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Structural assessment of a guyed mast through measurement of natural frequencies

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ABSTRACT

The structural investigation of 90 m. guyed communication tower was conducted using experimental and numerical analyses. Being unused for more than one decade, the structural evaluation was needed for recent loading configuration. As part of the investigation plan, a vibration based finite element model was built to predict the measured natural frequencies of the mast. The structural integrity of the tower was studied under expected dead and wind loading through non-linear analysis. The provisions of ANSI/**TIA-222-G** standards were employed to apply loadings and perform members' checks. The field inspection and vibration measurements of the natural frequencies provided real properties of the full-scale mast. This improved the accuracy of the produced 3D finite element model of the existing guyed mast. The significant parameters in calibrating the model were the inertial properties of the mast members and the modulus of elasticity of pre-tensioned guy cables. Successful structural rehabilitation strategy was finally developed based on the analysis results. This paper presents an exceptional study for the experimental identification of the dynamic properties of a full-scale guyed mast in terms of its natural frequencies. The dynamic behavior of the guyed mast was conceived through the spectral analysis of the measured ambient response and the finite element model calibration. The final reliable finite element model enhanced an effective structural assessment.

1. Introduction

These days, almost all communication is wireless in nature. Telecom towers form one of the most fundamental components of any telecom network which is used extensively for wireless communication. Guyed masts are telecom towers that have guy wires, which are tensioned cables used to stabilize the tower. The guyed mast is recognized as a slender structure that has highly non-linear geometrical behavior [1,2]. This nonlinearity is due to the increase in axial stiffness of guy cables with increasing tension and the decrease in the bending stiffness of the mast due to the increase of compression forces [3]. Structural analysis of guyed masts mostly relies on the analytical methods in regard to the complexity of applying full-scale testing. Simplified modeling techniques were adopted to perform wind response analysis [4,5]. Finite element models were developed to perform dynamic analysis. Both frequency domain and time domain methods were applied to guyed masts subjected to turbulent winds [6,7]. The response due to guy rupture was predicted using analytical studies [8,9]. Analytical investigations have been conducted on existing towers to study the vibration behavior under ice loading [10] and also for seismic loading [11–14]. It was clearly emphasized that careful validation of analytical models with full scale test results is still lacking. However, few studies carried out experimental investigations from tests applied to scaled models in wind tunnels [15,16].

Finite element method allows the application of various analyses to investigate the performance of existing structures under different loading conditions. Experience has, however, shown that finite element models often fail to predict the actual properties of structures as the fundamental natural frequencies [17]. Vibration measurements on full scale masts can enhance the accuracy of a finite element model through calibration with its measured properties. Such technique has been extensively applied to large civil structures as bridges, dams, high rise buildings, and large grandstands [18–22]. In this paper, the identification of natural frequencies through measuring the ambient response of a full scale guyed mast was performed. A detailed 3D finite element model was then built to simulate the measured dynamic properties. Structural parameters were tuned to produce the global modes interpreting the experimentally identified peaks in the spectral analysis. The modal behavior was investigated in the range 0–15 Hz. The fundamental natural frequency of the mast was identified at 1.25 Hz. The mast shown to exhibit very close flexural modes in the main horizontal orthogonal directions. The most

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significant parameters in the tuning process were the inertial properties of the steel members of the mast, and the modulus of elasticity of the guy cables. It was deduced that the members of the mast are in condition state of Level III rust according to ANSI/EIA/TIA-222-G standard. Also, the existing cables were found to be wire ropes with fiber core type, which are not normally used as permanent structural elements of masts [23]. The condition of the foundations is satisfactory as indicated through the field visual inspection. The non-linear analysis was performed under dead and wind loads. The structural capacity of all members was calculated. The most critical members were found to be the main legs of the mast as their structural capacity is deficient to carry the proposed antenna loads. According to the mentioned standard, an ultimate strength aspect was adopted to apply loads and check members. The final rehabilitation plan suggested the reinforcement of the main legs and the replacement of the guy cables by galvanized steel guys. In addition, all the members should be grinned to remove rust and be coated by a cold galvanizing compound before reinforcement work. The applied technique was found efficient and successful in modeling and investigating the structural adequacy of the guyed mast. It is believed to be cost effective solution for owners, where the realistic modeling of the existing structure provides reliable decisions for strengthening or future modifications.

2. The guyed structure

The guyed mast was constructed in 1982. The structure components are shown in Fig. 1. The geometrical properties were taken from the original design drawings (Fig. 2). The 90 m high steel mast is square in plan of size 90 cm × 90 cm for the full height from ground level and was built-up using four steel angles of size L 90 × 90 × 9 mm as verticals. These leg members are interconnected by bolted connections. Steel angles of size L 60 × 60 × 6 mm constitutes the inclined bracing at 200 cm spacing on all faces. Welded steel angles of size L 30 × 30 × 3 mm at 30 cm spacing on one face with 2 verticals of size L 50 × 50 × 5 mm are used as a ladder. The mast is supported by guys (0.75 in. diameter) at level 21 m and (1 in. diameter) at three levels 41, 61, and 82 m levels from ground. Each level is held by three guys with interval of 120° in plan between them. The guys are located at four different levels and aligned in a single vertical plane are anchored to two reaction blocks. The two lower guys are anchored to a reaction block at 20 m distance from the center of the mast. The reaction block at 40 m distance from the center of the mast anchors the two higher guys. The mast is supported on a reinforced concrete foundation with a fixed arrangement as shown in Fig. 1.

3. In situ vibration measurement

The ambient dynamic response was measured using 5 uniaxial piezoelectric accelerometers (4 PCB Model 393B04 and 1 B&k Model 4378) with high sensitivity. Actual sensitivity of each accelerometer was determined using Calibration Exciter Type 4294 from Brüel & Kjær. The measurement system consists of PULSE analyzer Type 3560/B from Brüel & Kjær, a notebook with LAN interface, PULSE software and IDA-based data acquisition front-end hardware with 5 input channels. The test grid consists of eight locations at the main legs of the shaft as illustrated in Table 1. Two reference

Fig. 1. The components of the guyed mast.