August 27-31, 2023
FLORENCE - ITALY
16th International Conference on Wind Engineering

Experimental studies on the vortex-induced vibration of parallel Π-shaped composite decks

Qiang Zhou[1,2], Chuan Qin[1], Mingshui Li [1,2]

[1]*Research Center for Wind Engineering, Southwest Jiaotong University, Chengdu, China, milan1023@gmail.com*
[2]*Key Laboratory for Wind Engineering, Southwest Jiaotong University, Chengdu, China*

SUMMARY:
The characteristics of vortex-induced vibration (VIV) of parallel Π-shaped composite decks are comprehensively investigated under different wind angles of attack (α = +5°, +3°, 0°, -3° and +5°) and space ratios (L/D = 3 ~ 8) by sectional model testing, where L and D are the gap length and deck height, respectively. The lock-in regions, amplitudes, frequencies and hysteresis effects for various cases are analyzed in detail. Results show that the maximum VIV amplitude of downstream deck is significantly increased comparing with that of single deck, while the onset wind velocity of both upstream and downstream decks are identical and almost same to that of single deck. The VIV characteristics of both upstream and downstream decks are sensitive to the wind angles of attack and space ratios. As with situations involving negative angles, the lock-in region is visibly delayed, and the maximum amplitude is likewise greatly diminished. On the contrary, the amplitude and lock-in region of the positive angle of attack become larger, resulting that the most unfavorable state of VIV occurs for α = +5°. The amplitude of both the upstream and downstream decks increase with increasing spacing ratio for all investigated space ratios. Additionally, clear hysteresis effects are detected.

Keywords: parallel Π-shaped composite decks, vortex-induced vibration, wind tunnel testing

1. GENERAL INSTRUCTIONS

The aerodynamic interference has a significant impact on the wind-induced vibration of the parallel structures, such as tandem square buildings, cooling towers, bridge piers, wind turbine towers, etc., which has attracted much attention of researchers (Zdravkovich, 1977; Alam and Zhou, 2003; Sumner, 2010; Zhou et al. 2019). The parallel decks of long-span bridge, as a typical parallel structure, has been widely applied in practical engineering due to powerful traffic capacity (Meng et al., 2001). However, the occurrence of VIV is very prominent for the parallel decks as a result of their interference effects (Park and Kim, 2017).

Prior research has focused more on the VIV of parallel box-girder decks, but parallel Π-shaped composite decks have received less attention. In present study, a series sectional model testing are conducted to investigate the VIV performance of parallel Π-shaped composite decks with focusing on the effects of attacking angle and spacing ratio.

2. EXPERIMENTAL SETUP

The section model wind tunnel testing were carried out within the smooth oncoming flow at

XNJD-1 wind tunnel of Southwest Jiaotong University. The closed-circuit wind tunnel has a work section that is 16.0 m in length, 2.4 m in width, and 2.0 m in height. The wind speed can be continuously adjusted from 0.5 to 45.0 m/s, and the turbulence intensity is less than 0.5%.

2.1. Sectional model

The parallel Π-shaped composite decks have a cross section with the width of B = 22.75m, and the height of D = 2.87m as shown in Figure 1. A 1:70 scale sectional model designed and had a length of 2.095m, which maintains the aspect ratio to satisfy the required value of 3. The entire deck model was made of wood and coated with an FRP shell to ensure its rigidity. The handrails were made of ABS. The end plates of section model, added onto the model ends, are about 5 times the area of the experimental cross section to reduce the effects of the end flow and to maintain a nominally two-dimensional flow.

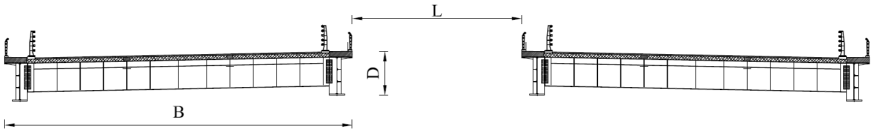

Figure 1. Cross section of parallel Π-shaped composite decks

2.2. Spring-suspended sectional model system

The spring-suspended sectional model system shown in Figure 2 is utilized to study the VIV performance of parallel Π-shaped composite decks under different attacking angles and spacing ratios. The testing system has four supports and sixteen tensile springs, allowed to oscillate in two degrees (vertical and torsional) of freedom for both upstream and downstream decks. In addition, the higher and lower springs are attached to the upper and lower slide rails, respectively, to provide distinct spacing ratios. The physical properties of the sectional model are presented in Table 1. The blockage ratio for this study is about 2.0%, which is less than the suggested value of 5%.

