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Numerical investigation of the effects of pedestrian barriers on aeroelastic stability of a proposed footbridge

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ABSTRACT

A numerical investigation into the aerodynamic characteristics and aeroelastic stability of a proposed footbridge across a motorway in the north of England has been undertaken. The longer than usual span, along with the unusual nature of the pedestrian barriers, indicated that the deck configuration was likely to be beyond the reliable limits of the British design code BD 49/01. In particular, the investigation focussed on the susceptibility of the bridge due to flutter, and to assess if the design wind speeds could be met satisfactorily. The calculations were performed using the discrete vortex method, DIVEX, developed at the Universities of Glasgow and Strathclyde. DIVEX has been successfully validated on a wide range of problems, including the aeroelastic response of bridge deck sections. The proposed deck configuration, which incorporated a pedestrian barrier composed of angled flat plates, was found to be unstable at low wind speeds with the plates having a strong turning effect on the flow at the leading edge of the deck. DIVEX was used to assess a number of alternative design options, investigating the stability with respect to flutter for each configuration. Reducing the number of flat plates and their angle to the deck lessened the effect of the barrier on the overall aerodynamic characteristics and increased the stability of the bridge to an acceptable level, with the critical flutter speed in excess of the specified design speed.

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1. Introduction

Much research has been undertaken in the field of bridge aerodynamics, and techniques for predicting the onset of flutter instabilities have been established for many years (Scanlan and Tomko, 1971; Scanlan, 1978, 1997), with more advanced techniques still being proposed (Chen and Kareem, 2003; Matsumoto et al., 1996). Assessment of the structural integrity due to the unsteady wind loading is not only important for long span suspension bridges, but also for much shorter span footbridges as recent studies indicate (Flaga et al., 2002; Pirner and Fischer, 1998; Tanaka et al., 2002). In certain respects, footbridges could be more susceptible to aeroelastic effects as the deck section is much lighter and thinner relative to the overall span, and they also tend to be much more flexible than longer span bridges. The oscillation of the London Millennium Bridge in 2000 (Dallard et al., 2001) memorably demonstrated the flexibility of footbridges and susceptibility to oscillation, although in this case the forcing mechanism was not due to the unsteady wind loading.

Planners and architects are increasingly commissioning and designing unique structures that can be used to provide a distinct landmark for the city or town. Whilst these structures are dramatic and impressive, they pose an extra problem and challenge for the engineer because of their unique nature. In the early design stages for these bridges, the engineer will seek to assess structural loading, including aerodynamic loads, from the available design codes (for example, British Standard BD 49/01, 2001). However, these codes use analysis methods and empirical correlations that are largely based on experience from previous designs or from experiments conducted on "generic" structures. Hence, design codes will provide limited information on novel "non-standard" structures for which alternative analysis techniques such as numerical and computational methods are required.

Numerical methods are increasingly being used for aerodynamic analysis as part of the design procedure for numerous wind-engineering structures. In particular, numerical techniques are considered to be particularly useful in the initial stages of the design, allowing designers to assess a range of options, to perform feasibility studies on novel configurations, or to provide useful aerodynamic and structural information on designs that lie beyond the scope of design codes.

A particular approach that is extremely well-suited to assessing unsteady aerodynamic effects and structural integrity is the discrete vortex method, with numerous researchers now using this type of numerical procedure very successfully as a design tool for bridge deck design (Larsen and Walther, 1997; MacKenzie et al., 2002; Taylor et al., 2002b; Vejrum et al., 2000).

Discrete vortex methods are based on the discretisation of the vorticity field rather than the velocity field, into a series of vortex particles, each of which is of finite core size and carrying a certain amount of circulation. The particles are tracked in time throughout the flow field that they collectively induce. As a result of this approach, the model does not require a calculation mesh and provides a very different method of analysis to more traditional grid-based computational fluid dynamics methods. Full and comprehensive reviews of the discrete vortex method are given in Leonard (1980), Puckett (1993) and Sarpkaya (1989).

DIVEX is a two-dimensional discrete vortex method that has been developed at the Universities of Glasgow and Strathclyde. To date, DIVEX has been used to analyse a range of bluff body flow fields (Taylor and Vezza, 1999a, b), and has also been extensively validated for a range of bridge deck analyses, ranging from predictions of static aerodynamics loads, flutter analysis and the study of flow control devices (Taylor and Vezza, 2001, 2002a). The capability of DIVEX is now well-recognised and the code has been used by Halcrow Group Ltd. during a number of recent design projects, a selection of which are summarised in Taylor et al. (2002b).

The results presented herein are based on a design study, commissioned by Halcrow Group Ltd., performed at the Universities of Glasgow and Strathclyde, on a proposed footbridge in the North of England. The study focused on assessing the structural integrity of the bridge with respect to flutter, as the proposed crossing was for a span longer than previously experienced by Halcrow for a bridge of this type, and also as the unusual pedestrian barriers were considered to be beyond the scope of the design code BD 49/01. This paper presents the results of the numerical analysis, which demonstrate the strong detrimental effect that these barriers have on the flutter instability, and the attempts to alleviate the problem by employing DIVEX to assess different design options relatively