BBAA VI International Colloquium on:
Bluff Bodies Aerodynamics & Applications
Milano, Italy, July, 20-24 2008

AERODYNAMIC INVESTIGATION OF GENERIC BRIDGE DECK SECTION MODELS

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Keywords: Bridge aerodynamics, force coefficients, Reynolds number effects, angle of attack, generic bridge decks, wind tunnel testing, Strouhal number, vortex shedding.

Abstract: This paper reviews the results of a comprehensive research effort underway at the TFHRC Aerodynamics Laboratory where the goal is to enhance understanding of performance characteristics associated with different bridge deck shapes under varying aerodynamic loading conditions. Results from wind tunnel tests of such bridge deck models would help in establishing a broad database of their aerodynamic response characteristics for use as an initiation point by bridge designers. Specifically, this paper will focus on five generic, or fundamental, bridge deck shapes and their experimentally obtained aerodynamic performance characteristics. Models were tested in smooth flow at different Reynolds numbers and angles of attack while measuring the wind-induced forces generated. The static component of the observations provided an insight into the effect of Reynolds number and angle of attack on mean forces and force coefficients. Fluctuations in the forces, however, yielded information about vortex shedding in the flow wake including shedding frequency which was then used to derive the corresponding Strouhal number. Tests were conducted at different wind speeds allowing for a Reynolds number range of ~ $4x10^4$ to $2x10^5$. To extend the scope of results beyond the range of typical wind tunnel tests for such models, angle of attack of the wind was varied between -15° to +15° in steps of 1°. It was observed that Reynolds number has a more pronounced effect on mean forces than on the corresponding force coefficients. However any change in the angle of attack causes significant changes in both the forces as well as the force coefficients. The shedding frequency increases with any increase in flow speed. Furthermore, due to the relative complexity of the model shape, there may occur more than one zone of separation giving rise to more than one shedding frequency. Based on these observations, conclusions regarding aerodynamic stability of such deck shapes have been made.

1 INTRODUCTION

In order to evaluate aerodynamic performance characteristics of any particular bridge deck shape, wind tunnel tests on an equivalent model are typically carried out in varying simulated wind conditions. However, for practical reasons such wind tunnel tests are often carried out for a limited range of parameters which results in an uncertainty related to the extrapolation of results. In order to address this issue and hence establish a comprehensive database of broad-ranged bridge deck performance characteristics, the Aerodynamics Laboratory at FHWA's Turner-Fairbank Highway Research Center has undertaken a research effort to study and catalog the aerodynamic behavior of many existing detailed as well as several simplified generic bridge deck models. This extended abstract deals with a subset of the complete research study and presents results and analysis of tests conducted on five generic bridge deck shapes. Specifically, the impact of change in flow conditions on forces, force coefficients and on the phenomenon of vortex shedding is briefly discussed.

2 EXPERIMENTAL APPROACH

Wind tunnel tests of all these models were carried out at a Reynolds number range spanning $4x10^4$ to $2x10^5$ with the angle of attack varying between -15° to +15°. Geometric details of the five generic bridge deck cross-sections are shown in Fig. (1). Principal dimensions of all the models, namely length (L), width (B) and depth (D) were kept constant at 60 in., 15 in. and 2.125 in. respectively. End plates were employed to insure two-dimensional flow near the ends of the model.

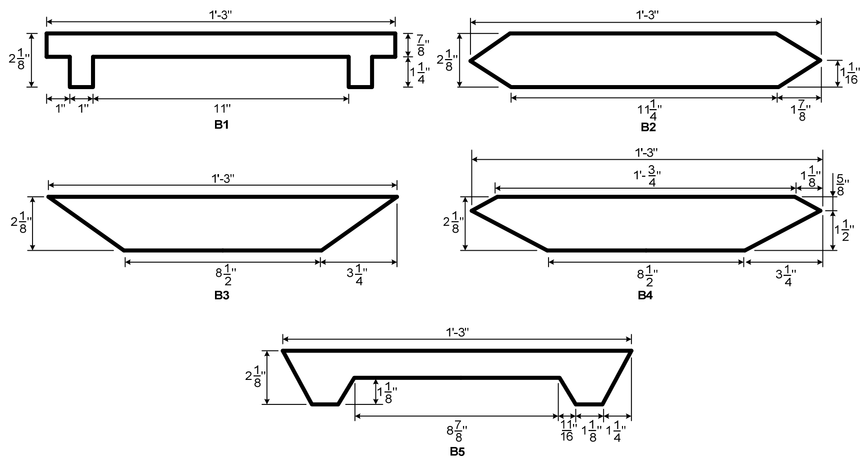


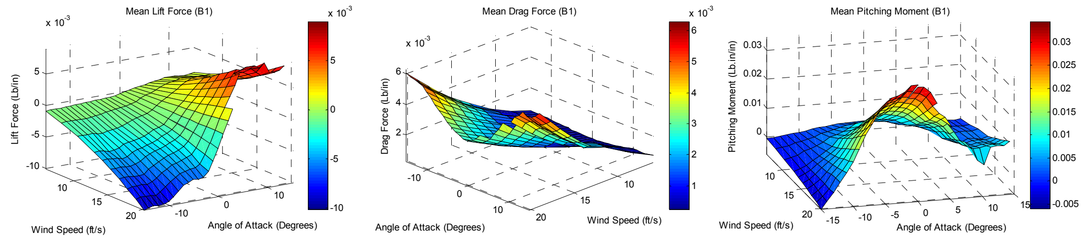
Figure 1: Generic bridge deck cross-sections.