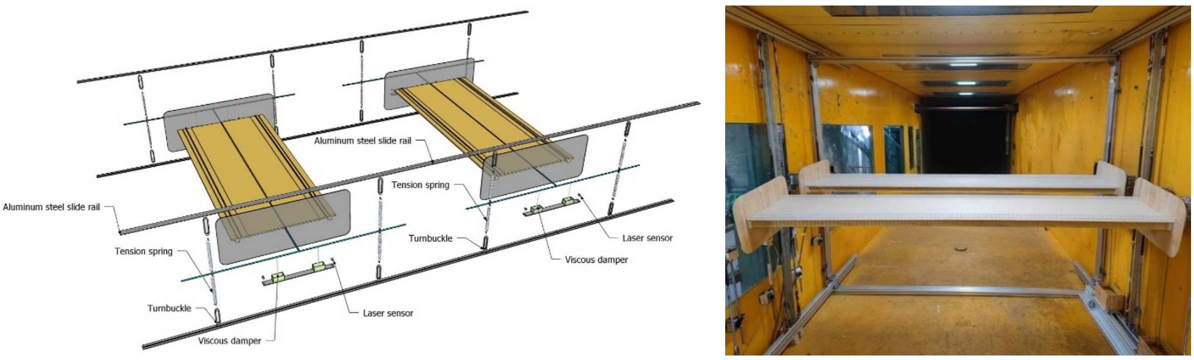

Figure 2. Spring-suspended sectional model system in wind tunnel

Table 1 Physical properties of dynamic sectional model.

Property	Unit	Scale	Prototype	Model
Vertical frequency (f_h)	Hz	/	0.432	5.729/5.705
Vertical damping ratio (ξ_v)	%	/	/	0.780/0.760
Torsional frequency (f_α)	Hz	/	0.892	2.034/2.021
Torsional damping ratio (ξ_t)	%	/	/	0.320/0.300

3. RESULTS AND DISCUSSIONS

3.1. Amplitudes and lock-in region

The VIV responses of both upstream and downstream decks with α = +5°, +3°, 0°, -3° and +5° at *L/D* = 6 is presented in Figure 3, where U and D refer to upstream and downstream, respectively, and S represents the VIV responses of a single Π-shaped composite deck. Figure 3(c) compared the maximum VIV amplitudes of both upstream and downstream decks with those of the single deck. Apparently, from the standpoint of amplitude, the maximum amplitude downstream is substantially greater than that upstream, which has a strong amplifying impact relative to the single amplitude, while the maximum amplitude upstream is near to or suppressed relative to the single amplitude. At an angle of attack of -3 degrees, for instance, the maximum amplitude of the upstream is lowered by 26% relative to a single amplitude, but at an angle of attack of 0 degrees, the maximum amplitude of the downstream is magnified by 56%. In accordance with previous studies (Meng et al., 2011; Park and Kim, 2017), the VIV of the downstream deck is greatly influenced by the same aerodynamic form and natural frequency. However, the lock-in regions of both upstream and downstream decks are almost unchanged within different attacking angles comparing with those of the single deck. It can be also found that the and the maximum amplitude is likewise greatly diminished for the cases of α = 0° and -3°. On the contrary, the amplitude and lock-in region of the positive angle of attack become larger, resulting that the most unfavorable state of VIV occurs for α = +5°.

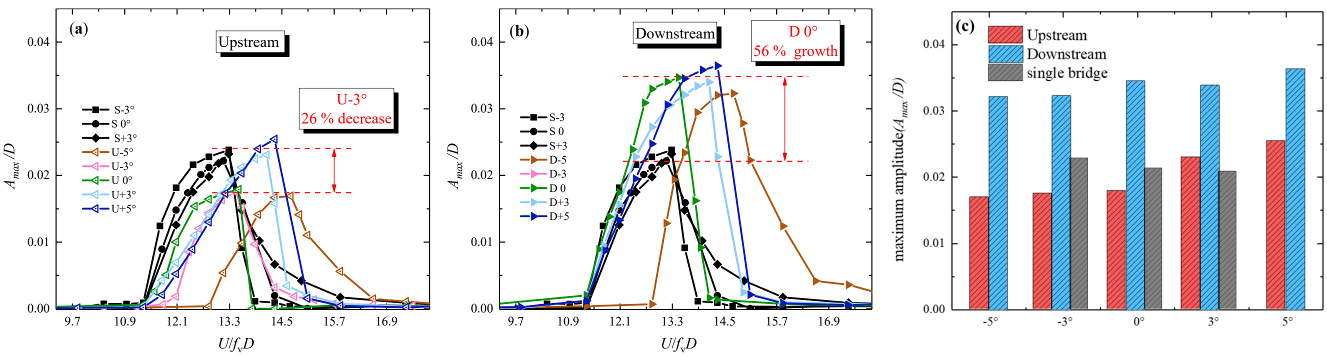

Figure 3. Vertical VIV performance within different attacking angles, (a) upstream, (b) downstream and (c) comparing with that of the single deck

Figure 4 shows the vertical VIV performance within different spacing ratios (*L/D* =6, 7 and 8) at (a) α = 0° and (b) α= -3°. Under these two different angles of attack, it is evident that the VIV characteristics exhibit a similar tendency. At various spacing ratios, the beginning wind speed of vortex-induced vibration remains essentially same, indicating that the original section may cause vortex-induced vibration, which is consistent with the results of single-section section tests. The amplitude of eddy vibrations in upstream and downstream portions rises as the spacing ratio increases, which results in that the most unfavorable spacing ratio of parallel Π-shaped composite decks is *L/D*=8.

