Aerodynamic influence of the catwalk's sectional dimension on steepled main cables in suspension bridges

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ABSTRACT

Sectional dimension of the catwalk may have influences on galloping of the steepled main cable in suspension bridges during construction. To search for an appropriate sectional dimension of the catwalk to control the galloping of the main cable, the influences of the catwalk's width and height on two typical main cables with different cross sections of a suspension bridge during construction are studied. Two main foci have been conducted. Firstly, aerodynamic coefficients of each main cable considering the aerodynamic interference of catwalks with different widths and heights are obtained based on the wind tunnel test in which the experimental main cable models are made by rigid plastic using the 3D Printing Technology. Then Den Hartog criterion is used to analyze the transverse galloping of the main cables considering the aerodynamic interference of catwalks with different widths and heights during construction. Results show that there is no any appropriate sectional dimension of the catwalk that can be used to control the galloping of the steepled main cable for the whole construction period.

1. INTRODUCTION

Galloping control of main cables in suspension bridges during construction is one of the most important research fields about bridge aerodynamics (Li *et al*. 2015a), which is directly related to the construction safety. The catwalk, as the construction scaffold of a main cable in the suspension bridge, is very close to the main cable. Thus sectional dimension of the catwalk may have influences on galloping of the main cable during construction.

Aerodynamic interference usually occurs between adjacent structures, which may have a significant influence on the aerodynamic characteristics of the structures (Blocken and Toparlar 2015, Lou *et al*. 2015). Many experimental and numerical investigations have been conducted to study the aerodynamic interference between various kinds of structures, for instance, the suspender cables of the suspension bridge (Li *et al*. 2015b), two drafting cyclists (Blocken *et al*. 2013), iced bundled conductors (Yan *et al*. 2010), vehicles and the bridge (Li *et al*. 2014) etc. Tokoro *et al*. (2000)

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studied the wake-galloping employing based on full aeroelastic twin-cable model through a series of wind tunnel tests, founding that the leeward cable remains stable or suffers typical wake-galloping vibration at different relative positions to the windward cable. Lou *et al*. (2015) investigated aerodynamic force characteristics of the six-bundle conductors with different icing thicknesses, initial ice accretion angles and sub-conductor; results show that these parameters all have certain influence on aerodynamic coefficients of the leeward sub-conductors. Assi and Bearman (2015) indicated that the variations in plate length and plate porosity can affect the galloping response of a circular cylinder fitted with three different splitter plates. In addition, it is worth mentioning that aerodynamic coefficients are key parameters for the analysis of transverse galloping (Den Hartog 1932, Ibarra *et al*. 2014).

According to these previous studies, there may be an appropriate sectional dimension of the catwalk which has positive influence on the galloping of the main cable. Therefore, this paper focuses on the influences of the catwalk's width and height on two typical main cables with different cross sections of a suspension bridge during construction. Two main foci have been conducted. Firstly, aerodynamic coefficients of each main cable considering the aerodynamic interference of catwalks with different widths and heights are obtained based on the wind tunnel test in which the experimental main cable model is made by rigid plastic using the 3D Printing Technology. Then Den Hartog criterion is used to analyze the transverse galloping of the main cables considering the aerodynamic interference of catwalks with different widths and heights during construction.

2. WIND TUNNEL TEST

Galloping of the main cable has been observed during the construction of the Xihoumen Bridge, China. To study this damaging phenomenon, the bridge's two typical main cables with different cross sections during construction are selected and named main cables Ⅰ and Ⅱ (Fig. 1), respectively. To investigate the influence of the catwalk's sectional dimension on the damaging phenomenon, five catwalk models with different sectional dimensions are selected as the research objects in this paper. The sectional dimensions of the design and experimental catwalks are presented in Table 1. The catwalks with different sectional dimensions are named catwalks 1# to 5#.

(a)main cable Ⅰ (b)main cable Ⅱ

Fig. 1 Cross sections of the selected main cables

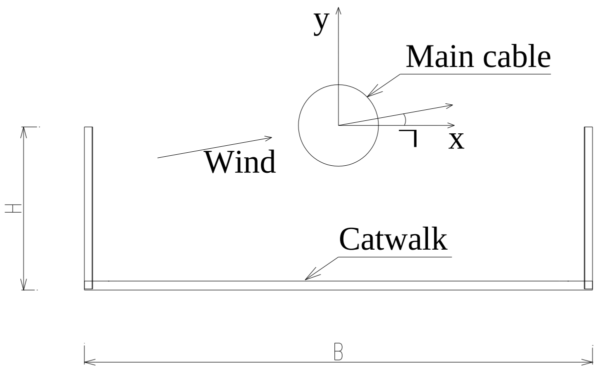


Fig. 2 The cross section of the catwalk

Table 1 Dimension parameters of the catwalks

Catwalk	Height H (m)	Width B (m)
Design	1.5	4.2
1#	1.4	4.2
2#	1.6	4.2
3#	1.5	3.6
4#	1.5	3.9
5#	1.5	4.5

