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Dynamic Response Mitigation of Enclosed Pedestrian Bridge

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SUMMARY: DYNAMIC RESPONSE MITIGATION FOR ENCLOSED PEDESTRIAN BRIDGE

Wind tunnel testing of a 200m long enclosed pedestrian bridge was conducted. Aeroelastic dynamic section testing and static section testing was performed using a scaled two dimensional bridge model. The results of the dynamic section testing conducted in smooth flow demonstrated that an aerodynamic instability occurred and this instability primarily occurred for vertical motion. A review of the literature identified that the most likely cause of the instability is 'impinging leading edge vortices'. It was demonstrated through additional testing that the response of the bridge to the vortices can be reduced by increasing the background level of turbulence in the wind tunnel or can be eliminated by making small changes to the proposed bridge sun-shading elements.

Keywords:bridge, aeroelastic, instability

1. INTRODUCTION

The enclosed pedestrian bridge is a 200m long bridge that is located at an airport. Wind tunnel testing of this bridge was conducted. Two separate section model tests of the bridge were performed to determine the dynamic response of the bridge and measure the static force coefficients. Design loads for the bridge were then calculated. In this paper only the results of the dynamic response wind tunnel tests are discussed.

2. WIND TUNNEL TESTING PROCEDURE

A 1:70 scale model of the bridge was constructed and tested (Figure 1). As the profile of the prototype bridge varies along its longitudinal axis, the cross section of the central span of the bridge was modelled. The main body of the bridge is 16m high and has a width/height ratio of ≈1:1.5. There are overhanging horizontal sunshade elements attached to the roof of the bridge. The model was mounted on a suspension style dynamic section test setup (Hjorth-Hansen, 1992).

The density and Scruton number of the model was matched to the prototype. The ratio between the first mode vertical and torsional natural frequencies was maintained between the model and the prototype bridge. The prototype bridge had a low density which resulted in a low Scruton number of ≈ 3 for the base damping case.

The initial wind tunnel tests measurements were conducted in smooth flow to analyse the susceptibility of the bridge section design to aerodynamic instabilities and vortex-induced-vibrations over a range of expected wind speeds (Holmes, 2015). Smooth flow testing is conducted as these effects maybe masked by the natural turbulent which occurs in the atmospheric boundary layer.

Following analysis of the smooth flow dynamic section test results, testing was also performed in turbulence flow. To match the full-scale turbulence in the wind tunnel, a partial turbulence matching methodology was used (Dyrbye and Hanson, 1999). Using this method, the longitudinal spectral density normalised by the mean wind speed squared measured in the wind tunnel is compared with the site full-scale spectra estimated using the Von-Karman Harris Spectral model (ESDU 85020, 2001). The wind tunnel conditions were then assumed to match the full-scale spectra which they completely enveloped. For this enveloping to occur typically the wind tunnel turbulence is less than the full-scale turbulence. For these tests the atmospheric boundary layer conditions were based on the local wind loading standard.

