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Experimental and numerical investigations on the aerodynamic admittance of twin-box bridge decks

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SUMMARY:
The Aerodynamic Admittance Functions, AAFs, of twin-box decks are particularly complex due to the presence of a central gap, so requiring performing dedicated studies to determine them. This study aims to systematically investigate the admittance function of twin-box decks by comparing three approaches: active wind tunnel tests, and Large Eddy Simulations, LES, using both sinusoidal gusts and continuous synthetic turbulence. In particular, wind tunnel tests equipped with an active gust generator are conducted to generate a series of single-frequency vertical sinusoidal gusts. Additionally, LES are performed aiming to provide valuable insights regarding the discrepancy between AAFs obtained in the two inflow conditions. Results obtained adopting all the aforementioned methodologies are compared, showing good agreement between the three approaches and values sometimes higher than the Sears function. It is also shown that buffeting forces are mainly produced by the upstream deck, so explaining the good agreement obtained between sinusoidal gust and continuous turbulent inflows.

Keywords: Aerodynamic admittance function, Twin-box deck, Active wind tunnel test, LES

1. INTRODUCTION

Twin-box decks with a central gap have been extensively used in the design and construction of super-long cable-supported bridges. With the increase of main-span length, the decrease in stiffness and damping makes such flexible structures prone to large-amplitude buffeting responses under strong turbulent wind fields (Barni et al., 2023). The accurate buffeting response requires to estimate the Aerodynamic Admittance Functions, AAFs, which link the incoming wind fluctuations to the corresponding exserted aerodynamic forces.

In order to evaluate the AAFs of bridge sections, two unsteady inflow conditions characterized by sinusoidal gusts and continuous turbulence can be adopted. In the first case, specially designed active wind tunnels can be used to generate sinusoidal gusts (Diana et al., 2002; Argentini et al., 2020). The second continuous turbulent inflows are usually generated by so-called passive turbulence generation techniques. However, owing to the lack of large-scale turbulence and the invalidation of the strip assumption in such passive continuous turbulence, the two aforementioned approaches often provide remarkable different results (Wang et al., 2020). For twin-box bridge sections, the aerodynamic behaviour is strongly dependent on the central gap and the adopted inflow conditions, so the AAFs require to dedicated studies using both WTT and CFD evaluations.

This study investigates the AAFs of a twin-box deck with different gap widths in gusty inflows by using active wind tunnel tests and LES simulations. Moreover, a strong wind sample measured in the Xihoumen bridge site have been generated relying on the PRFG^3 method (Patruno et al., 2018) and then applied to the LES domain to extract the AAFs of twin-box decks in continuous turbulence. On the one side, the study aims at contributing to increase our current understanding of the AAFs of twin-box decks, on the other side, the difference between AAFs obtained in the sinusoidal gusts and continuous turbulence need to be clarified.

2. ACTIVE WIND TUNNEL EXPERIMENTAL SETUP

Figure 1 (a) shows the stationary twin-box bridge section positioned in front of the active gust generator. The gust generator consists of nine synchronous NACA 0012 airfoils. Figure 1 (b) shows the rigid twin-box deck model composed of two separated boxes characterized by effective width *B*=750 mm. Four test configurations, i.e. *G/B* ratios equals to 0.1, 0.2, 0.3, and 0.4, are investigated by varying the gap between the upstream and the downstream box.

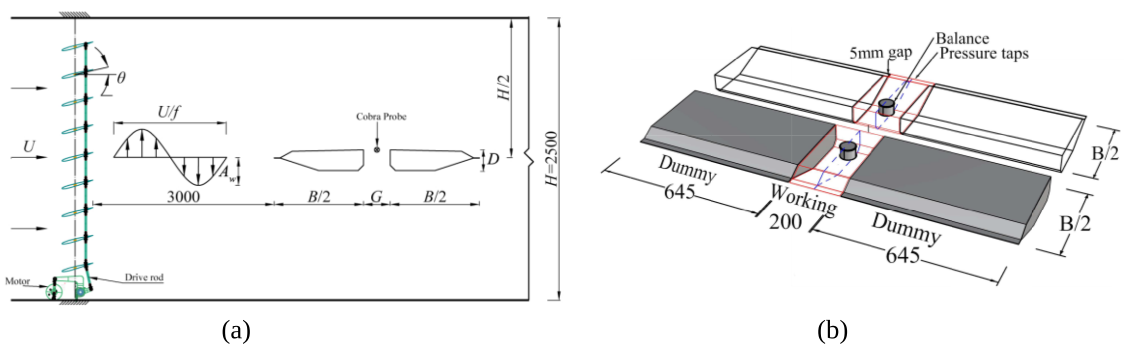


Figure 1. (a) Sketch of experimental setup of fixed twin-box girder encountering vertical sinusoidal gust (dimension in mm), (b) Rigid model used for pressure and force-balance measurements (dimensions in mm).

