9th International Operational Modal Analysis Conference
iomac
July 3 - 6, 2022
Vancouver, Canada

FINITE ELEMENT MODELLING AND OMA OF THE "LABORAL CITY OF CULTURE" TOWER

F. Pelayo[1], N. García-Fernández[2], M. Aenlle[3],

[1] Asociate Professor, University of Oviedo, fernandezpelayo@uniovi.es
[2] PhD Student, University of Oviedo, garciafnatalia@uniovi.es
[3] Professor, University of Oviedo, aenlle@uniovi.es

ABSTRACT

The building of the Laboral City of Culture is located in the city of Gijón (Spain) and it was built in the 1950s. The tower of this building is reminiscent of the famous Giralda tower in Seville and the Lighthouse in Alexandria. The tower has a height of 130 m and a square shape 12 x 12 m. In order to have data about the dynamic behaviour of the tower at a present state, operational modal analysis (OMA) was applied in order to identify its modal parameters (natural frequencies, mode shapes and damping ratios). However, due to the difficulty of measuring the response of steel cross 25 meters height located at the top of the structure, the modal identification is quite an intricate task. With the aim of improving the understanding of the dynamic behaviour of the tower, a detailed 3D finite element model (FEM) was assembled in ABAQUS. The correlation between the experimental and the numerical modal parameters are presented in this paper and it is concluded that the FEM model leads to a satisfactory identification of all the mode shapes of the structure.

Keywords: Heritage buildings, Finite element model, OMA. Model-updating

1. INTRODUCTION

The Laboral City of Culture is a building located in the city of Gijón (Spain) and it was built between 1946 and 1956. It is the most important architectural work constructed in the twentieth century in
Asturias. The origin of the building was a serious accident occurred in an Asturian mine in the mid1940s due to a firedamp explosion [1, 2]. The government of the time decided to construct an orphanage to attend around 1000 orphaned students whose parents were victims of accidents in mining. The building was transformed during its construction into a Technical College under the name of “Universidad Laboral de Gijón” [1, 2].

Figure 1. “Laboral City of Culture” Building (Gijón-Spain)

In 2001, the regional government of the Principality of Asturias decided to transform the building in order to give it a new life. The project became a reality in 2007 and the building was then renamed as “Laboral City of Culture” [2]. The Tower (Figure 2) is perhaps the most characteristic building of the Laboral City of Culture, as it serves to identify the City of Culture at first sight.

In this work, a detailed finite element (FE) 3D model of the structure, which was correlated with the OMA tests performed in the tower, is presented. Moreover, the FEM was used to improve the understanding of the dynamic behaviour of the tower, which was necessary to identify local and global modes of the structure.

Figure 2. Views of the Tower (from https://jenaroartirusuarezprendes.webs.tl)

2. FINITE ELEMENT MODEL OF THE TOWER

2.1. The structure

With a heigh of 130 mn, the tower is a 3D concrete frame structure and it has 21 floors (Figure 3). Up to 4th floor the vertical elements are 4 concrete big columns located at the corners and a central reinforced concrete column (Figure 3). From 5th floor to 17th floor all the columns are made of reinforced concrete and there are 4 columns at the corners, 8 columns at the sides (2 in each side) and a central column. From 17th floor to the top; the structure consists only of 4 reinforced concrete columns (Figure 3). Its marvellous vantage points on the 14th, 17th and 18th floors provide tourists and visitors with magnificent views of La Laboral's surroundings. A Steel cross structure 25 meters long is located on the top of the tower.