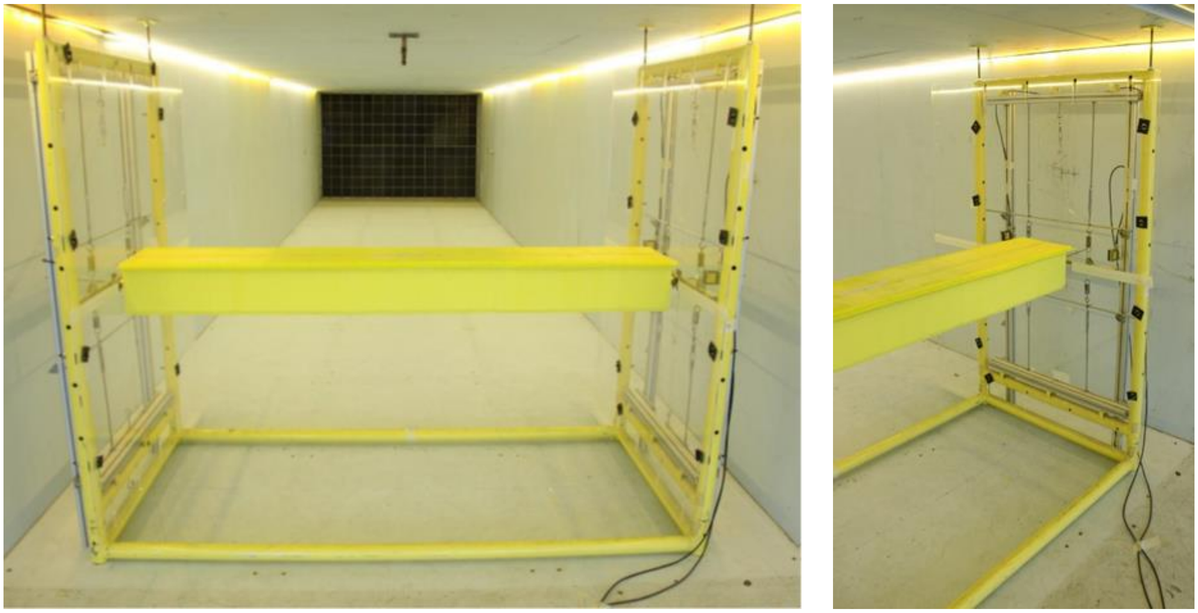

Figure 1. Sky Bridge during testing in smooth flow (left) Full model (right) Suspension Rig

3. RESULTS AND DISCUSSION

3.1. Initial Dynamic Testing in Smooth Flow

The results of the testing in smooth flow showed an instability. A vibration was found to occur primarily in the vertical motion of the bridge but not in the rotational motion. This vibration is shown by a distinct discontinuity in the response curve, starting at ≈45m/s (just below the design wind speed) and continuing until ≈65m/s (Figure 2 left). There is also a decrease in the observed peak factor (peak response divided by standard deviation response) from between 3 and 4 to ≈1.5 (Figure 2 right). The decrease occurs between 47m/s and 65m/s, and is most clear between 52m/s and 59m/s. The reduction in the peak factor from a typical value for turbulent buffeting of ≈3.5 to a value closer to the ideal sinusoidal value of ≈1.4 is an indicator of the presence of a forced vibration and an aerodynamic instability. Testing was conducted for three damping ratios as a percentage of critical: Case 1, 0.5%; Case 2, 0.7% and Case 3, 1.1%. The onset velocity of the instability did not vary although there was a decrease in response.

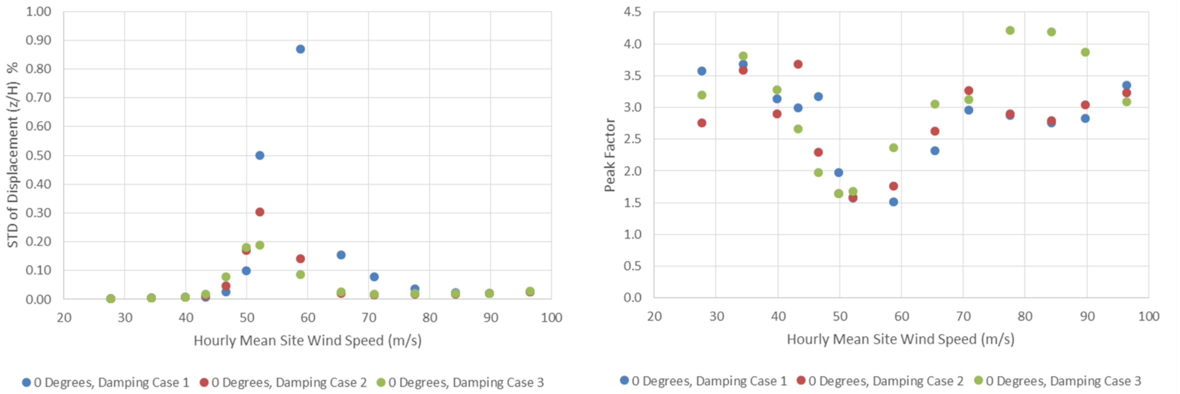

Figure 2. Vertical Motion in Smooth Flow for 0 degrees angle of attack and three damping ratios (left) Normalised Standard Deviation of Displacement (right) Peak Factor

3.2 Flow Mechanism in Smooth Flow

Stability diagrams from Naudascher and Wang (1993) for lightly damped rectangular prisms have been used to analysis and identify the observed response. The spectra of the lift force from the static tests were also examined for a range of wind speeds and the Strouhal number for this shape estimated to be 0.13 or a reduced velocity of 7.5. The vibration first occurs at a reduced velocity of ≈2 which is well below the critical velocity for leading edge vortex shedding vortex induced vibration based on the dimensions of the whole bridge section. However, it is close to that for impinging leading edge vortices. As the onset velocity did not vary for the three damping ratios tested this indicates that the instability is not sensitive to Scruton number, which is the case for impinging leading edge vortices. The instability is also similar to that shown in Mannini et al. (2016) who investigated a 1:1.5 aspect ratio rectangular prism for various Scruton numbers. They found that there was an instability starting at ≈25% of the critical velocity for sections with low Scruton numbers, which is a similar onset point to the present study.

