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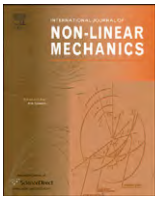

Performance evaluation of shape-memory-alloy superelastic behavior to control a stay cable in cable-stayed bridges

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ABSTRACT

This paper focuses on introducing and investigating the performance of a new passive control device for stay cable in cable-stayed bridges made with shape-memory alloys (SMA). The superelasticity and damping capability of SMA is sought in this study to develop a supplementary energy dissipation device for stay cable. A linear model of a sag cable and a one-dimensional constitutive model for the SMA are used. The problem of the optimal design of the device is studied. In the optimization problem, an energy criterion associated with the concept of optimal performance of the hysteretic connection is used. The maximum dissipation energy depends on the cross-sectional area, the length, and the location of the SMA on the cable. The effectiveness of the SMA damper in controlling the cable displacement is assessed. Furthermore, a study is conducted to determine the sensitivity of the cable response to the properties of the SMA device. The comparison between the SMA damper and a more classical passive control energy dissipation device, i.e., the tuned mass damper (TMD), is carried out. The numerical results show the effectiveness of the SMA damper to damp the high free vibration and the harmonic vibration better than an optimal TMD.

1. Introduction

Over the last few decades, cable-stayed bridges have attracted great interest because of their aesthetics, structural efficiency, and economy. This type of construction has become popular worldwide in recent years, largely due to the rapid progress in design methodology and construction technologies [26]. However, stay cables are critical structural components in these bridges. Owing to their large flexibility, relatively small mass and extremely low damping, stay cables have frequently exhibited large-amplitude vibrations under wind, wind–rain and support motion. Aerodynamic instability of stay cables with extremely large oscillation amplitude under specific rain and wind conditions has been observed in a number of cable-stayed bridges worldwide, and it is a conundrum to civil engineers [29,39]. Therefore, the mitigation of dynamic response quantities induced by environmental loads is of vital importance in terms of safety and serviceability [2,25].

In the past decade, cable vibration control techniques by means of passive countermeasures, including aerodynamic, mechanical and structural means, have been broadly investigated and successfully implemented [17]. In the meantime, researchers have also studied the active vibration control of cables by applying transverse force control and axial stiffness or tension (support motion) control [30,35].

A lot of researches have been conducted to investigate possible damping systems and to determine the optimal size of viscous dampers attached to cables for vibration control. Kovacs [15] was among the first to investigate the maximum attainable damping ratio for a taut cable with a viscous damper. Pachero et al. [3] proposed a “universal estimation curve” of normalized modal damping ratios versus normalized damper coefficient for a horizontal taut string model. This “universal estimation curve” is generalized by Cremona [5] for inclined cables by taking account of the sag-extensibility parameter. A transfer matrix formulation is developed by Xu et al. [40] to estimate the modal damping ratio of inclined cables attached with oil dampers. Main et al. [18] proposed an analytical formulation of a taut cable with an attached damper. Theoretical studies were also carried out to evaluate the increased damping level of a stay cable after installing passive viscous dampers [2]. It was found that there exists an optimum viscous coefficient of the damper by which the modal damping ratio of a stay cable can reach its maximum for a given mode of vibration. However, this passive device suffers from several drawbacks such as the modal damping ratio of the stay cable decreases rapidly when the viscous coefficient deviates from its optimal value. The use of a variable-orifice viscous damper and electrorheological or magnetorheological (ER/MR) fluid damper with semi-active control may be an alternative [38]. However, the semi-active control device is more complicated to implement.

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