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

OPERATIONAL MODAL ANALYSIS AND NUMERICAL MODELLING OF A FOOTBRIDGE GALLERY LINKING TWO BUILDINGS

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

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

ABSTRACT

The dynamic behavior of structures can be studied using numerical models, from which the numerical modal parameters can be extracted, or through the experimental modal parameters estimated with classical or operational modal analysis (OMA). On the one side, several identification methods proposed for operational modal analysis are easy to automate, which makes OMA an effective method for structural health monitoring and vibration serviceability. On the other side, numerical models can be used to predict the response of structures in operation. In this paper, the dynamic behavior of the footbridge located at the Milan’s campus (Oviedo, Spain) is studied. This lattice structure links two buildings at a height of 12 meters, and it has a complete glass enclosure, which favors the influence of the wind, and may therefore be subjected to greater dynamic loads than those predicted in the design of the structure. The experimental modal parameters of this structure were estimated with operational modal analysis and used to update a numerical model assembled in ABAQUS.

Keywords: Footbridge, Modal Analysis, OMA, Numerical Analysis, Model Updating.

1. INTRODUCTION

It is well known that Operational modal analysis (OMA) is an useful technique for estimating the modal parameters (natural frequencies, mode shapes and damping ratios) of medium/large structures [1-4] using natural and operational loads.

This paper reports the operational modal tests and anlayis applied to a footbride gallery (see Fig. 1). This footbridge structure was constructed between the late 80s and early 90s, with the objective of linking the two main buildings of the “Campus of Milán” at the University of Oviedo (Spain). The pedestrian footbridge was assembled in factory and then placed on the buildings with a crane. The structure is located at approximately 12 metres from the base of the building. The footbridge is a steel structure composed of two lateral Pratt trusses, which are connected through the top part by a gable roof.

The pedestrian bridge also has a glass cover on the top and in both lateral sides, which was not considered during the structural design. No information about the time when this enclosure was placed is available. This area of the city is subjected to moderate winds, and the glass cover can influence the dynamic behavior predicted for the structure. An updated finite element model could be useful to study the influence of the enclosure in the dynamic behavior of this structure.

Figure 1. Pedestrian Footbridge at the Milan’s campus.

The trusses are made of steel S275. UNP280 profiles, in a box-welded configuration, were used in the top and bottom chords, whereas the diagonals and the vertical posts were constructed with UNP140 profiles, also in a box-welded configuration. The total length of the structure is 34 meters, and it is supported in both buildings for a length of 5 meters. The width of the footbridge is 4.35 metres and the height 3.4 metres. These dimensions were measured in situ, and they are not consistent with the information provided by the original project of the structure (Fig. 2). Information about how the structure is supported in the buildings is not available either. The deck of the footbridge is made of concrete and supported by concrete T beams.

