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Review article

Eccentric-wing flutter stabilizer for bridges – Analysis, tests, design, and costs

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ABSTRACT

A device is presented that aims at preventing bridge flutter. It consists of wings positioned along the sides of, and fixed to, the bridge deck. Flutter suppression effectiveness is high provided the lateral eccentricity of the wings is large. It is a passive aerodynamic device that is presumably more cost-efficient than other passive measures or devices. Moreover, it does not contain moving parts. This is an advantage over devices with moving parts, which meet resistance due to reliability and durability concerns. Wind-tunnel tests were performed in which the flutter speed of a bridge deck sectional model without wings and with wings mounted in various configurations was measured. The experimental results are presented and compared with the results of flutter analyses using finite aeroelastic beam elements. Using the analytical approach, also the effect of the distribution of the wings along the length of a bridge was studied to optimize this distribution. Preliminary design studies for the wings and their support structures as well as quantity and cost estimates are presented. For a representative example bridge and wing configuration, an increase of 22% of flutter speed is reached at a cost increase of 2.5%.

1. Introduction

Flutter is a phenomenon that governs the design of long-span bridges. Various measures have been proposed and applied to raise the flutter resistance of bridges, that is, their critical wind speed for flutter onset (flutter speed).

The concept of the twin suspension bridge was described by Richardson [1] and since implemented in a few bridges. It is a passive aerodynamic measure that takes advantage of the gap between the two (or more) bridge decks. The flutter speed increase thus achieved comes at the additional cost of the cross beams that are needed to connect the individual decks.

An active aerodynamic device for raising the flutter speed was proposed by Ostenfeld and Larsen [2]. It consists of wings, installed along the sides of the bridge deck, whose pitch is controlled by actuators. A closed-loop control is envisaged in which, based on accelerometer measurements, an algorithm produces the control signals for the actuators such that the movement of the wings generate stabilizing wind forces. With such device, the safety of the bridge depends on energy supply and the proper functioning of control software and hardware – a condition that meets resistance with bridge owners and authorities due to reliability and durability concerns. A passive aerodynamic-mechanical device described by Starossek and Aslan [3] also includes variable-pitch wings along the sides of the bridge deck. Instead of being controlled by actuators, the pitch of the wings follows the movements of tuned mass dampers inside the bridge deck to which the wings are coupled by means of linkages or gears. With proper tuning, the flutter suppression effectiveness can be similar to that of actively controlled wings. Being a passive device, the safety of the bridge would not depend on energy supply and a control system. It still includes moving parts though, which raises the threshold of acceptance.

Diana et al. [4] examined the effect of various aerodynamic devices rigidly attached to the deck of the envisaged Messina Strait Bridge, including winglets positioned along the edges of the deck. The devices are positioned close to the deck without a distinct vertical or horizontal offset. Hence they form part of the aerodynamic contour of the deck and influence the flow field around it. Only qualitative indications are given in [4] concerning the impact of such devices on the flutter behavior of the bridge and it does not become clear whether and by how much the flutter speed is raised by the examined winglets.

Raggett [5] suggested a pair of wings rigidly mounted above, or slightly outboard of, the two edges of the bridge deck to stabilize the bridge against flutter. The wings are arranged with a distinct vertical offset from the deck so that they are aerodynamically independent of the deck. Liu et al. [6] considered a similar configuration and studied its influence on bridge flutter both analytically and by sectional model wind tunnel tests. When the wings are considered aerodynamically independent of the deck, their impact on the flutter speed of the bridge

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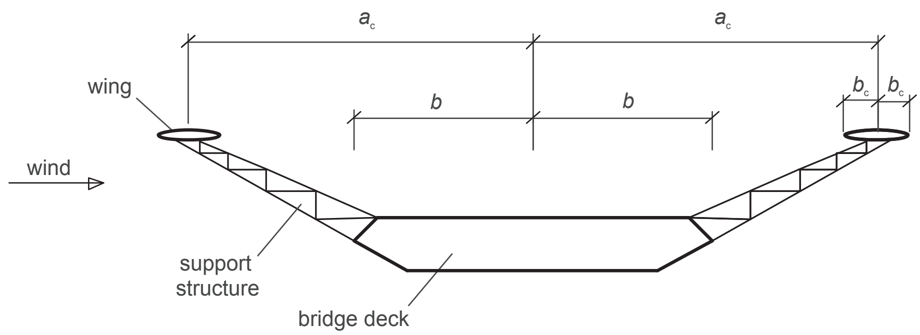

Fig. 1. Bridge with eccentric-wing flutter stabilizer – cross section.

