Effects of separation distance on wind-induced response of parallel box girders

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Abstract

Wind-induced response characteristics of parallel bridges were studied with various separation distances. Section models of box girders for a proposed and an existing cable-stayed bridges were tested in smooth flow. The two box girders have different cross-sections, and different response characteristics were observed with the opposite wind directions. Mostly, larger response was observed when the bridges were located in parallel than for the single bridge case; but in a few cases, smaller response was observed when the bluffer girder was located close leeward of the other girder. General conclusion could not be obtained, but the results of this study will serve as an example of complicated parallel bridge response characteristics. It was observed that the interference effects of between the bridges built in parallel can be significant even with a separation distance as large as 8 times the deck width.

Keywords: Parallel bridges; Wind tunnel test; Section model, Interference

1. Introduction

Bridges are sometimes constructed in parallel for reasons such as to accommodate increase of traffic flow, for more efficient construction procedure, due to the restriction of the alignment of the traffic lane, and so on (Grillaud et al, 1992; Honda et al, 1993; Larsen et al, 2000; Stoyanoff et al, 2003). When bridges are located in parallel, their wind-induced responses generally become more complicated due to the aerodynamic interference than a single bridge; therefore careful consideration for the wind resistance is necessary.

In this study, wind-induced responses of an existing box-girder cable-stayed bridge and a proposed bridge located parallel to the existing bridge were experimentally studied. It is difficult to have a general conclusion about the response characteristics of bridges built in parallel, but an effort was made show an example of how complicated the response characteristics and the effects of the separation distance can be.

2. Experimental setup

A wind tunnel with a closed circuit test section of 1070 mm wide by 1070 mm high was used. Experiments were conducted in smooth flow and with zero angle of attack. Section models with scale of 1/60 were elastically supported to allow heaving 1DOF motion for the existing bridge model, and heaving and torsional 2DOF motion for the newly proposed bridge model. The torsional natural frequency of the existing bridge is 2.1 times larger than that of the new bridge, and the wind-induced torsional motion of the existing bridge was considered to be insignificant; therefore only the heaving degree of freedom was considered for the existing bridge. Configurations of the models are shown in Fig. 1 and model characteristics are shown in Table 1. Structural damping was set at very small value so that the response characteristics can be studied in detail. The existing bridge has bluffer girder cross-section as compared with the new bridge girder. Model width including corner vanes and fairings were 215.6 and 296.6 mm for the existing and new bridges, respectively. The separation distance X was changed so that X/B was 2, 4, 6, and 8. The wind direction was changed from left and right direction in Fig. 1 so that the existing bridge became windward and leeward of the new bridge, and vice versa for the new bridge. Also the response was taken for the isolated existing or new bridges.

3. Experimental results

3.1. Heaving response of windward girder

Heaving responses of the existing and new bridges when they were located windward of the other bridge are shown in Figs. 2 and 3. Vortex-induced vibration occurred at around $Vr = 7$ for both single and parallel bridges. The maximum amplitudes of the vibration are plotted against the separation distance X/B in Fig. 4. For the existing bridge, the response amplitude did not change very much with X/B, and it was nearly the same with that of the single bridge. On the other hand, much larger response amplitude was observed for the parallel new bridge with $X/B = 2$ and it decreased with larger X/B.

These different characteristics may be explained by the different bluffness of the girders; the less bluff new bridge girder did not affect the response of bluff windward existing bridge girder; but the bluff existing bridge girder did affect the response of the windward new bridge girder with an amplification of the response when they were closely located.

3.2. Heaving response of leeward girder

Heaving responses of the bridges when they were located leeward of the other bridge are shown in Figs. 5 and 6. Limited-range-type wind-induced response was observed at around $Vr = 10$ and the wind speed with maximum response amplitude for the leeward bridge was slightly higher than that of the single bridge. The leeward girder response showed beating and the response amplitude in the figures was taken as the square-root two times the r.m.s. amplitude. The maximum amplitudes of the vibration are plotted against the separation distance X/B in Fig. 7. For the existing bridge, the response amplitude was about 1/3 of the single bridge when $X/B = 2$ and it increased with larger X/B; with $X/B = 6$ and 8, the response amplitude was nearly the same with that of the single bridge. On the other hand, about two times larger response amplitude was observed for the parallel new bridge and it did not decrease even with larger X/B such as $X/B = 8$.