Figure 5 presents the change of phase difference between the upstream deck and downstream deck within the lock-in range at α = 0° and +5°. At the point of onset wind speed, the phase difference exhibits apparent mutations and subsequently reduces with rising wind speed, as in the lock-in range.

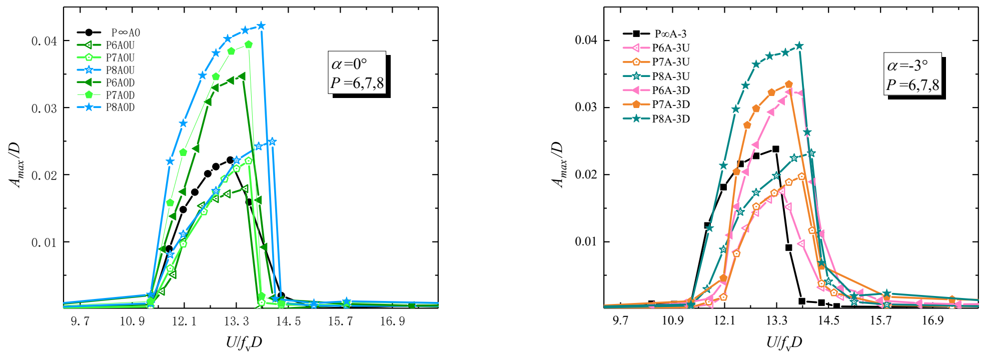

Figure 4. Vertical VIV performance within different spacing ratios at (a) $\alpha = 0°$ and (b) $\alpha = -3°$

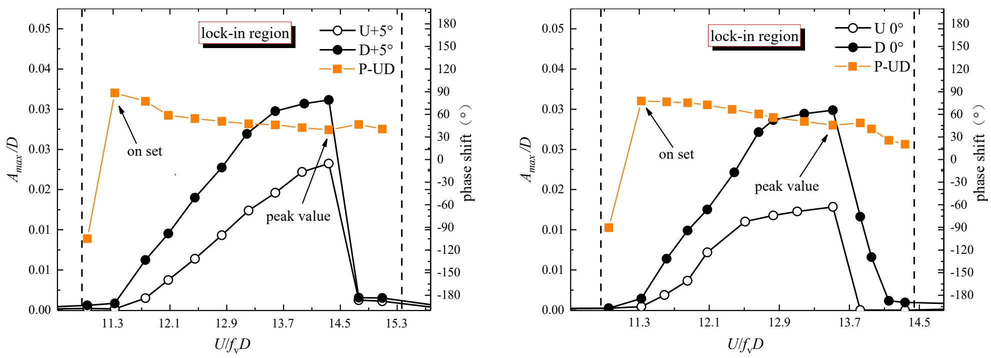

Figure 5. Phase difference of parallel decks

4. CONCLUSIONS REMARKING

The VIV characteristics of parallel Π-shaped composite decks are sensitive to the wind angles of attack and space ratios. The maximum VIV amplitude of downstream deck is significantly increased comparing with that of single deck, while the onset wind velocity of both upstream and downstream decks are identical and almost same to that of single deck.

ACKNOWLEDGEMENTS

This research was funded by the Natural Science Foundation of China (Grant No. 52078437) and Sichuan Province Science and Technology Program (No. 2021YJ0075).

REFERENCES

Zdravkovich, M., 1977. Review of flow interference between two circular cylinders in various arrangements. Journal of Fluids Engineering 99 (4), 618.

Alam, M.M., Zhou, Y., 2007. Flow around two side-by-side closely spaced circular cylinders. Journal of Fluids and Structures 23 (5), 799-805.

Sumner, D., 2010. Two circular cylinders in cross-flow: a review. Journal of Fluids and Structures 26 (6), 849-899.

Zhou, Q., Alam, M.M., Cao, S., Liao, H., Li, M., 2019. Numerical study of wake and aerodynamic forces on two tandem circular cylinders at Re= 103. Physics of fluids 31 (4), 045103.

Meng, X., Zhu, L., Guo, Z., 2011. Aerodynamic interference effects and mitigation measures on vortex-induced vibrations of two adjacent cable-stayed bridges. Frontiers of Architecture and Civil Engineering in China 5, 510-517.

Park, J., Kim, H.-K., 2017. Effect of the relative differences in the natural frequencies of parallel cable-stayed bridges during interactive vortex-induced vibration. Journal of Wind Engineering and Industrial Aerodynamics 171, 330-341