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Experimental study on bridge aeroelastic model subjected to wind-rain actions

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Abstract

Under the combined actions of wind and rain, the performance of full bridge aeroelastic model will be more or less different with that of just with wind. Up to now, no related researches have not be documented. In this study, take the suspension bridge type as an example, with three different deck sections, i.e., bluff, thin flat plate, quasi-streamlined types, the aeroelastic model at erection stage is focused. Under different conditions of wind speed, rainfall intensity, and initial attack angle, the vertical and torsional responses at the deck end tips and middle section are recorded. The aerostatic and aerodynamic responses are comparatively investigated. Finally, some conclusions are drawn.

Introduction

The wind-rain excited vibrations of stay cables have been extensively investigated by using theoretical analysis, wind tunnel test, numerical simulations, and field measurement[1]. The geometrical ratio of 1:1 can be used for experimental and numerical studies, and the Reynolds number effect is almost negligible. The configuration, mass, frequency similarities requirements can be satisfactorily met. Therefore, the results accuracy can be easily ensured. For the wind-rain effects on the rigid sectional model of bridge deck, some researches[2-3] haven been carried out by using wind tunnel tests and numerical simulations. Usually, the scaled model is much smaller than that of the prototype bridge, and the simulations of the rain parameters (rain size, rainfall intensity, raindrop spectra) and actions on the deck are very challenging. Thus, it is difficult to obtain satisfactory accuracy. To the authors' knowledge, no studies have been attempted to reveal the responses of bridge aeroelastic model under the combined actions of wind and rain loads. In this study, take the flexible suspension bridge as an example, with three different deck sections, i.e., bluff, thin flat plate, quasi-streamlined types, the aeroelastic model at erection stage is concerned. Under different conditions of wind speed, rainfall intensity, and initial attack angle, the aerostatic and aerodynamic responses are measured and analyzed. The rainfall intensities are the same with the observed in natural surroundings, and this kind of condition is very extreme for scaled aeroelastic model. If the influence of the rainfall on the model is not obvious or even negligible, it can offer a convincing proof that the rainfall effects on real bridges can be omitted.

Bridge type and cross sections of bridge

For suspension bridges, at the erection stage, they are more flexible compared to the completion state, and thus are more sensitive to wind loads. If the deck are symmetrically erected from the middle sections to the pylons, when the erection ratio (erection length/main span length) is between 20%-40%, the wind-resistance performance is relatively worse. Usually, the pylon stiffness is highly enough, and its vibration is almost negligible compared to that of deck. Therefore, the pylon models are not fabricated, and the main cables are directly anchored to the wind tunnel walls, by which the model geometrical scale can be as large as possible. The deck, hangers, and main cables are simulated, and the schematic aeroelastic model is shown in Figure 1. The side span is omitted to increase the geometrical scale. The concerned deck sections include three types: bluff, thin plate, and quasi-streamlined sections, which are shown in Figure 2. The initial attack angel include: ±5°, ±3°, 0°. The deck width is 30cm, and the suspended model length is 4m. In virtue of most bridge deck size, and geometrical scale can be considered as in the range of 1:50~1:150.

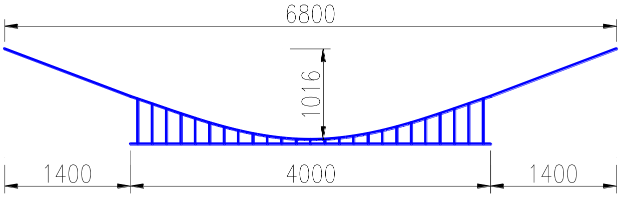


Figure 1. Elevation of full bridge aeroelastic model (unit: mm)

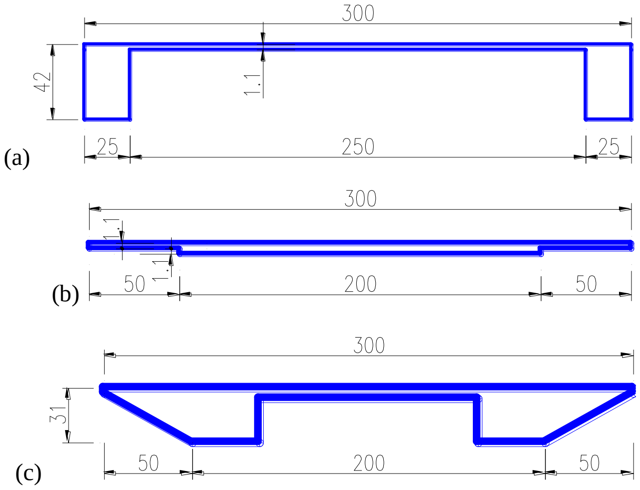


Figure 2. Cross sections of bridge deck (unit: mm)

Descriptions of testing cases

In order to study the influence of deck section, initial attack angle (α, degree), wind speed (U, m/s), and rainfall intensity (RI, mm/h) on the aerodynamic performance of bridges, a large amount of tests were attempted. Brief information is summarized in Table 1.