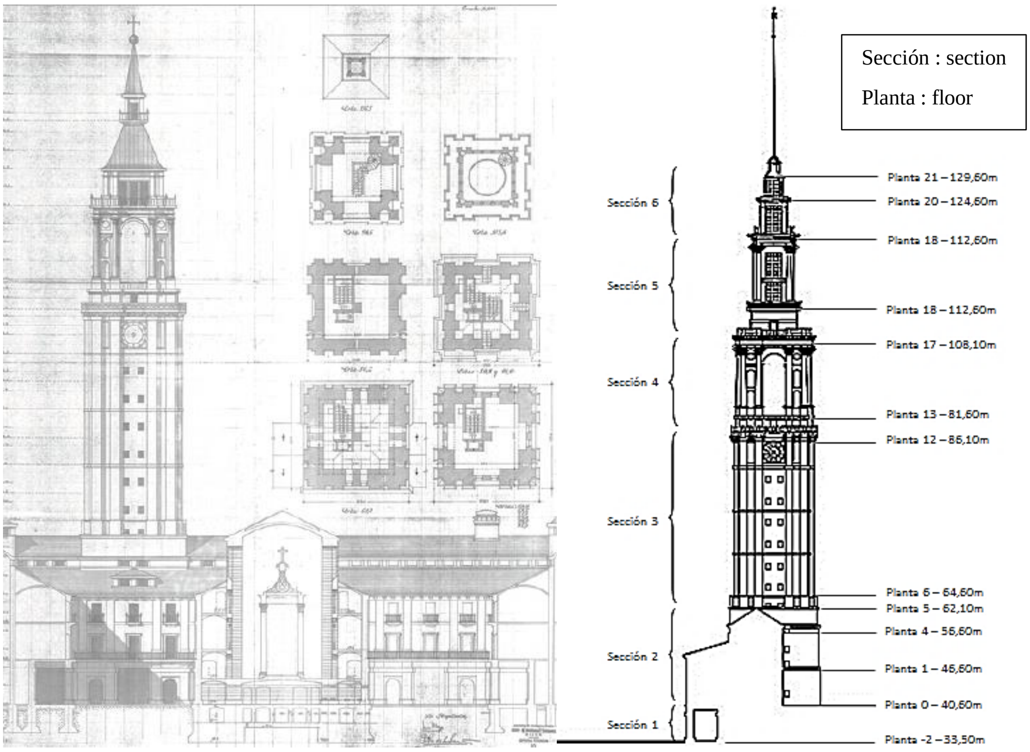


Figure 3. Original design and skecth of the different sections of the tower (from repository of Fernando González Verdesoto)

To modelling of the tower structure was quite complex due to the impossibility of obtaining the drawings used in the building process. The drawings of original design (see Figure 3) were available but they underwent several modifications before and during the construction process. Only the AUTOCAD drawings based on recent measurements in the structure, together with some photos corresponding to the construction of the structure, were used to assemble the finite element model. However, some important details were still missing and many assumptions about dimensions, materials, mechanical properties, etc., were considered. Some details of the different sections are presented in Figure 4.

