Aerodynamic interference effects of two cable-stayed bridges with triple separated parallel decks

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SUMMARY:
In this study, the wind tunnel tests were conducted to investigate aerodynamic interference effects on wind-resistance performance, namely aerostatic coefficients, vortex-induced vibration (VIV) and flutter stability, of two cable-stayed bridges with triple-separated parallel decks, which are Quanzhou Bay railway cable-stayed bridge (QZRB) with single deck hybrid girder, and Quanzhou Bay highway cable-stayed bridge (QZHB) with twin-composite parallel decks. Furthermore, the effects of the horizontal and vertical distances between the main decks were considered, respectively. The results indicated that the main decks exhibit different aerodynamic characteristics due to the aerodynamic interference effects and different factors. Regarding the aerostatic coefficients, the effects were most significant when the railway bridge was located windward (RW). For the VIV, the VIV performance of QZRB was more affected than that of QZHB by aerodynamic interference effects and changing the horizontal net and vertical distance just only affected the maximum amplitude. For the flutter stability, the effects of the aerodynamic interference make flutter stability better for the triple-separated parallel decks.

Keywords: triple-separated parallel decks, aerodynamic interference, wind tunnel test

1. OUTLINE OF THE EXPERIMENTAL

1.1. Engineering Background

With the popularity of bridges with separated parallel decks, more and more scholars have paid attention to the aerodynamic interference effects. Many research results show that the aerodynamic interference affected the aerostatic coefficients (Liu et al., 2009; Ma et al., 2019) and the dynamic responses (Seo et al., 2013; Liu et al., 2021). The aerodynamic interference effects on aerostatic coefficients, VIV and flutter stability of the triple-separated parallel bridge girders with new QZRB and an existing QZHB were investigated. Figure 1 shows the layout of the three bridge girders.

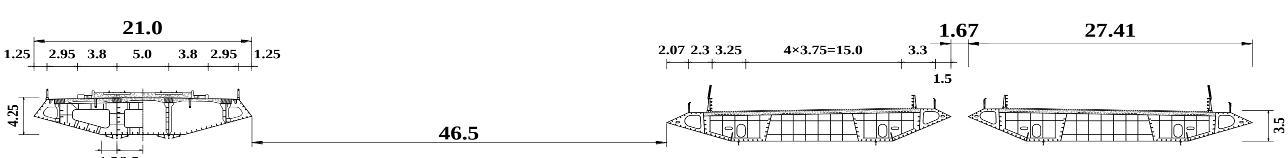

Figure 1. The relative positions of the three bridge girders (unit: m)

1.2. Wind Tunnel Tests

The length scale of 1:60 was used to design and fabricate the rigid segmental model of main decks, and the parameters of the segmental models of the main decks of QZRB and QZHB are shown in Table 1. The experimental photos and schematic diagram for force- and vibration-measurements of the triple main decks are shown in Figure 2, and the test cases are shown in Table 2.

Table 1. Parameters of the section model of the main deck of QZRB and QZHB.

Parameters	QZRB prototype	Model	QZHB prototype	Model
Length, L(m)	/	1.60	/	
Width, B(m)	21.0	0.35	27.41	0.457
Height, H(m)	4.25	0.071	3.50	0.058
Equivalent mass, m_{eq}(kg/m)	5.21×10^4	14.472	3.565×10^4	9.903
Equivalent mass inertial moment, J_{meq}(kg.m2/m)	2.130×10^6	0.1644	1.850×10^6	0.1427
Vertical frequency, f_h(Hz)	0.3946	3.946	0.3353	3.353
Torsional frequency, f_α(Hz)	1.3504	8.008	0.9497	5.981
Vertical damping ratio, ξ_h(%)	/	0.14	/	0.22
Torsional damping ratio, ξ_α(%)	/	0.17	/	0.31

Figure 2. Photos and schematic diagram of wind tunnel tests: (a) vibration-measurement test; (b) force-measurement test; (c) schematic diagram.

Table 2. Test cases.

