Spacing effect of VIV of twin asymmetrical parallel decks for a long-span rail-cum-road bridge

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SUMMARY: In this study, a number of dynamic sectional model wind tunnel tests for VIV performance were carried out. A wide range of spacing-width ratios (*L/Br*) varying from 0.25 to 2.0 for twin asymmetrical parallel girders are selected to investigate the spacing effect of VIV performance under two opposite incoming flow directions at $FR = 1$ and $FR \neq 1$. Results indicated that spacing effect of twin asymmetrical decks' overall VIV performance are more complicated and prominent considering the different wind direction and different frequencies ratio. There exhibited the worst VIV response for upstream highway and downstream railway girder with $FR = 1$ when $L/Br = 1.25$, which shown the phenomenon that the VIV amplitude of the downstream girder exceeds that of the upstream girder. Therefore, it is necessary to consider the incoming flow direction and frequency ratio (FR) when studying the spacing effect. In addition, $FR = 1$ is the necessary condition that caused deterioration of interactive VIV of twin girder at the appropriate spacing and incoming flow direction.

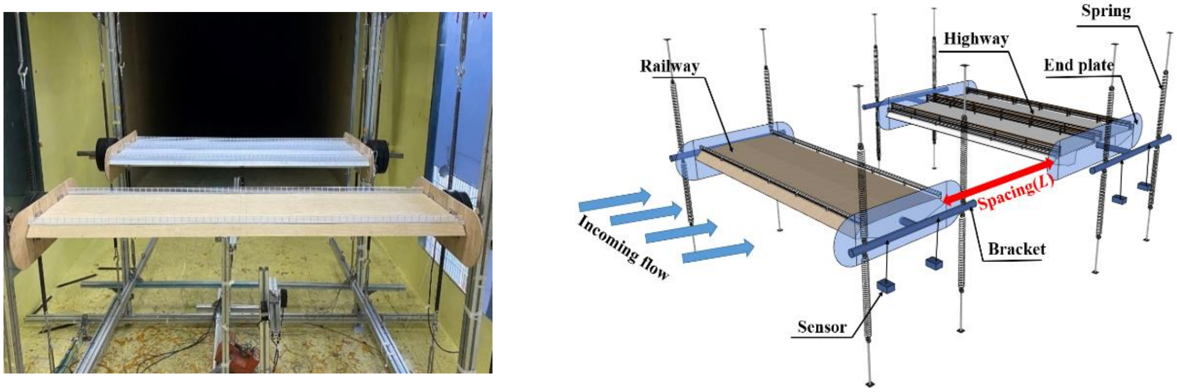
Keywords: Vortex-induced vibration（VIV）, twin separated parallel decks, Spacing effect, Wind tunnel test

1. Introduction

Although many scholars have clarified the effect of spacing on parallel bridges, summarized the relevant laws of the VIV characteristics under different spacing (Park and Kim, 2017; Park et al., 2017). However, the cross-section of twin girders is the same, and the effect of different incoming flow directions and different frequency ratios caused by the asymmetry-decks is not considered (Stoyanoff et al., 2019). The previous view has limitations and is not fully applicable to the twin asymmetric parallel girders (Liu et al., 2022). Therefore, the study of spacing effect of interactive VIVs for twin asymmetrical parallel girders under two opposite incoming flow directions at $FR = 1$ and $FR \neq 1$ is interesting.

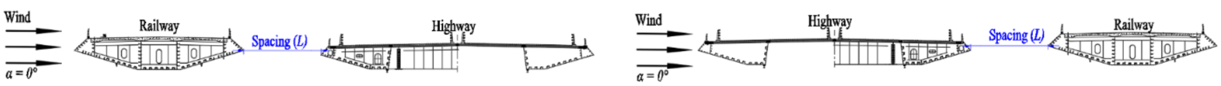
2. Experimental setup

A bridge across the Yangtze River was used as its theoretical framework in this study (Liu et al., 2022). As shown in Figure 1, the VIV measurement test was carried out. Vertical and torsional vibration could occur freely. The test model was chosen with 1:50 under the condition that the geometric shape, elastic parameters, inertia parameters, and damping parameters were equivalent. (Liu et al., 2022). To investigate exhaustively the influence of spacing, a wide range of spacing-width ratios (L/Br) varying from 0.25 to 2.0 for twin asymmetrical parallel girders are selected under two opposite incoming flow directions at *FR* = 1 and *FR* ≠ 1 (see Table 1).



