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Experimental investigation on effects of wind barrier on the aerodynamic performance of the bridge

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SUMMARY

This research experimentally investigated the effects of the wind barrier on the aerodynamic response and aerodynamic forces of the bridge. The wind-barrier parameter under investigation is the section configuration, i.e., Straight-line Type (ST) and Curved-line Type (CT), and Opening-area Ratio (*OR*), the ratio of the area of its total openings to its windward-surface area. A streamlined box girder (width-to-height ratio: 9) installed with different wind barriers was scaled by 1/60. Through torsional free vibration tests, owing to the wind barrier of *OR*=0% and 20%, the girder showed vortex-induced vibration and torsional flutter, however, by increasing *OR* from 0% to 50%, the girder became stable against these vibrations. By measuring the aerodynamic forces coefficients (*Cl*: lift; *Cd*: drag; *Cm*: moment) of the girder, the wind barriers increased *Cd* of the girder by almost two times compared with the bare girder, while the wind barrier slightly increased the absolute value of *Cl* and slightly reduced absolute value of *Cm*. Increasing *OR* slightly reduced the absolute value of *Cd* and slightly increased the absolute value of *Cl*, while increasing *OR* has limited effects on *Cm*. The aerodynamic response and aerodynamic force coefficients showed no significant difference for the ST and CT wind barrier.

Keywords: torsional flutter, wind barrier, aerodynamic force

1. INSTRUCTION

There are many long-span bridges in Japan and vehicle safety against the strong winds on these bridges is under concern. Even with traffic regulations such as the vehicle-speed limit or bridge closure based on wind velocity, wind-induced traffic accidents still occasionally occur. The wind barrier is an effective countermeasure to protect the vehicle from the wind. However, past research (Honshu-shikoku Bridge Authority, 1994, 1995) in Japan showed that the wind barrier made the bridges more unstable in aerodynamic response and larger drag force. Therefore, the wind barrier is not widely installed on bridges in Japan. However, the wind barrier is installed on several bridges recently built abroad (Yang et al., 2016; Martin et al., 2004). The wind barrier utilized in these bridges has different section configurations. With the motivation to install the wind barrier for the already-built long-span bridges in Japan, this research intends to clarify the relationship between the parameter of the wind barrier and the aerodynamic performance of the bridge, regarding the aerodynamic response and the aerodynamic forces.

2. SET-UP FOR WIND TUNNEL TESTS

A streamlined box girder model scaled by 1/60 is utilized in this research. The model is with a width-to-height ratio of 9.4 and four traffic lanes (Fig. 1(a)). The aerodynamic response and the aerodynamic forces (Fig. 1(b)) are measured at the wind tunnel of Yokohama National University. The wind barrier is with the section configuration of Straight-line Type (ST) and Curved-line Type (CT) (Fig. 2). The Opening-area Ratio (*OR*) of the wind barrier was defined as L2/(L1+L2), where L2 is the opening height and L1 is the plate height and was set to 0%, 20%, and 50%.

The 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 structural parameter of the model is shown in Table 1. The aerodynamic forces were measured by two loadcells with the approaching wind of $U = 6$m/s in the smooth flow. 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/m3), *l* is the model length (1.25m).

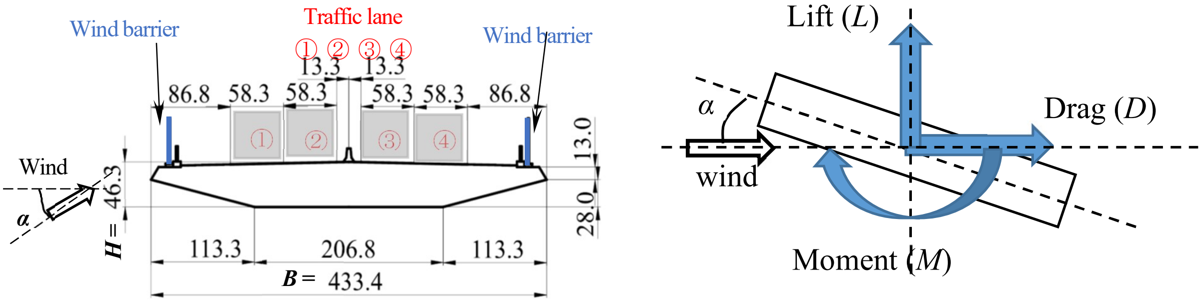

Figure 1 (a) Section of the model for the wind tunnel test (unit: mm; 1/60), (b) aerodynamic forces on wind axis