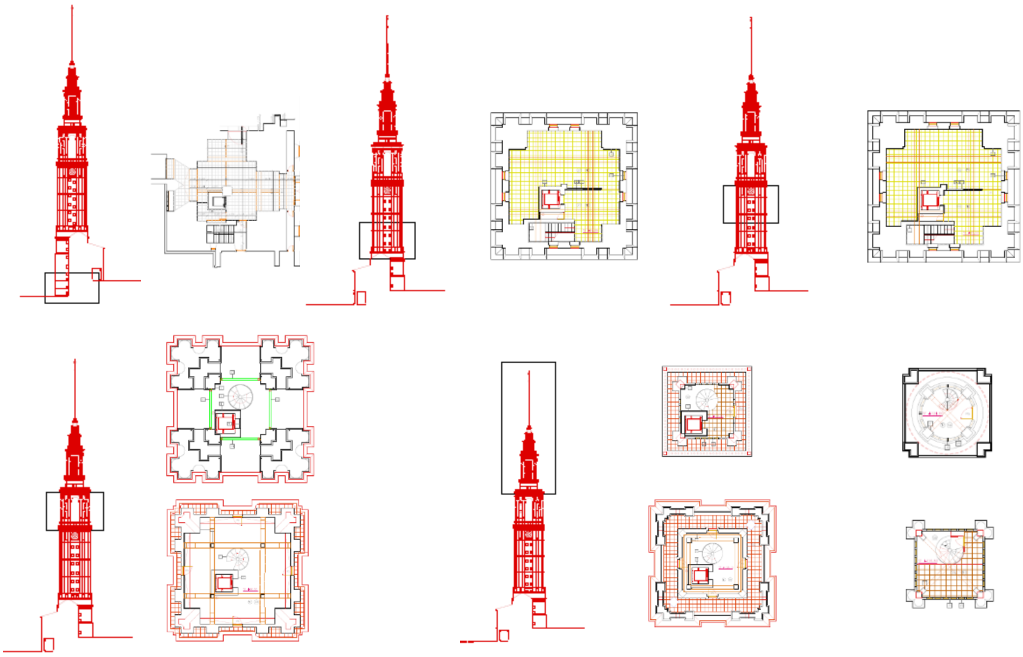


Figure 4. Different sections of the tower strcuture

2.2. The FE Model

Due to the complex geometry of several structural elements (columns, floors, walls, steel cross, etc.), a 3D finite element modellization was selected for this structure. The different sections presented in Figure 3 were modelled in different parts, in order to take easier control of the geometry and the mechanical properties of the materials), and then assembled in ABAQUS CAE []. 3D brick elements were used to mesh the sections 1 to 5 of the tower, whereas section 6 and the steel cross were meshed with 3D wegde elements. In order to get a good quality mesh, a large number of carefully partitions were made. The finite element model is presented in Figure 5

Figure 5. Details of the FEM of the Laboral city of Culture Tower.

The natural frequencies and mode shapes extracted from the finite element model are presented in in Table 1 and in Figs. 10 to 12 (Section 4).

3. OMA OF THE TOWER

In the OMA tests, the response of 21 DOF's in floors 8,12, 17 and 10 (see Figure 3) were measured with uniaxial and triaxial Guralp acceleration sensors. Two Guralp digital acquisition systems, synchronized via an internal cable, and with a total of 24 channels, were used to acquire the experimental responses using the Scream software. (see Figure 3). An skecth of the measurement layout and the location of accelerometers are presented in Figure 6. The sampling frequency was 25 Hz and the acceleration responses were recordered for approximately 24 hours.

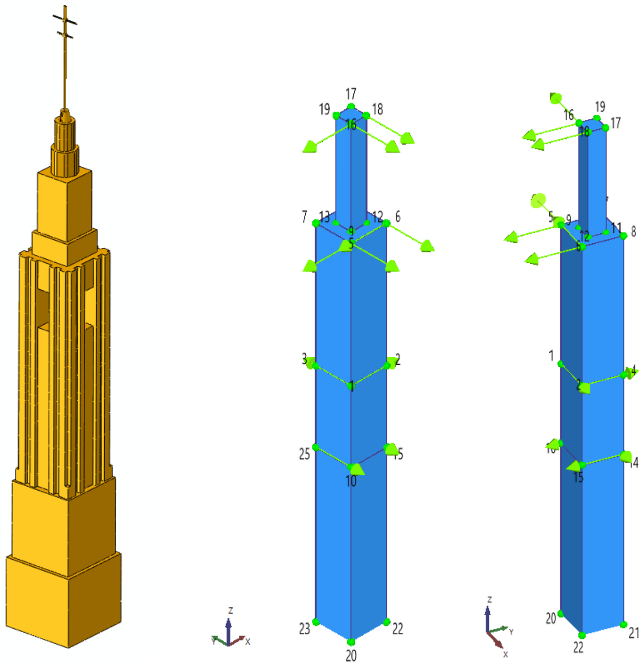


Figure 6. Test setup.

During the OMA tests, the temperature changed in the range 7º-19ºC (see Figure 8). The wind speed (slower during evening and night) during the OMA tests is also presented in Fig. 8, where 0 hours corresponds with the start of the data acquisition: 12:00 PM.

In order to analyze the effect of temperature in natural frequencies of the tower, the Short Time Fourier Transform were applied to the data, the results being presented in Figure 8. Yellow dashed lines correspond to constant frequency. It can be observed that natural frequencies decreases slightly with decreasing temperature. The results presented in Table 1 were estimated with the first 4 hours of testing. This period also coincide with the higher wind speeds.

