Sectional Pressure Tests of a Twin-deck Bridge:
Part 2: Effects of Gap-width on a Twin-deck Configuration

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Abstract. Pressure measurements were carried out on a stationary section model of a twin-deck bridge for five configurations with different gap-widths. Details of the experimental techniques and the effects of angle of wind incidence for the design configuration have been presented in Part 1. The purpose of this paper is to investigate the effects of different gap-widths of the twin-deck configuration on the aerodynamic characteristics of the bridge in a smooth flow and a turbulent flow. Stream-wise mean and fluctuating pressure distributions around the deck were studied to investigate the flow excitation mechanisms caused by different gap-widths. The influences of the gap-width on the static aerodynamic coefficients and span-wise correlation of the forces and moment were also analyzed. The results demonstrated that the gap-width has the potential to significantly affect the pressure distribution and hence the corresponding aerodynamic performance of the bridge.
Keywords: aerodynamic forces; cable-stayed bridge; force coherence; pressure distribution; pressure measurement; twin-deck.

1. Introduction

Super long-span cable-supported bridges are very sensitive to wind-induced vibration phenomena such as vortex shedding, flutter and buffeting. The aerodynamic configuration of the bridge deck is one of the most critical design considerations in controlling the wind excitation. In previous studies [e.g.1], it was found that a twin-deck configuration with a center gap was an effective means of improving the aerodynamic responses, particularly with regard to flutter. In this study, a series of static pressure measurements for a section model, which features a twin-deck structure, were conducted to investigate its aerodynamic performance with various center gap-widths. Simultaneous pressures were measured at 448 locations to calculate the time history of aerodynamic forces and moment by spatial integration of the surface pressures. The corresponding pressure distribution, span-wise correlation and coherence were determined in order to gain an insight into the wind excitation mechanisms.

2. Wind Tunnel Experiments

The experimental setup, characteristics of the flow fields and information of the section 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. All tests were conducted at 0° angle of wind incidence and only the bare deck configuration was considered.

3. Results and Discussions

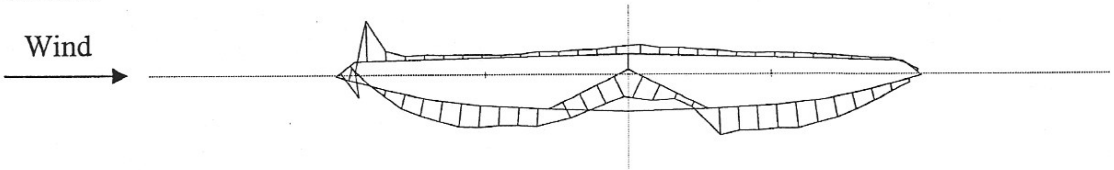
3.1. Stream-wise Pressure Distribution

One of the main advantages of a pressure section test is to obtain a clearer picture of the pressure distribution on the deck, which allows a better understanding of the flow excitation mechanisms [2]. The results of the two extreme test configurations, i.e. 0% and 35.1% gap-width, are described in this section.

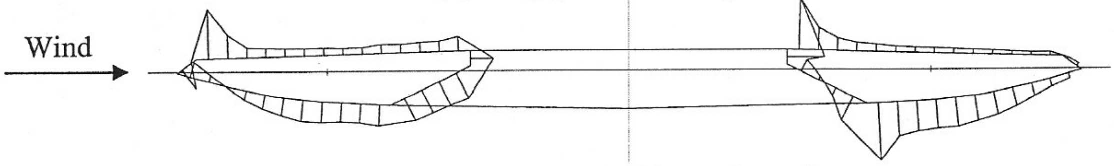
For the 0% gap-width configuration in smooth flow, the large negative pressures on the top surface near the leading edge region, as depicted in Figure 1a, highlight the flow separation. The flow appears to reattach shortly afterward as indicated by the mildly negative resultant surface pressures. Furthermore, the flow over the streamlined bottom surface appears to be largely attached flow with no apparent flow separation except at the transition points.

For the 35.1% gap-width configuration, shown in Figure 1b, the mean pressure distribution on the upstream deck is similar to that of the 0% gap-width configuration. However, due to the larger negative pressures on the top surface, the total lift is expected to be smaller in magnitude, although remaining negative. For the downstream deck, the flow separates at the windward corner of the top surface and appears to reattach shortly afterward. Flow separation also occurs at the transition point on the bottom surface as indicated by the large negative pressures. There is no apparent flow reattachment as the surface pressures remain negative thereafter.

The overall mean pressure distribution pattern for the turbulent flow is qualitatively similar to that for the smooth flow. However, the magnitude of the pressure coefficients are generally smaller in the turbulent flow, decreasing the magnitude of the (negative) lift coefficients, as discussed in following section.