3.3 Dynamic Testing in Turbulent Flow

Atmospheric boundary layer turbulence is known to suppress the formation of vortex induced vibrations. As vortex induced vibrations generated by an impinging leading-edge vortices (ILEV) mechanism were identified in the previous smooth flow tests, the sensitivity of the formation of impinging leading edge vortices to turbulence was investigated. By comparing the smooth to turbulent flow results the vibrations were still visible. However, the response of the bridge was reduced in magnitude as well as the range of wind speeds over which the vibrations occur. The instability is now concentrated at 52m/s. The observed peak factor has reduced from to ≈3 to ≈1.9. These results indicate that levels of turbulence similar to those expected at the site partially suppress the mechanism creating the vibration. An increase in the vertical response due to buffeting is also seen at the higher wind speeds.

3.4 Testing of Mitigation by Changes to Leading Edge Sunshade

The bridge design includes open lattice style horizontal sunshade elements extending from the roof of the bridge. As the instability identified is related to the generation of vortices from the leading edge of the bridge an alteration to the leading edge was trialled to disturb the formation of these vortices. The proposed solution was to in-fill every second sunshade bay with an impermeable panel (Figure 3). This solution could be implemented using clear panels or panelling matching the roof of the bridge and could be attached to the existing supports.

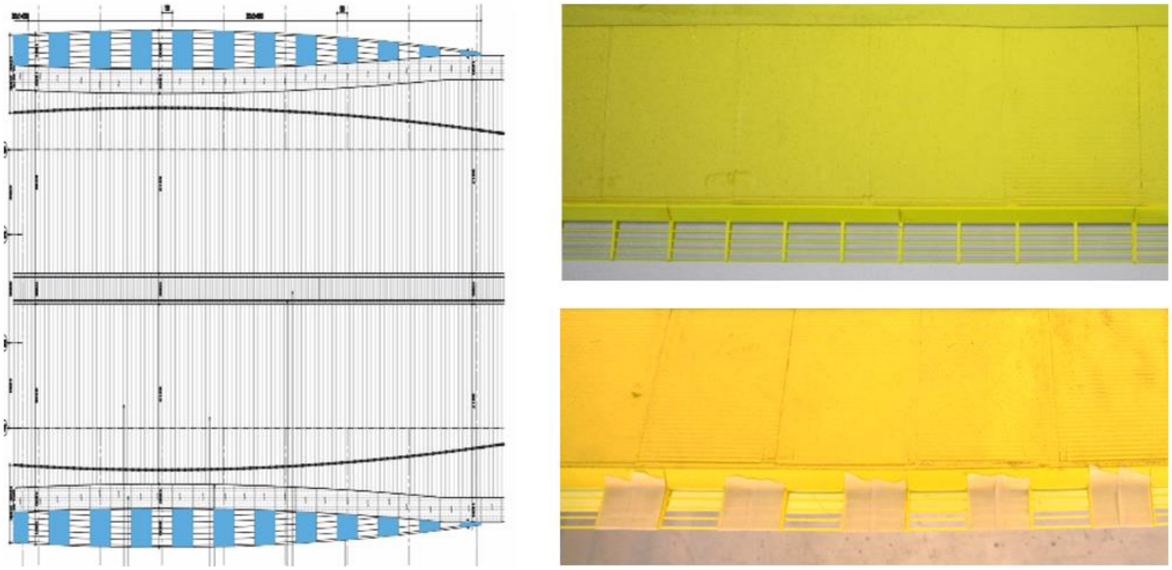

Figure 3. Sunshade Modification (Left) Drawing (right top) without modifications (right bottom) and with modifications (bottom)

By comparing the results with and without the infill panels the effect of the vortex induced vibration is almost completely removed. The standard deviation response is < 5% of the original design and the peak response <10% of the original design. Also, the peak factor has not decreased below 3. This demonstrates the effectiveness of the infill panel mitigation proposed.

4. CONCLUSIONS

The results of the wind tunnel test demonstrate that under smooth flow conditions there is a dynamic instability that occurs at a wind speed similar to the design wind speeds. This instability is most likely generated by impinging leading edge vortices and is enhanced by the bridge's low Scruton Number. The response of the prototype bridge to this instability will be reduced compared to the smooth flow results due to the natural turbulence present in the atmospheric boundary layer. The instability can be further reduced to the point of being almost eliminated by making additions to the sunshade elements.

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