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Experimental Investigation of Vortex-Induced Vibration Characteristics on Dual Circular Cylinders in Tandem

Lang Tianyi[1], Wang Hao[1], Guiseppe Piccardo[2], Xu Zidong[1], Hui Gao[1], Han Zhang[1]

[1]Key Laboratory of C&PC Structures of Ministry of Education, Southeast University, Nanjing,
211189, China
[2]Department of Civil, Chemical and Environmental Engineering, University of Genova, Via
Montallegro 1, 16145, Genoa, Italy

SUMMARY:
A wind tunnel test investigation was carried out on the vortex-induced vibration (VIV) characteristics of dual circular cylinders in tandem. Two circular cylinders with the same diameter and natural frequency simulate the hanger cables of a suspension bridge under design to analyze the potential hazards of the hangers subjected to wind loads. The results show that the VIV of the circular cylinder would occur in a limited wind speed range (lock-in region). Compared with the single circular cylinder, the lock-in region and vibration characteristics of dual circular cylinders in tandem are different, owing to the aerodynamic interaction between the cylinders.
Keywords: vortex-induced vibration, circular cylinder, aerodynamic interaction

1. INTRODUCTION

The hanger cable of the suspension bridge is a typical wind-sensitive structure with inherent characteristics of low frequency, lightweight, small damping, and a large slenderness ratio. Under the action of wind loading, the problem of wind vibration of the hanger cables of a suspension bridge becomes increasingly severe. Fatigue crack sets in the hanger cable subjected to frequent and large amplitude dynamic loads, shortening the cable's service life. In addition, the large amplitude of vibration will cause a negative social impact. The hanger cable in suspension bridges has often been subjected to wind-induced vibrations[1-3]. Therefore, this has become one of the critical problems affecting the service of the ganger cables.

Since the hanger cable generally has a circular cross-section, it is usually considered a circular cylinder for investigation. As the basis of research on the flow around the double circular cylinder, scholars first paid attention to the single circular cylinder[4-5]. Due to the influence of aerodynamic interference between cylinders, the vibration performance is much more complicated than a single cylinder[6]. According to the direction of the incoming flow angle of attack, the double-cylinder system can be divided into three basic formats: tandem, parallel, and staggered[7].

In order to simulate the wind-induced performance of the hanger cable, the test model is made from the design information of the suspension bridge hanger cable. The vortex-induced vibration performance of the single cylinder and the dual circular cylinders in tandem is studied by wind tunnel tests for the purpose of analyzing the aerodynamic interaction.

2. WIND TUNNEL TEST

In the wind tunnel test, the hanger cable model is made into 116mm diameter (D) circular cylinders with a natural frequency of 3.67Hz and damping ratios of 1.1‰. Moreover, the distance between the columns is 5D. The springs mounted in an X-crossing manner achieved free vibration of the cylinder in two dimensions longitudinal and transverse axis. Side plates are set at both ends of the circular cylinder to minimize three-dimensional flow effects.

(a) Single cylinder (b) Two tandem cylinders

Figure 1. Wind tunnel test installation

3. EXPERIMENTAL RESULTS

The VIV occurs on both single and double cylinders. As shown in figure 2, the onset reduced wind velocity of the VIV of the single cylinder is close to 5. When the reduced wind velocity increases further to 5.52, the amplitude of the VIV of the single cylinder reaches the maximum. For the case of dual tandem cylinders, the apparent VIV also occurs in the upstream and downstream cylinders. Due to the interaction influence of the double tandem cylinders, the locked-in region of the dual tandem cylinders moves backward. Around the reduced wind velocity of 6, the VIV occurs in the dual cylinders system, but the amplitude of the downstream cylinder is smaller than that of the single one.

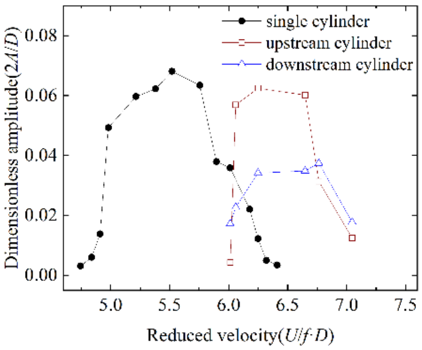
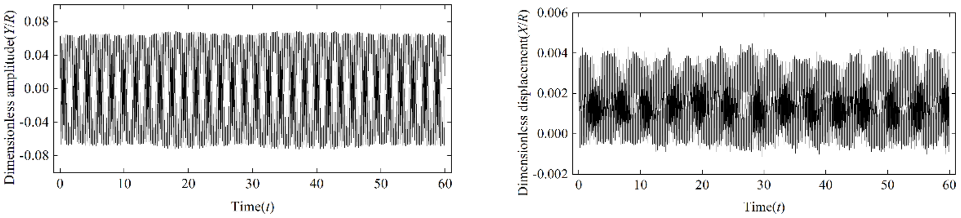


Figure 2. Transverse amplitude response for the VIV of the circular cylinder

Fig. 3 presents the vibration response of the single cylinder at the reduced wind velocity of 5.52.