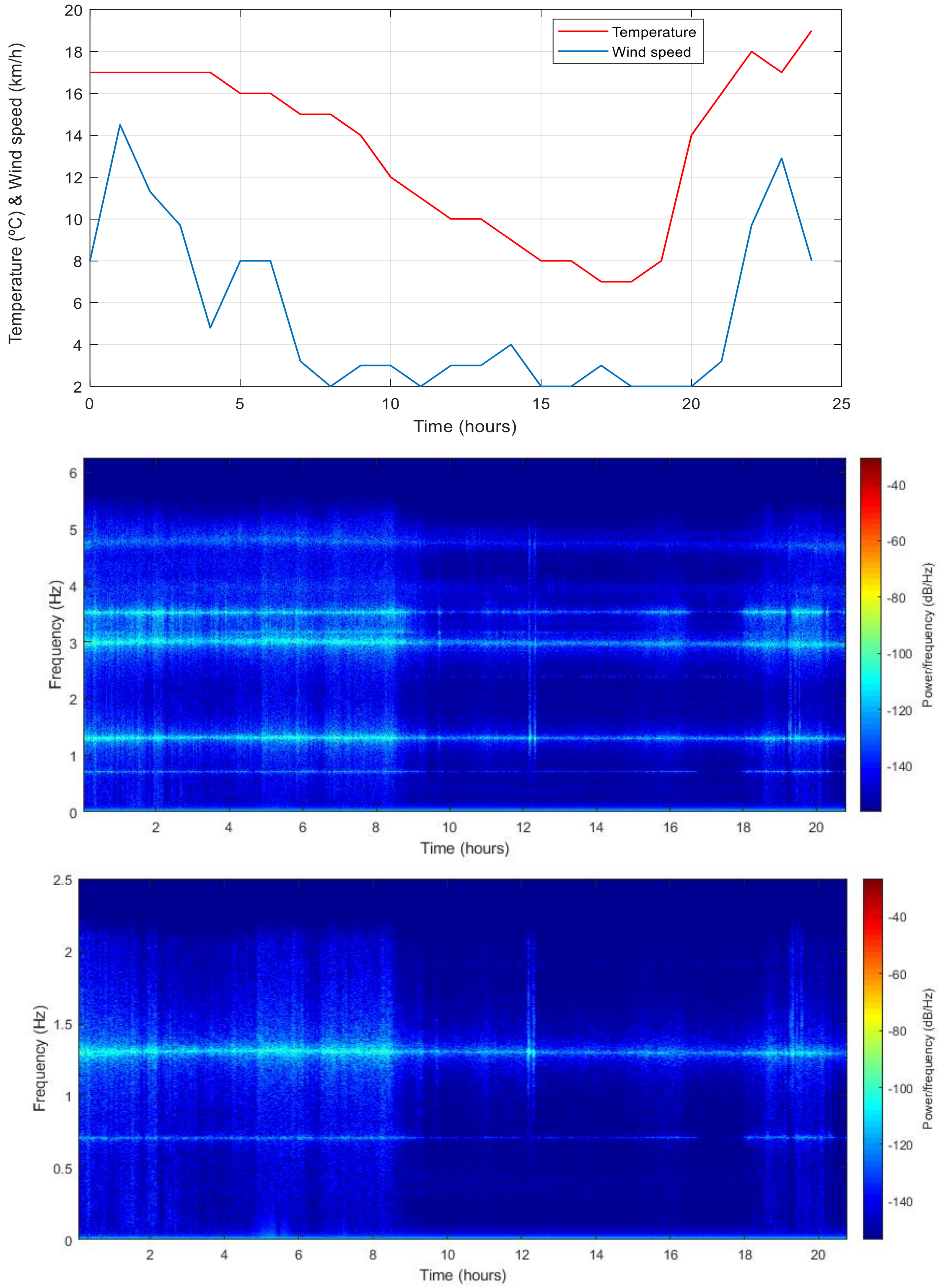


Figure 7. Temperature and wind speed during recording and STFT of the data.

