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Dynamics of suspended cables under turbulence loading: Reduced models of wind field and mechanical system

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Abstract

In cables, turbulent wind may cause large amplitude oscillations. The prediction of cable response under wind action requires the use of high-dimensional numerical models either to describe the spatial wind field or to model the expected large cable oscillations. The paper discusses the ability of reduction techniques, for loading and cable descriptions, in reproducing accurately the dynamic response of a suspended cable excited by an artificially generated 3D turbulent wind field. Both the mechanical system and the spatially varying wind velocities are projected on the basis of cable eigenfunctions, retaining in the reduced models few degrees-of-freedom associated with the low-frequency modes. A numerical investigation performed by a refined finite element model provides novel findings on the cable response to wind and permits to demonstrate the effectiveness of the reduced models in the description of cable dynamics.

Keywords: Cables; Wind turbulence; Aerodynamic damping; Finite element models; Reduced order models; Nonlinear oscillations

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1. Introduction

The cable is a simple but important structural element; indeed cables are frequently used to sustain themselves, as in high-voltage transmission lines, or within tall or wide structures, as in the case of guyed towers and suspended/stayed bridges. It is characterized by high resistance, high flexibility and a very small damping, which leads to the fact that a cable is often prone to undergo large amplitude oscillations mainly due to wind loading.

The dynamic response of cables has been thoroughly investigated in linear and nonlinear regime under deterministic and stochastic excitations. Since the behavior is inherently nonlinear and the nonlinearities of this system are very rich, a large amount of papers have been devoted to the study of nonlinear dynamic phenomena in the stationary oscillations ([17,27,22,23]), typically in the presence of some resonance conditions, when these phenomena become relevant ([14,1]).

In these conditions it has been observed that low-dimensional models, obtained by expanding the displacement functions in a suitable bases—like the eigenfunctions of the modes involved in the resonances—are able to capture most of the nonlinear response. Even though a new generation of numerical methods facilitates the general description of solutions for large-dimensional ODEs, efforts are still necessary to select more refined bases able to minimize the nonlinear coupling terms. Within this framework, it has been shown in a recent paper ([11]) that even when the classical approach based on the use of eigenfunctions of the linearized equations of motion is followed, a reduced model with a low number of modes is usually sufficient; indeed such models are able to describe accurately the response of cables, both qualitatively and quantitatively, predicting all the main bifurcated stable branches highlighted by means of a refined nonlinear finite element model (FEM).

Less experience exists when the cable is excited by non-periodic force with varying spatial distribution, such as the case of wind turbulence loading. In this case the degree of approximation of reduced models depends on two conditions: the ability of low-dimensional mechanical system in reproducing the main characteristic of the response and the representation of the loading features through a simple description. This item is tackled diffusely in the literature devoted to the response of linear systems excited by a stochastic process and is, for example, discussed in [2].

In the present work the description of the dynamical response of a non-resonant suspended cable under wind excitation is considered. The aim of the study is mainly to investigate the effect of adopting reduced order models, for both dynamical system and excitation loadings, in the computation of the cable response to wind. In this light, the influence of the characteristics of the turbulent wind field on the cable response was preliminarily analyzed by means of a finite element (FE) based numerical procedure ([19]); more precisely, the effects of the coupled in-plane and out-of-plane turbulence, of the dimensionality of the wind field (1D vs 3D) and of the turbulence coherence were characterized. Based on this investigation, the accuracy of reduced models was analyzed comparing the results of these models to those of a refined FEM, in describing the cable nonlinear response to turbulent loading. To investigate the reduced order modeling of the excitation, the artificially generated wind velocity fields is compared to a reduced one which is represented by a few components obtained projecting the complete wind onto the cable eigenfunctions basis.

The paper is organized as follows. The wind model is discussed first (Section 2) and, on the basis of a few numerical results, wind complete and reduced descriptions are compared