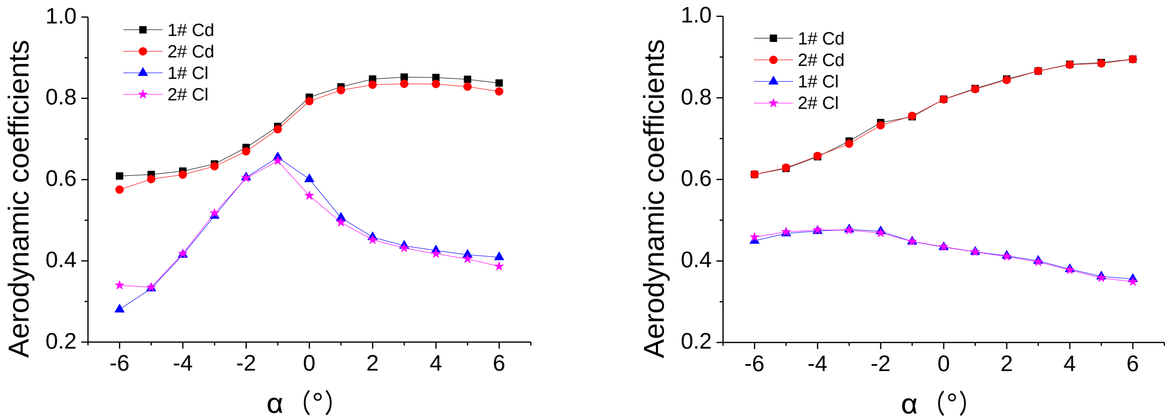
A series of wind tunnel tests were performed to obtain the aerodynamic coefficients of the main cables considering the aerodynamic influences of catwalks 1# to 5#. The tests were performed in the close-circuit boundary layer wind tunnel at Dalian University of Technology, China. The test section had a cross section of 3 m in width and 2.5 m in height. The segmental models of the main cables are made by rigid plastic using the 3D Printing Technology. The same material with the real catwalk is used in the segmental models of catwalks. Each experimental model is 1 m in length with a scale ratio of 1:4. In each test, a main cable segmental model was fixed to a high-frequency (100Hz) six-component force balance at its bottom end, and a catwalk segmental model is fixed beside the main cable model. The segmental models of the main cable and the catwalk are put in the wind tunnel according to the real case (Fig. 3). In addition, a rectangular plate hung over the main cable model. The velocity of the wind in the tests is 13.8 m/s.

Fig. 3 Experimental model in the wind tunnel

3. RESULTS ANALISIS

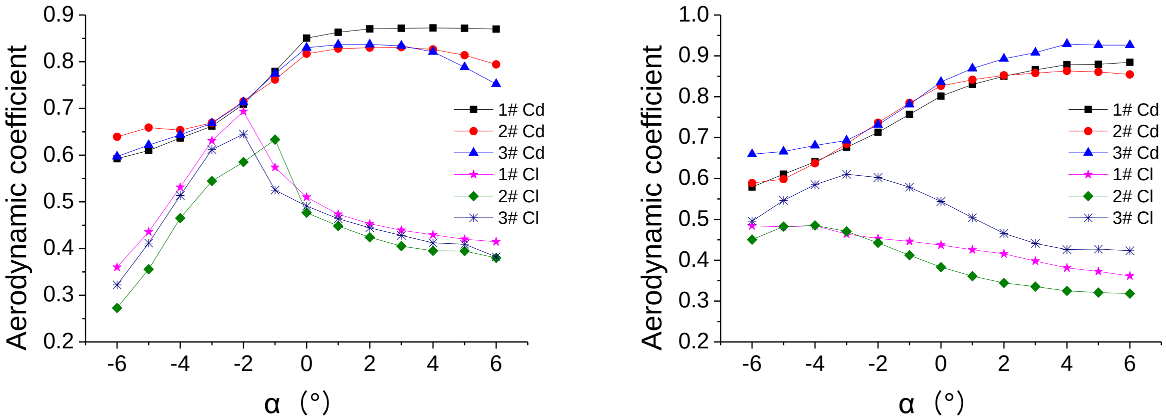
3.1 Aerodynamic coefficients of the main cables

The mean aerodynamic forces of the main cables considering the aerodynamic influences of catwalks were obtained based on the experiment, and the corresponding aerodynamic coefficients were calculated according to the definition formulas (Den Hartog 1932), as shown in Figs. 4 to 5.



(a) (b)

Fig. 4 The aerodynamic coefficients of the main cables considering the aerodynamic influence of catwalks with different heights: (a) main cable Ⅰ (b) main cable Ⅱ



(a) (b)

Fig. 5 The aerodynamic coefficients of the main cables considering the aerodynamic influence of catwalks with different widths: (a) main cable Ⅰ (b) main cable Ⅱ

3.2 Den Hartog coefficients of the main cables

To study the galloping of the main cables, Den Hartog coefficients are obtained based on the aerodynamic coefficients, as shown in Figs. 6 to 7. The Den Hartog coefficients of the two main cables almost remain unchanged with the change of the catwalk's height from 1.4 m to 1.6 m (Fig. 6), which indicates that the simple change of the catwalk's height has very little influence on the galloping of the main cable. There are negative values in Den Hartog coefficients of the two main cables, thus galloping may occur in the two periods corresponding to main cables Ⅰ and Ⅱ (Fig. 6).