The OMA identification was performed with the ARTEMIS Modal Pro software using the Frequency Domain Decomposition (FDD) technique. The singular value decomposition (SVD) of the responses is presented in Figure 7 with the modes identified in the range 0 – 5 Hz.

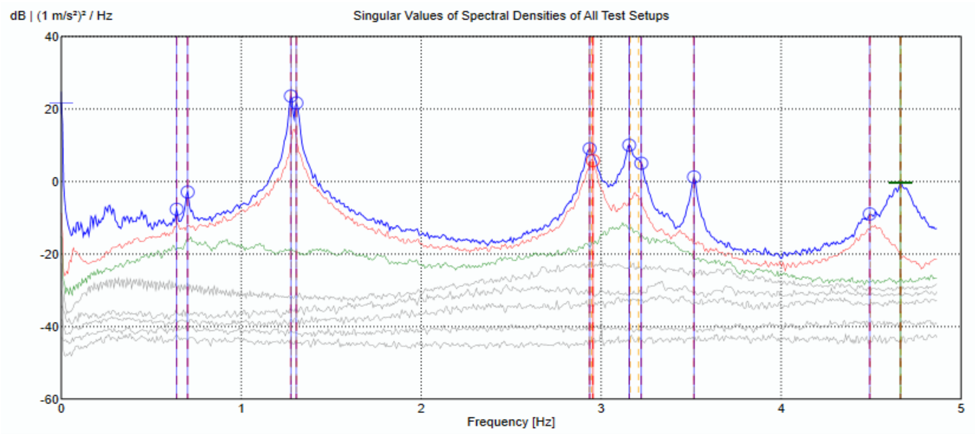


Figure 8. SVD of the registered signals.

The natural frequencies and the mode shapes estimated with OMA are presented Table 1 and in Figs. 10 to 12 (Section 4).

4. NUMERICAL AND EXPERIMENTAL RESULTS

The main drawbacks of the OMA identification in this structure, are the local mode shapes of the top steel cross, as well as the symmetry of the structure which implies closely or even repeated modes. In both cases, the FEM model was a valuable tool for improving the understanding of the dynamic behaviour of the tower.

In the operational modal analysis, the MAC between the modes at approximately 0.7 Hz and 1.3 Hz, is very close to unity. From the finite element model was inferred that the experimental modes at 0.657 Hz and 0.704 Hz (see Figure 9) correspond to the first bending modes of the top steel cross. On the other hand, the modes at 1.302 Hz and 1.341Hz corrrespond the first bending modes of the tower. Due to the fact that no sensors were located at the steel cross, the local bending modes of the steel cross and first bending modes of the tower look similar (spatial aliasing) due to the insufficient number of DOFs used in the measurements.

Five modes were identified in the range 2.8-3.6 Hz. It can be observed in Figure 9 that the local second bending modes of the steel cross are mixed with thesecond bending and the first torsional modes of the tower.

Finally the the modes identified in the range 4-6 Hz correspond to the 3rd bending modes and the second torsional mode of the tower.