Table 1. Brief descriptions of different testing cases

Cases	Section	Attack angle	Descriptions
1	a	0°	wind and rain, 3 wind speeds
2		3°	Wind, 5 wind speeds
3		-3°	wind, 4 wind speeds

4	b	0°	wind and rain, 4 wind speeds
5		+5°	wind and rain, 6 wind speeds
6		-5°	wind and rain, 3 wind speeds
7	c	0°	wind, 1 high wind speed
8		+5°	wind and rain, 3 wind speeds

Introduction of wind tunnel laboratory and equipment

The tests were carried out in the wind tunnel laboratory of Harbin Institute of Technology, and the size of testing area is 6.0m in width, 3.6m in height, and 50m in length. The artificial simulating rainfall equipment (Figure 3) is available for the tests under conditions of combined wind and rain actions.

Figure 3. Artificial Simulating Rainfall Equipment

The rainfall intensity (RI) include four levels, i.e., 60mm/h, 100mm/h, 150mm/h, 200 mm/h, which almost cover the possible rainfall intensity in natural surroundings. The rain drop size ranges from 0.1 to 3mm, and the median value is around 1.8mm, and they are lower than the size of natural rain drop. It is unfortunate that the detailed raindrop size distribution are unavailable. Obviously, the raindrop size cannot be simulated according to the model geometrical scale ratio. The rainfall intensity should be the most important parameter to influence the dynamic response of models. The laser displacement sensors (Types: 1215, 1282, ANR Company, Japan) are used to record the vertical (positive, upward) and torsional displacement (positive, clockwise) at the middle and end tip sections. Some measures were taken to protect the sensors against water. The influence of water drip on displacements were also checked. Some typical testing photos and the arrangement of laser sensors are shown in Figure 4.

Figure 4. Testing photos in wind tunnel

Typical vertical and torsional vibration histories

Due to the limitation of length, only some typical responses are offered in this study. For Case 1, when U=4m/s, with different rainfall intensity, the vertical and torsional displacement histories at the end tip and middle section are shown in Figure 5. It can be seen that: the vertical vibrations at the end tips are much larger than those of at the middle section; the torsional displacements at the end and middle sections are almost the same with the same phase. The symmetric torsional amplitudes exceed 2°, and the vibrations are very close to sinusoidal type, which indicate the limited cycle oscillations. In addition, the vibrations are almost independent of rainfall intensity. The aerostatic displacements for different rainfall intensity are very small.

