Engineering Structures 112 (2016) 162–171

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Movable anchorage systems for vibration control of stay-cables in bridges

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ARTICLE INFO

Article history:
Received 9 June 2015
Revised 30 November 2015
Accepted 11 January 2016
Available online 28 January 2016

Keywords:
Cables dynamics
C–S bridges
Cables' shape functions
Movable anchorages
Vibrations control
Damping systems

ABSTRACT

Cables are efficient structural elements that are used in cable-stayed bridges, suspension bridges and other cable structures. These cables are subjected to environmental excitations such as rain and wind induced vibrations. Rain–wind induced stay-cable vibrations may occur at different cable eigenfrequencies. Therefore, external transverse dampers have to be designed for several targeted cable modes in order to decrease the oscillations amplitude and to finally diminish them. For the analytical study of such problems, one may usually employ finite series or sinusoidal forms. In this paper, the real eigenfrequencies and shape functions are determined and used. This paper aims to study the optimum state and characteristics of such a damper as well as its influence on the cable's vibrations using the real cable modes.

1. Introduction

Cable-stayed bridges have been known since the beginning of the 18th century, but they have been of great interest only in the last fifty years, particularly due to their special shape and also because they are an alternative solution to suspension bridges for long spans. The main reasons for this delay were the difficulties in their static and dynamic analysis, the various non-linearities, the absence of computational capabilities, the lack of high strength materials and construction techniques. There are several studies related to the static behavior [1–8], the dynamic analysis [9–18], or the stability of cable-stayed bridges [19–22].

A significant problem, which arises from practical applications, is the cables' rain–wind induced vibrations. Large amplitude Rain–Wind-Induced-Vibrations (RWIV) of stay cables are a challenging problem in the design of cable-stayed bridges. Such phenomena were first observed on the Meikonishi bridge in Nagoya, Japan [23] and also later on other such bridges, as for instance the fully steel Erasmus bridge in Rotterdam, the Netherlands (1996) and the Second Severn Crossing, connecting England and Wales [24]. It was found that the cables, which were stable under wind action only, were oscillating under a combined influence of rain and wind, leading to large amplitude motions, even for light-to-moderate simultaneous rain and wind action. The frequency of the observed vibrations was much lower than the critical one of the vortex-induced vibrations, while it was also perceived that the cable oscillations took place in the vertical plane mostly in single mode; for increasing cable length however, higher modes (up to the 4th) appeared. Most importantly, during the oscillations a water rivulet appeared on the lower surface of the cable, which was characterized by a leeward shift and vibrated in circumferential directions [23,25,26].

The so-induced vibrations can cause reduced life of the cable and its connection due to fatigue or rapid progress of corrosion.

Several methods, including aerodynamic or structural concepts and tools, have been investigated in order to control the vibrations of bridge's stay cables. Aerodynamic methods, just as change of the cables' roughness were effective only for certain classes of vibration [6]. Another method is the coupling of the stays with secondary wires, in order to reduce their effective length and thereby to avoid resonance [27,28]. This method changes unfavorably the bridge's esthetics.

In C–S bridges, the stays are generally fixed in anchorages on the deck through an anchor head as it is shown in Fig. 1.

The most commonly applied method is the one of external dampers attached transversely to a point of the stay-cable being at some distance from the anchorage [29–31]. Many researchers have proposed passive control of cables with the use of viscous dampers.

The last method is applied in a system of movable anchorage by using a Friction Pendulum Bearing or an Elastomeric Bearing to

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http://dx.doi.org/10.1016/j.engstruct.2016.01.014
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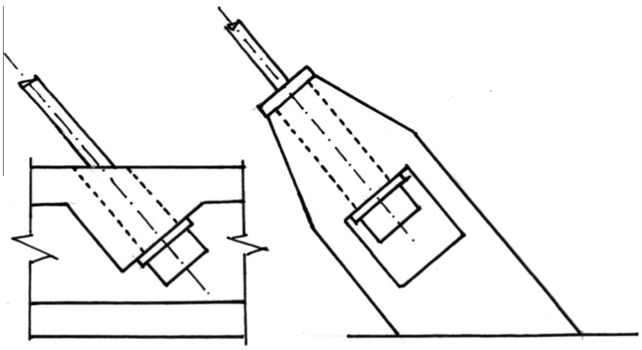

Fig. 1. Anchorage of stay-cables.

replace the conventional fixed support of stay cables or in a system of springs and dampers attached to the point of anchorage [32].

It must be stated at this point that this work does not aim to study the aeroelastic phenomena developed due to the interaction between the cable and rain–wind, or to propose an aerodynamic model for this type of loading.