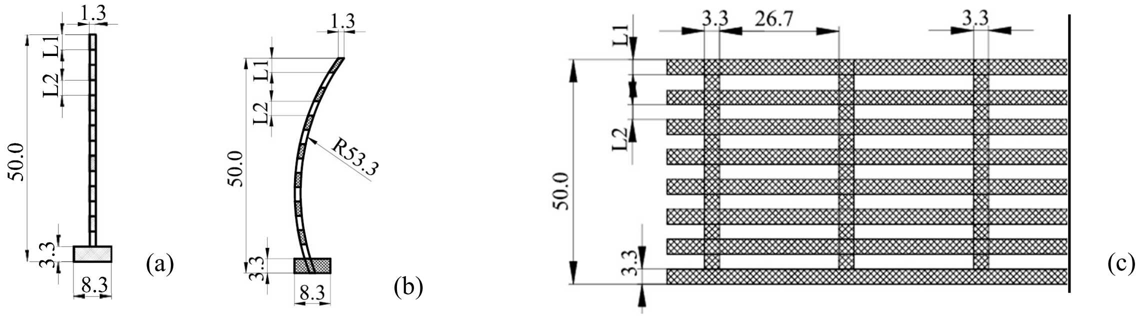

Figure 2 (a) Straight-line Type (ST) wind-barrier section; (b) Curved-line Type (CT) wind-barrier section; and (c) the wind-barrier side view (unit: mm; 1/60; the height of the plate (L1) is 200/60mm.)

Table 1 Characteristic parameter for free vibration tests

Wind barrier type	OR (%)	α	Torsional 1DOF			
			I (kg·m^2/m)	f (Hz)	$\delta\varphi$	$Sc\varphi$*
No wind barrier	100	0°, +3°	0.170	6.57	0.0066	411
Straight-Type (ST)	0	0°, +3°	0.179	6.40	0.0059	387
	20	0°, +3°	0.178	6.43	0.0071	463
	50	0°, +3°	0.175	6.46	0.0061	391
Curved-Type (CT)	0	0°, +3°	0.179	6.41	0.0057	374
	20	0°, +3°	0.177	6.44	0.0071	460
	50	0°, +3°	0.176	6.47	0.0059	380

* Scruton number is defined as $S_{c\varphi} = (2I\delta_{\varphi})/(\rho H^4)$, where ρ is air density (kg/m^3).

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

Fig. 3 shows the torsional vibration amplitude of the girder with the ST and CT wind barrier at the angle of attack α = 3°. According to Fig. 3 (a), without the wind barrier, the girder showed the torsional Vortex-induced Vibration (VIV) with a maximum amplitude of less than 0.5°. The wind barrier of *OR* = 0% and 20% resulted in VIV at *Ubr* = 26m/s ~ 43m/s and torsional flutter. Increasing *OR* caused the continuous decrease in the maximum amplitude of VIV from 1.2° to 0.17°, while with the increase of *OR*, the critical wind velocity of torsional flutter showed continuous growth from 60m/s ending stable for *OR* = 50%. A similar conclusion can be summarized for the CT wind barrier (Fig. 3 (b)). By comparing Fig. 3 (a) and (b), regarding *OR* = 0% and 50%, the girder showed no difference in the response between the ST and CT wind barriers. For *OR* = 20%, there was a minor difference between the maximum amplitude of VIV between the ST and CT wind barrier. Meanwhile, the ST wind barrier induced the torsional flutter, and the CT wind barrier caused no torsional flutter. Therefore, the section configuration of the wind barrier has limited effects on the torsional aerodynamic response.

Fig .4 shows the coefficient of drag force (*Cd*), lift force (*Cl*), and Moment (*Cm*) of the girder with the ST wind barrier. According to Fig. 4 (a), *Cd* of the girder with the wind barrier was about two times that of the bare girder. Additionally, the wind barrier resulted in a slightly larger absolute value of *Cl* and a smaller absolute value of *Cm*, compared with that of the bare girder. Even though increasing *OR* decreased the absolute *Cd* and increased the absolute *Cl* and *Cm*, the change of these coefficients with *OR* is minor. According to Fig. 5, for *OR* = 0%, 20%, and 50%, the difference between the *Cd* of the girder with the ST and CT wind barrier was insignificant.

5. CONCLUSIONS

There is no difference between the torsional response of the girder with the ST and CT wind barrier for *OR* = 0% and 50%, while for *OR* = 20%, the ST wind barrier made the girder more stable in VIV and more unstable in the torsional flutter. Increase *OR* resulted in a continuous decrease in the amplitude of VIV and an increase of onset wind velocity of torsional flutter. As a result, the girder with the wind barrier of *OR* = 50% is more stable than the bare girder.