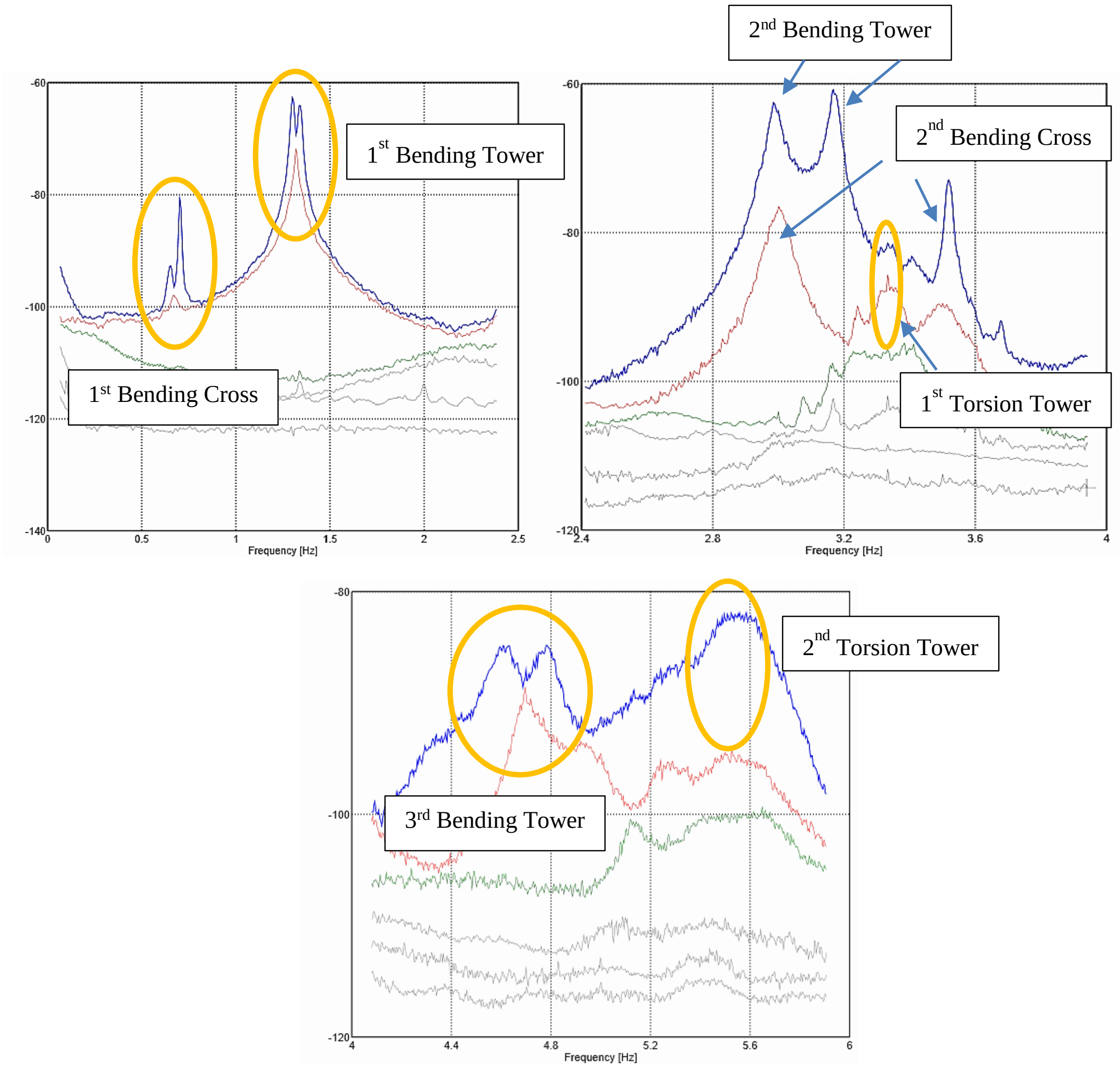


Figure 9. Details of the OMA identification modes of the tower.

The experimental and the numerical natural frequecies, together with the MAC between the numerical and the OMA mode shapes, are presented in Table 1. It can be inferred that a good correlation exists between the experimental and the numerical global bending modes, the maximum error being 10%.

A larger error exists in the torsional modes of the tower and the local modes of the steel cross, which indicates that the numerical model has to be modified in order to get a better correlation.

Table 1. Natural frequencies, error and MAC between the OMA and the FE model.

