Aerodynamic static coefficients of two parallel cable-stayed bridges by wind tunnel test and CFD

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SUMMARY:
Wind tunnel tests are typically used to investigate the effect of wind load on the bridge deck. This process takes 6 to 8 weeks and is highly expensive. To design bridges, computational fluid dynamics (CFD) seem to be a rival to wind tunnel testing. There is currently a lack of knowledge and a need for more research on the aerodynamic static coefficients of bridges deck by computational fluid dynamics. The objective of this study is to a comparison of the aerodynamic static coefficients of the parallel cable-stayed bridges between a wind tunnel tests and a numerical simulation. The 2D steady-state RANS simulations in the CFD analysis of the parallel decks were applied. The results show that a steady simulation for parallel decks has been in good agreement with the data from wind tunnel tests but the advantage of CFD is to show the visualized flow patterns around the parallel decks.

Keywords: Aerodynamic coefficient, Computational fluid dynamic, Parallel cable-stayed bridge, Wind Tunnel Testing

1. INTRODUCTION

Due to the bridges' parallel location, they exhibit more complicated wind-induced response than a single standalone bridge. As a result, several researchers have studied the aerodynamic interferences between the two-bridge decks (Meng et al., 2011; Argentini et al., 2015). The essential parameters utilized in the estimation of the aerodynamic static instability, buffeting response, galloping stability are aerodynamic static coefficients (Attia and Ahmed, 2016). Computational fluid dynamics (CFD) technology has become widely employed as an analytical approach for wind engineering due to repeatability, less manpower demanding, and the visibility of the flow field compared with the wind tunnel test. In this research, the 2D steady-state RANS (k-ω SST) simulations in the CFD analysis were applied to determine the aerodynamic static coefficients of the two parallel cable-stayed bridges. They were also used to identify the complex flow field of the parallel decks caused by wind loading and examine whether a computer approach may decrease the number of expensive physical model testing.

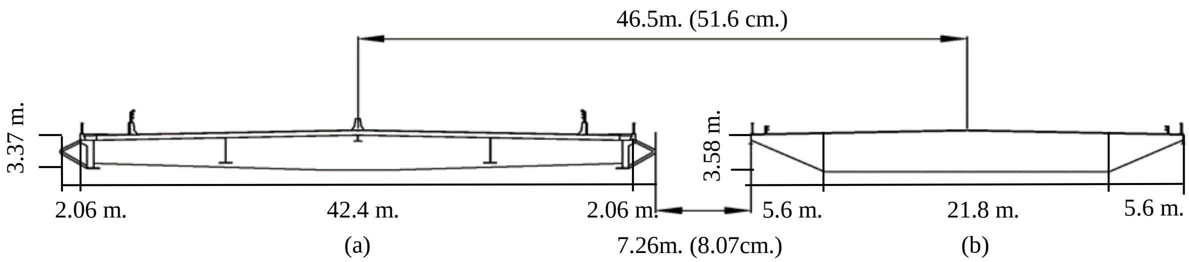
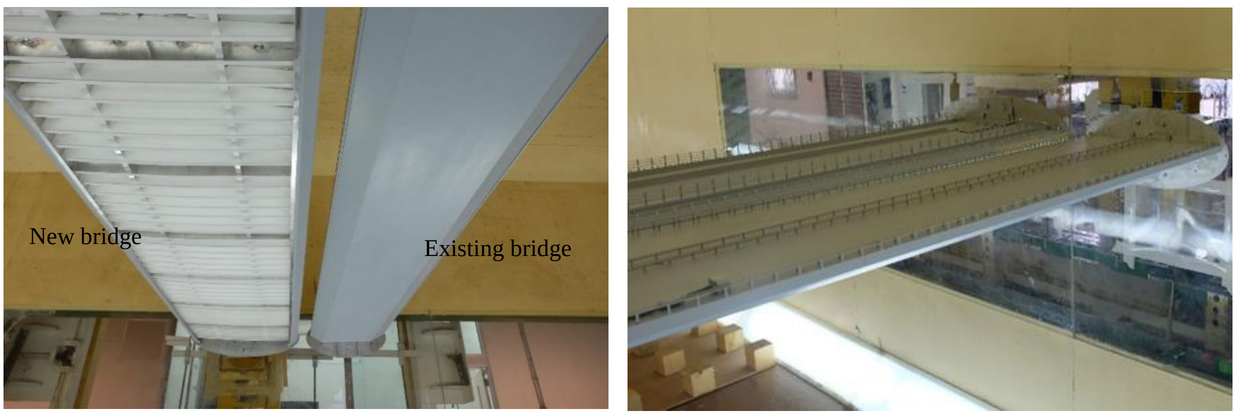


Figure 1. Cross section of prototype and position of two parallel bridge deck sections (Dimension for the scaled model are shown in parentheses) (a) new bridge and (b) Rama IX bridge.