Force-measurement test cases	D/B	L/H	Vibration-measurement test cases	D/B	L/H
Case-F-SRB	/	/	Case-V-SRB/DHB	/	/
Case-F-RW1/RL1	0.5		Case-V-RW1/RL1	1.5	
Case-F-RW2/RL2	1		Case-V-RW2/RL2	2.2	0
Case-F-RW3/RL3	1.5	0	Case-V-RW3/RL3	3	
Case-F-RW4/RL4	2.2		Case-V-RW4/RL4	2.2	-1
Case-F-RW5/RL5	3		Case-V-RW5/RL5		1
Case-F-RW6/RL6	2.2	-1	/		
Case-F-RW7/RL7		1			

2. RESULTS

2.1. Aerostatic Coefficients

The force-measurement tests were only carried out on the main deck of QZRB. Figure 3 shows the results of the force-measurement tests. According to Figure 3, Case-F-RL1~7 have significant effects on the QZRB than Case-F-RW1~7. For Case-F-RW1~7, the aerostatic coefficients are smaller than those of Case-F-SRB and increased with the increasing of horizontal net distance of D/B, while vertical distance L/H has a negligible effects on the aerostatic coefficients of the QZRB.

The aerostatic coefficients reached the minimum value at the Case-F-RW1, where the mean drag coefficient and RMS of lift and pitch coefficients decreased by 11.93%, 36.89% and 18.91%, respectively. For Case-F-RL1~7, the aerostatic coefficients increased with the increase of D/B, while changing vertical distance only affects the drag coefficient. Compared with Case-F-SRB, the mean drag coefficient reached the minimum value at Case-F-RL 6 and decreased by 49.1%. In comparison, the RMS of lift and pitch coefficients reached a maximum value at Case-F-RL5 and increased by 138.2% and 164.6% respectively.

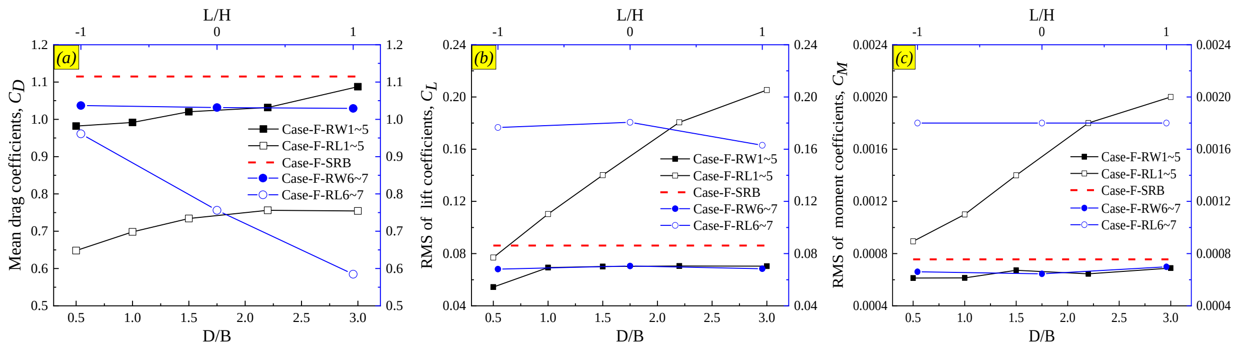

Figure 3. Results of force-measurement test: (a) C_D; (b) C_L; (c) C_M.

2.2. Wind-induced Vibration Responses

The vibration-measurement tests were carried out on the railway and highway bridge girders. Figure 4 showed the experimental results. Based on the results, the influence of the aerodynamic interference effect is most intuitively reflected in the maximum amplitude of VIV and the aerodynamic interference effect increases the flutter critical wind speed. The test results are analyzed specifically in sections 2.2.1 and 2.2.2.