(a) 0% gap-width configuration



(b) 35.1% gap-width configuration

Figure 1: Mean pressure distribution of: (a) 0% gap-width configuration; (b) 35.1% gap-width configuration; in smooth flow (flow from left to right). The depth of the deck equals 1.0 C_p and negative pressures are away from the surface.

3.2. Aerodynamic Forces and Moment

Figure 2 depicts the static coefficients of lift, drag and moment, respectively, as a function of the gap-width ratio (*b/B*) for the deck in the smooth and turbulent flows. The static aerodynamic force and moment coefficients are defined as follows:

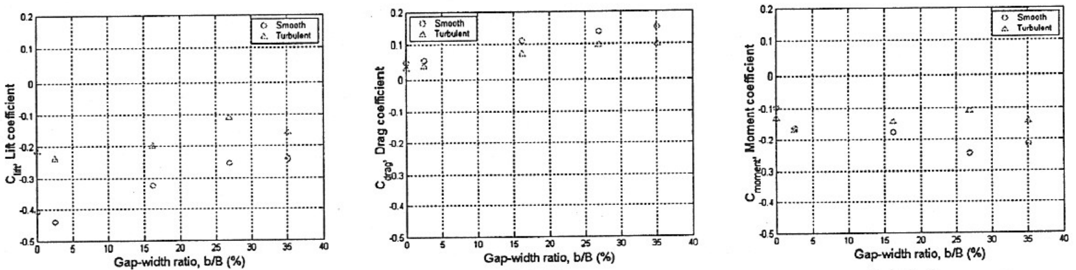
$$C_L = \frac{F_L}{\frac{1}{2}\rho_a U^2 C}; \qquad C_D = \frac{F_D}{\frac{1}{2}\rho_a U^2 C}; \qquad C_M = \frac{M}{\frac{1}{2}\rho_a U^2 C^2};$$

where F_L, F_D and M are the mean values of lift, drag and moment per unit length of the bridge deck respectively, calculated by spatial integration of the mean pressure distribution; ρ_a is the air-density, U is the test mean wind speed and C is the chord length of a single deck (19.5m in prototype scale) which remained a constant parameter in all tests.

In smooth flow, the magnitude of the negative lift coefficients (downward force) decrease gradually with the increase in gap-width, as shown in Figure 2a. This is consistent with the observations for the mean pressure coefficient distribution discussed above. As the gap-width increases, the decks will eventually be sufficiently separated for them to act as aerodynamically independent decks. Hence, at that point, the total lift is expected to stay relatively constant. In general, the magnitudes of the lift coefficients in the turbulent flow are smaller than those determined in smooth flow and also tend to decrease with increasing gap-width.

The drag coefficients increase with the gap-width in both smooth and turbulent flow as indicated in Figure 2b, although smaller magnitudes were determined in the turbulent flow. This is attributed to the positive surface pressures at the non-streamlined windward portion of the downstream deck, which is exposed to the approach wind.

The variation of the moment coefficients with gap-width is shown in Figure 2c. The wind-induced moment is the combined effect of the wind forces acting on the upstream deck and the downstream deck as a result of the wind pressure distributions which differ in smooth flow and turbulent flow. The moment is also a function of the moment arm which depends on the gap-width. It is evident in Figure 2c that the magnitude of the negative moment generally increases with the gap-width in the smooth flow but remains comparatively constant in the turbulent flow.



(a) Lift (b) Drag (c) Moment

Figure 2: Static aerodynamic coefficients of (a) Lift; (b) Drag; and (c) Moment of the twin-deck bridge as a function of gap-width.

3.3. Span-wise Coherence

The root-coherences of the 35.1% gap-width configurations are shown in Figure 3. Peaks in the coherence functions were observed at around 80 Hz, and similar characteristics were also observed for gap-widths of 16.1% and 26.8%, although no such peaks were observed for the 0% gap-width configuration. It is believed that these peaks are due to the vortex shedding processes of the upstream deck acting on the downstream deck.