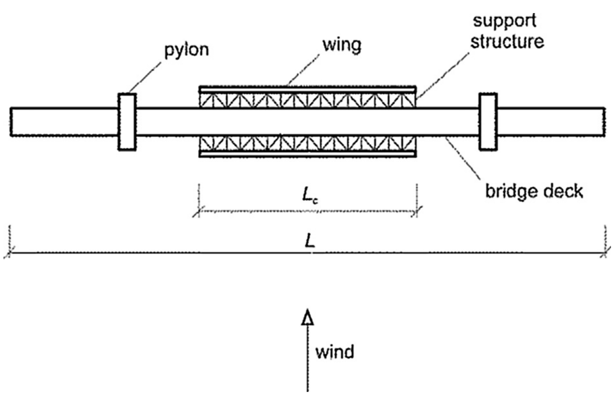

Fig. 2. Bridge with eccentric-wing flutter stabilizer around center of main span – plan view (not to scale).

can easily be assessed analytically as will be outlined below. The authors' own parametric studies show that this impact is small for the configurations described in [5,6], that is, for wings arranged above, or slightly outboard of, the edges of the deck. A significant rise of flutter speed only is produced by wings arranged with large lateral eccentricity.

2. Eccentric wing flutter stabilizer

In view of the development described above, it seems promising, for raising the flutter speed of a bridge, to pursue passive aerodynamic measures that do not include moving parts but, at the same time, are sufficiently effective to eliminate the need for substantial additional structural elements or structural stiffening. The eccentric-wing flutter stabilizer presented in the following meets these requirements.

The device consists of wings positioned along the sides of the bridge deck. An arrangement with wings equally positioned on both sides of the deck is shown in Fig. 1. In certain cases, further discussed below, it is advantageous to provide wings on only one side of the deck or to provide wings on both sides, but to design them differently, that is, with different widths and lateral eccentricities (dimensions $2b_c$ and a_c).

The wings are mounted on transversely orientated support structures that are laterally attached to the bridge deck. Hence they do not move relative to the deck. It can be shown that the flutter suppression effectiveness of the device is high provided the lateral eccentricity of the wings is large. Wings and support structures are envisaged as lightweight components. The wings are aerodynamically shaped such that the lift under inclined flow is large and the resistance is small. Their cross section can be symmetric to a horizontal plane or double symmetric approaching an elliptical shape. The lateral eccentricity of the wings is on the order of the bridge deck width ($a_c/b \approx 1.5$ to 2.5). The width of a wing in direction transverse to the bridge axis is on the order of one tenth of the bridge deck width ($b_c/b \approx 0.05$ to 0.20). The wings are preferably positioned above or below the bridge deck with sufficient vertical offset to avoid aerodynamic interference between the wings and the bridge deck including traffic.

For optimum cost efficiency, the wings are not placed over the entire length of the bridge but only at regions where large vibration amplitudes occur ($L_c < L$). In case flutter is governed by the first symmetric modes of vibration, these regions lie around the center of the main span (Fig. 2). In case flutter is governed by the first antisymmetric modes of vibration, these regions lie around the quarter points of the main span.

In an alternative configuration, a single wing is replaced by a certain number of wings stacked above each other [7,8]. The flutter-suppression effectiveness of such a group of wings is approximately the same as for a single wing provided the sum of the widths of the wings is the same as the width of the single wing and the vertical distance between the individual wings is not too small. A larger effective wing width can thus be achieved at a possibly lower cost.

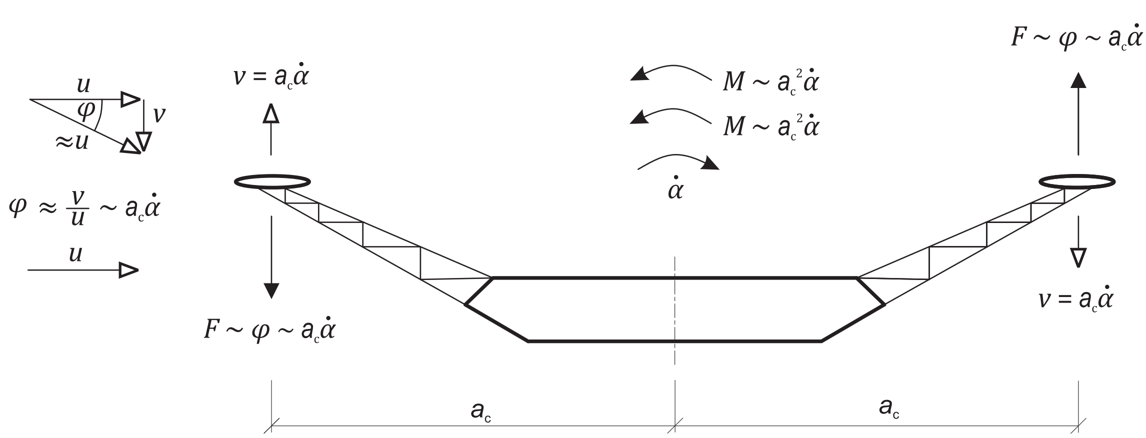

Fig. 3. Reasons of effectiveness – angular velocity.