Effects of Gap-width on a Twin-deck Bridge:
Part 2 – Aerodynamic Admittance Functions

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Abstract. Pressure measurements were carried out on a rigid sectional model of a twin-deck bridge for five configurations with different gap-widths. Details of the experimental techniques have been presented in Part 1. The aim of this paper is to investigate the effects of gap-width on the aerodynamic admittance functions of a twin-deck bridge in a turbulent flow. The accuracy of the measured aerodynamic admittance function has been verified with that in the literature. It was found that the lift admittance function of the twin-deck bridge is insensitive to the variation of gap-width at low reduced frequencies. The increase in gap-width of the twin-deck bridge does not change the effectiveness of larger gusts to transfer energy into the structure.

Keywords: aerodynamic admittance function; buffeting force; gap-width; twin-deck bridge.

1. Introduction

One of the essential elements in buffeting analyses of long-span bridges is the identification of the aerodynamic admittance functions, which are dimensionless frequency response functions dependent on the aerodynamic geometry of a bluff body and the turbulence characteristics of the approach flow. In this research, a twin-deck bridge with various gap-widths was tested in a turbulent flow to investigate the effects of gap-width on the aerodynamic admittance functions. The value of the functions at any particular frequency represents the effectiveness of the fluctuating approach wind velocity to generate buffeting forces on a bridge deck or other bluff body. This effectiveness is expressed relative to the buffeting forces that could be produced by velocity fluctuations of the same size (frequency) in a quasi-steady situation (i.e. the amplitude of the transfer function equals unity at all frequencies). In other words, the aerodynamic admittance functions are transfer functions which relate the velocity fluctuations in the approaching turbulent wind flow to the buffeting forces experienced by a bridge deck or other bluff body subjected to that wind.

The identification of aerodynamic admittance functions is by no means a simple process. It involves the measurement of spectra of both the longitudinal and vertical components of the approaching velocity fluctuations; the force and moment coefficients at various angles of wind incidence; the corresponding first derivatives of the force and moment coefficients; and the spectra of the aerodynamic forces acting on the bluff body. This paper describes the theories and data analysis procedures that were used to determine the aerodynamic admittance functions for each of the tested configurations. The effects of gap-width on the aerodynamic admittance functions of the lift and pitching moment are discussed in the following sections.

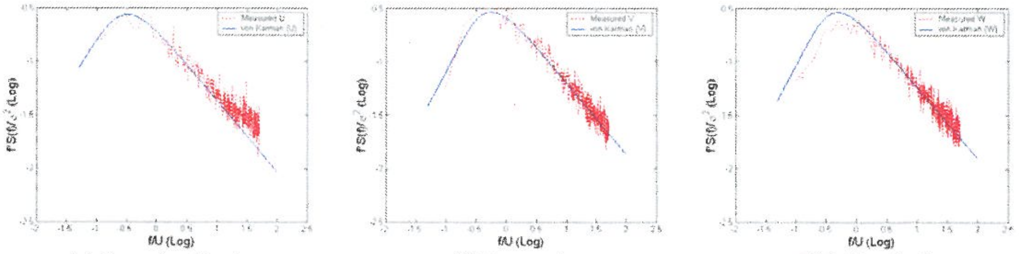
2. Wind Tunnel Tests

The experimental setup and information of the sectional model have been described in Part 1. In the second part of this study, five test configurations of gap-width (b) to total chord (B) ratios of 0%, 2.5%, 16.1%, 26.8% and 35.1% were investigated, in which the gap-widths are equal to 0m, 1m, 7.5m, 14.3m and 21.1m at prototype scale. The test configurations are denoted as Gap1, Gap2, Gap3, Gap4 and Gap5, respectively, and only the results at 0° angle of wind incidence are presented.

The tests were conducted in a turbulent flow. A TFI Cobra probe, which is capable of measuring the three-components of velocity and local static pressure simultaneously, was used for the measurements of wind velocity and turbulence characteristics. The characteristics of the flow fields are summarized in Table 1. The equivalent prototype turbulence length scales were determined by fitting von-Karman turbulence spectral models (von Karman, 1948) as shown in Fig. 1.