These different characteristics may also be explained by the different bluffness of the girders, but further study is needed for a clear understanding of the mechanism.

3.3. Torsional response of the new bridge girder

Torsional response of the new bridge when it was located windward and leeward of the existing bridge is shown in Figs. 8 and 9, respectively. When the new bridge is located windward, dominant wind-induced response with limited wind speed range was observed at around *Vr* = 15 for most cases, which is the same wind speed as the single bridge. When *X*/*B* = 2, the response amplitude became much smaller and the wind speed with maximum response became *Vr* = 13. With *X*/*B* = 4, 6, and 8, limited-range-type response at around *Vr* = 6 became significant.

For the new bridge located leeward of the existing bridge, clearly different torsional response from the single bridge was observed. With *X*/*B* = 2, only small amplitude response was observed at around *Vr* = 8. With *X*/*B* = 4, 6 and 8, limited-range-type response was observed at around *Vr* = 13, which is lower than that with the single bridge.

4. Discussions

In order to clarify the response characteristics in detail, effects of the motion of the windward new bridge on the leeward existing bridge response were studied for a few cases as example.

The heaving response time histories of the bridges at *Vr* = 7.9 with *X*/*B* = 2 are shown in Fig. 10. When the windward new bridge motion was restricted, the beating motion of leeward existing bridge changed to pure sinusoidal motion, and the response amplitude increased. Therefore, it is implied that the motion of windward new bridge suppressed the leeward existing bridge response. This is opposite to the behaviour observed in a previous research where the windward girder motion enhanced the leeward girder response (Shino et al, 1989).

On the other hand, for *X*/*B* = 4 case, leeward existing bridge response amplitude did not change very much with restriction of windward bridge motion (Fig. 11); and for *X*/*B* = 6 case, leeward bridge response amplitude increased with the restriction of the windward bridge, but not as much as $X/B = 2$ case (Fig. 12).

The above observation shows that the effects of windward bridge motion are complicated, and they apparently depend on the separation distance. Because the windward bridge motion had the significant influence on the leeward bridge response, it is recommended that both bridges are to be modeled aeroelastically in order to accurately study their interference effects of parallel bridges in general.

5. Conclusions

Wind-induced response characteristics of two parallel girders with different cross-sectional shape were studied with various separation distances using elastically supported section models. Response characteristics were complicated, which varied with different separation distances and wind directions. Effects of windward bridge motion were studied for a few cases and they also depended on the separation distance. From this study, it was clarified that the effects of parallel bridge can be significant even with a separation distance as large as 8 times the deck width; but in order to obtain general conclusions on the response characteristics of parallel bridges, further studies are needed.

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Figure Captions

Table 1 Model characteristics

Fig. 1. Model configuration

Fig. 2. Heaving response of windward existing bridge

Fig. 3. Heaving response of windward new bridge

Fig. 4. Maximum heaving response amplitude of windward bridge

Fig. 5. Heaving response of leeward existing bridge

Fig. 6. Heaving response of leeward new bridge

Fig. 7. Maximum heaving response amplitude of leeward bridge

Fig. 8. Torsional response of windward new bridge

Fig. 9. Torsional response of leeward new bridge

Fig. 10. Heaving response time history of parallel bridges when the windward new bridge motion was restricted (X/B = 2, Vr = 7.9)

Fig. 11. Heaving response time history of parallel bridges when the windward new bridge motion was restricted (X/B = 4, Vr = 7.9)

Fig. 12. Heaving response time history of parallel bridges when the windward new bridge motion was restricted (X/B = 6, Vr = 7.9)

