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Operational Modal Analysis on a Full Scale Self Supported Tower

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ABSTRACT

This paper presents an operational modal analysis (OMA) of a full scale existing 100 m self-supported tower. The investigation was carried using seismic accelerometers which are located on different positions to capture the mode shapes. The dynamic behavior of the self-supported tower was carried via spectral analysis of the measured ambient response. The mode shapes of the full scale tower were identified.

Introduction

Telecommunication towers play a vital role in our daily lives, the majority of communication are wireless. Towers are used to transmit the signal between senders and receivers, that transmission is extremely important for critical emergency services (e.g. police stations, ambulance system, …etc.) in order to be capable of playing their vital role across the globe. Many studies over the years been carried to study the effect of dynamic effects on telecommunication towers due to their vital role.
On another hand, the majority of the studies investigated the towers analytically by building a finite element model (FEM). The FEM would predict the behavior of the structure and assuming the model would provide accurate characterization. However, it is clear that the results aren't always satisfying. Therefore, field tests are required to assess the validity of the FEM.
Some researches took that approach for different structures and carried out experimental investigations either from existing structures or scaled their models in order to be fit for the purpose or lab size [1,2,3]. That technique also have been applied into different civil structures (e.g. bridges [4,5,6,7], high rise buildings [8], towers [1, 2, 3, 9, 10], monuments [11, ,12, 13]. In this research the identification of natural frequencies was carried by measuring the ambient response of a full scale self-support tower. The experimental investigation took place in the range between 0-34.95 Hz.

The fundamental natural frequency of the tower was identified at 0.53 Hz. In structural dynamics, system identification methods are applied in order to identify experimental models that describe the true behavior of a structure. In Operational

Modal Analysis (OMA), the structural identity of natural frequencies, mode shapes and damping are extracted from experimental models, which are identified from output only data. One of the main advantages of OMA that the structure is tested in its normal operational conditions.

The basics that form OMA are three assumptions: linear dynamic behavior, stationary white noise excitation where no forced excitation takes place and a significant contribution of the modes of interest to the measured response quantities.

The Self-supported Tower

The tower was constructed over three decades ago located in Cairo, Egypt. The tower is shown in figure (1) & tower levels and dimensions are shown in figure (2). The tower is of 100 m height steel self-supported tower of an equilateral triangle cross section, at base of the tower the equivalent triangle is of dimensions of 9 m while at the top the equivalent triangle is of dimensions of 1.35 m. The lower part of the tower starting from the ground level consists of three main legs (vertical) of steel hollow pipe cross sections with of diameter 130 mm and 10.5 mm thickness. The connection between the leg members is by bolted connections. Steel hollow pipes cross section bracings with dimensions of diameter 75 mm and 5.5 mm thickness. At the base the tower is supported on a reinforced concrete foundation.