3. NUMERICAL SETUP

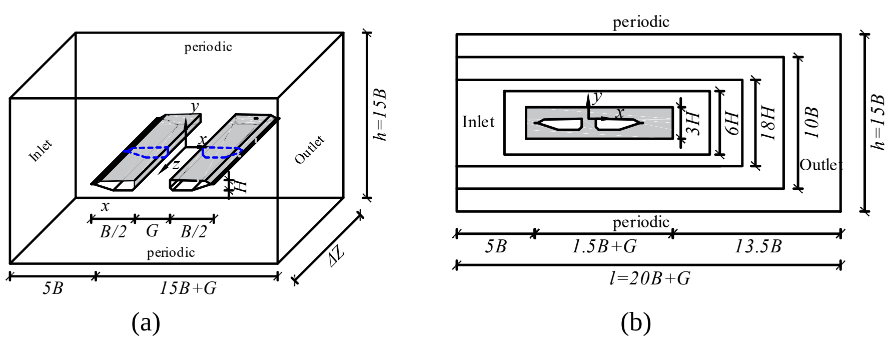
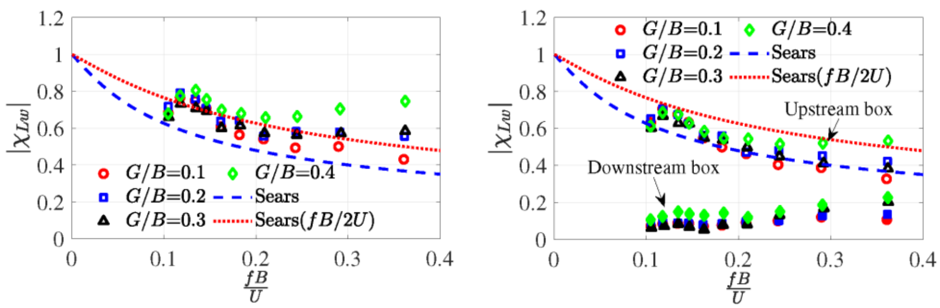


Figure 2. Numerical model: (a) computational domain, (b) mesh zones.

Figure 2 shows the computational domain adopted to extract the AAFs of twin-box decks. At the inlet boundary conditions, a time-varying Dirichlet condition is used to impose the vertical sinusoidal flow and the synthetic continuous turbulence. In particular, the generation of sinusoidal gusts has been performed following the method proposed by the authors (Li et al., 2021), while the turbulent turbulence is generated by targeting the strong wind sample measured in the mid-span of Xi-houmen bridge. The turbulence intensities, i.e. I_u, I_v, and I_w, are 13.64%, 11.12% and 5.12% respectively, and the integral length scales for u, v, and w in the along-wind directions are 192 m, 54 m, and 95 m in the real scale, respectively.