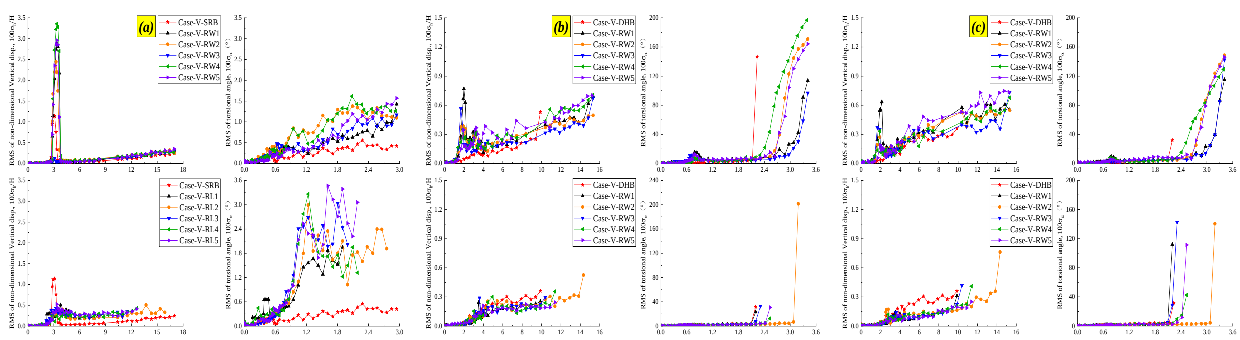

Figure 4. Results of the VIV and flutter responses: (a) RB; (b) HB-1; (c) HB-2.

2.2.1. VIV performance

As shown in Figure 4, compared with Case-V-SRB and Case-V-DHB, the triple-separated parallel decks showed different VIV performances due to the aerodynamic interference effects. Changing the horizontal net distance D/B and vertical distance L/H have negligible effects on the lock-in interval wind velocity. For Case-F-RW2, compared with Case-V-SRB, the maximum amplitude of the QZRB increased by 114.1% and the VIV of QZHB occurred by aerodynamic interference effects. For Case-F-RW1 and 3, compared with Case-F-RW2, reducing D/B increased the maximum amplitude by 18.5%, and enlarging D/B suppressed the occurrence of VIV completely.

Accordingly, the maximum torsional and vertical amplitudes of QZHB-1 increased by 42.1% and 99.5%, and the QZHB-2 increased by 111.8% and 133.9% respectively. In addition, for Case-F-RW4~5, compared with Case-F-RW2, the maximum amplitude of QZRB increased by 37.3% and 21.2% respectively, and the maximum vertical amplitude increased by 16.9% and reached the maximum value at L/H=1.0. In contrast, the maximum torsional amplitude shows decreasing trend and reached the minimum value at L/H=-1.0. The maximum vertical and torsional amplitudes of QZHB-2 increased by 4.3% and 22.9% respectively, which reached the maximum at L/H=-1.0. For Case-F-RL1~5, the VIV responses of the QZRB and QZHB were significantly suppressed.

2.2.2. Flutter stability

As shown in Figure 4, for Case-V-DHB, when the reduced wind velocity was V_r=2.23, the torsional vibration responses increased sharply, showing flutter characteristics. For Case-V-RW1~5, compared with Case-V-DHB, the triple-separated parallel decks showed better flutter stability. The flutter critical wind velocity increased and reached the highest value of V_r=3.3 for Case-V-RW3, showing soft flutter characteristic. For Case-V-RL1~5, the flutter critical wind velocity reached the lowest value of V_r=2.20 at Case-V-RL1 and reached the highest value of V_r=3.19 at Case-V-RL2, showing flutter characteristic.

3. CONCLUSIONS

This experimental investigation of aerodynamic interference effects on aerostatic coefficients, VIV performance and flutter stability of tow cable-stayed bridges with triple-separated parallel decks were conducted in this study and the main conclusions are presented as follows: (1) In Case-F-RL1~5, the aerodynamic interference effects have the significant effects on the aerostatic coefficients, the maximum change amplitude of the mean drag coefficient, the RMS of lift and moment coefficient reached 49.4%, 138.2% and 164.6% respectively. (2) The aerodynamic interference can worsen the VIV performance, especially in the case of the RD-W. Compared with Case-V-SRB, the maximum VIV amplitude of RB increases by 114.1% and reaches the maximum at Case-V-RW1. Compared with Case-V-DHB, VIV of the QZHB occurs. (3) The triple-separated parallel decks exhibit better flutter stability with the aerodynamic interference.

ACKNOWLEDGEMENTS

This research was financially supported by the National Natural Science Foundation of China (grant numbers 52178475 and 51778225), for which the authors are grateful. The authors also gratefully acknowledge China Railway Siyuan Survey and Design Group Co., Ltd., China, for its financial support.

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