Table 1: Characteristics of flow fields employed.

	I_u (%)	I_v (%)	I_w (%)	L_{ux} (m)	L_{vx} (m)	L_{wx} (m)
Smooth	<1	-	-	-	-	-
Turbulence	17.4	17.9	15.6	35	15	17



(a) Longitudinal (b) Lateral (c) Vertical

Fig. 1: Power spectral density of wind velocity fluctuations: (a) longitudinal component (u); (b) lateral component (v); and (c) vertical component (w)

3. Results and Discussions

3.1. Data Verification

For bridge aerodynamics, the aerodynamic admittance functions of lift and pitching moment are commonly determined from a combination of spectral functions as expressed in Eq. 1 and 2, respectively (for excellent summaries and derivations of the formulation, see Davenport, 1962; Scanlan and Jones, 1990; Larose and Mann, 1998; Hann, 2000; and Macdonald, 2003).

$$|\chi_L(k)|^2 = \frac{S_L(k)}{\left(\frac{1}{2}\rho_a U^2 B\right)^2 \left[4C_L^2 \frac{S_u(k)}{U^2} + (C_L' + C_D)^2 \frac{S_w(k)}{U^2}\right]} \tag{1}$$

$$|\chi_M(k)|^2 = \frac{S_M(k)}{\left(\frac{1}{2}\rho_a U^2 B^2\right)^2 \left[4C_M^2 \frac{S_u(k)}{U^2} + (C_M')^2 \frac{S_w(k)}{U^2}\right]} \tag{2}$$

where $|\chi_L(k)|^2$ and $|\chi_M(k)|^2$ are the admittance functions of lift and pitching moment ; ρ_a is the air density in kg/m^3; U is the approach mean wind speed in m/s; B is the total chord length of the bridge deck in m; k is the reduced frequency = fB/U and f is frequency in Hz; $S_L(k)$ and $S_M(k)$ are the power spectral densities of lift and pitching moment, respectively; $S_u(k)$ and $S_w(k)$ are the power spectral densities of the longitudinal (u) and vertical (w) components of the approach velocity fluctuations, respectively; C_L and C_M are the static aerodynamic coefficients of lift and pitching moment, respectively; and C_L' and C_M' are the first derivatives of the static aerodynamic coefficients of lift and pitching moment with respect to the angle of wind incidence, respectively.

Before proceeding, it is worth comparing the accuracy of the measured aerodynamic admittance function with that measured for a similar situation using a typical closed-box girder bridge deck section (Larose and Mann, 1998). The aspect ratio (i.e. ratio of total chord length to deck depth, B/H = 10) and vertical length scale ($L_{wx}/B = 0.29$) of their test configuration were of similar order of magnitudes to those of Gap1 (B/H = 11.08 and $L_{wx}/B = 0.38$) in the current study and Fig. 2 shows the similarity of the cross-sections of their bridge deck and Gap1. The lift admittance functions are plotted in Fig. 3 with reference to Liepmann's approximation to Sears' function (Liepmann, 1952). It can be seen that there is quite good agreement between the measured lift admittance function of Gap1 and that of Larose and Mann's (1998) bridge deck over the available range of reduced frequencies tested. Therefore, this result represents the experimental verification of the validity and accuracy of the aerodynamic admittance functions measured in this study.

(a) Gap1 (b) Larose and Mann's bridge deck

Fig. 2. The cross sections of Gap1 and that of Larose and Mann's bridge deck (of the same scale)

3.2. Effects of Gap-width

The lift admittance functions for each of the tested configurations at 0° angle of wind incidence in the turbulent flow are presented in Fig. 4. The figures have been plotted on a log-log scale and Liepmann's approximation to Sears function was also plotted on each graph. It can be seen that the effect of gap-width at low reduced frequencies (for reduced frequencies below 0.1) is generally insignificant for either generating or diminishing the buffeting lift force, i.e. the lift admittance function of the twin-deck bridge is insensitive to the variation of gap-width at low reduced frequencies. The increase in gap-width of the twin-deck bridge does not change the effectiveness of larger gusts to transfer energy into the structure and the admittance function at low reduced frequencies remains small. However, it can be noted that the lift admittance function at high reduced frequencies increases slightly with increasing gap-width. This is believed to be associated with the additional smaller scale turbulence in the wake of the upstream deck as the gap-width is increased. The vortex induced turbulence buffeting excitation acting on the downstream deck resulted in an increase of the buffeting lift force on the twin-deck bridge at high reduced frequencies.

