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Experimental identification of two-dimensional aerodynamic admittance functions of different bridge decks and its application

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SUMMARY:
Wind tunnel tests were carried out on sectional models of airfoil, streamlined box girder, rectangle and truss girder in five passive grid-generated turbulent flow fields. New strategies are proposed to identify the two-dimensional aerodynamic admittance functions (2D AAFs) using the two-wavenumber approach. The 2D AAFs of airfoil do not change with the turbulence characteristics and fit well with Sears function. The cable-stayed bridge of service state and longest-double-cantilever state are modelled. The AAFs are considered through the equivalent wind spectrum. Buffeting responses are calculated by the identified 2D AAFs of different bridge decks, the Sears function and taking 1.0 for AAFs. A more dangerous result may be obtained by taking Sears function for AAF. It is significant to accurately identify the 2D AAF of different bridge decks for the calculation of buffeting response.

Keywords: aerodynamic admittance function, two-wavenumber method, buffeting response

1. INTRODUCTION

The aerodynamic admittance function (AAF) is a transfer function from the fluctuating wind to the buffeting force and reflects the unsteady characteristics of the aerodynamic force. The AAF of a bridge deck is obviously different from the Sears function and should be identified through the experiment. However, when the characteristic size of a bridge deck approaches the turbulence integral scale, the well-known strip assumption fails due to the three-dimensional effects of turbulence and the AAF is significantly affected by the turbulence characteristic of the oncoming fluctuating wind, which is defined as the 3D one-wavenumber AAF. It is necessary to identify the 2D AAF of the bridge deck for facilitating the engineering application. This paper identifies the 2D AAFs of airfoil, streamlined box girder, 5:1 rectangle and truss girder in the turbulent flow field. Finite element models have been built to analyze the influence of different AAFs on buffeting responses.

2. EXPERIMENT OVERVIEW

The test was carried out in the Wind Tunnel Laboratory of Central South University. Five turbulent flow fields are generated by girds. Two Cobra Probes are used to measure the time history of wind speed. The turbulence integral scales (L_u^x and L_w^x) can be obtained by fitting the von Kármán spectrum. The turbulence integral scales and turbulence intensities ($I_u = \sigma_u / U$ and I_w

= σ_w / U, σ_u and σ_w are the root-mean-square of longitudinal and vertical component of turbulence fluctuating wind, U is the mean wind velocity) of five turbulent flow fields are shown in Table 1. The uniformity of turbulence characteristics is good. The airfoil, streamlined box girder, 5:1 rectangle and truss girder sectional models are measured in the five turbulent flow fields. Fig. 1 shows the four model cross-sections.

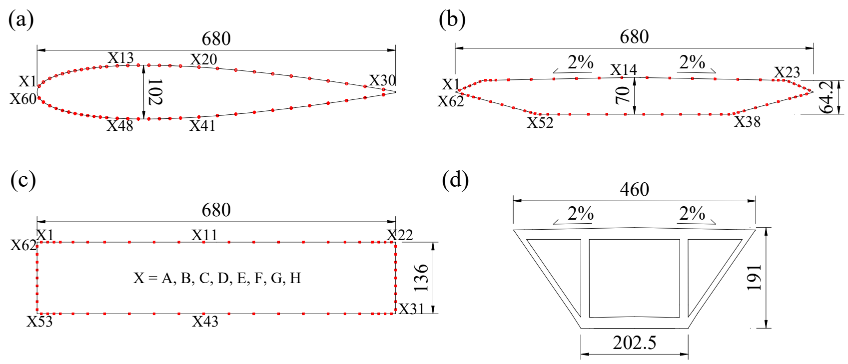

Figure 1. Diagram of model cross-sections (unit: mm). (a) Airfoil. (b) Box girder. (c) Rectangle. (d) Truss girder.

Table 1. Turbulence characteristics of different turbulent flow fields.

Turbulent flow field	U / m·s^{-1}	L_u^x / m	L_w^x / m	I_u / %	I_w / %
Grid B1	9.568	0.242	0.088	**3.67**	**3.09**
Grid B2	9.776	**0.265**	**0.100**	**8.85**	**7.37**
Grid B3	9.736	0.244	0.102	**11.67**	**10.22**
Grid A2	9.350	**0.156**	**0.054**	9.26	7.32
Grid C2	9.615	**0.380**	**0.159**	9.43	8.15

3. AAF OF DIFFERENT BRIDGE DECK

Eq. (1) shows the 3D one-wavenumber AAF based on the equivalent aerodynamic admittance method (Larose and Mann, 1998). The 2D AAF is identified based on the two-wavenumber approach to consider the three-dimensional effects of turbulence. The 2D AAF can be expressed as Eq. (2) (Yan et al., 2023).