(a) Photo of twin models (b) 3D diagram of support system

Figure 1. Wind tunnel tests



(a) Wind flows from railway to highway (b) Wind flows from highway to railway

Figure 2. Graphical view of opposite incoming flow directions

Table 1. Test conditions

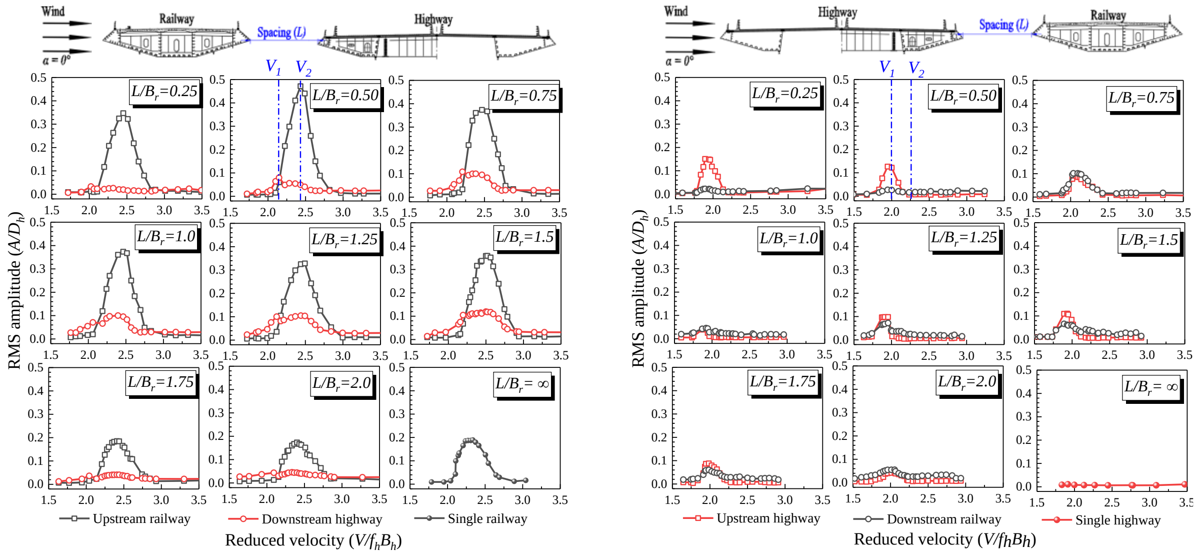
Test content	Incoming flow direction	Frequency ratio	Vertical frequency of highway	Vertical frequency of railway	*L/Br*
Vertical VIV amplitude	Wind flows from railway to highway (see Figure 2(a))	*FR* = 1	6.83	6.83	0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, 2.0
		FR ≠ 1	6.83	7.08	
	Wind flows from highway to railway (see Figure 2(b))	*FR* = 1	6.83	6.83	
		FR ≠ 1	6.83	7.08	

Note: the frequency *ratio is FR* = *fr/fh. Where, fr* is the vertical frequency of railway girder, *fh* is the vertical frequency of highway girder, *L* is the spacing-width, and *Br* is the width of railway girder.

3. Results of VIV tests

3.1. VIV performances when *FR*≠1

As shown in Figure 3(a), when the wind flows from railway to highway, the vibration responses are obviously influenced by the spacing. For upstream railway, it has been undergoing vertical VIV under different spacings, and the VIV interval is almost constant, while, the VIV amplitude is different. For downstream highway, when *L/Br* = 0.25, there was no VIV occurred. As the spacing increases, the downstream highway girder is subjected to the wake vortex of railway girder, and the VIV phenomenon appears. In addition, the amplitude is maximum when *L/Br* = 1.5. Unlike the VIV interval keep constant for the upstream railway girder, the VIV interval of the downstream highway girder is also affected by the spacing. Within the test spacing, the interaction effect law is basically the same. As shown in Figure 3(b), when the wind flows from highway to railway, the VIV characteristics of girders with the spacing completely different from that when the incoming flow is in the opposite direction. Therefore, it is necessary to consider the incoming flow direction. In addition, regardless of the incoming flow direction, there is no phenomenon that the VIV amplitude of the downstream exceeds that of the upstream.