Fig. 3 (a), (b), and (c) show the cylinder's transverse and longitudinal responses and the actual displacement trajectory, respectively. The size of the responses differs by an order of magnitude in two directions, resulting in considerable transverse displacements when VIV vibration occurs. Because of the presence of many high-frequency components in the longitudinal vibration, the motion trajectory of the cylinder behaves confusingly. After filtering out the high-frequency parts of the vibration response of the cylinder, Fig. 3 (d) illustrates the filtered motion trajectory. It can be seen that the pattern of the filtered motion trajectory is relatively common, even if the figure is actually very flattened in the *X*/*R* direction due to the different entities of the vibrations in two directions.

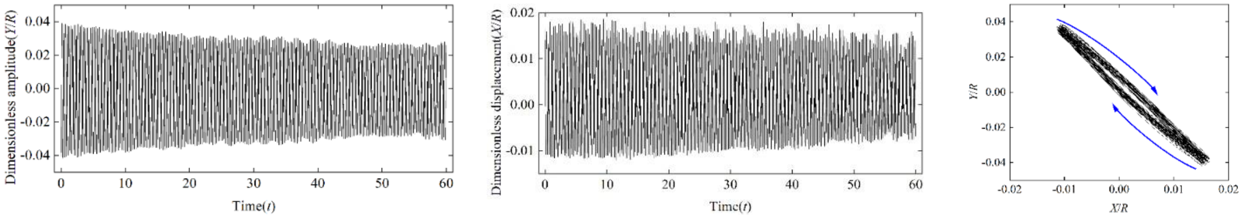


(a) transverse response (b) longitudinal response

(c) motion trajectory (d) filtered motion trajectory

Figure 3. Vibration response of the single cylinder

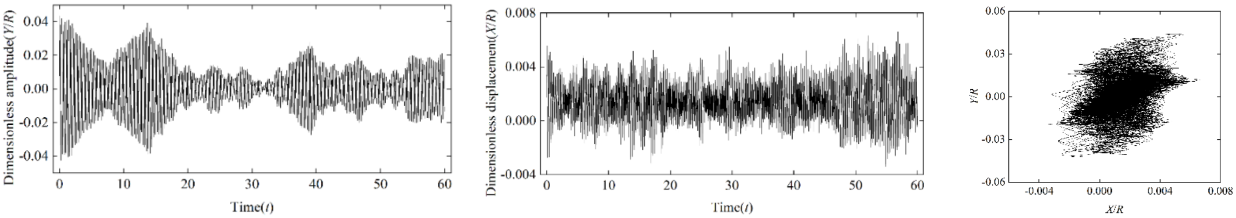
For the case of two tandem cylinders, the vibration response of the upstream cylinder at the reduced wind velocity of 6.25 is shown in Fig. 4, including Fig. 4 (a) for the transverse response, Fig. 4 (b) for the longitudinal response, and Fig. 4(c) for the filtered motion trajectory. It can be observed that the displacements in two directions are now of the same order of magnitude. The motion trajectory of the unfiltered cylinder is still chaotic and inconvenient for analysis, so the vibration response is suitably filtered, as observed in Fig. 4(c). It is shown that the filtered motion trajectory of the upstream cylinder is still in a typical limit cycle form.



(a) transverse response (b) longitudinal response (c) filtered motion trajectory

Figure 4. Vibration response of the upstream cylinder

The vibration response of the downstream cylinder at the reduced wind velocity of 6.76 is shown in Figure 5. Due to the aerodynamic interference between the cylinders, the vibration response of the downstream cylinder is significantly affected. The transverse response behaves similarly to a beat phenomenon, and the longitudinal response is an irregular and small-amplitude vibration response. The phenomenon indicates that under the influence of the wake flow of the upstream cylinder, the frequency characteristics of the vibration of the downstream cylinder are more complicated. When removing the high-frequency components, the motion trajectory is still very chaotic and irregular, which is different from the typical VIV form.



(a) transverse response (b) longitudinal response (c) filtered motion trajectory

Figure 5. Vibration response of the downstream cylinder

4. PRELIMINARY CONCLUSIONS

In this study, dual circular cylinders in tandem are used to simulate the hanger cables of a suspension bridge. The vortex-induced vibration will occur in both the single and double tandem cylinders in a limited wind speed range. Due to the aerodynamic interference between the two cylinders, the amplitude of the downstream cylinder is significantly smaller than that of the single cylinder. Moreover, the lock-in region of the double cylinder moves backward compared with the single cylinder, and the magnitude of the downstream cylinder is smaller than that of the upstream cylinder.

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