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Nonlinear dynamics of guyed masts under wind load: Sensitivity to structural parameters and load models

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A R T I C L E I N F O

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A B S T R A C T

As the wireless communications spread, there is an increasing demand of antenna supporting structures. Guyed lattice towers (masts) are chosen for economical reasons when there is enough space for their location. Radio and television industries employ structures that can attain heights up to 600 m and communication towers for mobile phones are approximately 60 m though higher structures are also constructed. For the latter, guyed masts are indicated. Nowadays, the demand for more accurate and reliable communication systems poses more stringent structural requirements since to attain high quality in signal transmission, small magnitude motions of the supporting structures are usually needed. The design of these structures is, in general, carried out following the standard codes and simplified models. Despite the large potential of adverse impact, the dynamic actions as wind and earthquakes, are not usually addressed in detail with exception of special cases. In this work, a parametric study on the effect of three relevant parameters (i.e. guy pretension, structural damping, mast stiffness) on a guyed mast is carried out. A typical structure under wind load is analyzed using a finite element model. Two load representations are employed; the mean component is obtained following procedures from standards and is the same for both load models. The fluctuating part of the wind load is then added. In the first model, the turbulent component is represented by a time series obtained by means of the Spectral Representation Method including temporal and spatial correlations. The second model is a simpler approach, in which the temporal component of the wind load is represented through a harmonic function. The resulting transverse displacements and cable tensions histories are analyzed to assess the dynamic structural response. It is observed that the structure is more sensitive to the guy pretension when compared with the other two variable parameters. Also, it was verified that the stochastic load is a more adequate option to model the wind. These two findings are crucial in the design of this type of structures.

1. Introduction

For many years, guyed masts have been used to support antennas for radio, TV and other communication signals. These structures have clear advantages in the open country where there are no restrictions on the position of the cable anchors. Sometimes they are also found in urban areas due to the low cost compared with other typologies. A typical configuration comprises of a lattice mast with triangular cross-section (three legs, horizontal and diagonal members) and several levels of guys (see Fig. 1). The height is variable depending on the application but nowadays it is not exceptional to see 300 m-high towers. The main structural characteristics are the large slenderness of the mast and the taut guys. Dynamic actions are, in general, assumed as quasi-static loads that represent the mean of the dynamic phenomena amplified with factors that account for the dynamics characteristics, following standard codes and recommendations. Since wind loads are essentially dynamic, a strong interaction with this flexible system can be expected.

Research on this subject includes works by Kahla (1993) who employs equivalent beam methods in order to simplify five lattice masts and carries out a static analysis. Wahba et al. (1998) and Madugula et al. (1998) evaluate the behavior of guyed towers and use the finite element method (FEM) to model the mast as a lattice and an equivalent beam-column. They study the influence of ice accretion, guy initial tensions and outriggers (torsion resistors) on the dynamic response of the structure. A finite difference approximation and FEM is proposed by Kewaisy (2001). The dynamics of cable supported structures using a

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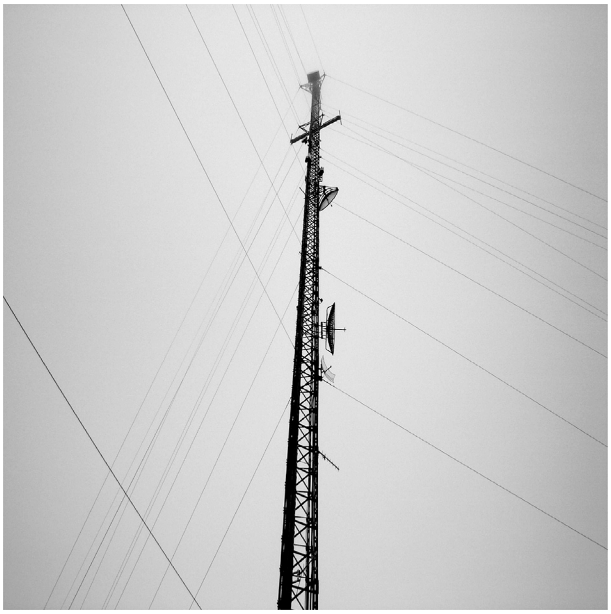

Fig. 1. Typical guyed mast.

generalized FEM is addressed by Desai and Punde (2001). In this work, the free and forced responses of a simple guyed tower model show the efficiency of the approach with a few number of degrees of freedom. An interesting work was reported by Preidikman et al. (2006) in which the dynamic response of guyed masts using different models for cables is tackled. The variation of the stiffness of the complete system using different levels of pretension on the guys is evaluated. Meshmesha et al. (2006) study a guyed tower subjected to static and seismic loadings through an equivalent beam-column analysis based on a thin plate equivalence for lattice structures. The FEM was also employed to solve the dynamics of guyed towers by Shi (2007) and de Oliveira et al. (2007). Lu et al. (2010) employ the principle of harmonic wave superimpose method for the wind velocity simulation, as well as an improved approach that introduces the Fast Fourier Transform (FFT) to simulate the wind velocity time series along the height of a guyed mast. A study regarding the issue of the assessment and structural rehabilitation of a guyed mast was published by Saudi (2014).