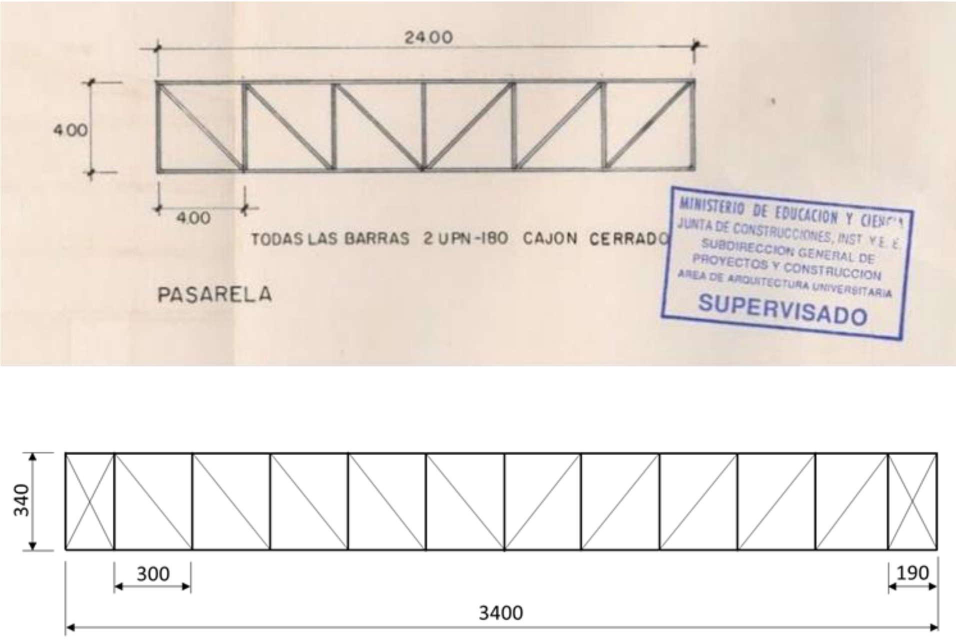

Figure 2. Real dimensions of the built (bottom image) structure and original drawings (top image).

In this work, a finite element model of the structure was assembled and updated with the experimental modal parameters estimated with operational modal analysis. The experimental modal parameters will be used for a future periodic structural health monitoring (SHM) of the footbridge, and the structural behavior with and without glass cover will be investigated with the updated finite element model.

2. OPERATIONAL MODAL ANALYIS

The experimental odal parameters (natural frequencies, mode shapes and damping ratios) of the structure, in the range 0-50Hz, were estimated with Operational Modal Analysis (OMA).

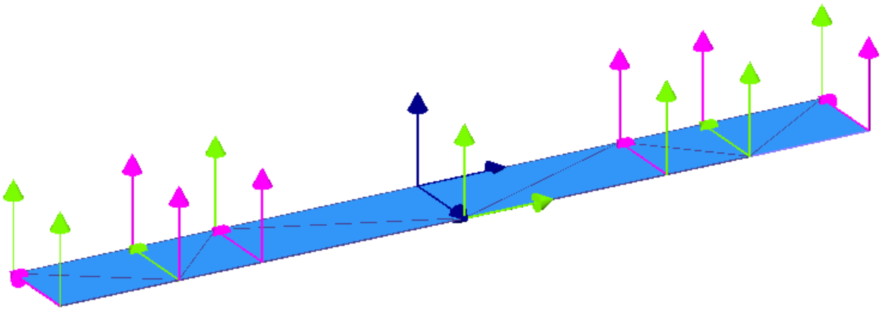

Figure 3. Experimental DataSet

The experimental responses were measured in 14 nodes and 23 DOF's (Fig. 3) using 6 accelerometers (PCB 393B31) with a sensitivity of 10 V/g (Fig .4) using 3 data sets. The responses were measured with a TEAC-LX 120 acquisition system using a sampling frequency of 100 Hz. The responses were measured for approximately 20 minutes in each data set Apart from the natural excitation, the structure was also excited by 3 people walking and jumping randomly over the structure.

Figure 4. PCB 393B31 accelerometers

The modal identification was performed using the Artemis Modal software and the modal parameters were estimated with the CFDD (Curve-fit frequency domain decomposition) and SSI (subspace stochastic identification) techniques [5]. The singular value decomposition of the SSI stabilization diagram is presented in Figure 5 for the vertical DOF's.