To the extent possible, every model was tested for the same set of wind speeds and angles of attack. Aerodynamic forces, namely lift, drag and pitching moment were recorded using a dual force balance. These measurements were used to compute the mean and rms forces, force coefficients and Strouhal number.

3 RESULTS AND OBSERVATIONS

Results have been presented in the form of surface plots showing the variation of these physical quantities simultaneously with both wind speed (Reynolds number) and angle of attack. Although analysis was carried out for all the models, this extended abstract presents the results for only a few models as a sample representation.

Mean Aerodynamic Forces: Dependence of all the three mean aerodynamic forces on both angle of attack and Reynolds number can be clearly observed from Fig. (2). Except for minor variations, overall trends for each force component remain similar for all the models.



(a) (b) (c)

Figure 2: Mean Aerodynamic Forces, Model B1, (a) Lift, (b) Drag, (c) Pitching Moment

RMS Force Fluctuations: These plots (see Fig. (3)) are used to identify the flow regime where the model exhibits greatest sensitivity or susceptibility towards structural instability. In general, RMS force values from the three forces point towards the same general flow characteristics which may possibly lead to model instability.

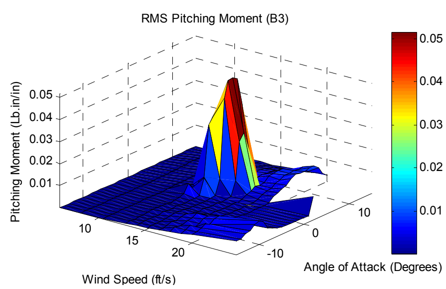
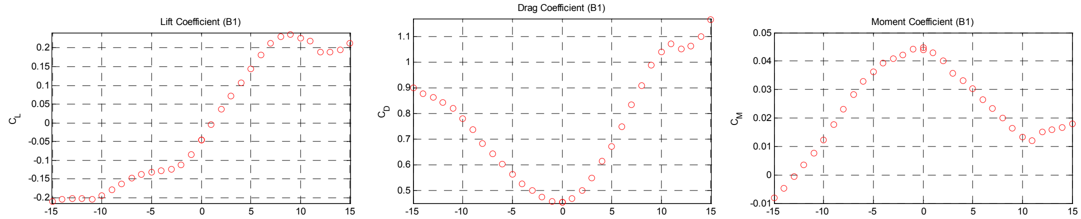


Figure 3: RMS Pitching Moment, Model B3

Force Coefficients: These values for all the models were observed to be essentially independent of wind speed or the Reynolds number. However, a distinct variation with angle of attack could clearly be observed. This variation was used as a basis of ascertaining the model's tendency towards galloping and autorotation by evaluating the sign of the criteria $\left(\partial C_L / \partial \alpha\,|_{0^\circ} + C_D\right)$ and $\left(\partial C_M / \partial \alpha\,|_{0^\circ}\right)$. Positive sign in both the cases indicates stability and the values of these expressions provide a measure of stability or instability.

As shown in Fig. (4), in case of model B1 the slope of the C_L plot and the value of C_D at 0° are both positive implying stability of the model against galloping in the bending mode. However, the C_M plot changes its slope from positive to negative while going through 0° which indicates that the model has a tendency to develop autorotation in torsional mode at positive wind angles. Using the same stability criteria, conclusions have been drawn for the other models as well.



(a) (b) (c)

Figure 4: Force Coefficients, Model B1, (a) Lift, (b) Drag, (c) Pitching Moment

Spectral Analysis: This analysis of the force data provided information about vortex shedding frequency under different test conditions for all the models. This analysis was helpful in shedding light on the presence of multiple zones and frequencies of vortex shedding in some cases. Pitching moment exhibited the most susceptibility to vortex shedding since the amplitude of its power spectral density (PSD) was more than that of lift and drag forces. Strouhal number, calculated using the shedding frequency identified from PSD plots, was found to be largely uniform with respect to Reynolds number. However, its dependence on angle of attack was clearly observable for all the models (Fig. (5)). Sets of models (B1 & B5 and B2 & B4), having "similar" geometrical configurations, were found to exhibit similar trends. At angles close to 0° incidence, Strouhal number for models B2, B3 and B4 was in the range of 0.20 to 0.25, whereas that for models B1 and B5 was around 0.10. Absence of any clearly defined frequency peak in the PSD plots for model B4 at angles between -12° and -15° prevented the determination of Strouhal number for this range.

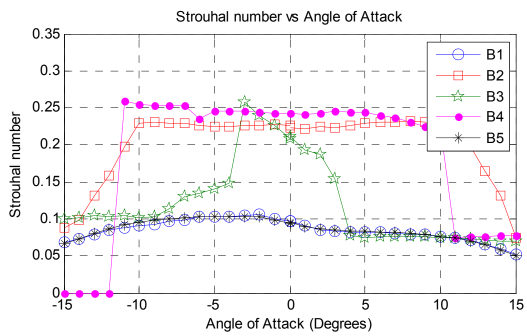


Figure 5: Strouhal number vs. Angle of attack, All Models

4 CONCLUSIONS

This extended abstract provides a brief overview of an ongoing research study to catalog the aerodynamic properties of actual as well as simplified "generic" bridge deck sections. A representative sample of results obtained in smooth flow using a high frequency force-balance is presented. Variation of forces with wind speed and angle, as well as vortex shedding properties, are briefly discussed.

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