

Uncertainty quantification in the dynamics of a guyed mast subjected to wind load



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ARTICLE INFO

Article history:

Received 20 May 2015

Revised 8 September 2016

Accepted 10 November 2016

Keywords:

Guyed mast

Wind loads

Nonlinear dynamics

Uncertainty quantification

ABSTRACT

A study of the stochastic dynamics of a guyed mast under wind action is reported in the present work. The simplified structural model consists of a beam-column accounting for the second order effect due to axial loads and one inclined guy which is represented by a nonlinear extensible cable. The governing system is discretized with finite elements and a reduced order model is afterwards constructed using a basis of vibration modes.

Both, the load and the structural model are considered stochastic. The wind load is derived from a wind velocity field after the application of the Spectral Representation Method. Since nonlinear structures show special sensitivity to dynamic loads, the reference nominal wind velocity (suggested by the codes) is also considered a random parameter. The guy pretension is a significant parameter in the behavior of guyed structures and its variation is a relevant issue. Furthermore, the bending stiffness can vary due to the structure reinforcements. Since it is not easy to foresee their behavior, an uncertainty quantification study appears necessary.

After performing Monte Carlo simulations, the outcomes are evaluated accounting for each statistical parameter (guy tension, bending stiffness and wind nominal velocity) separately. Also, parameters combinations are studied. Six illustrative cases are reported. The results are shown in different ways (probability distribution functions (PDFs), correlation, exceeding limits, etc.). The stochastic variables have different effects on the statistics of the dynamic response. The guy pretension and the nominal wind velocity are found to be the most influential random quantities. Despite the potential of adverse impact, detailed studies of guyed structures under natural actions, as wind or earthquake, are not frequent. The involved variables are usually uncertain and it can be concluded that an uncertainty quantification study leads to a more realistic approach of the dynamic behavior of the structural system, in particular regarding the sensitivity to some parameters.

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1. Introduction

Guyed masts are extensively employed, e.g. from simple masts to more complex structures, to support devices such as antennas for radio, TV and other types of communication as well as ancillaries (Fig. 1a). This structural typology has clear advantages in the open country, where there are no restrictions on the position of the cable anchors. However, it can also be found in urban areas, due to its low cost compared with other typologies.

Despite the large potential of adverse impact (e.g. fatigue of structural members or affected quality of the transmission in

communication guyed towers), dynamic actions as wind and earthquakes are not addressed in detail with exception of special cases (e.g. [1–4]).

Other authors' works show that guyed structures have special sensitivity to the type and amplitude of the excitation [5–7], even avoiding the resonance effects. After the derivation of the equations of motion of a cable-stayed beam, the in-plane and out-of-plane eigenvalue problems are solved by Wang et al. [8]. Also, nonlinear modes are studied along with the contribution of the coupling term. Then, a stochastic study appears appropriate not only due to the random wind load but also to the randomness of some relevant structural parameters.

A study on this regard, related to mechanical systems is reported by Bellizzi and Sampaio [9]. The smooth decomposition method combined with the Petrov-Galerkin projection for