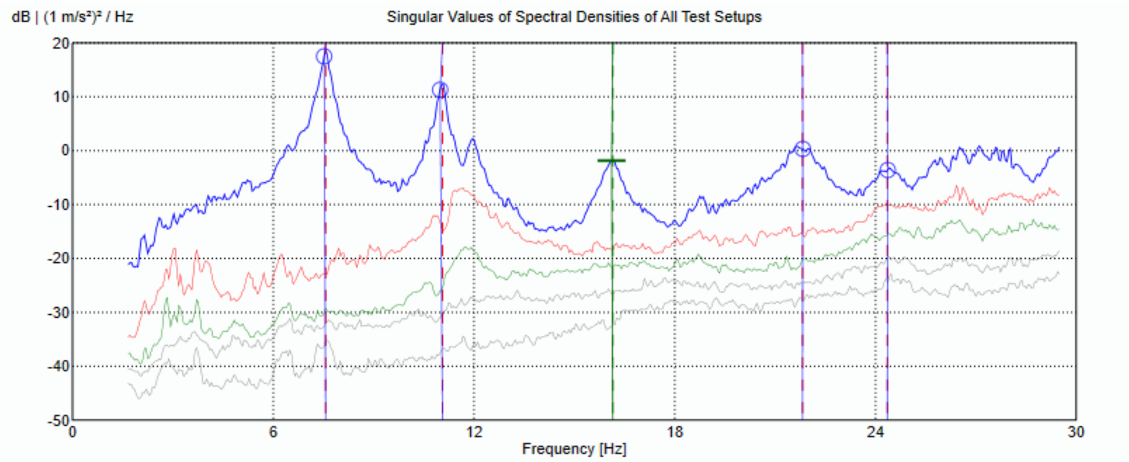

Figure 5.SVD of the acceleration vertical responses.

2.1. Experimental results in vertical direction

The experimental mode shapes in the vertical direction, obtained with the CFDD technique, are presented in Figure 6, whereas the natural frequencies are presented in Table 1.

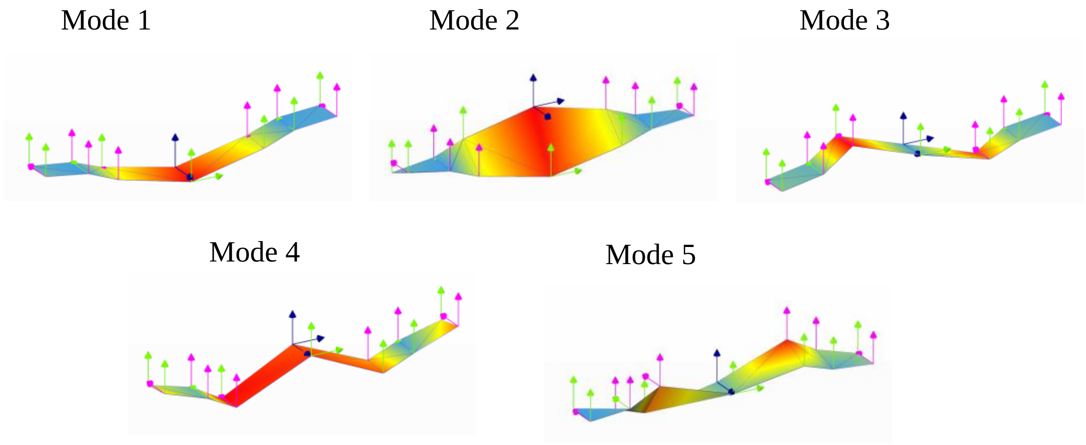
Mode 1
Mode 2
Mode 3
Mode 4
Mode 5

Figure 6. Experimental mode shapes

As it can be observed, the DOF's located in the supporting area are moving in the vertical direction, which means that the footbridge is not completely fixed to the buildings, i.e. there is a non-linear relative motion of the footbridge with respect to the buildings.

2.2. Experimental results in lateral direction

With respect to the lateral modes, the analysis is more complex, because no sensors were attached to the buildings. Moreover, the gable roof introduces additional local lateral modes which are dificult to identify considering only the sensors located at the deck. Only three lateral modes were identified with a reasonable reliability. The natural frequencies correspoding to these modes are presented in Table 2 and the mode shapes in Figure 8.