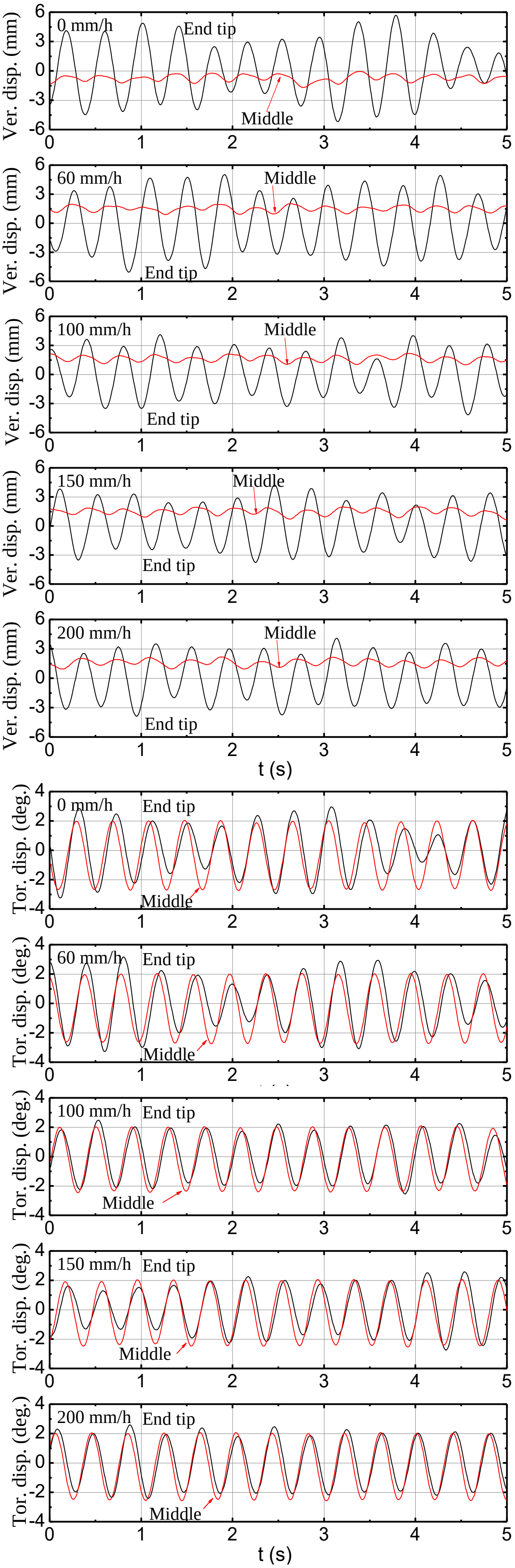
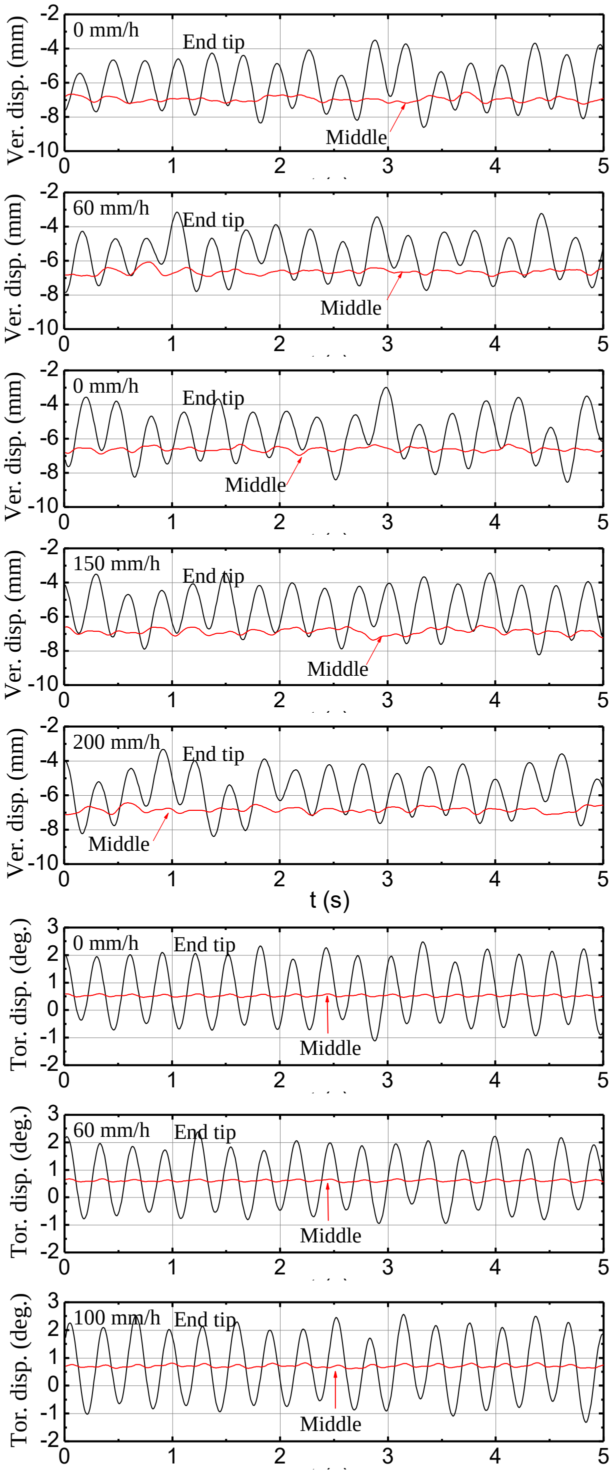


Figure 5. Vertical and torsional vibrations at the end tip and middle sections (Case 1, U=4m/s, different rainfall intensity)

For Case 5, when U=6 m/s, the displacement histories are shown in Figure 6. It can be seen that the vertical and torsional fluctuating displacements at the end tip are much higher than those at the middle section, which indicate the coupled vibration of antisymmetric vertical and torsional modes. The aerostatic vertical displacements are approximately -6 and -7mm for the end tip and middle section. The added attack angles range from 0.5° to 0.8° under different rainfall intensity. Similar to Case 1, the vibrations are almost independent of rainfall intensity.