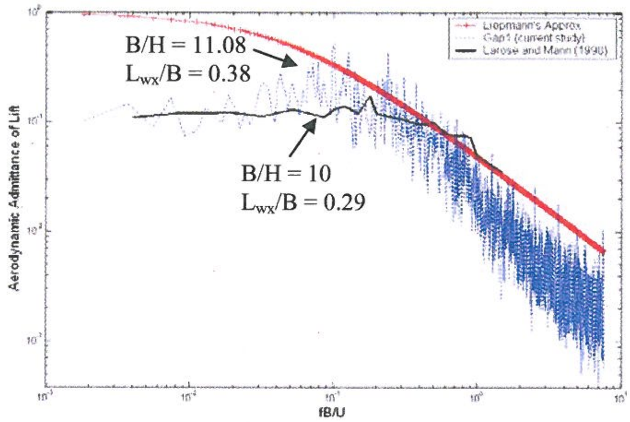
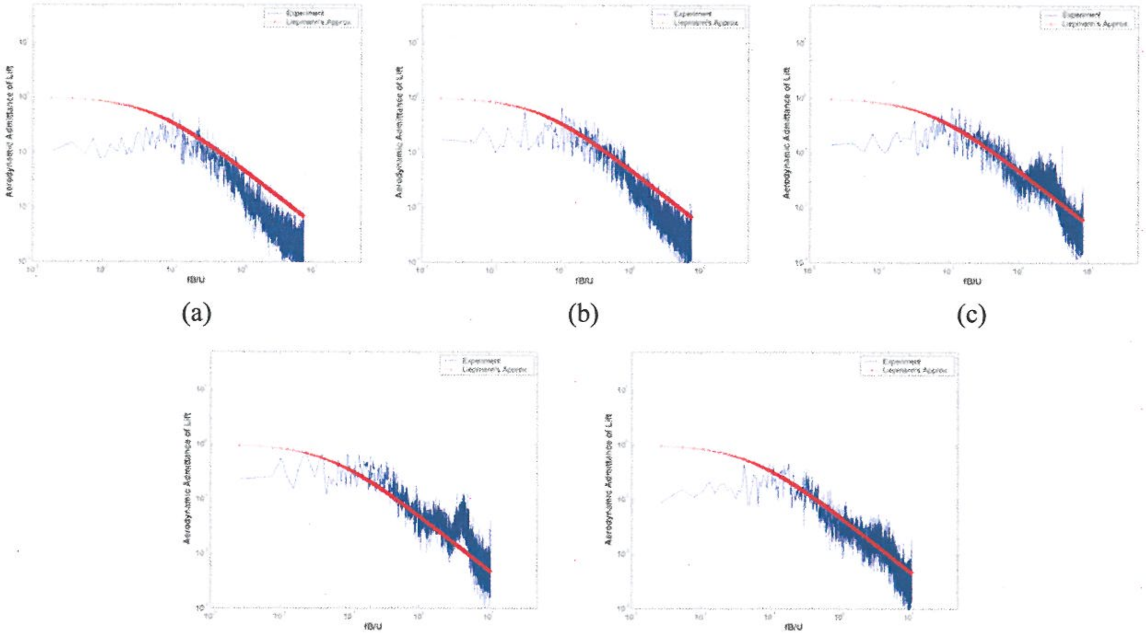