	Mode	Frequency OMA [Hz[	Frequency FEM [Hz]	Error [%]	MAC
1	1st bending Y (cross)	0.657	0.626	4.72	0.914
2	1st bending X (cross)	0.704	0.608	13.64	0.978
3	1st bending X	1.302	1.187	8.83	0.962
4	1st bending Y	1.341	1.212	9.61	0.975
5	2nd bending Y (cross)	2.991	3.571	19.39	–
6	2nd bending X	3	2.795	6.83	0.975
7	2nd bending Y	3.173	2.857	9.96	0.96
8	1st torsion	3.334	3.903	17.07	0.504
9	2nd bending X (cross)	3.52	3.602	2.27	–
10	3rd bending Y	4.613	5.147	11.58	0.639
11	3rd bending X	4.772	4.783	0.23	0.876
12	2nd torsion	5.551	ND	–	–

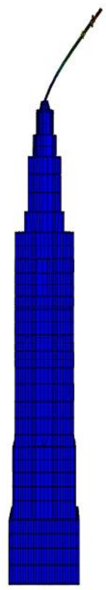
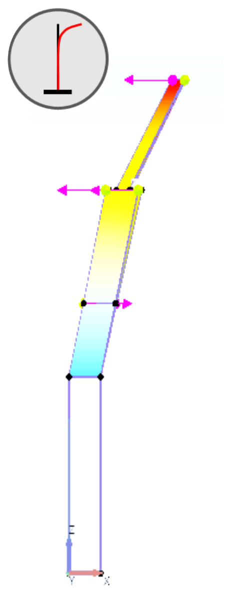
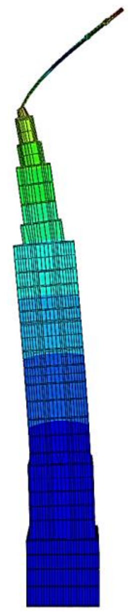
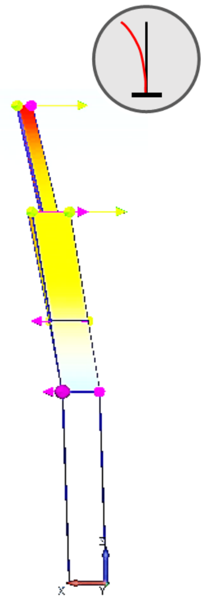
1st bending modes of the top cross		1st bending modes of the tower	
			
FEM	Experimental	FEM	Experimental
X – 0.626 Hz	X – 0.651 Hz	X – 1.187 Hz	X – 1.302 Hz
Y – 0.608 Hz	Y – 0.704 Hz	Y – 1.122 Hz	Y – 1.340 Hz

Figure 10. Mode shapes in the range 0-1.5 Hz.

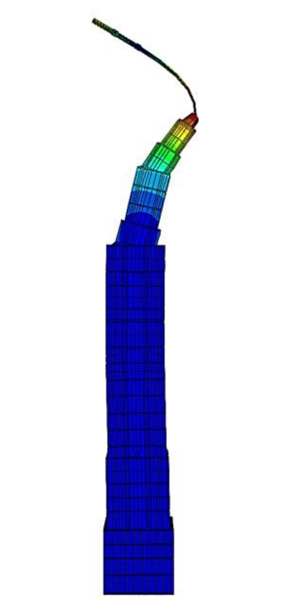
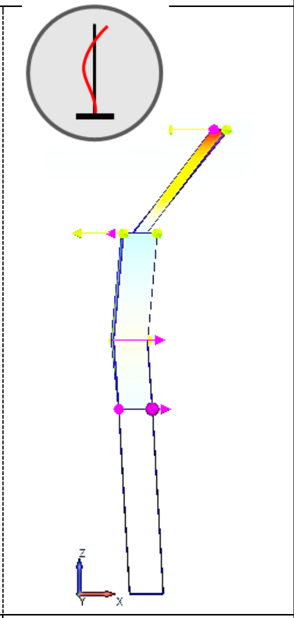
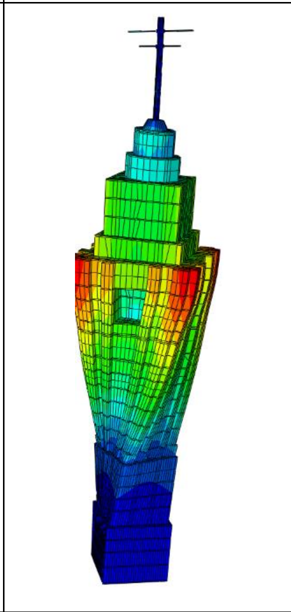
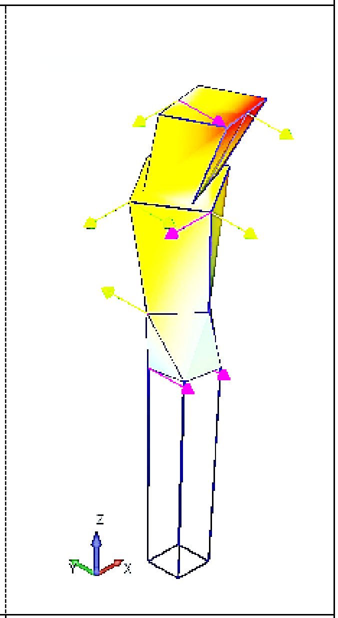
2nd bending modes of the tower		1st torsional mode of the tower	
			
