Numerical investigation of 2D aerodynamic admittances of a flat-box bridge deck using SST *k-ω* turbulence model

Yan Li [1], Lei Yan [1,2,3], Xuhui He[1,2,3]

[1] *School of Civil Engineering, Central South University, Changsha, China, 410075*
[2] *National Engineering Research Center for High-speed Railway Construction, Changsha, China, 410075*
[3] *Hunan Provincial Key Laboratory for Disaster Prevention and Mitigation of Rail Transit Engineering Structures, Changsha, China, 410075*

SUMMARY:
This study investigates the two-dimensional aerodynamic admittance functions of thin plate and flat-box bridge decks in both vertical sinusoidal gusts and random turbulent fields. The self-preservation of the turbulent flow is verified in the empty computational domain. The turbulence decays with the increase of frequency, and when the frequency is higher than 10Hz, the turbulence decays sharply. The wind pressure distributions on the model obtained by the numerical simulation are in good agreement with that obtained by the wind tunnel experiment. The deviation between the aerodynamic admittance function of the thin plate in the vertical sinusoidal gust and the Sears function is slight, and the superposition of sinusoidal speed of different frequencies does not change the results. The aerodynamic admittance with random turbulent field is ideal in low frequency band, but distorted in high-frequency range, which is closely related to the attenuation of high frequency wind speed. The turbulence intensity and turbulence integral scale of random turbulent fields have little influence on two-dimensional aerodynamic admittance functions.

Keywords: aerodynamic admittance function, computational fluid dynamics, flat-box bridge deck

1. INSTRUCTIONS

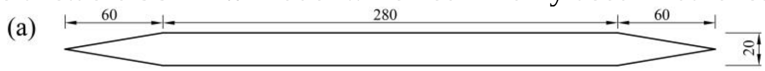
Bridge girders are located in the atmospheric boundary layer, so they are subject to buffeting force. Aerodynamic admittance function (AAF) establishes the relationship between wind speed and buffeting force, which is important in the wind resistance design of bridges. Two-dimensional AAF (2D AAF) of a thin airfoil in a sinusoidal gust has been analytically derived (Sears, 1941). However, the geometry of the real bridge sections and the turbulence characteristics in atmospheric is too complex to analytically derive their AAFs. Grids with different sizes were used in wind tunnel laboratory to generate 3D turbulence and identified 2D and 3D AAFs of girders (Ma et al., 2019; Yan et al., 2019). Given the high cost and complex procedures of wind tunnel experiments, computational fluid dynamics (CFD) is a promising method in the identification of AAF. The AAF of bridge girders can be identified in sinusoidal flow fields and by CFD synthesizing random flow with specified turbulence intensity and turbulence integral scale (Li et al., 2022; Chen & Zhu, 2020). However, in general, there are few researches on AAF by CFD, and further investigations on prediction accuracy and turbulence retention are needed.

2. NUMERICAL METHODS

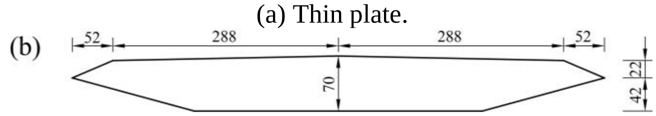
2.1. Geometric model and mesh generation

The thin plate and flat-box bridge girder sections investigated in this paper are shown in Fig. 1. The width of model, B, equal to 0.4 m and 0.68 m respectively. The length of the computational domain is 34B and the distance between the inlet boundary and the front end of models is 8B. The height of the computational domain is 16B, and the model is placed in the middle.

The computational domain is discretized by uniform square meshes. The horizontal size of the meshes around the models are set to $5\times10^{-4}B$. The first mesh height on the models is $6.6\times10^{-5}B$, and the y^+ is less than 1. The total numbers of meshes of thin plate and flat-box girder are 1.37 million and 1.61 million respectively. With the time step setting of 0.001 s, the total flow time of 30 s was calculated. Both independence of mesh size and time step have been verified. The turbulence model is unstable SST k-ω model which commonly used in other studies.



(a) Thin plate.



(b) Flat-box bridge girder.

Figure 1. Cross-sections of the computational models (units: mm).

2.2. Wind field in empty computing domain

The longitudinal wind speed (U_0) of thin plate and flat-box girder is uniform with magnitude of 8 m/s and 9.5 m/s, respectively. Sinusoidal and random turbulent field are used for vertical wind speed in this paper. The self-preservation of turbulence is tested in an empty computational domain without the model. The amplitude of sinusoidal gust (A_w) on inlet boundary is 0.23 m/s, as shown in Fig. 2(a), A_w is distorted along the computational domain. The model will be placed at the grey area in the figure with fine meshes and there is slightly increasing of gust amplitude. The turbulence intensity (I_w) of the random turbulent field shown in Fig. 2(b) is 0.9% and the turbulence integral scale (L_w^x) is 1 m. The input wind speed (solid blue line at x=-3.4 m) conforms to the von Kármán spectrum (red dashed line). But after the filtering of meshes, the power with low frequency is slightly reduced, but rapidly attenuates when frequency is higher than 11Hz.