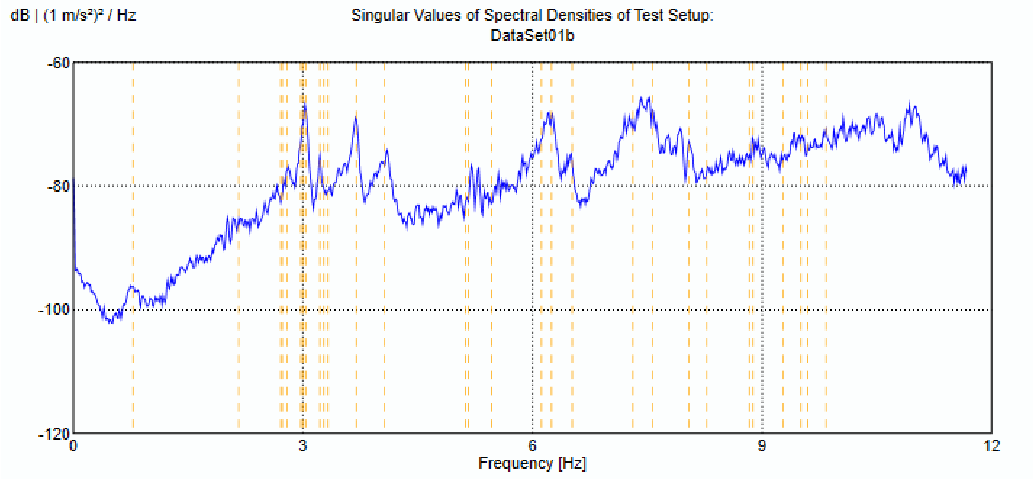

Figure 7. First singular value of the acceleration lateral responses.

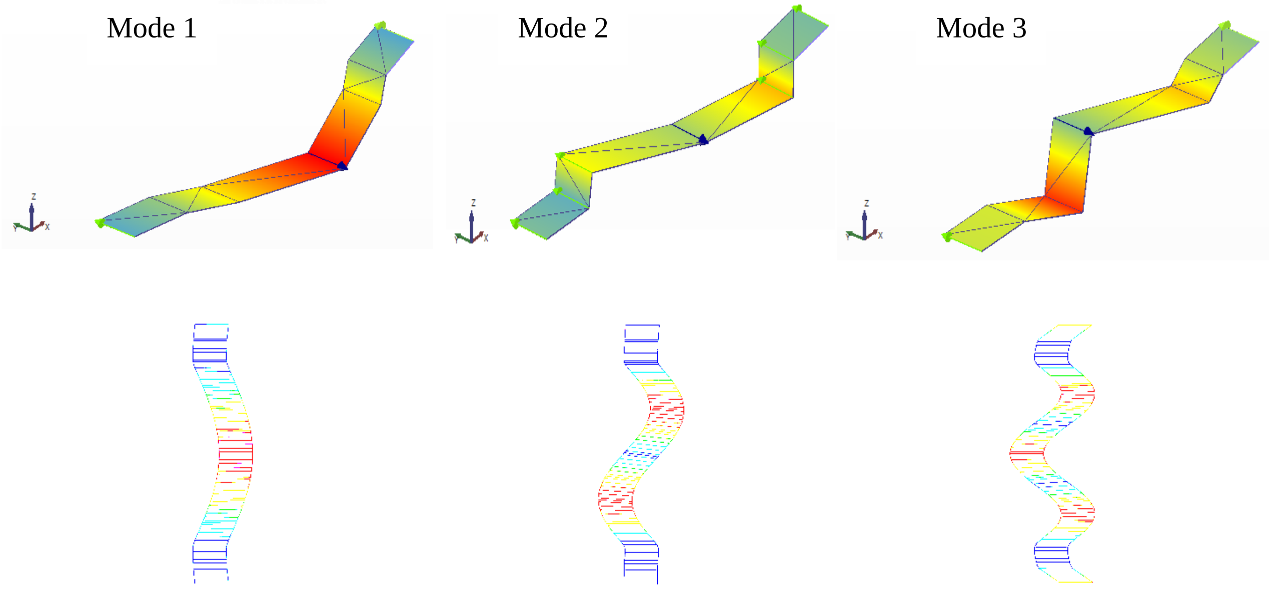

Figure 8. Experimental and numerical lateral modes

3. FINITE ELEMENT MODEL

3.1. First finite element model

The finite element model of the pedestrian footbridge was modeled in ABAQUS CAE. The model was meshed using 1-D beams elements (B3D3) for all the structural elements (see Fig. 9). The mass of the footbridge enclosure (glass + aluminum frames) were modeled as point-masses, whereas its effect on the stiffness of the structure was not considered.