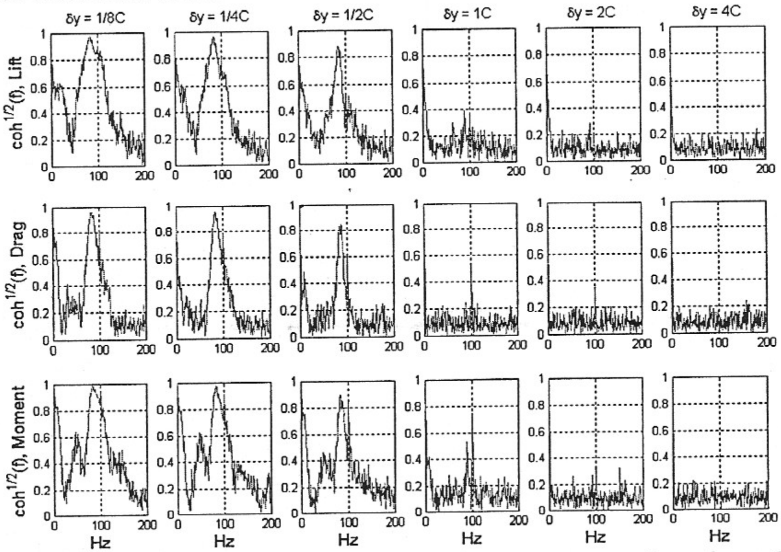


Figure 3: Span-wise root-coherence of the lift, drag and moment, as a function of frequency, for the 35.1% gap-width in smooth flow.

3.4. Span-wise Correlation

The results for the turbulent flow are depicted in Figure 4. The aerodynamic forces and moment exhibited a higher correlation along the bridge span than the span-wise correlation of the approaching wind velocity fluctuations. This suggests that the *strip assumption*, which assumes that the aerodynamic forces acting on a strip are only due to the incident wind fluctuations on the strip, is not universally applicable in buffeting analysis of bridges [3 & 4]. Furthermore, the span-wise correlation coefficients of the lift and moment were almost identical for each of the five gap-widths tested. This suggests that the span-wise correlations of the lift and moment are generally independent of the gap-width in the turbulent flow.

Greater variability over the range of gap-widths tested was observed for the drag coefficients, with a clear distinction between the smaller gap-widths (0% and 2.5%) and the larger gap-widths (16.1% to

35.1%). It is believed that the vortex shedding processes of the upstream deck acting on the downstream deck are responsible for the increase of span-wise correlation of the drag for larger gap-width configurations.

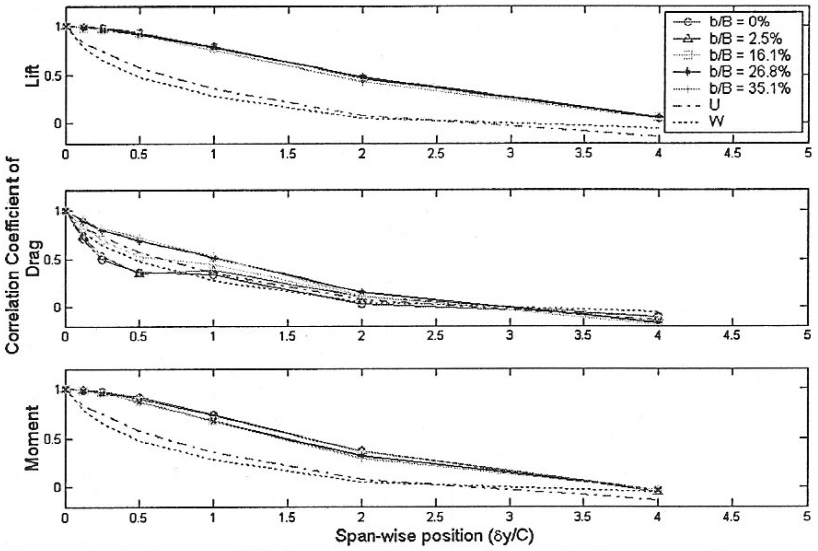


Figure 4: Span-wise correlation coefficients of the aerodynamic forces and moment for the five deck configurations (solid lines) and the wind velocity fluctuations of the U and W components (dashed lines) in the turbulent flow.

4. Conclusions

A stationary pressure section model was used to systematically study the effects of gap-widths of a twin-deck bridge. Five gap-width ratios (*b/B*) were tested at the 0° angle of wind incidence. It was shown that the wind-induced excitation mechanism changes with different gap-widths, which affects the aerodynamic forces and moment acting on the deck. In general, the magnitudes of the aerodynamic forces and moment in the turbulent flow are smaller than those determined in smooth flow. Moreover, as the gap-width increases, the decks will eventually be sufficiently separated for them to act as aerodynamically independent decks.

Furthermore, in the turbulent flow, the lift and moment exhibited a higher correlation along the bridge span than the approaching wind velocity fluctuations and almost identical for each of the five gap-widths tested. This suggests that the span-wise correlations of the lift and moment are generally independent of the gap-width in the turbulent flow. The span-wise correlation of the drag increases for the larger gap-width configurations due to the vortices generated by the upstream deck impinging on the downstream deck. Evidence of the vortex shedding mechanism is also reflected in the results of the span-wise coherence.

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6. References

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