(a) Bottom view of the two sectional models (b) Top view of the two sectional models

Figure 2. Setup of wind tunnel tests for two parallel bridges

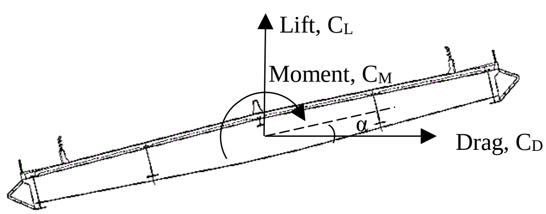
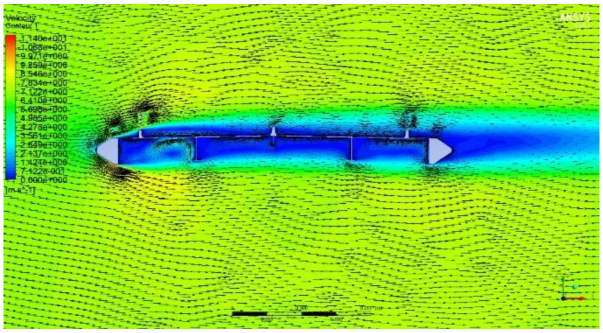


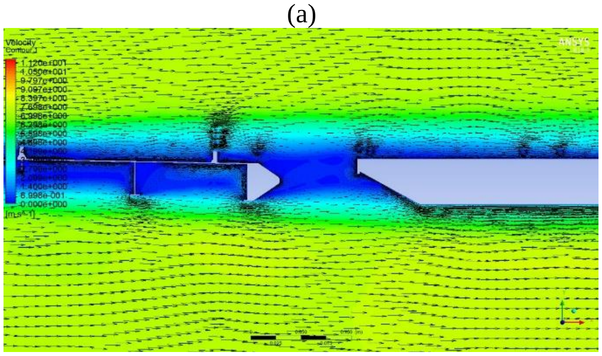
Figure 3. Sign conventions for aerodynamic coefficients

2. AERODYNAMIC STATIC COEFFICIENTS BY WIND TUNNEL TESTS

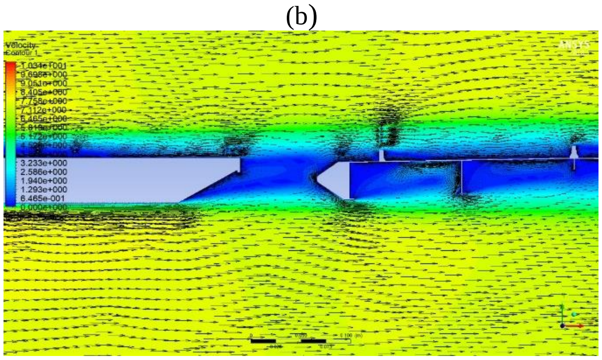
The new bridge (see Fig. 1a) runs parallel to the Rama IX cable-stayed bridge (see Fig. 1b) in Bangkok, Thailand. The 450-m. main span of the new bridge has the same length as the existing bridge, suspended from 152 cables attached to two giant H-shaped pylons. The separation between the two bridges is 7.26 meters. For more information about dynamic properties of the two parallel cable-stayed bridges have been reported by Junruang and Boonyapinyo (2020). The aerodynamic static tests of 1:90 scale models (see Fig. 2) were carried out in the TU-AIT boundary layer wind tunnel at Thammasat University in Thailand. Three configuration cases, including the Isolate new bridge (case 1), the upstream new bridge and downstream existing bridge (case 2), and the downstream new bridge and the upstream existing bridge (case 3), were investigated in this study. The section model was fixed to the force gauges sensors at both ends of section model, wind attack angles were varying in steps of 3^o from -12^o to $+12^o$. The aerodynamic coefficients were then found using Eq. 1 as:



(a)



(b)



(c)

Figure 4. Streamwise velocity component of the flow around (a) Case 1 (b) Case 2 (c) Case 3

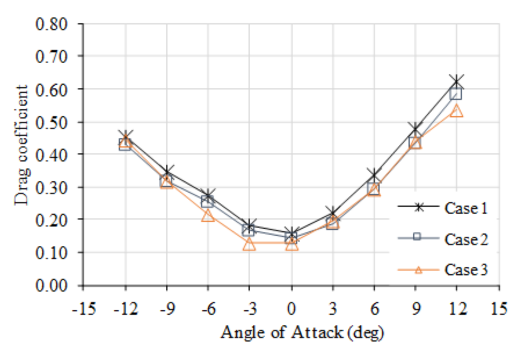


Figure 5. Experimental results of C_D of a new bridge for three configuration cases