$$\left|\chi_L(k_1)\right|^2 = \frac{S_L(k_1)}{(0.5\rho UB)^2\left[4C_L^2 S_u(k_1) + \left(C_L' + C_D\right)^2 S_w(k_1)\right]}, \tag{1}$$

$$\left|\chi_L(k_1,0)\right|^2 = \frac{S_L(k_1)\Phi_L(k_1,0)}{(0.5\rho UB)^2\left[4C_L^2 S_u(k_1)\Phi_u(k_1,0) + \left(C_L' + C_D\right)^2 S_w(k_1)\Phi_w(k_1,0)\right]}, \tag{2}$$

where ρ is the air density and ρ = 1.225 kg/m^3. B is the width of the bridge deck in m. f is the natural frequency in Hz. k_1 is the chordwise wavenumber and $k_1 = f / U$. L is the buffeting lift on the bridge deck per unit span length. u and w are the longitudinal and vertical components of turbulence, respectively. $\left|\chi_L(k_1)\right|^2$ is defined as the 3D one-wavenumber AAF of L. S_i (k_1) is the one-wavenumber spectrum of i (i = L, u, w). C_L and C_D are the mean lift and drag coefficients. C_L $'$ is the first derivative of mean lift coefficient corresponding to the wind angle of attack. Φ_i (k_1, 0) are the two-wavenumber coherence function of i when the spanwise wavenumber is zero and can be expressed as:

$$\Phi_i\left(k_1,0\right)=2\int_0^{\infty}\mathrm{Coh}_i^{1/2}\left(k_1,\Delta y\right)d\Delta y\ (i=L,u,w)\,, \tag{3}$$

A lot of scholars proposed special empirical models to fit the spanwise root-coherence function $\mathrm{Coh}_i^{1/2}\left(k_1,\Delta y\right)$ and obtained the display expression of two-wavenumber coherence function. However, different empirical models of spanwise root-coherence function lead to different two-wavenumber coherence function, which leads to uncertainty in the identification of AAF. Yan et al. (2023) proposed a new strategy to identify the 2D AAF. The spanwise root-coherence function is obtained through the normalized co-spectrum, which is defined as follows:

$$\mathrm{Coh}_i^{1/2}\left(k_1,\Delta y\right)=C_i\left(k_1,\Delta y\right)/S_i\left(k_1\right)\ \ (i=L,u,\ w)\,, \tag{4}$$

where C_i (k_1, Δy) is the normalized co-spectrum, which is the real part of cross-spectrum. All the values of the spanwise root-coherence function at spanwise spacings greater than the spanwise spacing $\Delta y_{\max}$ at which the root-coherence function appears a negative number are regarded as zero for a certain value of k_1. The integral from zero to infinity in Eq. (3) can be replaced by zero to $\Delta y_{\max}$. Therefore, the two-wavenumber coherence function can be obtained through the numerical integration directly without using the empirical models of spanwise root coherence.

Fig. 2 shows the AAFs of the airfoil in different turbulent flow fields. The 2D AAFs do not change with the turbulent flow fields and are close to the Sears function when the normalized frequency $\tilde{k}_1=\pi fB/U$ is larger than 0.3. Therefore, it can be concluded that the strategy can identified the 2D AAF accurately.

Fig. 3 shows the 2D AAF of streamlined box girder, 5:1 rectangle and truss girder in Grid B2. The 2D AAFs of streamlined box girder and truss girder are larger than the Sears function when $\tilde{k}_1\geq 0.3$. The 2D AAF of rectangle is smaller than the Sears function.

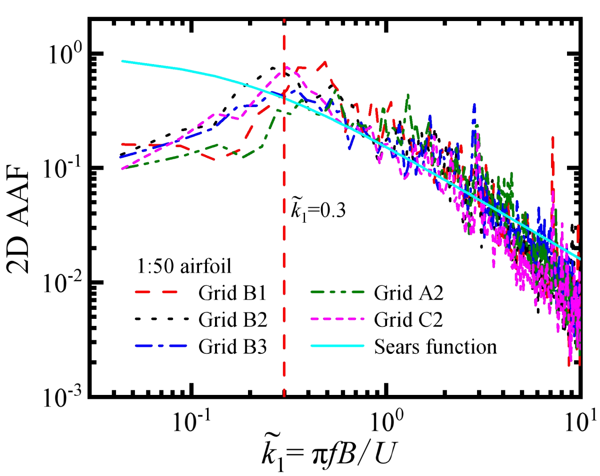

Figure 2. 2D AAFs of airfoil in different turbulent flow fields.

