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Seismic assessment of guyed towers: A case study combining field measurements and pushover analysis

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Abstract Telecommunication structures are essential components of communication and post-disaster networks that must remain operational after a designlevel of earthquake. This study provides dynamic field measurements of 138 m guyed tower located at Qussia city, Upper Egypt. In situ measurements of ambient tower vibrations are used to determine the dominant natural frequencies of the tower. The measurements were made using a LMS SCADAS system and four wireless vibration sensors for recording the ambient vibrations of the mast. The tension in the guy wires was measured by mechanical equipment. The dynamic properties of the guyed mast (natural frequencies and mode shapes) were extracted from these measurements. Results of the eigenvalue analysis of numerical models of the tower were compared with the natural frequencies and mode shapes extracted from the in situ measurements. The field measurements were used to update the finite element model. The nonlinear static analysis based on the updated finite element model was carried out. Seismic assessment and comparison between the original and updated models taking into account the deterioration in elements are presented.

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Introduction

Guyed towers are characterized by their light weight, flexibility and often large size. All these characteristics make them very sensitive to time dependent loading such as wind and earthquake loadings. In emergency situations like especially after a severe earthquake, the access to telecommunication and broadcast services is one of the main advantages of using telecommunication masts.

Several published studies have used detailed nonlinear dynamic analysis of tall guyed masts using finite element models, either to predict the response of specific structures or to develop simplified analysis procedures more amenable to design practice. Amiri [1] applied three-dimensional components of the El Centro, Parkfield, and Taft earthquakes to eight guyed telecommunication masts with heights varying

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from 150 m to 607 m. The base shear, vertical force in the mast, and guy tensions were examined. Amiri et el. [2] analyzed a 342 m-tall mast with seven guy levels, and a 607 m-tall mast with nine levels. A single horizontal component from the 1978 Tabas earthquake in Iran was applied. The study included the spatial effect of the distances between the anchorage points (multiple-support excitation). Time histories of lateral tip displacement, axial force in the mast, mast base shear and cable tension were presented. Guevara and McClure [3] considered a 24 m-tall mast with two guy levels, and a 107 m-tall mast with six guy levels. A scaled horizontal component from the El Centro earthquake and one from the Parkfield earthquake were applied. The time delay between the excitations at different anchorage points of the guys and the mast was included in part of the study. Time histories of guy tensions, shear forces, vertical forces, and displacements were presented. Madugula et al. [4] determined the natural frequencies of guyed masts by modelling the mast as truss elements in one model and as beam-column elements in another model. Guys were modeled as cable elements in both the cases. For verifying the models, two triangular steel latticed scale-modeled guyed masts were fabricated and tested on a shake table specially designed to test guyed masts. The experimental results were compared with the results from the finite element analysis. Then, the finite element modeling was applied to six existing towers. Meshmesha et al. [5] introduced an equivalent beam-column analysis based on an equivalent thin plate approach for lattice structures. A finite-element modeling, using ABAQUS software, is used to investigate the accuracy of utilizing the methods in determining the static and dynamic responses of a guyed tower of 364.5 m subjected to static and seismic loading conditions. Then, the results are compared to those obtained from a finite-element modeling of the actual structure using 3-D truss and beam elements. Fantozzi [6] studied the nonlinear analysis of a 607 m guyed tower, located in California region, with and without mass irregularities. The analysis considered both in-phase and out-of-phase base motion for comparison. The results of the nonlinear analyses were compared to those obtained using the equivalent lateral force method introduced by codes. Hensley [7], developed a finite element model of a 120-m tall mast using ABAQUS. The three-dimensional response of the mast was modeled when subjected to two ground motion records, Northridge, and El Centro, with three orthogonal components. Hensley conducted a parametric study on the dominant structural parameters, and the results were used to characterize the trends in the structural response of guyed masts. The recent work of Oskoei Ghafari and McClure [8,9] proposed a simplified seismic analysis procedure based on the evaluation of the equivalent horizontal dynamic stiffness of guy clusters supporting the mast.

In recent years, nonlinear static analyses (pushover analysis) have received a great deal of research attention within the earthquake engineering community. Their main goal is to describe the nonlinear capacity of a structure when subject to horizontal loading with a reduced computational effort with respect to nonlinear dynamic analysis. Pushover methods are particularly indicated for assessing existing structures (Ferracuti et al. [10]).

Mara [11] compared the capacity estimates obtained using the incremental dynamic analysis (IDA) and nonlinear static pushover (NSP) procedures. The analyses consider both geometric and material nonlinearities. The NSP analysis is used to estimate the capacity of the tower under various wind profiles for the transverse and longitudinal wind directions. Zhang [12] presented a detailed study of the post-elastic response of latticed towers combining advanced (highly nonlinear) finite element analysis and full-scale dynamic testing of four tower section prototypes. He performed the nonlinear static and transient dynamic analysis of transmission towers and compared the results with results obtained from the dynamic tests.

Qian et al. [13] checked common software SAP2000 in nonlinear static analysis of complex large span steel structures. The results showed that it is possible to get a good accuracy of the highest load that a complex steel structure can reach through the pushover analysis in SAP2000 [14].

Ambient vibration measurements (AVM) have been widely touted as a practical modal identification technique, mainly due to the easy and relatively inexpensive setup required to perform them, as well as the fact that the dynamic properties are obtained under the actual operating conditions of the structure. Many methods have been developed over the years to extract the dynamic properties of structures from their measured ambient response. It is a simple yet robust technique, known as Frequency Domain Decomposition (FDD), which has gained wide popularity in the last decade (Brincker et al. [15,16]; Brownjohn [17]; Gentile and Saisi [18]; Lamarche et al. [19]). Refinements of this method have led to the development of the Enhanced Frequency Domain Decomposition method (EFDD).

Although the ambient vibration measurements (AVM) have recently been extensively applied to large civil structures such as bridges, dams, high rise buildings and large grandstands, there are a few works concerning dynamic assessment of guyed towers using field measurements. Oskoei Ghafari et el. [20] provide a case study of experimental validation using ambient vibration measurement (AVM) tests for evaluating the accuracy of numerical studies. These tests were done on a 111.2-m tall mast owned by Hydro-Québec and located at St. Hyacinthe, Québec, Canada. The dynamic properties of the guyed mast extracted from AVM records are compared with those obtained from nonlinear finite element analysis models. The first few natural frequencies of the structure obtained from adjusted finite element models are compared with those obtained by AVM identification. A series of earthquake simulations on the ‘‘verified’’ model explore the influence of cable tension variability on a few salient tower response indicators.

In this study, a full scale dynamic test using AVM of a 138 m guyed tower was conducted. An updated 3D finite element model was then built taking into consideration the structure's parameters and atmospheric corrosion of the steel sections. Finally, the pushover analysis was carried out for the tower models, the updated models and the initial design model according to manufactured requirements. The comparison of the results is presented.

Tower geometry

The latticed steel tower was constructed in 1966. It is squared with panel dimensions of 1.15 m × 1.15 m. It is supported laterally at five stay levels attached at three ground anchor groups at distances 18.0 m, 76.8 m and 136.6 m from the tower axis (Fig. 1a). Each level is held by four guys with interval of 90

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