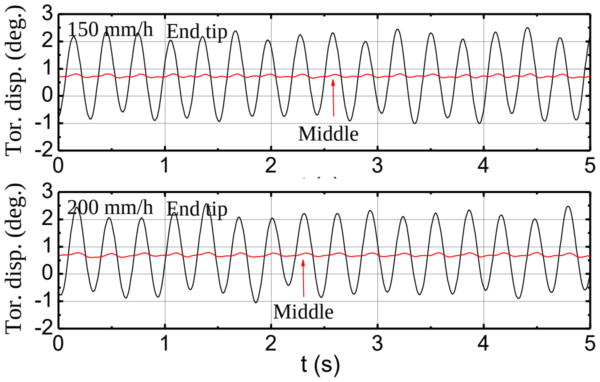


Figure 6. Vertical and torsional vibrations at the end tip and middle sections (Case 5, U=6m/s, different rainfall intensity)

Statistics of typical vertical and torsional vibrations

The averages and standard deviations of Case 4 are shown in Figure 7 and Figure 8, respectively.

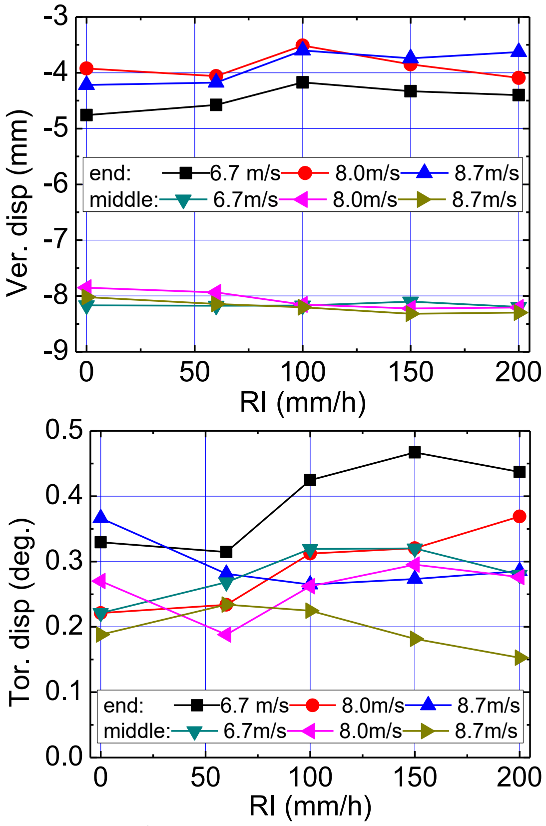
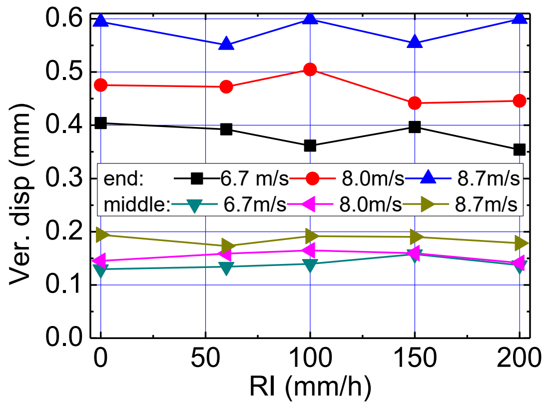


Figure 7. Average of vertical and torsional vibrations at the end tip and middle sections (Case 4)



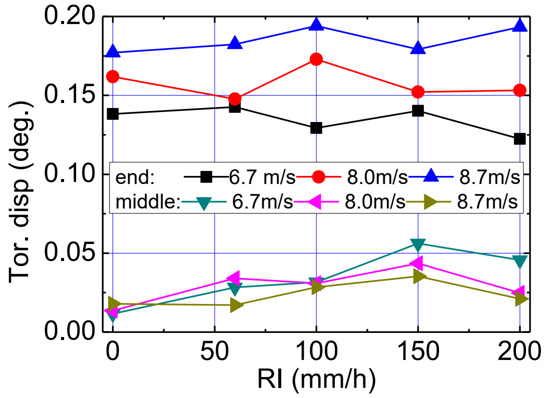


Figure 8. Standard deviation of vertical and torsional vibrations at the end tip and middle sections (Case 4)

The averages and standard deviations of Case 8 are shown in Figure 9 and Figure 10, respectively.