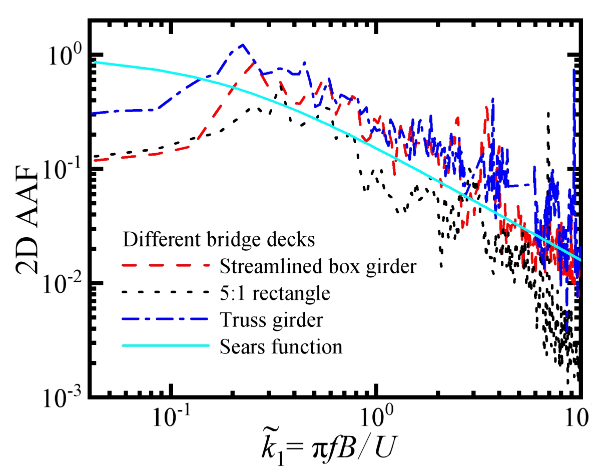

Figure 3. 2D AAFs of different bridge decks.

4. CALCULATED BUFFETING RESPONSE

The longest-double-cantilever state is the most vulnerable state during the construction state. The finite element models of the longest-double-cantilever state and service state are modelled using the finite element program ANSYS. The length of the longest-double-cantilever is 524 m and 35 nodes distribute along the longest-double-cantilever. The length of the main girder in the service state is 1376 m and 93 nodes distribute along the main girder. It is necessary to take the same random phase angle to simulate the fluctuating wind speed for analyzing the difference of AAFs. Three sets of random phase angles are generated considering the randomness of buffeting. Three sets of the time history of u component and w component fluctuating wind speed are generated for each AAF. The simulated fluctuating wind speeds of the first 3584 s are taken for buffeting force calculation. Fig. 4 shows the mean value of three sets of root-mean-square (RMS) of vertical displacement calculated by different 2D AAFs. The maximum RMS of vertical displacement of the longest-double-cantilever state appears at the end of the cantilever. The maximum RMS of vertical displacement of the service state appears near 97 m from the midspan. A more conservative result is obtained by taking 1.0 for AAF and a more dangerous result may be obtained by taking Sears function for AAF. It is necessary to identify the AAF accurately when calculating the buffeting response.

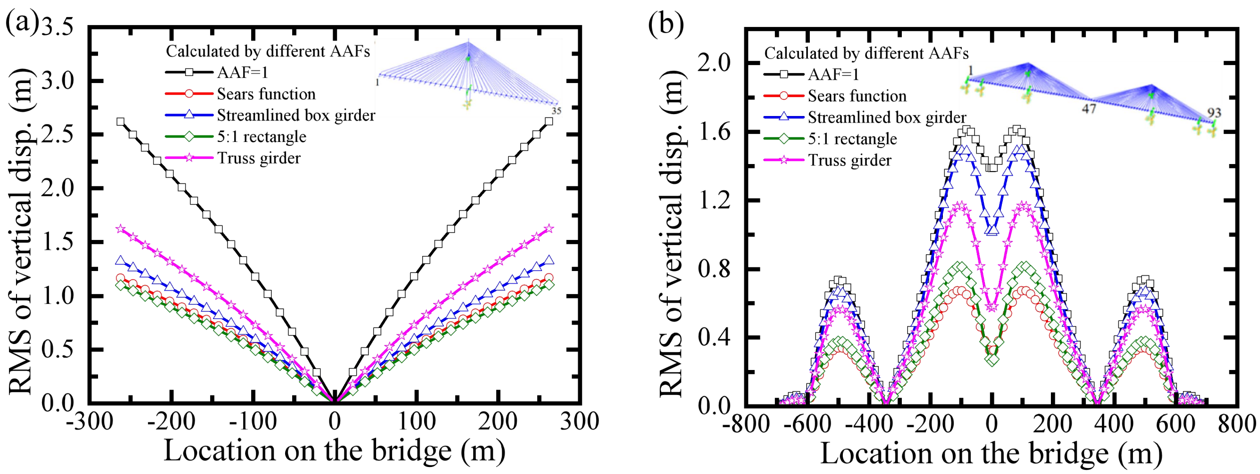

Figure 4. RMS of buffeting response. (a) Longest-double-cantilever state. (b) Service state.

5. CONCLUSIONS

A new strategy based on two-wavenumber method is presented to identify 2D AAFs of different bridge decks in five turbulent flow fields. The 2D AAFs of airfoil do not change with the turbulence characteristics and fit well with the Sears function. The buffeting responses are calculated by different 2D AAFs. The 2D AAFs have a significant influence on the buffeting responses. It is necessary to accurately identify the 2D AAF of different bridge decks.

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REFERENCES

Larose, G. L., and Mann, J., 1998. Gust loading on streamlined bridge decks. Journal of Fluids and Structures 12(5), 511-536.

Yan, L., Lin, Z., He, X. H., Jing, H. Q., and Shi, M. J., 2023. Strategies for identifying the two-dimensional aerodynamic admittance functions of a bridge deck. Journal of Wind Engineering and Industrial Aerodynamics 233, 105309.