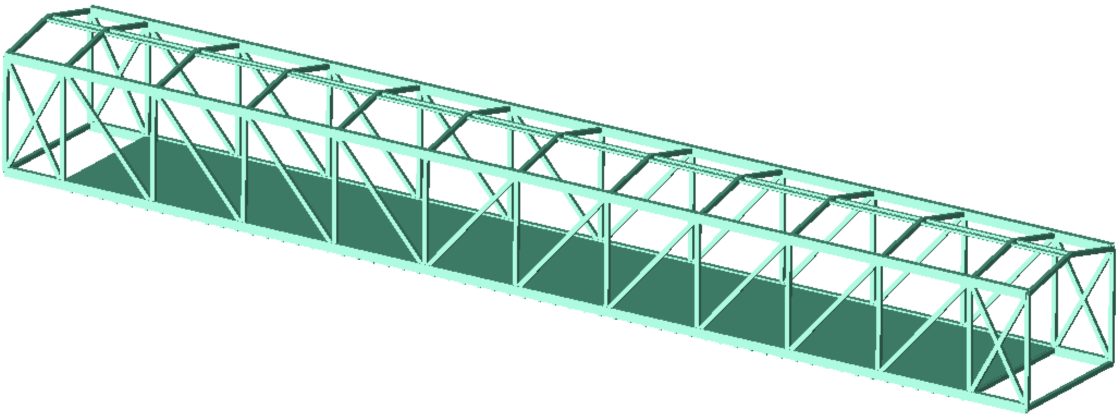

Figure 9. Finite element model of the structure

As it was previously mentioned, the boundary conditions are not known in detail. Pin supports were considered along the 4,9 meters of the bottom chords resting on the buildings (see Figure 10) The numerical natural frequencies corresponding to the vertical modes are presented in Table 1, whereas the those corresponding to the lateral modes are shown in Table 2.

Table 1. Experimental and numerical natural frequencies for the vertical modes.

Mode	Frequency		
	Experimental [Hz]	Numerical [Hz]	Error [%]
1 (bending)	7.56	7.43	1.67
2 (torsion)	11.05	11.11	0.52
3 (bending)	15.87	14.67	9.19
4 (bending)	21.79	19.17	12.02
5 (bending)	24.32	23.46	3.52

It can be observed in Table 1 that a good correlation exists for the modes 1,2 and 5, the errors being less than 3.5%, whereas a larger error has been obtained for modes 3 and 4. With respect to the lateral modes (see Table 2) the discrepancies are significantly large, which can attribuited to the boundary conditions assumed in the numerical model.

Table 2. Experimental and numerical natural frequencies for the lateral modes.

Mode	Frequency		
	Experimental [Hz]	Numerical [Hz]	Error [%]
1	4.06	4.35	7.14
2	8.09	13.68	69.08
3	15.14	20.64	36.32

3.2. Model updating

In order to get a better numerical-experimental correlation, the numerical model was manually updated [6] using the modal parameters estimated with OMA. Only the boundary conditions were modified in the updating process (see Fig. 10), diminishing the length and the number of the pin supports. This changes mainly affect the lateral modes decreasing the stiffness in this direction.

After the updating process, a good correlation was obtained for the vertical modes, the errors being less than 5.1% (see Table 3). With respect to the lateral modes (See Table 4), the numerical-experimental discrepancies also decrease significantly, confirming the fact that the structure is not firmly or fully attached to the buildings. However, although the errors were reduced for the identified lateral modes, the second bending mode (see Figure 8) still presents a large error (33 %).

