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Estimation of torsional-flutter probability in flexible bridges considering randomness in flutter derivatives

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ABSTRACT

Torsional-flutter instability is an aeroelastic phenomenon of interest to the bridge engineer, corresponding to a torsionally unstable vibration regime of the deck driven by wind excitation and appearing beyond a certain critical wind velocity. In this study a method for the derivation of the flutter probability for long-span bridges with bluff decks is proposed.

In the first part of this study the deterministic problem is addressed. In contrast with the classical solution method in the frequency domain based on a numerical procedure for assessing the critical wind velocity, a single-mode "closed-form" algorithm for the derivation of the critical velocity was investigated. A polynomial representation of the aeroelastic-loading coefficients (flutter derivatives), necessary for torsional-flutter analysis, was utilized.

In the second part an algorithm for estimating the torsional-flutter probability was developed, considering randomness in bridge properties, and flutter derivatives in particular due to their preeminent role in torsional-flutter velocity estimation.

Experimental errors in the extraction of flutter derivatives from wind tunnel tests were analyzed. The "closed-form" algorithm, developed in the first part, allowed for a direct numerical solution of the flutter probability in a simple way.

The torsional-flutter probability for three simulated bridge models with rectangular closed-box and truss-type girder deck was numerically determined. A set of experimental data, available from the literature, was employed. The simulations enabled the validation of the proposed algorithm.

1. Introduction

Flutter instability is one of the major matters of concern in the design of long-span, flexible bridges also because of the increasing trend in the span length over the last decades. Aeroelastic instability occurs when a bridge is exposed to a wind speed above a certain critical threshold. Beyond this limit, diverging vibration of the deck is possible, which may result in a catastrophic structural failure. Aeroelastic stability can be predicted by analyzing the aeroelastic coefficients of bridge decks (flutter derivatives, FD) [1], which are employed for simulating the dynamic response of the bridge. Flutter derivatives are force coefficients per unit length, routinely measured in wind tunnel tests. However, such parameters are random in nature with uncertainties. It is therefore useful to determine the flutter probability by performing a probabilistic analysis.

Current methods, employed for the derivation of the flutter probability of a bridge, are based on the multi-mode analysis approach [2] and incorporate the effects of uncertainty either through numerical simulation (Monte Carlo, MC) or through reliability-based methods [3–6]. Existing literature studies have suggested that the flutter probability can be successfully assessed either by the first-order reliability method (FORM) [3] or an extension of the "response surface method" [7]. In both cases some of the parameters used to describe the dynamic response, are treated as random quantities with an appropriate probability distribution. Another method [8] has proposed the solution to the flutter probability problem by perturbation of the deterministic flutter velocity through a set of dimensionless multiplicative random parameters.

Nevertheless, many bridges may be susceptible to single-mode torsional flutter [9]. This phenomenon corresponds to a torsionally-driven unstable motion of the deck, and is mainly associated with a vibration in the first torsional structural mode, being the most vulnerable to the unstable excitation.

In these cases, the use of a probabilistic method, based on multi-mode flutter, may become unnecessary since the instability onset can be estimated by a reduced number of dynamic modal equations

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