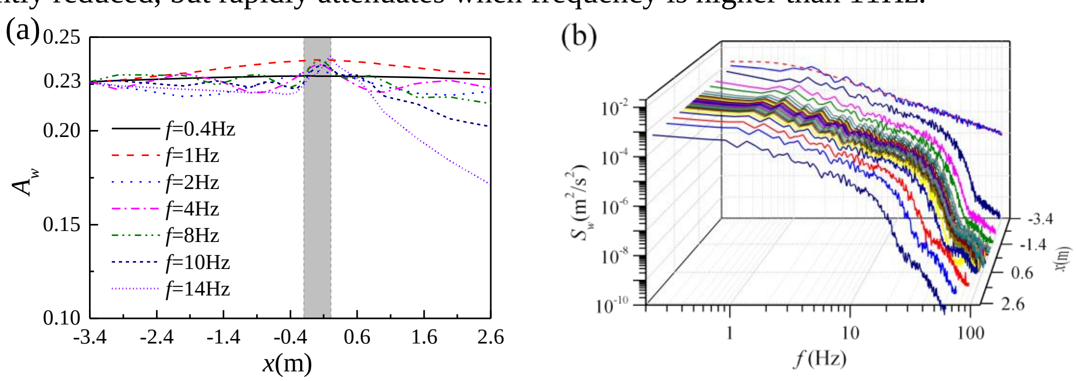


Figure 2. Longitudinal distribution of sinusoidal amplitude and power spectrum in empty computational domain.

3. AERODYNAMIC ADMITTANCE

3.1. Thin plate

The time-averaged pressure coefficients distributions at null attack angle for the thin plate obtained by CFD and wind tunnel experiment (EXP) are reported in Fig. 3. The pressure coefficient is defined as the ratio of the dynamic pressure on the model surface to $0.5\rho U_0^2$. It can be seen that the error between CFD and EXP is very small. At the narrow edge of the plate, the pressure cannot be measured by EXP, but can obtained by CFD easily. Except for the two edges of the plate, the pressure on the plate is negative. 2D AAF of thin plate identified with the sole frequency sinusoidal flow, superposition of multiple frequency sinusoidal flows and random flow are shown in Fig. 4. The identified AAF with sinusoidal flow is in good agreement with Sear function, and the superposition of multiple frequency flows has no negative effect on results. The I_w and L_w^x of the random flow is 0.9% and 1 m respectively. The identified AAF with random flow conforms to Sear function in low-frequency range, and while k is greater than 2, the AAF distorts due to the wind speed attenuate to a very small value. Therefore, the method of using CFD to identify 2D AAF in this paper is accurate in interesting frequency range.

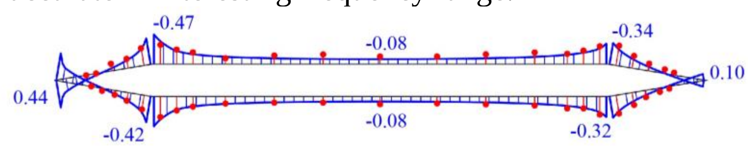


Figure 3. Comparison of pressure coefficients distributions on the thin plate obtained by CFD and EXP.

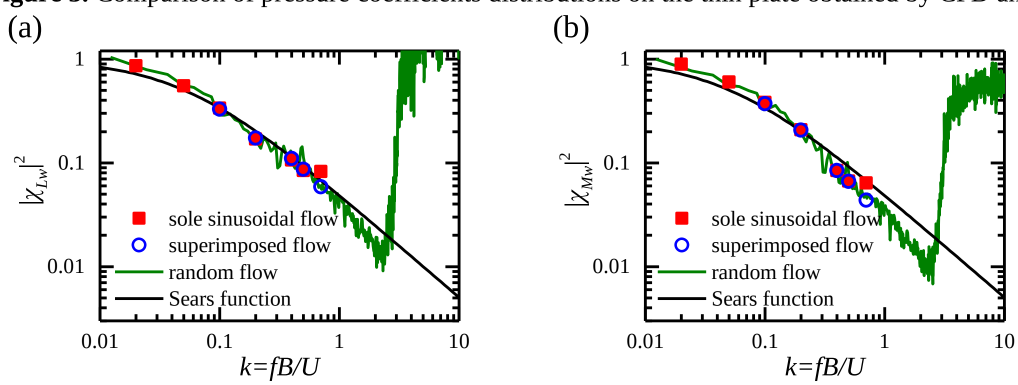


Figure 4. 2D AAF of thin plate identified from vertical sinusoidal gust and random turbulent field.