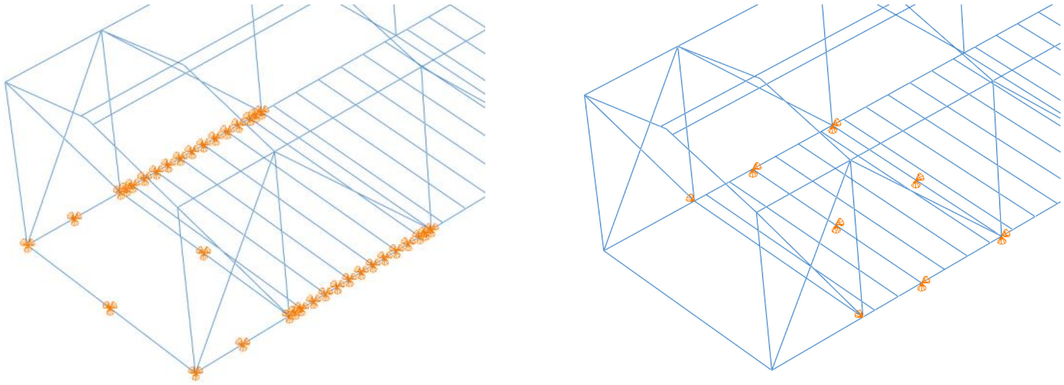

Figure 10. Original (left) and updated (right) boundary conditions used in the FEM model.

Table 3. Experimental and updated numerical natural frequencies for the vertical modes.

Mode	Frequency		
	Experimental [Hz]	Numerical [Hz]	Error [%]
1 (bending)	7.56	7.50	0.81
2 (torsion)	11.05	11.21	1.46
3 (bending)	15.87	15.06	5.10
4 (bending)	21.79	21.50	1.32
5 (bending)	24.32	24.11	0.86

Table 4. Experimental and updated numerical natural frequencies for the lateral modes.

Mode	Frequency		
	Experimental [Hz]	Numerical [Hz]	Error [%]
1	4.06	4.02	0.98
2	8.09	10,76	33.01
3	15.14	16.28	7.52

4. CONCLUSIONS

- A footbridge connecting two builinding in the Campus of Milan (University of Oviedo) was modelled in ABAQUS and the numerical modal parameters were correlated with the experimental modal parameters estimated with operational modal analysis (OMA).
- The boundary conditions were not known in detail and the numerical model was manually updated using the experimental modal parameters in both lateral and vertical directors, in order to get a better correlation.
- From the updated numerical model, it is concluded that the structure is not fully fixed to the buildings.
- Further studies, numerical and experimental, will be carried out in order to model this structure more accurately.
- A fatigue analysis should be carried out in order to identify damage and to stablish an initial state for the future structural health monitoring of the footbridge.

ACKNOWLEDGEMENTS

The economic 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] Gentile, C., & Gallino, N. (2008). Ambient vibration testing and structural evaluation of an historic suspension footbridge. *Advances in Engineering Software*, *39*(4), 356–366. https://doi.org/10.1016/j.advengsoft.2007.01.001

[2] Hu, W.-H., Caetano, E., & Cunha, Á. (2013). Structural health monitoring of a stress-ribbon footbridge. *Engineering Structures, 57*, 578–593. https://doi.org/10.1016/j.engstruct.2012.06.051

[3] Reynders, E., Degrauwe, D., De Roeck, G., Magalhães, F., & Caetano, E. (2010). Combined Experimental-Operational Modal Testing of Footbridges. *Journal of Engineering Mechanics, 136*(6), 687–696. https://doi.org/10.1061/(ASCE)EM.1943-7889.0000119

[4] Brincker, R., & Ventura, C. (2015). Introduction to Operational Modal Analysis (Wiley).

[5] Chen, H.-P., & Ni, Y.-Q. (2018). Structural Health Monitoring of Large Civil Engineering Structures (Wiley-Blac). John Wiley & Sons, Ltd. https://doi.org/10.1002/9781119166641

[6] Friswell, M. I., & Mottershead, J. E. (1995). Finite Element Model Updating in Structural Dynamics (Vol. 38). Springer Netherlands. https://doi.org/10.1007/978-94-015-8508-8