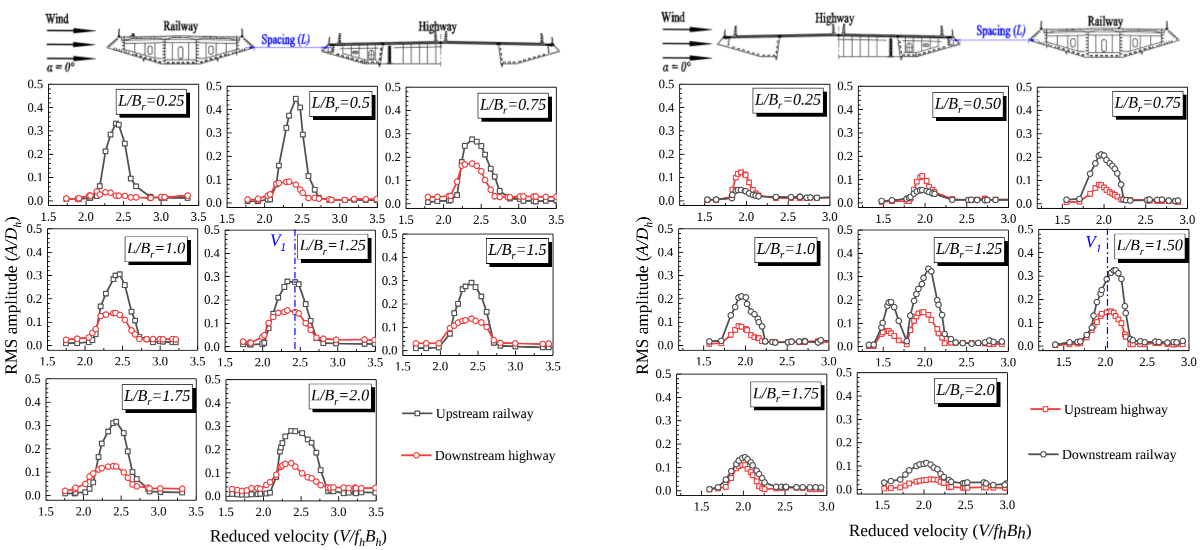


(a) Wind flows from railway to highway (b) Wind flows from highway to railway

Figure 3. VIV amplitude with different separation spaces of *FR* ≠ 1

3.2 VIV performances when *FR* = 1

In order to study the VIV performance when the upstream and downstream girders frequencies are the same, the frequencies are uniformly set to *f* = 6.83. As shown in Figure 4(a), the VIV characteristics of the upstream and downstream girders with the spacing generally consistent with that when *FR* ≠ 1. There is also no phenomenon that the VIV amplitude of the downstream highway girder exceeds that of the upstream railway girder. As shown in Figure 4(b), the VIV characteristics of the upstream and downstream girders with the spacing generally consistent with that when *FR* ≠ 1. When *L/Br* = 0.75-1.5, Vertical VIV occurred in both upstream and downstream girders, and the VIV amplitude of the downstream railway girder was significantly enlarged, it is much larger than that of the upstream highway girder. Therefore, there exhibited the worst VIV response for upstream highway and downstream railway girder with *FR* = 1 when *L/Br* = 1.25.

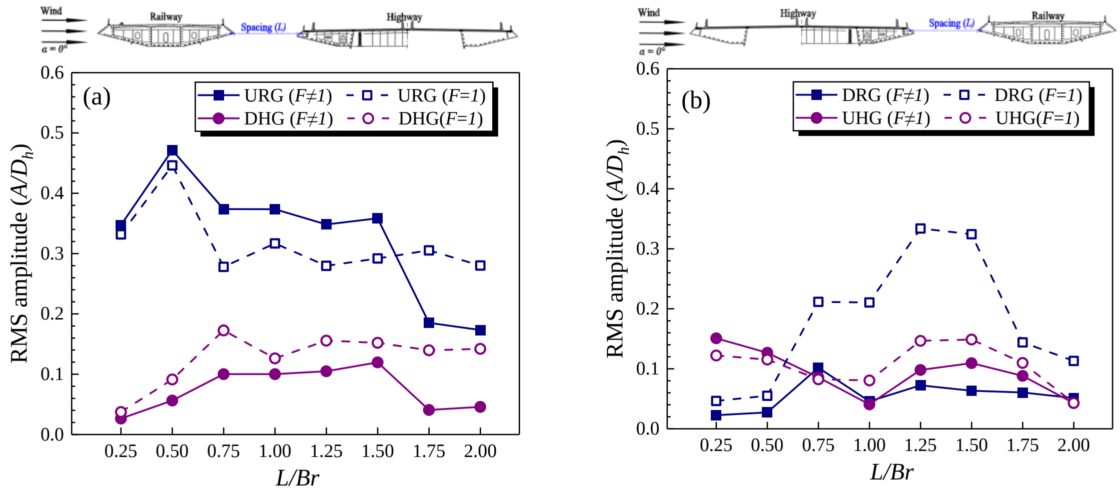


(a) Wind flows from railway to highway (b) Wind flows from highway to railway

Figure 4. VIV amplitude with different separation spaces of *FR* = 1

3.3 Comparison

As shown in Figure 5(a), when the wind flows from railway girder to highway girder, The variation curves of VIV amplitude with spacing for the upstream railway girder and the downstream highway girder have the same trend under *FR* = 1 and *FR* ≠ 1. The downstream highway girder showed vertical VIV, its amplitude did not exceed that of the upstream railway girder. However, when the wind flows from highway girder to railway girder (see Figure 5(b)), a different pattern is revealed under the comparison of *FR* = 1 and *FR* ≠ 1. The variation curves of VIV amplitude with spacing for the upstream highway girder still have the same trend. However, for the downstream railway girder, it occurred vertical VIV under wake vortex of the upstream highway girder, and its amplitude exceed that of the upstream highway girder.



(a) Wind flows from railway to highway (b) Wind flows from highway to railway

Figure 5. Peak VIV amplitude

4. Conclusions

The variation patterns of VIV with spacing for the upstream and downstream highway girder are different *FR* = 1 and *FR* ≠ 1 under different flow direction, which must be considered. *FR* = 1 maybe caused deterioration of interactive VIV of twin girder at the appropriate spacing and incoming flow direction. More in-depth discussions on the flow field, the indicated wind pressure distribution, and vortex force characteristics will be added to the full-paper.

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