There are some differences in Den Hartog coefficients of the main cable Ⅰ when the catwalk's width changes from 3.6 m to 4.5 m, but negative values of Den Hartog coefficients always exist (Fig. 6). When it comes to main cable Ⅱ, all Den Hartog coefficients obviously have negative values with the aerodynamic influences of catwalks 2# and 3#, but the values of Den Hartog coefficients with the aerodynamic influences of catwalks 1# are all or almost all positive. In other words, main cable Ⅱ almost have no possibility of the onset of galloping with the aerodynamic influences of catwalks 1#, while main cable Ⅰ have the potential to suffer galloping with the aerodynamic influences of all the three catwalks 3#~5#.

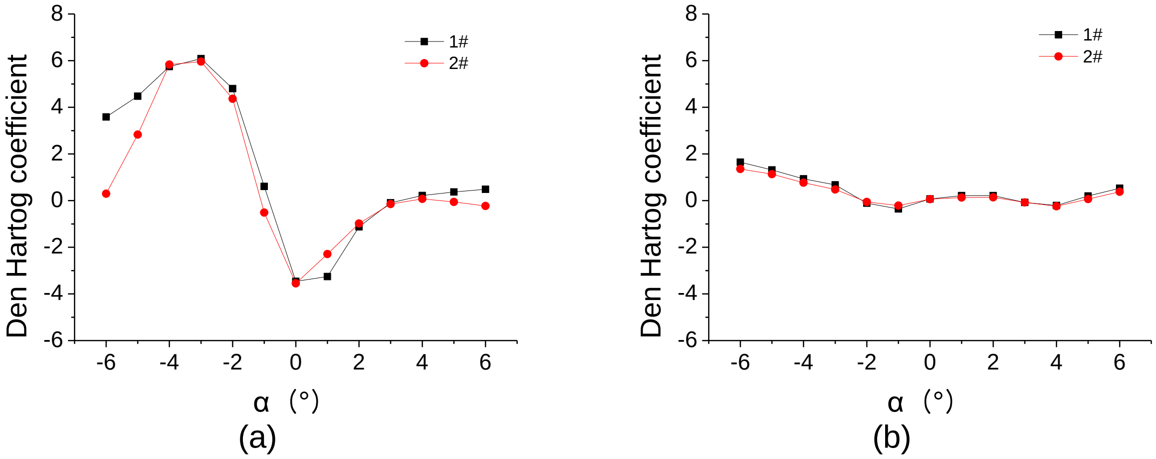


Fig. 6 Den Hartog coefficients of main cables considering the aerodynamic influence of catwalks with different heights: (a) main cable Ⅰ (b) main cable Ⅱ

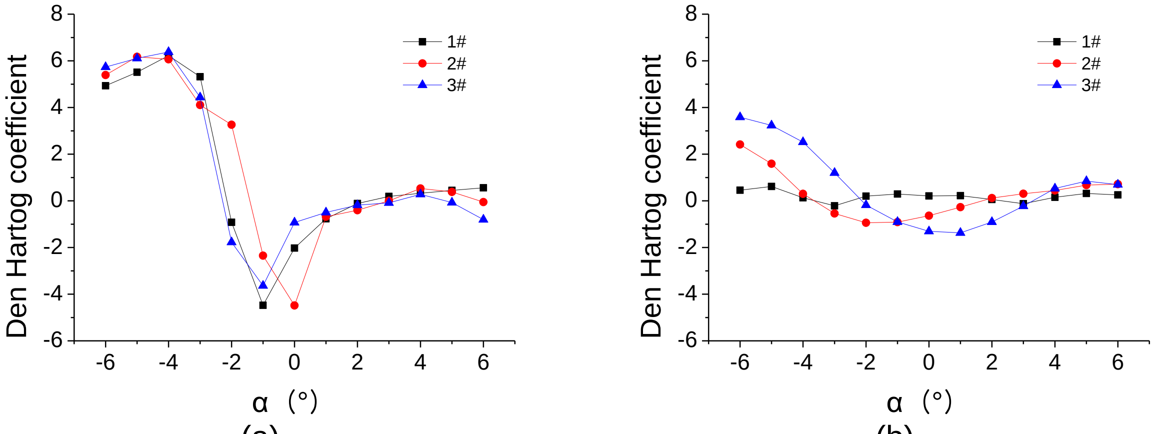


Fig. 7 Den Hartog coefficients of main cables considering the aerodynamic influence of catwalks with different widths: (a) main cable Ⅰ (b) main cable Ⅱ

4. CONCLUSIONS

To search for an appropriate sectional dimension of the catwalk to control galloping of the main cable, influences of the catwalk's width and height on two typical steepled main cables with different cross sections during construction are studied based on the Den Hartog criterion through a series of wind tunnel tests. Results indicate that the catwalk's height has very little influence on galloping of the main cable, while the catwalk's width has obvious influence on galloping of the main cable. There is no any appropriate sectional dimension of the catwalk that can be used to control the galloping of the steepled main cable in the whole construction period.

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