Table 1 Model characteristics

	Existing bridge	New bridge
Width *B’*, *B* (mm)	197.6	246.6
Height *D’*, *D* (mm)	44.6	45.0
Mass per unit length (kg/m)	1.81	2.99
Polar moment of inertia (kg m^2/m)	-	0.0305
Heaving natural frequency (Hz)	3.70~3.74	3.54~3.58
Torsional natural frequency (Hz)	-	7.71~7.84
Heaving logarithmic decrement	0.004~0.008	0.003~0.004
Torsional logarithmic decrement	-	0.001~0.002

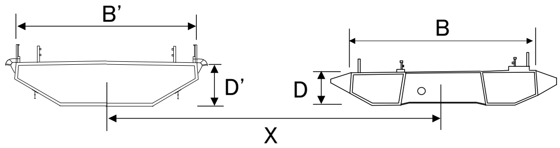


Fig. 1. Model configuration

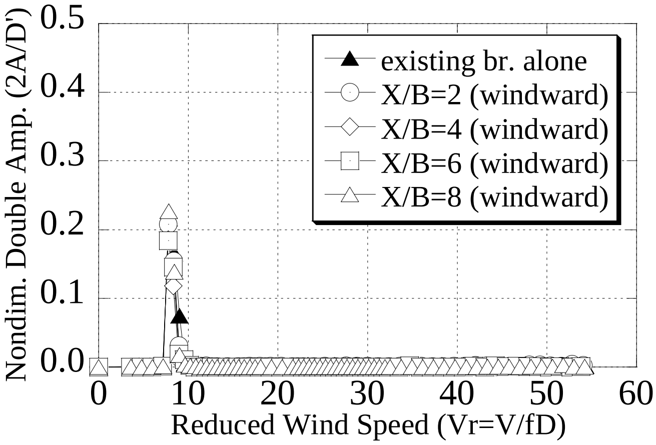