The tower foundations

Tower base

The 100 m self-supported tower

Fig (1): The components of self-supported tower

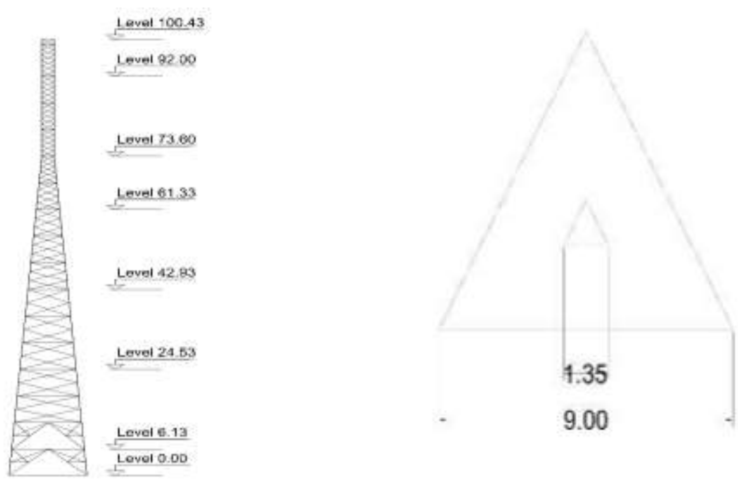


Fig (2): Geometric Properties of the self-supported tower

Measurements setup

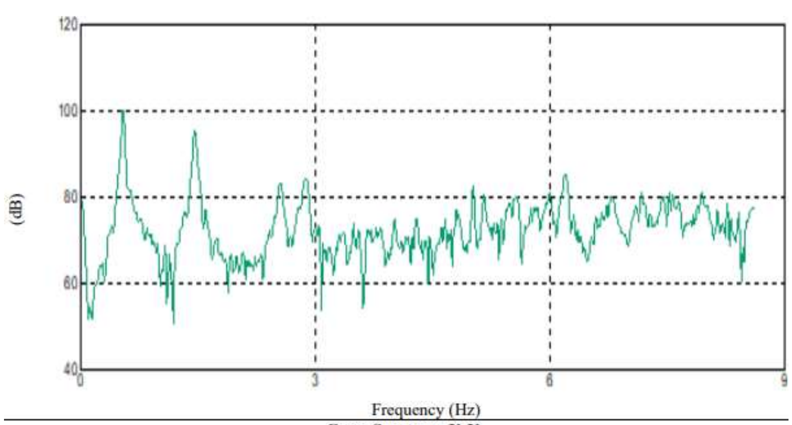
The response of the tower was measured using sixteen uniaxial piezoelectric accelerometers of type PCB Model 393B04 (sensitivity 1000 mV/g). PULSE LAN-XI analyzer with dynamic range of 160dB, a notebook with LAN interface, PULSE software developed by Brüel & Kjær and data acquisition front-end hardware with eighteen input channels. The measurements are carried in one setup, the measurements locations are shown in the test grid consists of sixteen locations on the main legs of the tower as shown in (Table 1). Sixteen accelerometers were used together to measure 32 DOF at the test points. Acceleration was recorded in two horizontal directions (X and Y) for three different levels. The accelerometers were mounted the tower by magnetic bases. One data setup was executed to identify the natural frequencies of the using OMA principles. In all cases the sampling frequency on site was 512 Hz and total duration of 230 seconds.

Table 1. Measurements locations in the test grid consists of sixteen locations on the main legs of the tower

Chanel No.	Height (m)	Test Grid Point	Direction	Remarks	Setup No.
Chanel 1-1	6.13	21	X	-----	
Chanel 1-2	6.13	21	Y	-----	
Chanel 1-3	6.13	23	X	-----	
Chanel 1-4	6.13	23	Y	-----	
Chanel 1-5	6.13	22	X	-----	
Chanel 1-6	6.13	22	Y	-----	
Chanel 2-1	73.60	31	X	-----	
Chanel 2-2	73.60	31	Y	-----	
Chanel 2-3	73.60	33	X	-----	Setup 1
Chanel 2-4	73.60	33	Y	-----	
Chanel 2-5	73.60	32	X	-----	
Chanel 2-6	73.60	32	Y	-----	
Chanel 3-1	100.45	41	X	-----	
Chanel 3-2	100.45	41	Y	-----	
Chanel 3-3	100.45	43	X	-----	
Chanel 3-4	100.45	43	Y	-----	

System identification

PULSE labshop [14] was used to record the data during the test. As for signal processing it was carried via ARTeMIS extractor [15]. Before system identification all signals are down sampled and filtered. The filter is applied in both the forward and reverse direction in order to remove low frequency components due to noise contamination. After that the spectral density matrices are estimated at discrete equally spaced frequency lines. This is a radix-2 number due to the use of Fast Fourier Transform (FFT). Overlap between data segments is set to 66.67%. The frequency resolution used 0.01707 Hz. The measurement data were recorded in the range of 0-256 Hz. The filtered signals are resampled at 8 Hz in this analysis. Typical coherence functions between spectra at the levels of 6.13 and 73.6 m for X and Y directions as shown in figure 3. Good correlation is obtained from the analysis. Peak picking method is used in order to identify natural frequency. The theory behind it is that the frequency response function goes through an extreme value around the natural frequency. In OMA the frequency response function is replaced by the auto spectra and cross spectra of the output-only data [16]. The spectra of acceleration showed the resonant frequencies (spectral peaks) at 0.532, 1.428, 4.249, 5.012 and 6.196 Hz.



Cross Spectrum X-X

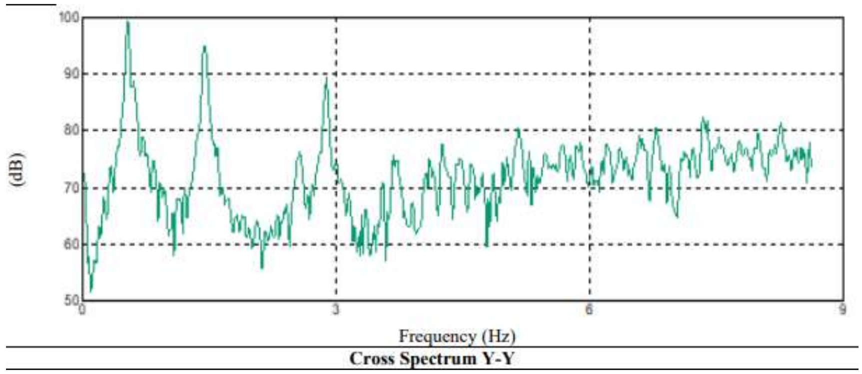


Fig (3): Results of Signal Processing

Conclusions

The paper shows OMA study of an existing self-supported tower. Setting up the test grid and mounting the sensors along the height of the tower was a real challenge; as no platforms do exist along the tower, a ladder wasn't presented along the whole tower height. All the mounting of sensors and attachment of cables to data acquisition units was performed on the tower's main legs. This part of the test lasted for over 20 hours reflecting the difficulty of carrying the equipment to the required heights and installing them. There was a need to secure the cables at the tower's main legs for every single sensor cable, also for all the heavy coaxial cable (RG-58) connecting the LAN-XI units to the controlling laptop. This type of configuration allowed the capture of global bending modes in both main directions of the telecommunication tower. Five bending modes were successfully identified using EFDD, as shown in tables (2 & 3). This identification process shows reliable data. These results can be reliably used in updating a finite element model for the tested tower, where further structural dynamic studies are required.

