Journal of Fluids and Structures 83 (2018) 372–385

Contents lists available at ScienceDirect

Journal of Fluids and Structures

journal homepage: www.elsevier.com/locate/jfs

A statistical approach to the identification of the two-dimensional aerodynamic admittance of streamlined bridge decks

Ming Li [a,b], Mingshui Li [b,*], Yang Yang [b]

[a] Department of Bridge Engineering, Southwest Jiaotong University, Chengdu 610031, China
[b] Wind Engineering Key Laboratory of Sichuan Province, Southwest Jiaotong University, Chengdu 610031, China

ARTICLE INFO

Article history:
Received 29 November 2017
Received in revised form 10 July 2018
Accepted 25 September 2018
Available online xxxx

Keywords:
Two-dimensional aerodynamic admittance
Identification approach
Streamlined bridge decks
The strip assumption
Buffeting
Long-span bridges

ABSTRACT

The two-dimensional aerodynamic admittance function (2D AAF) is of great importance in the buffeting evaluation of slender, line-like structures. This paper aims to propose a simple and practical approach to identifying the 2D AAF of streamlined bridge decks. The effects of the aspect ratio (the ratio of span to width) and turbulence characteristics on the accuracy of buffeting loads calculated from the strip assumption were investigated. It was shown that both the aspect ratio and the integral length scale of turbulence play important roles in controlling the accuracy of the strip assumption. By increasing these two parameters, the 2D AAF of a streamlined bridge deck can be obtained within an acceptable error margin. Thus, for a section model with a large enough aspect ratio in an appropriate turbulent field, the 2D AAF of a streamlined bridge deck can be easily identified by the direct measurement of the velocity fluctuations and unsteady aerodynamic forces. The identification approach was validated through wind tunnel tests of streamlined bridge decks with three different aspect ratios in grid-generated turbulent flow. The proposed statistical approach can also be used for the identification of the 2D AAF of other slender, line-like structures.

1. Introduction

The aerodynamic admittance function (AAF) is a transfer function that links wind turbulence with generated fluctuating aerodynamic forces and can take into account the unsteadiness of gust loading in a linear time-invariant system. The AAF is one of the most important factors in the evaluation of the buffeting responses of slender, line-like structures such as airfoils, wind-turbine blades and long-span bridge decks in natural wind.

Based on the unsteady thin airfoil and linear potential flow theories, Sears (1941) calculated the lift acting on an infinite two-dimensional (2D) wing in a transversely fully coherent sinusoidal vertical gust. The corresponding transfer function, namely the Sears function, was presented in his analysis as a 2D AAF with a single streamwise wavenumber. Following Sears' study, Liepmann (1952) introduced statistical concepts to develop a buffeting analysis method for airfoils in the frequency domain and proposed an approximate expression of the Sears function. In fact, the AAF is associated with both streamwise and spanwise wavenumbers. Liepmann (1955) extended his research to include the 3D buffeting analysis of wings with finite spans. The spanwise variations in velocity were taken into account by the introduction of the two-wavenumber aerodynamic admittance. With consideration to the 3D characteristics of turbulence, Ribner (1956) proposed a 3D spectral tensor method

---

[*] Corresponding author.
E-mail address: lms_rcwe@126.com (M. Li).

https://doi.org/10.1016/j.jfluidstructs.2018.09.008
0889-9746/© 2018 Elsevier Ltd. All rights reserved.