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Nomenclature

\bar{a}	coefficient (Appendix A)	F_j	force per unit length
c	relative damping coefficient	G	gust factor
\bar{c}	coefficient (Appendix A)	H	chord component of T
\bar{d}	coefficient (Appendix A)	$\mathbf{H}(\omega_n)$	Cholesky transform of $S^0(\omega)$
$f^0(t)$	Gaussian stationary random process	I	importance factor
f_L	nondimensional frequency	I_b	second moment of area of the cross-section
f_X	probability density function of the random variable X	L_c	length of cable chord
i	subindex, c (cable), b (beam)	L_u	length scale of turbulence
k_d	wind direction factor	P_H	guy force component along the mast axis direction
k_{zt}	topographic factor	R_N	normalized power spectrum
l_i	structural element length	S	entropy (information theory)
m_i	mass per unit length	$S^0(\omega)$	cross-spectral density matrix
\bar{m}_i	coefficient (Appendix A)	T	cable pretension force
\bar{p}	coefficient (Appendix A)	$U(z)$	mean wind velocity
\mathbf{q}	modal amplitude vector	V	reference wind velocity
q_z	wind pressure	V_n	nominal wind velocity
\bar{q}_z	wind pressure including $u(z, t)$	Y_c	cable initial configuration
t	time variable	\mathcal{C}	damping operator
$u(z, t)$	fluctuating wind velocity	\mathcal{F}	force operator
u_i	axial displacement	\mathcal{K}_L	linear stiffness operator
v_i	transverse displacement	\mathcal{K}_{NL}	nonlinear stiffness operator
x_i	spatial variable	\mathcal{BC}	boundary conditions operator
z	mast length variable	α	power law parameter
z_g	roughness parameter	ϵ_c	elongation of the cable
A_f	exposed area of mast	Φ_{kn}	random phase angles
A_i	cross-sectional area	ψ_{kn}	random values
A_t	exposed area of mast without holes	σ	standard deviation
C_f	shape parameter	$\Delta\omega$	frequency interval
C_z	coherence coefficient	Φ	admissible function
E	modulus of elasticity	H	random cable pretension
D	displacement	I	random moment of second order of the mast cross-section
\bar{D}	cable sag	V_n	random nominal velocity
F	wind load magnitude		

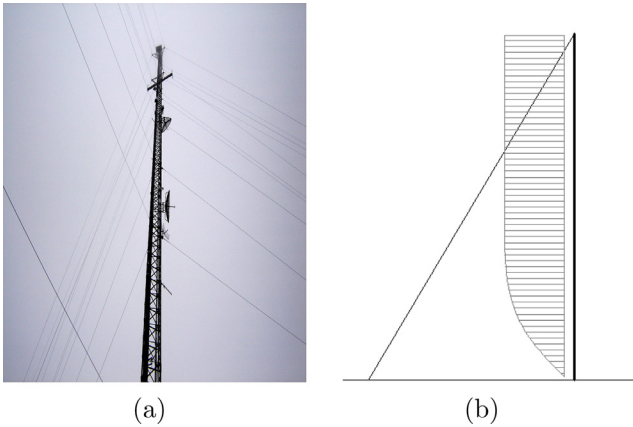


Fig. 1. Guyed mast. (a) Typical guyed tower for mobile signal transmission; (b) reduced model under study.

structure-preserving model reduction is used to analyze second-order discrete nonlinear structural systems under random excitation. Nonlinear mechanical systems under random excitation with homogeneous and non-homogeneous mass distribution were considered.

In the present study, the stochastic dynamics of a guyed mast is analyzed under wind load action. The simplified structural model

consists of a beam-column accounting for the second order effect due to axial loads and one inclined guy (Fig. 1b). The analyzed system includes a stochastic load and also a stochastic structural model through random parameters.

Since the wind load contains energy that interacts with flexible structures, the dynamic response becomes important in the analysis of guyed masts. The mast acts strongly in a nonlinear fashion when the guys vary between slack and taut states.

The wind load is variable in space and time (during an event) and it changes from one event to the other. Hence, a study considering the wind load as a stochastic event, and the analysis of the response of the structure to a variety of events with different nominal velocities (that can be considered stochastic as well), is desirable to understand the behavior of the structural system.

Although the guy pretension is determined at the design stage, it can change during the construction procedure and also along the structure service life with respect to the design value, affecting the system performance and even its stability [10]. As the guy pretension is a significant parameter of the structure, its variation is a relevant issue and the introduction of uncertainty appears adequate.

Also, the column-beam stiffness can be a variable value. For example, various companies can share the use of one structure to install their antennas; this situation requires, in most of the cases, the retrofit of the mast and one strategy consists in the total or partial reinforcement of the legs of the lattice mast. However, the stiffness of the reinforced mast is uncertain due to the construction procedures. Thus, a stochastic treatment of the mast bending stiffness seems indicated.

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