Compared with the bare girder, the wind barrier resulted in larger absolute *Cd* and *Cl*, smaller absolute *Cm*. Even though increasing *OR* decreased *Cd*, *Cd* of the girder with the wind barrier was still about two times that of the bare girder. The change of *Cl* and *Cm* with *OR* was insignificant. Meanwhile, for *OR* = 0%, 20%, and 50%, the difference between *Cd* of the girder with the ST and CT wind barrier is insignificant.

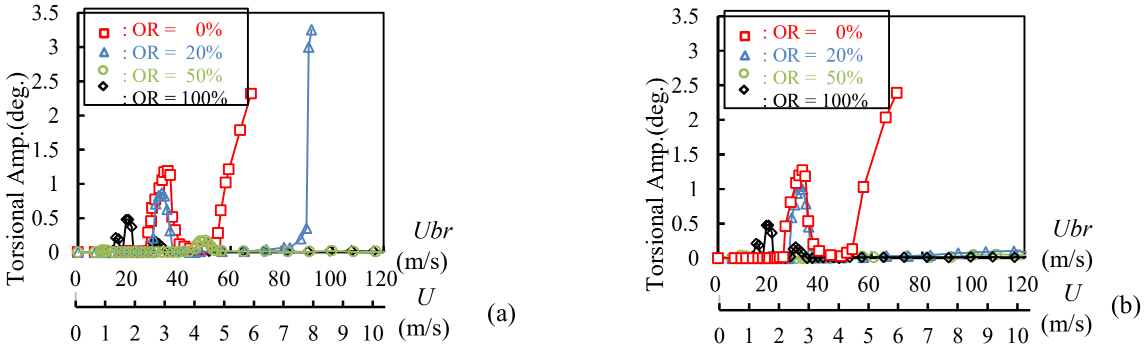

Figure 3 Torsional response of girder with the wind barrier of (a) Straight-line Type (ST), (b) Curved-line Type (CT). (α = +3°, smooth flow, *U* and *Ubr* are the wind velocity in the wind tunnel and at the bridge site, respectively)

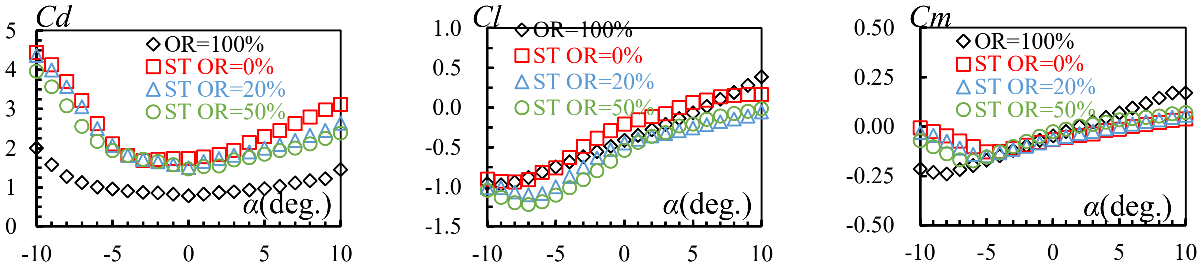

Figure 4 (a) Drag force coefficients *Cd*, (b) Lift force coefficient *Cl*, (c) Moment coefficient *Cm*, of the girder with the ST wind barrier. (α = 0°, smooth flow, *U* = 6m/s)

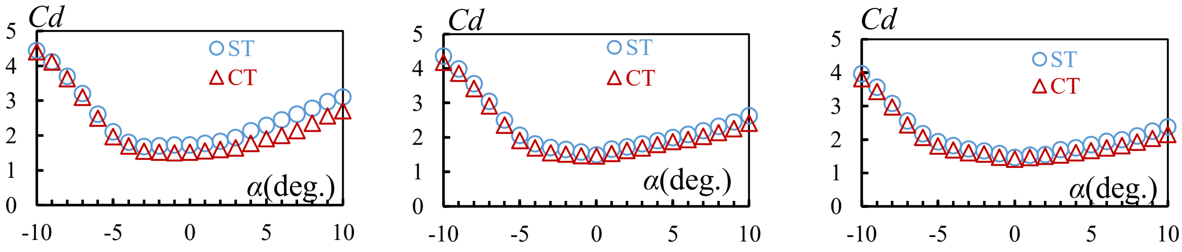

Figure 5 Comparison between the drag force coefficients *Cd* of ST and CT wind barrier for (a) *OR* = 0%, (a) *OR* = 20%, (a) *OR* = 50%. (α = 0°, smooth flow, *U* = 6m/s)

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