However, more setups were needed to obtain more detailed mode shapes.

Table 2: Modal results identified using EFDD

Mode No.	Description	Frequency Identified Using EFDD (Hz)	Damping Ratio EFDD (%)
1	First Bending (Y-Y)	0.532	2.294
2	Bending (Y-Y)	1.428	0.7764
3	Bending (Y-Y)	4.249	0.3107
4	Bending (X-X)	5.012	0.2372
5	Torsion	6.196	0.3571

Table 3: Identified Bending Mode Shapes

Natural Frequency = 0.532 Hz
Damping = 2.294 %
Bending about Y-axis

Natural Frequency = 1.428 Hz
Damping = 0.7764 %
Bending about Y-axis

Natural Frequency = 4.249 Hz
Damping = 0.3107 %
Bending about Y-axis

Natural Frequency = 5.012 Hz
Damping = 0.2372 %
Bending about X-axis

Natural Frequency = 6.196 Hz
Damping = 0.3571 %
Torsion

References

1. Wahba Y.M.F., Madugula M.K.S., and Monforton G.R., "Dynamic Response of Guyed Masts", Engineering Structures, Vol. 20, No. 12, pp. 1097-1011 (1998)
2. Wahba Y.M.F., Madugula M.K.S., and Monforton G.R., "Effect of Icing on the Free Vibration of guyed Antenna Towers", Atmospheric Research, Vol. 46, pp. 27-35 (1998)
3. Wahba Y.M.F., Madugula M.K.S., and Monforton G.R., "Evaluation of Non-Linear Analysis of Guyed Antenna Towers", Computer and Structures, Vol. 68, pp. 207-212 (1998)
4. Abdel-Ghaffer, A.M., Scanlan, R.H., "Ambient vibration studies of Golden Gate Bridge. I: Suspended Structure", J. of Engineering Mechanics, ASCE, Vol 111, No 4, pp. 463-482 (1985).
5. Okauchi, I., Miyata, T., Tatsumi, M. and Sasaki, N., "Field vibration test of a long span cable-stayed bridge using large exciters", J. of Structural Engineering & Earthquake Engineering, Tokyo, Vol. 14, No. 1, pp. 83-93 (1997).
6. Chuna, A., Caetano, E. and Delgado, R., "Dynamic test on large cable-stayed bridge", J. of Bridge Engineering, ASCE, Vol. 6, No. 1, pp. 54-62 (2001).
7. Ren, W.X., Zhao, T. and Harik, I.E., "Experimental and analytical modal analysis of a steel arch bridge", J. of Structural Engineering, Vol 130, No. 7, pp. 1022-1031 (2004).
8. Brownjohn, J.M.W., "Ambient Vibration Studies for System Identification of Tall Buildings", J. of Earthquake Engineering & Structural Dynamics, Vol 32, pp. 71-5 (2003).
9. Saudi, G. "Structural Assessment of a Guyed Mast Through Measurement of Natural Frequencies", Engineering Structures (2014)
10. Saudi, G. and Kamal, H., "Ambient Vibration Testing of Full-scale Wind Turbine Tower", Tenth International Conference on the role of engineering towards a better environment, 15-17 December, Alexandria, Egypt (2014).
11. Jaishi, B., Ren, W.X., Zong, Z.H. and Maskey, P.N., "Dynamic and seismic performance of old multi-tiered temples in Nepal", J. of Engineering Structures, Vol. 25, No. 14, pp. 1827-1839 (2003).

12. Dyck, C., Ventura, C.E., "Ambient Vibration Measurement of Heritage Court Tower", IMAC 18: Proceedings of the International Modal Analysis Conference (IMAC), San Antonio, Texas, USA, February 7-10, 2000
13. Kyung-Won, M., Junhee, K., Sung-Ah, P. and Chan-Soo, P., "Ambient Vibration Testing for Story Stiffness Estimation of a Heritage Timber Building", The Scientific World Journal, Vol 2013, Article ID 198483 (2013).
14. PULSE, "Labshop, Version 11.2.2", Brüel & Kjær Sound and Vibration Measurements A/S (2006).
15. Structural Vibration Solutions ApS., ARTeMIS Extractor, User's Manual, Denmark (2019).
16. Bendat JS, Piersol AG, Engineering applications of correlation and spectral analysis, John Wiley and Sons (1993).