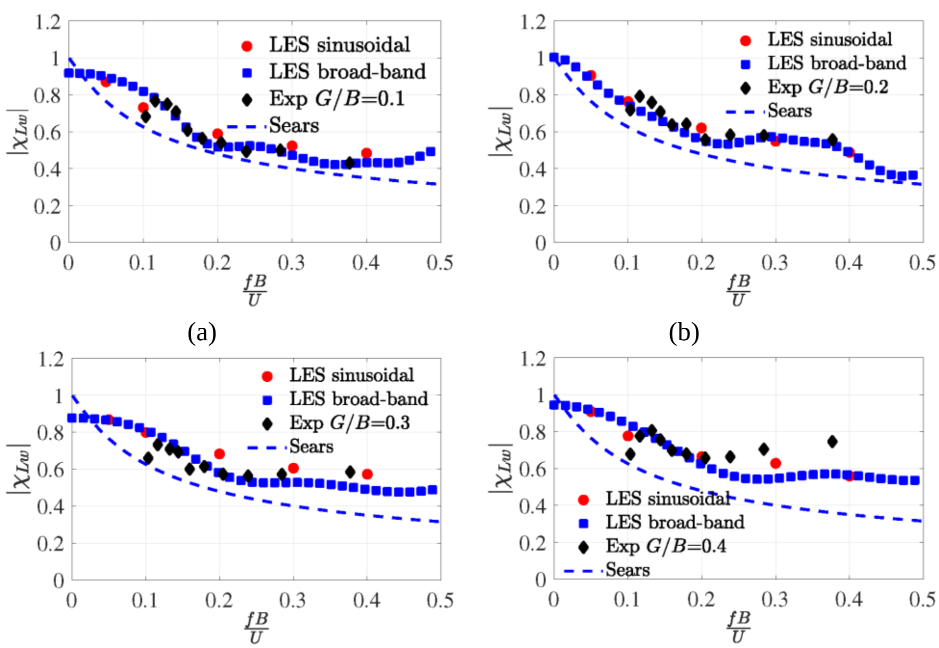
4. RESULTS

Figure 3 (a) reports the AAFs of twin-box decks at different gap-width ratios obtained from the active wind tunnel tests. It can be found that for G/B=0.1 the value of the AAFs is the smallest and it is closer to the Sears function. As G/B increases, AAFs increases and for G/B=0.4 show a non-monotonic behavior in the investigated frequency range. Moreover, Figure 3 (b) shows that the AAFs of the upstream box are much larger than those of the downstream box.



(a) (b)

Figure 3. Aerodynamic admittance functions of the twin-box deck at different gap-width ratios obtained from wind tunnel tests: (a) Entire, (b) Separate.



(a) (b)

(c) (d)

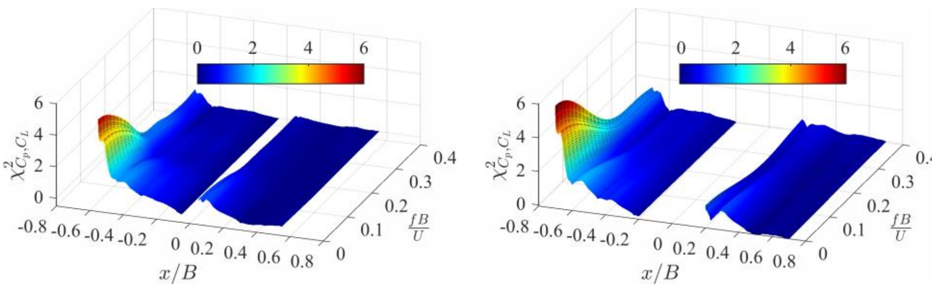
Figure 4. AAFs obtained by LES: (a) G/B = 0.1, (b) G/B =0.2, (c) G/B =0.3, (d) G/B =0.4.

Figure 4 reports the AAFs of the twin-box decks obtained in sinusoidal gusts and continuous turbulence. It can be found that the AAFs extracted from the LES show good agreement with the above experimental results. Furthermore, for all considered gap-width ratios, the AAFs obtained in continuous turbulence show also a good agreement with the ones extracted in sinusoidal gusts, indicating that the AAFs of twin-box appears insensitive on the inflow conditions.

In order to provide further details regarding the AAFs, the pressure admittance is calculated:

$$\chi^2_{C_p,C_L}\left(f_{\mathrm{red}}\right)=\frac{U^2\,\mathrm{Co}^*\left(\Delta Cp, C_L\right)}{\left[4\bar{C}_L^2 S_u+\left(\bar{C}_D+\bar{C}_{L,\alpha}\right)^2 S_w\right]} \tag{1}$$

in which Co^* is the cospectrum of ΔCp (i.e., the pressure difference between the upper and lower surfaces) and the lift coefficient. Figure 5 shows that the maximum pressure admittance occurs at the windward surface of the upstream box for the analyzed gap ratios, while the admittance of the downstream box is relatively small.



(a) (b)

Figure 5. Pressure admittance distribution in broad-banded turbulence obtained by LES: (a) *G/B* = 0.1, (b) *G/B*=0.4.

5. CONCLUSIONS

The AAFs of twin-box deck subjected to sinusoidal gusts and turbulent inflows have been evaluated in an active wind tunnel and LES simulations. A good agreement has been found between results obtained using LES in both sinusoidal gusts and continuous turbulence. Active wind tunnel results also well-comply with numerical simulations. The study confirms that LES might be a useful and viable tool for the extraction of AAFs of twin-box decks.

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