Fig. 2. Heaving response of windward existing bridge

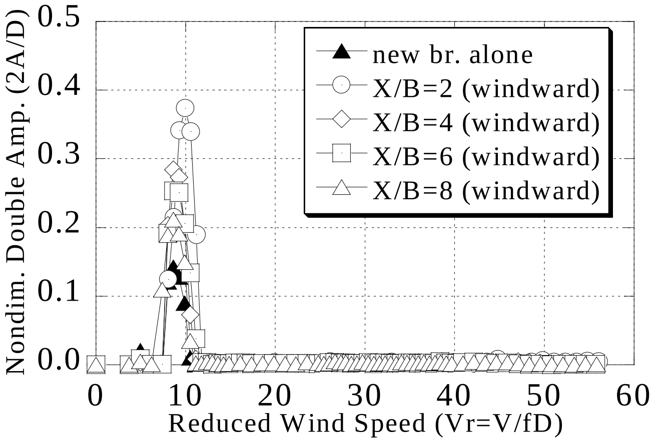


Fig. 3. Heaving response of windward new bridge

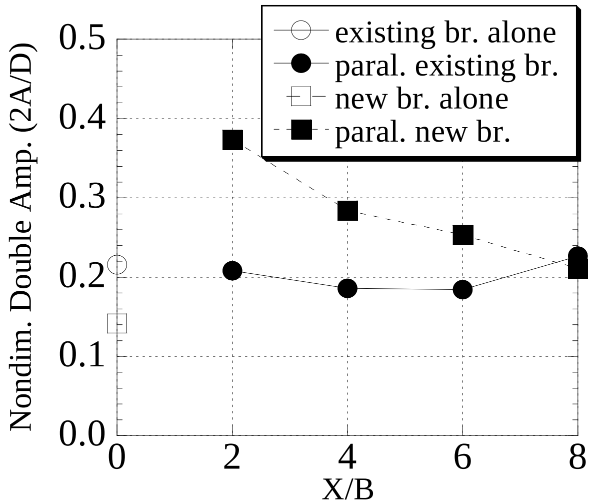


Fig. 4. Maximum heaving response amplitude of windward bridge

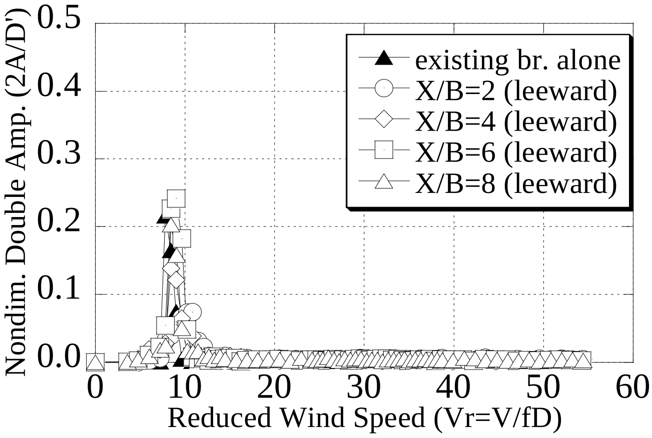


Fig. 5. Heaving response of leeward existing bridge

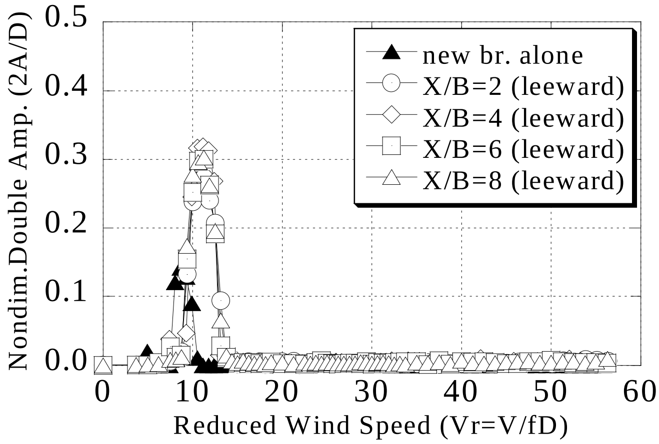


Fig. 6. Heaving response of leeward new bridge

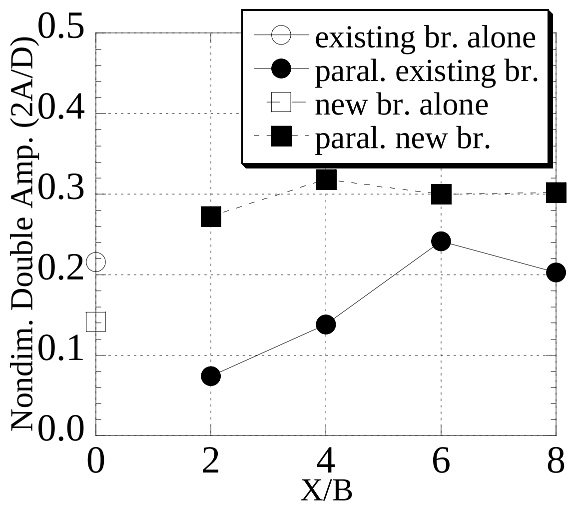


Fig. 7. Maximum heaving response amplitude of leeward bridge