Table 1. Comparison of aerodynamic coefficients of new bridge between experimental result and simulation Case 1 Isolate new bridge

	Wind tunnel result			Simulation		
AOA	C_D	C_L	C_M	C_D	C_L	C_M
-6^0	0.28	-0.58	-0.11	0.25	-0.41	-0.15
0^0	0.16	-0.02	-0.05	0.16	-0.02	-0.06
6^0	0.34	0.47	0.07	0.29	0.46	0.08

Table 2. Comparison of aerodynamic coefficients of new bridge between experimental result and simulation Case 2 New bridge located at up stream

	Wind tunnel result			Simulation		
AOA	C_D	C_L	C_M	C_D	C_L	C_M
-6^0	0.26	-0.50	-0.10	0.31	-0.36	-0.13
0^0	0.14	-0.10	-0.05	0.16	-0.13	-0.06
6^0	0.30	0.39	0.05	0.32	0.38	0.06

Table 3. Comparison of aerodynamic coefficients of new bridge between experimental result and simulation Case 3 New bridge located at down stream

	Wind tunnel result			Simulation		
AOA	C_D	C_L	C_M	C_D	C_L	C_M
-6^0	0.22	-0.51	-0.09	0.20	-0.37	-0.13
0^0	0.13	0.16	-0.01	0.15	0.19	-0.02
6^0	0.29	0.50	0.09	0.37	0.71	0.15

$$C_L = \frac{L}{0.5\rho U^2 Bl} \qquad C_D = \frac{D}{0.5\rho U^2 Bl} \qquad C_M = \frac{M}{0.5\rho U^2 B^2 l} \tag{1}$$

where ρ is the air density B and l are the deck width and length of the section model, respectively. L, D, M are total lift forces, drag forces and pitching moment, respectively. The sign convention used in the presentation of the test results is shown in Fig. 3.

The aerodynamic coefficients of new bridge in three configuration cases under smooth wind are shown in Fig. 5. The results showed that a drag coefficient of new bridge in parallel configuration were drop for all attack angles when compare with the isolate new bridge. Drag coefficient of new bridge in case 2 was lowest at attack angle 0^o (drop about -10%) and in case 3 was lowest at attack angle -3^o (drop about -29%). A drag coefficient of new bridge was drop significantly in case 3 due to the new bridge was sheltered by existing bridge.

3. AERODYNAMIC STATIC COEFFICIENTS BY COMPUTATIONAL FLUID DYNAMIC AND COMPARISONS

The static flow around parallel decks were performed by using 2D steady-state RANS (k-ω SST) simulations, which are considered a good compromise between the achievable quality of the results and the computational effort for the analysed problem. They have been performed to compute the mean pressure, shear stress distributions and the static forces.

The aerodynamic static coefficients C_D, C_L and C_M of the parallel decks under different wind attack angles are compared between the experimental results and CFD as shown in Table 1-3. The wind flow visualization around the parallel decks shown in Fig. 4. The numerical results show a good agreement of the C_D with the experimental results in all angle of attacks (AOA) range. C_L and C_M show a good agreement with the experimental results in all AOA range except AOA ±6°. The abrupt drop of the lift coefficient is due to the turbulence modelling in CFD, which is inadequate to reflect the flow structure in this case. As AOA increases, there are greater accelerations over the decks, which might result in simulations of the flow over the decks being overly and rapidly compared to the actual flow. Since the present study does not take into account the 3D flow impact, it can be deduced that the k-ω SST turbulence model has a limitation of estimating the parameters in high AOA where the high acceleration exists. This limitation of the k-ω SST turbulence model in high AOA is also discussed in Sánchez et al., (2015).

4. CONCLUSIONS

The study of aerodynamic interference of two parallel decks by means of wind tunnel and CFD can be summarized as follows.

- Interference effects of two bridges decks on aerodynamic static coefficients of new bridge depend on a girder shape, a gap distance between parallel deck, and an angle of wind attack. As a result, drag coefficient of the new bridge in parallel configurations was less than that in the isolate new bridge.
- The present study results show in general a good agreement between the wind tunnel experimental results and CFD in terms of C_D, C_L and C_M.
- The k-ω SST turbulence model is in general a good model for evaluating the flow around the bridge although there is a trend of over or under estimation of the coefficients at high AOA range.

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