The present work focuses on the effectiveness of movable anchorage systems consisting of a spring and a damper, where optimum combinations of which are investigated. Thus, the considered loading model is a simple sinusoidal excitation of the form $p(x,t) = p(x) \cdot \sin \omega t$ where $p(x)$ is the load distribution function and ω is the frequency of the excitation.

For the analytical study of such problems, sinusoidal series solutions are usually employed. In this paper the exact eigenfrequencies and shape functions are determined and used.

2. Basic assumptions

a. The elastic line of the cable under study has, due to dead and live loads, a catenary shape with transverse displacement w_o and tensile force T_o (see Fig. 2).
b. Under the action of the dynamic loads $p_y(x,t)$ and $p_z(x,t)$, the cable takes the shape of Fig. 3, with additional displacements u_d, υ_d, w_d and tensile forces T_d.
c. The deformed shape of the cables (under static and dynamic loads) is a catenary curve which, due to its shallow form, can be replaced by a second-order parabola.
d. The static and dynamic tensile forces are connected with the following relations:

$$\begin{aligned} T(t) &= T_o + T_d(t) \\ H(t) &= H_o + H_d(t) \end{aligned} \tag{1}$$

where H, is the projection of T on x-axis.
e. The $\bar{m}(x)$ and $m(s)$ of Fig. 2, are connected through the relation

$$\bar{m}(x) = m(s)\frac{ds}{dx} \tag{2}$$

f. The studied cables are referred to the inclined axis system x–y–z of Fig. 3.

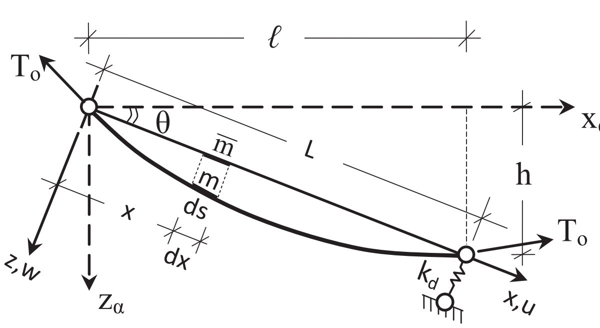

Fig. 2. Cable and reference axes.

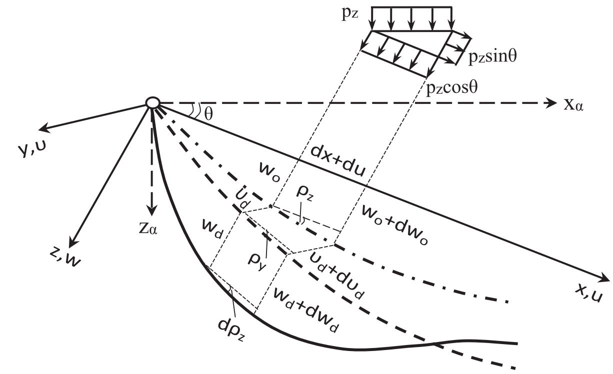

Fig. 3. Deformation of the cable.

3. The equations of motion

3.1. Projection on xz-plane

For a shallow form of the cable, the following relations are valid:

$$\begin{aligned} &\cos\rho_z = dx/ds \cong 1 \\ &\sin\rho_z = dw/ds \\ &\sin d\rho_z \cong 0 \end{aligned} \tag{3}$$

3.1.1. Equilibrium of horizontal forces

Projecting on the xz-plane (Fig. 4) and taking the equilibrium of horizontal forces we obtain:

$$-T\frac{dx}{ds} + T\frac{dx}{ds} + \partial\left(T\frac{dx}{ds}\right) + p_x ds - c\dot{u}ds - m\ddot{u}ds = 0$$

or finally:

$$\frac{\partial H}{\partial s} - c\dot{u} - m\ddot{u} = -p_x(x,t) \tag{4}$$

3.1.2. Equilibrium of vertical forces

Projecting on the xz-plane (Fig. 4) and taking the equilibrium of vertical forces we obtain:

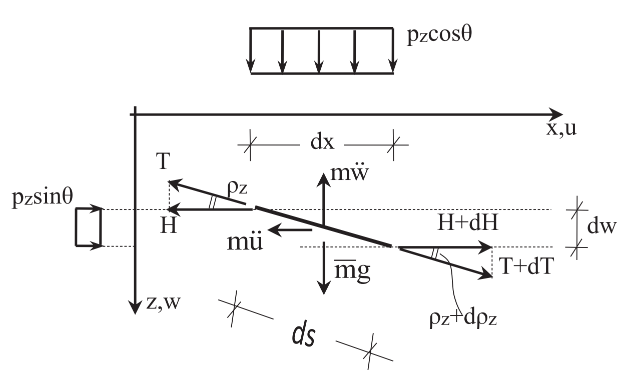

Fig. 4. Projection on xz-plane.