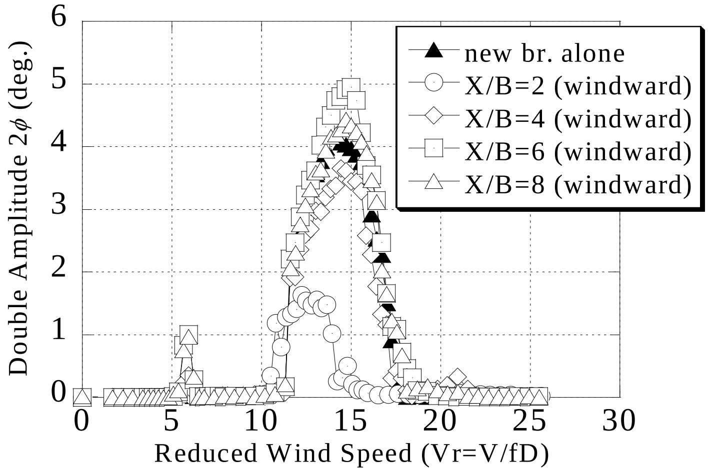


Fig. 8. Torsional response of windward new bridge

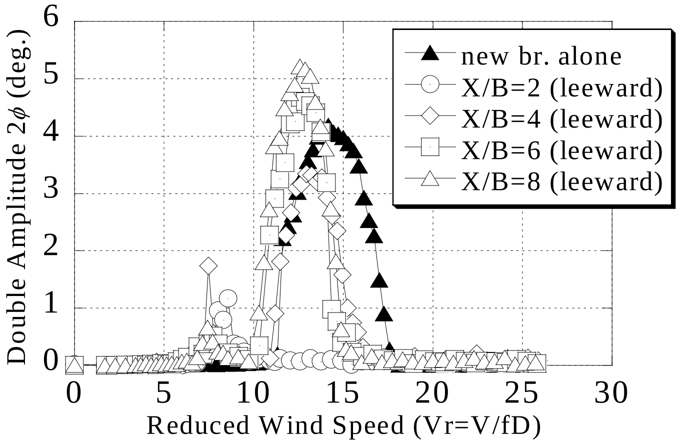
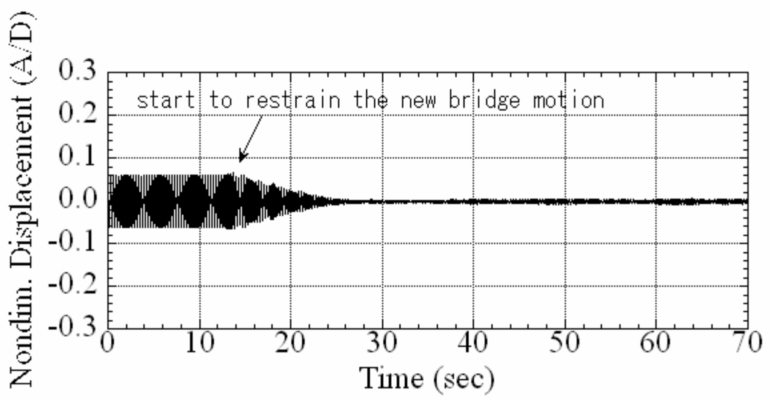
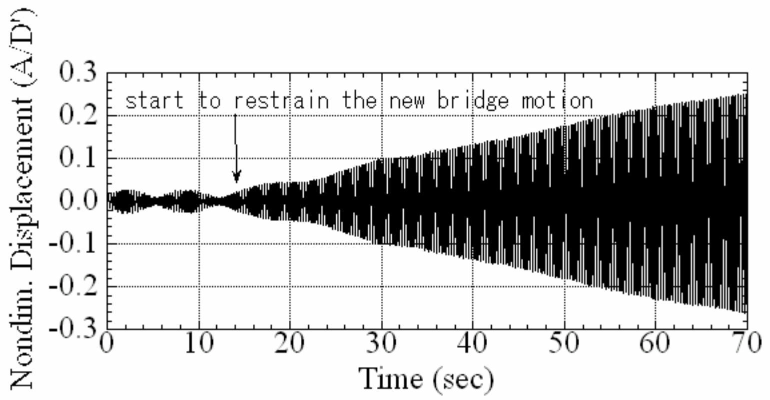


Fig. 9. Torsional response of leeward new bridge

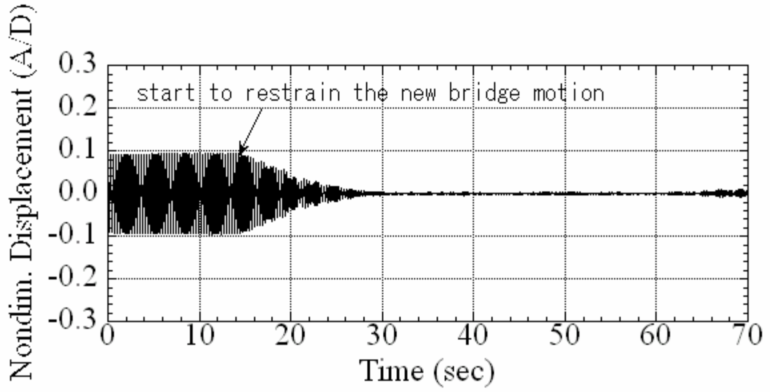


(a) Windward new bridge



(b) Leeward existing bridge

Fig. 10. Heaving response time history of parallel bridges when the windward new bridge motion was restricted (X/B = 2, Vr = 7.9)