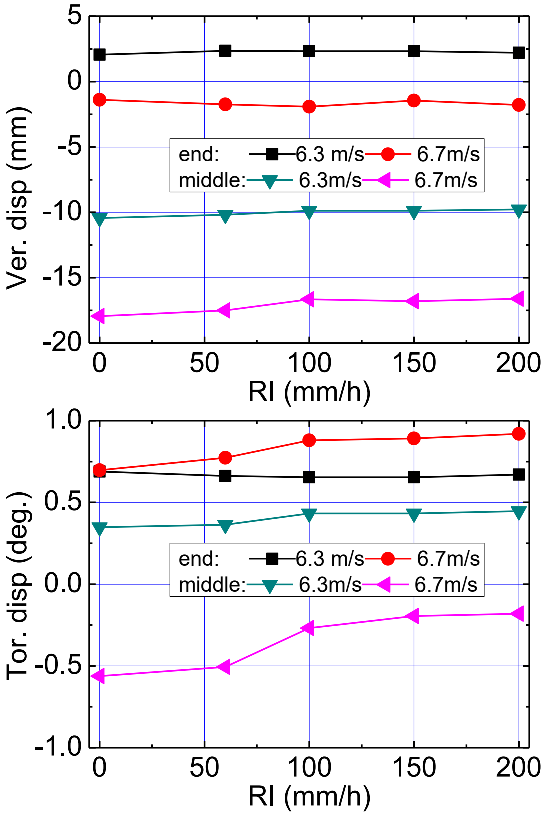
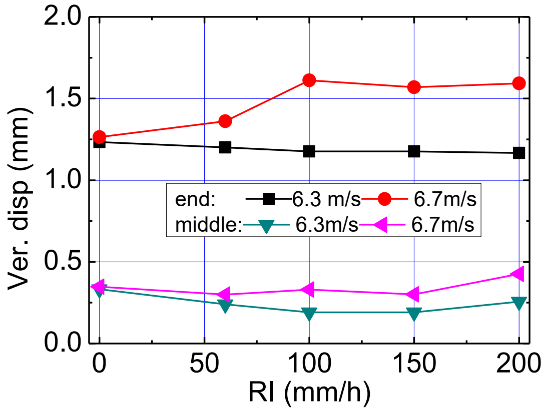


Figure 9. Average of vertical and torsional vibrations at the end tip and middle sections (Case 8)



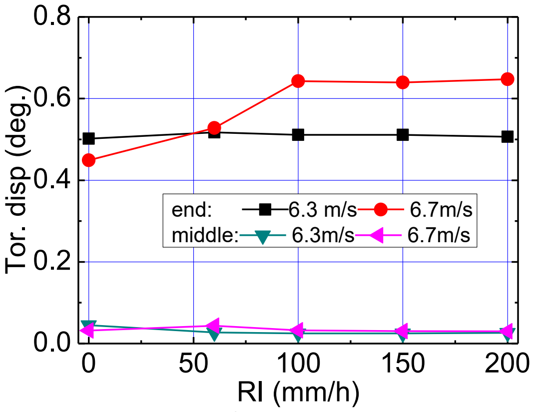


Figure 10. Standard deviation of vertical and torsional vibrations at the end tip and middle sections (Case 8)

It can be seen that the average vertical and torsional displacements at both ends and middle sections are almost independent of rainfall intensity. In other words, the rainfall has negligible influence on average responses. The vertical and torsional vibration amplitudes at both ends are much larger than those of at middle section. The influence of rainfall intensity is also insignificant for the vibration amplitude.

Conclusions

Based on the wind tunnel tests on the suspension bridge model with different conditions, some concluding remarks can be summarized as follows:

(1) For the concerned four rainfall intensities, their influences on the critical flutter wind speed are within 5%. This characteristic is applicable for all the three kinds of deck sections with different initial attack angles.

(2) The dynamic responses (standard deviations) at different rainfall levels are very close to those of without rainfall cases. The aerostatic responses are also insensitive to rainfall intensity. The influence of rainfall intensity on buffeting response are related to deck sections and initial attack angle.

(3) The rainfall increases the mass of the bridge system, and it also alters the aerodynamic configuration of the bridge. Undoubtedly, the abovementioned two effects on the scaled model are farther remarkable than on the prototype bridge. According to a large amount of wind tunnel tests on scaled model, the aerostatic difference due to the influence of various rainfall intensities are within 15%. So it can be concluded that the effect of possible rainfall on prototype bridge is almost negligible.

Acknowledgments

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References

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