Nomenclature

b, B	Semi-width and full-width of bridge deck
C_D, C_L, C'_L	Static drag and lift coefficients, static lift coefficient slope
$F_L^{3D}(k_1, k_2)$	Correction factor for 3D two-wavenumber AAF
g	Span-correction factor of turbulence
k_1, k_2	Non-dimensional streamwise and spanwise wavenumbers
$\widetilde{k}_1, \widetilde{k}_2$	Streamwise and spanwise wavenumbers
L	Lift buffeting force per unit length
L_u^x, L_w^x	Integral length scales of longitudinal and vertical turbulence
s, S	Semi-span and full-span length of bridge deck
$S_L^{2D}(k_1)$	Non-dimensional 2D one-wavenumber spectrum of lift force
$S_L^{3D}(k_1)$	Non-dimensional 3D one-wavenumber spectrum of lift force
$S_L^{3D}(k_1, k_2)$	Non-dimensional 3D two-wavenumber spectrum of lift force
$S_u(k_1)$	Non-dimensional one-wavenumber spectrum of longitudinal turbulence
$S_u(k_1, k_2)$	Non-dimensional two-wavenumber spectrum of longitudinal turbulence
$S_w(k_1)$	Non-dimensional one-wavenumber spectrum of vertical turbulence
$S_w(k_1, k_2)$	Non-dimensional two-wavenumber spectrum of vertical turbulence
u	Streamwise fluctuating velocity component
U	Mean wind velocity
w	Vertical fluctuating velocity component
x, y, z	Chordwise, spanwise and vertical coordinates
Γ	Gamma function
δ	Aspect ratio (the ratio of span to width)
ϑ_u, ϑ_w	Influence functions by a unit downwash impulse of longitudinal and vertical turbulence
ρ	Air density
σ_u^2, σ_w^2	Mean square of longitudinal and vertical turbulence
$\left\lvert\chi_L^{2D}(k_1)\right\rvert^2$	2D AAF
$\left\lvert\chi_L^{2D}(k_1)\right\rvert^2_{\text{strip}}$	2D AAF obtained from the strip assumption
$\left\lvert\chi_L^{3D}(k_1)\right\rvert^2$	3D one-wavenumber AAF
$\left\lvert\chi_L^{3D}(k_1)\right\rvert^2_{\text{strip}}$	3D one-wavenumber AAF obtained from the strip assumption
$\left\lvert\chi_L^{3D}(k_1)\right\rvert^2_{\text{two-wavenumber}}$	3D one-wavenumber AAF obtained from the two-wavenumber analysis
$\left\lvert\chi_L^{3D}(k_1, k_2)\right\rvert^2$	Equivalent 3D two-wavenumber AAF
ψ	Ratio of 3D and 2D one-wavenumber lift spectrum
Λ	Non-dimensional integral length scale of vertical turbulence

for aerodynamic forces in which the 3D turbulent gust field was regarded as the superposition of harmonic 2D wavenumber components of arbitrary wavelengths and orientations. Based on the lift-surface theory, Graham (1970, 1971) numerically computed the exact value of the two-wavenumber aerodynamic transfer function for the lift on a thin airfoil with infinite span length. The gust was assumed to have arbitrary horizontal wavevectors. In addition, other researchers (Filotas, 1969a,b; Mugridge, 1970, 1971; Blake, 1986) theoretically derived approximate closed-form expressions of Graham's exact solution. Graham's theoretical results for the two-wavenumber transfer function were indirectly verified by Jackson et al. (1973) via wind tunnel tests. A general approach to identifying the two-wavenumber transfer function of the buffeting forces on line-like structures was proposed by Li et al. (2015). The accuracy of the theoretical 3D two-wavenumber AAF was directly validated by wind tunnel tests. More recently, Li et al. (2018) investigated the applicability of the strip assumption to the estimation of the unsteady lift response of a two-dimensional wing in turbulent flow and measured the Sears function directly.

For bluff bodies, such as rectangular cylinders, the spatial characteristics of aerodynamic forces are far more complex due to the separation and reattachment of flow. Shirato and Matsumoto (1997) studied the unsteady pressure on an oscillating rectangular cylinder using the vortex method and concluded that the shedding vortex movement plays the most important role in giving reliable pressure convection. Matsumoto et al. (2003) evaluated the spanwise coherence of surface pressure on 2D rectangular and hexagonal cross sections in three different flow conditions. The results showed that the pressure fluctuations slightly upstream from the reattachment point played the most significant role in the evaluation of the buffeting force. Le et al. (2009) studied the spatial distribution of turbulence-induced forces on a rectangular cylinder in both the