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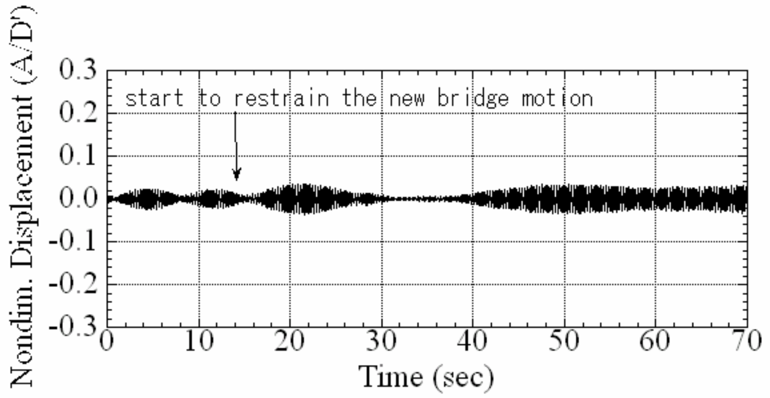
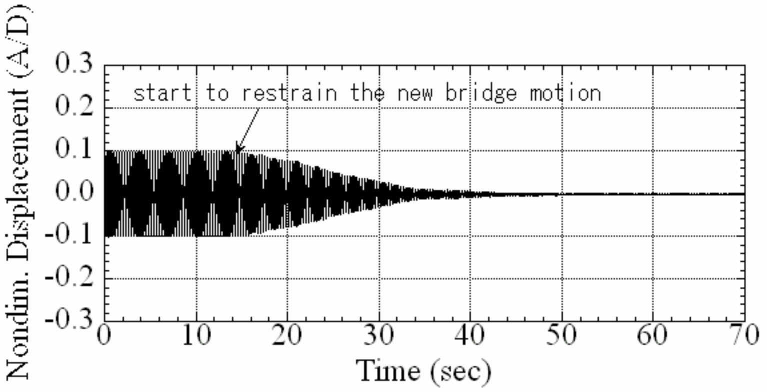
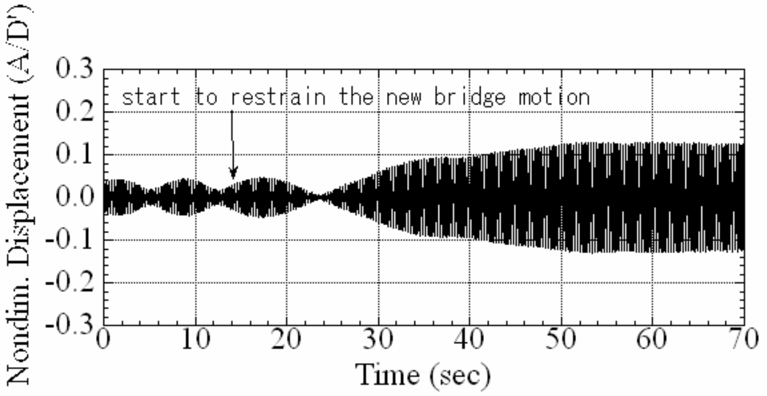


(b) Leeward existing bridge

Fig. 11. Heaving response time history of parallel bridges when the windward new bridge motion was restricted (X/B = 4, Vr = 7.9)



(a) Windward new bridge



(b) Leeward existing bridge

Fig. 12. Heaving response time history of parallel bridges when the windward new bridge motion was restricted (X/B = 6, Vr = 7.9)