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Original Research Article

Experimental research of cable tension tuning of a scaled model of cable stayed bridge

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ABSTRACT

The paper describes the idea and the algorithms of a method for reducing the resonant vibration of the cables in a footbridge. The method relies on change of the static tension in chosen cables of the footbridge. The changes in static tension are introduced when resonance vibration occurs. The paper delineates empirical research employed to experimentally verify the numerical prediction. It has been demonstrated that it is possible to select some stay cables in which applicable change in static tension force value ensures amplitude reduction of forced resonance oscillations of any cable of the whole system. The choice of cables and the magnitude of tension change in them were based on the sensitivity analysis of an eigenproblem formulated in accordance with second order theory. The experimental research was designed to demonstrate practical effectiveness of amplitude reduction of stay cable resonant vibration method. A physical laboratory model of the footbridge was built in compliance with dimensional analysis on a scale of 1:10. Operational Modal Analysis (OMA) method was applied to identifying modal characteristic of a footbridge model.

1. Introduction

Cable-stayed structures, especially bridges and footbridges, have comparatively little stiffness, and are therefore very sensitive to vibration. As the supporting cables are usually the most supple elements of the cable-supported structure, restricting the excessive resonant forced vibration in the cables is often important. The great amplitudes of the transversal forced vibration of the cables are due to small damping and the high suppleness of these elements. The small damping is due to the fact that the cables are usually made of materials with small damping, e.g. steel. Usually, the cables are numerous and of various length. This makes it highly probable that the excitation frequency will become resonance synchronized with one of the many natural frequencies connected to the transversal eigenforms of the cables.

The vibration of the cables may be divided into two groups. The first encompasses the resonant vibration of cables caused by excitations directly acting on the length of the cable, e.g. wind, rain, etc. The second group encompasses resonant vibration of cables caused indirectly by vibration of the deck or pylon, which cause the cable anchor points to oscillate and, as a consequence, lead to kinematic forced vibration of the cables. In most cases, the cause of vibration cannot be eliminated as they are connected to the loads inherent in the

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structure's function (e.g. traffic) or are independent of the designers (e.g. climate). Therefore, it is now becoming the more common approach to address not the causes of vibration, but the results – to limit or reduce the amplitudes of the excessive resonant vibration. Usually, *passive devices* are used to reduce cable vibration [1,2]. They are external devices or structure elements built in or attached to the structure, whose function is to create additional motion resistance and, thanks to heightened friction, disperse or absorb the mechanic energy of vibration [3]. Dampers as passive eliminators are characterized by a constancy of parameters (e.g. viscosity coefficients), which cannot be modified during vibration.

It is now becoming more and more common to use *semi-active devices* in reducing the cable vibration in cable-stayed bridges. Among those, there are: semi-active viscotic dampers, semi-active friction dampers, semi-active dampers that change the structure stiffness, and semi-active magnetorheological dampers [1,2], etc. Elements of control systems of semi active equipment can automatically change the dynamic parameters of the system, such as the resistance movement. Semi-active systems of regulation do not destabilize the structure they are affixed to, as they do not add energy to the system; instead, they disperse the energy of its vibration [3].

In the case of long cables, the passive and semi-active devices affixed near the anchoring are ineffective. In such cases, the cable vibration reduction is achieved through cross tying them with lines or stiffer elements. As this is a simple and cheap method, it is the one most often used in vibration reduction when unforeseen resonant vibration of cables occurs [4]. Additionally, special shields, i.e. profiled shielding pipes with internal parallel or spiral ribbing, are used for preventing cable vibration due to wind-rain loads.

In the last three decades, a small number of papers have been published that analyze, theoretically and experimentally, the methods of *active vibration reduction* in cable-supported bridges. Among those discussed is the method of active reduction of cable vibration, which relies on additional forces or vibration which are automatically generated, in real time, in a given point of the structure [2]. The process of active vibration reduction is performed in real time, with a feedback mechanism. After a change in the forces of active adjustment, another measurement is taken to gauge the system response to the excitation. The analysis is repeated until the planned vibration reduction is achieved [2].

A few authors have discussed the use of active vibration reduction in cable-supported bridges. In their 1979 paper [5], Yang and Giannopoulos were the first to consider the use of active vibration reduction in bridge structure under wind load. Using a simple model of a cantilever with a cable, Warnitchai, Fujino et al. [6] showed, both experimentally and analytically, that the vibration connected to the first bending eigenforms of the deck can be reduced using changes in the vibration amplitudes of the cable's anchor point to the deck. Fujino and Susumpow considered the vertical vibration of the cable in the plane of its sag due to the horizontal motion of the foundation and found the method to be effective even for a cable with a small sag [7]. Fujino et al. performed a numerical and experimental analysis of a system consisting of one cable connected to a structure which was a mass with a single degree of freedom. The paper focused on the horizontal cable vibration transverse to the plane of its sag [8].

The algorithms of active vibration reduction presented in the above papers pertain to vibration connected to eigenforms of both the deck and the cables. Achkire [9] presents the analytical and experimental analysis of the method as applied to a single cable and a whole cable structure using Integral Force Feedback (IFF). The motion is performed according to the changing cable tension measured in that anchoring point. Achkire and his co-authors (Preumont, Bossens) give detailed information on the IFF method [10]. In [9], Achkire studied the possible use of flatter vibration reduction in a cable-stayed bridge model in the form of a beam with two cables. The problems of active vibration reduction in civil engineering, including the cable-stayed bridge, are discussed in a comprehensive report of the studies performed between 1997 and 2000 by a number of universities and companies [11].

It must be highlighted that the suggested solutions described above have not yet been implemented in real bridge structures. However, the large number of analytical solutions and experimental studies presented by various authors implies that the application of active methods for reducing vibration in real cable supported bridges will not be long in coming.

2. Aim of the paper

The paper presents the method of resonant stay cable vibration reduction in footbridges and cable-stayed bridges. The method relies on an obvious assumption that it is possible to reduce excessive resonant vibration of any stay cable of a footbridge by change of the static tension in some, purposely selected stay cables [12–14].

The tension tuning method presented in this paper consists in the following. When large resonance vibration occurs in a given cable, a change should be introduced in the static tension of appropriate cables of the system. Usually, the most effective approach is changing the tension in the cable that undergoes the large resonance vibration. However, such a change is not always applicable or even possible. It should also be taken into account that changing the tension of one cable changes the tensions of all the cables in the system. A sensitivity analysis of the eigenproblem of the system makes it possible to determine those cables, in which a tension change will ensure the most effective resonant vibration reduction. It also determines whether the tension should be decreased or increased and what magnitude of the tension change affords the greatest effectivity. The method is made more complex by the fact that the eigenproblem must be formulated according to second order theory. The design parameters in the sensitivity analysis are the tension values in the cables. When the cause of resonant vibration ceases, tensions in the cables return to their initial state.

In the paper, a physical laboratory model of the footbridge, built on a scale of 1:10 is described. Dimensional analysis is also presented in order to explicitly determine the dependence of the magnitude of the elements tested on the model from those occurring in the hypothetical prototype of a footbridge. Some parts of the research were designed to verify compliance