3.2. Flat-box bridge girder

As for the flat-box bridge girder, the mean pressure obtained by CFD and EXP is shown in Fig. 5. The pressure of the flat-box girder obtained by CFD is slightly lower than that obtained by the EXP. The deviation between CFD and EXP is small and the trend of pressure change along the model is consistent. At the leading edge of the bridge section, the wind pressure of the upper panel is positive, while that of the lower panel is negative. Throughout the upper side of the bridge panel, the wind pressure is close to zero at most places. The 2D AAFs of the flat-box girder identified by CFD and EXP are shown in Fig. 6(a). When the k (reduction frequency) is in the range of 0.1 to 2, the results of CFD is consistent with the EXP's. But when k is less than 0.1, the AAF identified by CFD is higher than the EXP. Fig.6(b) compares the AAFs identified with different inlet boundary. The I_w and L_w^x of the inlet flow have little influence on AAF. When the L_w^x is equal to 0.5 m, the discretization of AAF is larger than other cases.

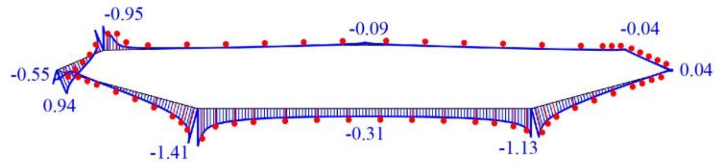


Figure 5. Comparison of pressure coefficients on flat-box girder obtained by CFD and EXP.

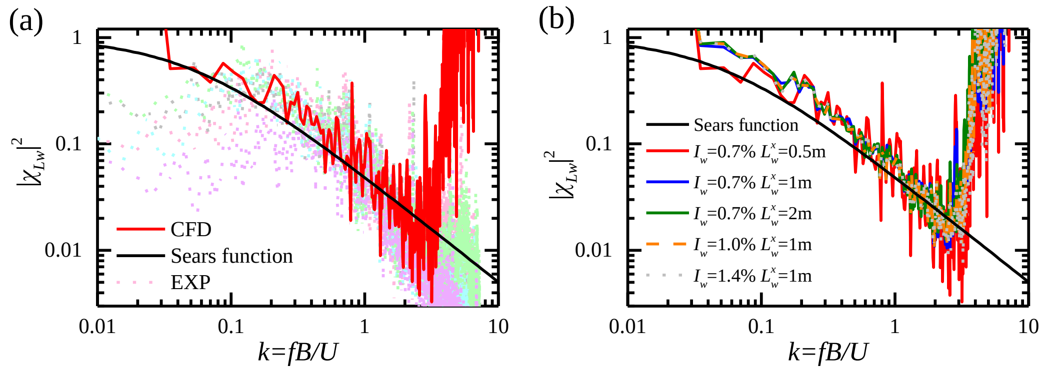


Figure 6. 2D AAF of flat-box girder identified from random gust by CFD and EXP.

4. CONCLUSIONS

The pressure distributions on the model obtained by CFD in this paper are in good agreement with that obtained by EXP, and CFD can obtain the pressure at narrow edge easily which EXP cannot measure. The 2D AAF of thin plate and flat-box identified by CFD is in good agreement with Sears function and that identified by wind tunnel experiment. The gust characteristics on inlet boundary have little influence on AAF.

ACKNOWLEDGEMENTS

The work described in this paper was supported by the National Natural Science Foundation of China (Grant 52178516, 51925808). Any opinions and concluding remarks presented in this paper are entirely those of the authors.

REFERENCES

Chen, W. and Zhu, Z., 2020. Numerical simulation of wind turbulence by DSRFG and identification of the aerodynamic admittance of bridge decks. Engineering Applications of Computational Fluid Mechanics 14(1), 1515–1535.

Li, H., Zhang, L., Wu, B., Yang, Y., and Xiao, Z., 2022. Investigation of the 2D aerodynamic admittances of a closed-box girder in sinusoidal flow field. KSCE Journal of Civil Engineering 26(3), 1267–1281.

Ma, C. M., Wang, J. X., Li, Q. S., and Liao, H. L., 2019. 3D aerodynamic admittances of streamlined box bridge decks. Engineering Structures 179, 321–331.

Sears, W. R., 1941. Some aspects of non-stationary airfoil theory and its practical application. Journal of the Aeronautical Sciences 8, 104–108.

Yan, L., Xu, L. D., He, X. H., and Flay, R. G. J., 2019. Experimental determination of aerodynamic admittance functions of a bridge deck considering oscillation effect. Journal of Wind Engineering and Industrial Aerodynamics 190, 83–97.