Fig. 3. Lift admittance functions of Gap1 and Larose and Mann's bridge deck

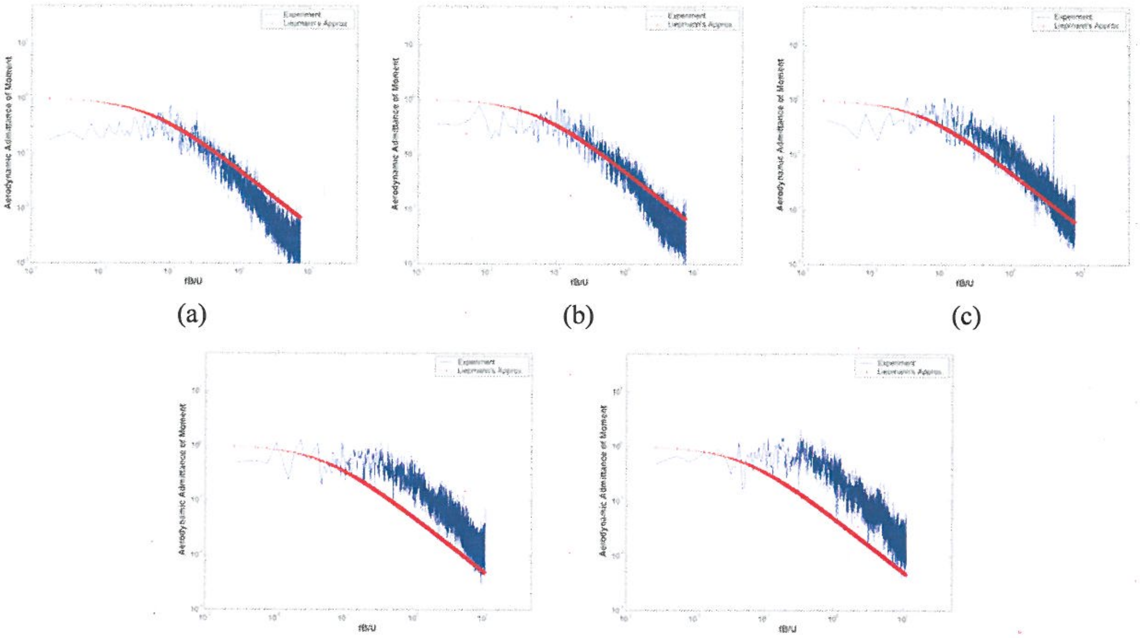


(a) (b) (c)

(d) (e)

Fig. 4. Lift admittance functions of: (a) Gap1; (b) Gap2; (c) Gap3; (d) Gap4; and (e) Gap5

The aerodynamic admittance functions of the pitching moment for each of the tested configurations are shown in Fig. 5. In general, the shape of the pitching moment admittances is similar to those of the measured lift admittances. Since the pitching moment is mainly the resultant of the integrated effect of the localized lift forces around the sectional model, the pitching moment is expected to retain some aerodynamic properties of its complementary lift force. It can also be seen that the aerodynamic admittance function of the pitching moment increases gradually with increasing gap-width over the measured range of reduced frequencies. It is evident that the larger the gap-width, the more effective the approach velocity fluctuations in generating the buffeting pitching moment on the twin-deck bridge. The enhanced effectiveness is believed to be associated with the increase in lever arms of the local surface pressures from the rotational centre, whereby the pitching moment of the twin-deck bridge becomes more sensitive to the instantaneous changes of the surface pressures, which show an apparent increase in the correlation with the mid to high frequencies gusts. As a result, the buffeting pitching moment increases with increasing gap-width.



(a) (b) (c)

(d) (e)

Fig. 5. Aerodynamic admittance functions of pitching moment of:
(a) Gap1; (b) Gap2; (c) Gap3; (d) Gap4; and (e) Gap5

4. Conclusions

A rigid pressure sectional model was used to investigate the effects of gap-width on the aerodynamic admittance functions of a twin-deck bridge. Five test configurations with different gap-widths were tested at 0° angle of wind incidence. It was shown that the effect of gap-width at low reduced frequencies (for reduced frequencies below 0.1) is generally insignificant for either generating or diminishing the buffeting lift force. The increase in gap-width of the twin-deck bridge does not change the effectiveness of the larger gusts to transfer energy into the structure. However, the aerodynamic admittance function of the pitching moment increases gradually with increasing gap-width over the entire range of reduced frequency. This is believed to be associated with the increase in lever arms of the local surface pressures from the rotational centre.

5. Acknowledgements

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