FEM	Experimental	FEM	Experimental
X – 2.795 Hz	X – 2.991 Hz	3.903 Hz	3.340 Hz
Y – 2.857 Hz	Y – 3.173 Hz		

Figure 11. Mode shapes of the tower in the range 2-4 Hz.

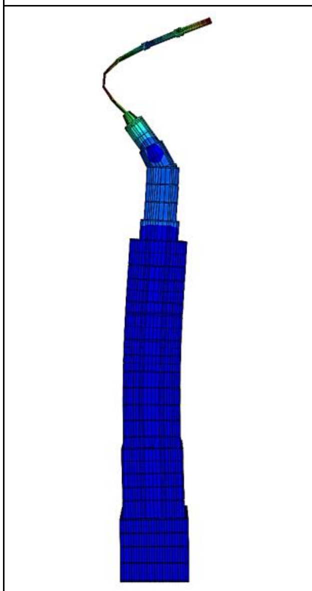
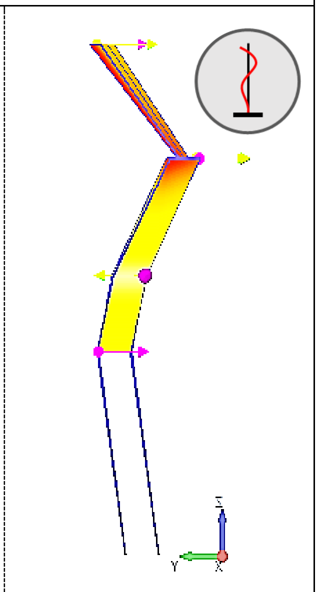
3rd bending mode of the tower	
	
FEM	Experimental
X – 4.783 Hz	X – 4.772 Hz

Figure 12. Third mode shape of the tower.

CONCLUSIONS

- A symmetric finite element model of the tower was assembled in ABAQUS using 3D elements. This model provided valuable information to understand the dynamic behaviour of the tower, in particular, to identify the local bending modes of the top part of the tower and the global modes of the tower.
- Operational modal analysis has been applied to the tower of "Laboral City of Culture" in order to determine its dynamic behaviour under ambient working conditions.
- Within the frequency range 0-6 Hz, 10 bending modes and 2 torsional modes were identified by OMA.
- The FE model presents a quite reasonable correlation between the numerical and the experimental identifiy modes.

ACKNOWLEDGEMENTS

The financing support given by the Spanish Ministry of Education through the project MCI-20-PID2019-105593GB-I00/AEI/10.13039/501100011033 is gratefully appreciated.

REFERENCES

[1] J. Zatón, J.C. Alvárez (1993). *Guía Histórico-Artística del C.E.I. de Gijón* –Antigua Universidad Laboral. Ediciones Júcar.

[2] (n.d). Retrieved from http://www.laboralciudaddelacultura.com/

[3] Brincker, R., Zhang, L. and Andersen, P. (2001). Output-Only Modal Analysis by Frequency Domain Decomposition. *Smart Materials and Structures* 10, 441-445.

[4] Van Overschee, P. and De Moor, B.(1996). *Subspace identification for linear systems:* Theory, implementation, applications. Kluwer Academic Publishers