In the present work, the dynamics of a guyed mast under the action of wind loads is evaluated. The aim of the study is to analyze the sensitivity of the structural response to changes in three relevant parameters. The lattice mast is modeled with an equivalent beam-column and the guys are represented by nonlinear prestressed cables. The selected parameters are the guy pretension, the structural damping and the mast stiffness. The guy pretension is known to be a critical variable in guyed systems and its impact can be significant to the structure behavior. An appropriate structural damping model is generally a controversial issue and its influence is also assessed in this study. Finally, the need of rehabilitation of this type of structures sometimes leads to a change in the mast stiffness which effect is also evaluated in the present work. The governing system is discretized using FEM, in particular using the software package Algor (Autodesk Inc., 2009). The fluctuating part of the stochastic wind load is found using the Spectral Representation Method (SRM), presented by Shinozuka and Jan (1972). With this methodology, it is possible to account for the spatial and temporal correlations. This load model is used by Venanzi et al. (2015) in a optimization study of cable-stayed masts. In the present work and for the sake of comparison, a simpler approach is used in which the wind dynamics is reproduced by a harmonic function. The statistical analysis of the outcomes allows to conclude that the guyed mast under wind action is more sensitive to the variation of the initial pretension, among all the considered parameters.

2. Structure description and fem modeling

The structure studied in this paper is a typical guyed mast (addressed also by Desai and Punde (2001)) 120 m tall, with four guy levels separated by 30 m, three guys at each level, oriented in vertical planes separated by 120° and two sets of guy anchors contained in each of the three planes (see Fig. 2).

The finite element software ALGOR (Autodesk Inc., 2009) is used to model the structure and solve the nonlinear dynamic problem in the time domain. The mast, fixed at the base, is modeled using an equivalent beam-column with twelve 6-DOF beam elements. Each guy is approximated using twenty 3-DOF two-node pretensioned truss elements. For both element types, large displacements are allowed. The material properties and parameter values used in this work are listed in Table 1. The label "standard case" (SC) denotes the reference case and it is highlighted in bold font.

2.1. *Sensitivity studies*

For various reasons, a guyed mast may suffer changes from its original design. Sometimes, there is public opposition to install antenna supporting structures due to potential environmental effects. This limitation can give place to the installation of new antennas and ancillaries by the structure owner and even the same structure could be shared by more than one company. Usually, some type of reinforcement must be implemented, say changes in the guy tensions, leg reinforcements, etc. A study of these changes impact on the dynamic response is presented herein. Also, since the literature suggests a wide range of values for the damping ratio, this coefficient is within the considered parameters.

2.1.1. *Initial pretension of the guys IP*

As mentioned before, the design guy pretension values may be modified due to some type of retrofitting. Also, the pretension can change during the service life of the structure due to temperature effects, failure of the guy anchors, etc. The initial pretension is given by the tensile force per area of the guys that is needed to attain the desired structural system stiffness. For design purposes, the standard code ANSI/TIA-222-G (ANSI/TIA-222-G, 2009) sets the pretension in a range of 7–15% of the ultimate breaking strength of the guys. In several situations, the initial pretension does not match the design value and may even be out of the recommended range and the whole structure behavior can be compromised. This work is intended to cover the range proposed by the standards. Based on the cross section and material of the guys assumed in the present study, the adopted values of initial pretension (as a force in kN) are 15, 20, 25, 30, 35 kN.

2.1.2. *Equivalent structural damping D*

Rayleigh damping is a usual approach in structural dynamics. Since it attempts to model the real damping of the structure, the use of an appropriate damping coefficient is necessary. As is known, the mass and stiffness coefficients are proportional to two natural frequencies of the structure. In order to obtain them, two steps are followed. First, the initial tension of the cables and the self-weight are applied within a static analysis from which a nonlinear equilibrium configuration is obtained. Second, this deformed configuration is adopted as the new geometry of the structure over which a linear frequency analysis is performed. Harikrishna et al. (2003) found, from experimental measures on a lattice guyed mast, values in the range of 1–3% of the critical damping. The International Association for Shell and Spatial Structures (International Association for Shell and Spatial Structures, 1991) recommends a 3% for bolted unions, the Argentinian standard code CIRSOC (CIRSOC-INTI, 2008), a 2%. It is observed that the values are included in a 1–3% range. In this paper, three values of the Rayleigh damping are considered: 1%, 2% and 3% of the critical damping. The proportional coefficients for the mass and stiffness matrix (*e.g.* Clough and Penzien (1993)) result 0.118 and 0.00070, 0.237 and 0.00144 and, 0.356 and 0.00209, for each