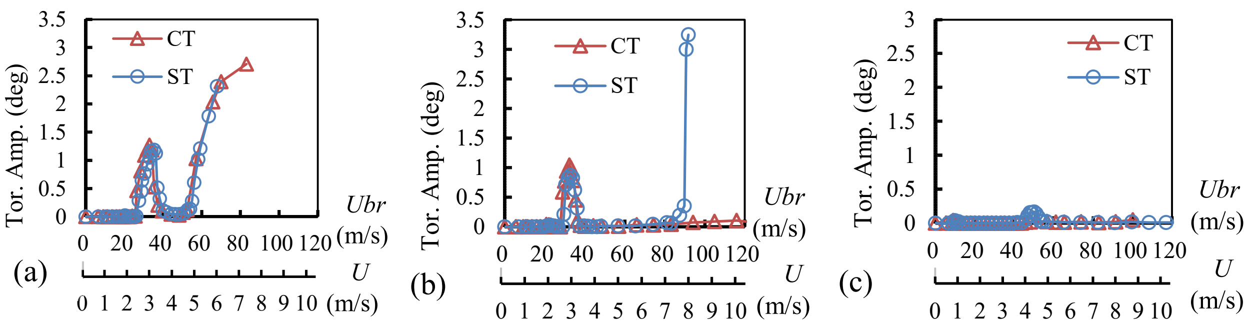

Figure 4 Comparison of the torsional aerodynamic response of girder with ST and CT wind barrier for: (a) *OR* = 0%, (b) *OR* = 20%, (c) *OR* = 50%. ($\alpha = +3°$, smooth flow)

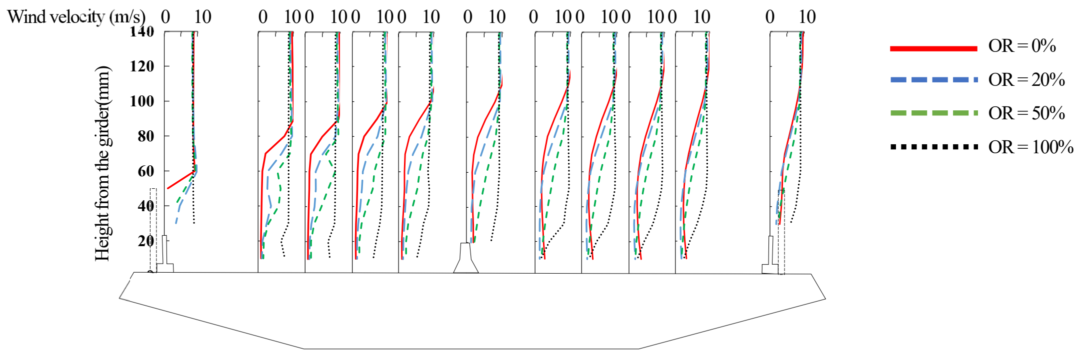

Figure 5 Time-averaged wind velocity distribution (α = 0°, smooth flow, U = 9m/s)

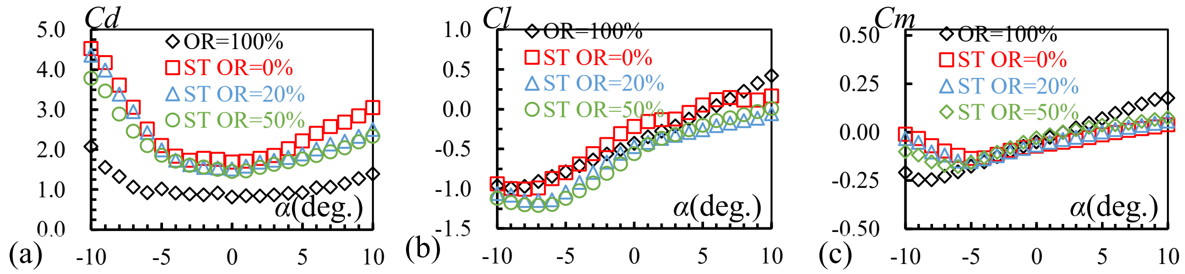

Figure 6 (a) Drag force coefficients *Cd*, (b) Lift force coefficient *Cl*, (c) Moment coefficient *Cm*, of the girder with the ST wind barrier. (α = 0°, smooth flow, U = 10m/s)

Fig. 5 compares the mean wind velocity for different ORs of the ST wind barrier. Below 60mm (vehicle height), with the decrease of *OR*, the wind velocity decreased significantly. However, for *OR* =50%, the wind velocity on the girder was about half of that on the bare girder. Fig. 6 shows the aerodynamic force coefficients of the model with the ST wind barriers. *Cd* of bare model (*OR*=100%) increased by two times due to the wind barriers. *Cd* showed no significant difference by increasing *OR* from 0% to 50%. The wind barrier has limited effects on *Cl* and *Cm*.

5. CONCLUSIONS

No significant difference was observed in the response between the ST and CT wind barrier. Compared with the bare girder, the wind barrier of *OR* = 0% and 20% resulted in VIV and the torsional flutter. These vibrations were stabilized by increasing *OR* from 0% to 50%. Increasing *OR* resulted in an increase in the mean wind velocity below the vehicle height on the girder. For *OR* = 50%, the wind velocity was about half of that of the bare girder. The wind barrier has limited effects on the lift and moment force of the girder, while increases the drag force by two times.

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