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DYNAMIC IDENTIFICATION AND MODELLING OF A RC HOSPITAL BUILDING

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Abstract. *The conservation of structures mainly relies on our ability to monitor their aging and to promptly detect relevant damage. Dynamic characterization is considered a powerful technique for testing the conservation status of buildings as their natural frequencies, damping and modal shapes are directly related to their stiffness and structural integrity. In this work a dynamic monitoring based on ambient vibrations measurements has been performed on a case-study, i.e. a RC 4-storey Hospital building. An identification procedure based on the Enhanced Frequency Domain Decomposition has been performed to evaluate the modal parameters of the building. The dynamic information provided by the experimental analysis have been compared to the one found by performing the analytical modal analysis. To this purpose a structural model has been built, by representing all the major geometrical and mechanical properties of the building, through the Seismostruct software. The comparison has pointed out the role of the non-structural component and of the interaction between the monitored structure and the adjacent buildings on the dynamic response of the case-study.*

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1 INTRODUCTION

The seismic assessment of existing buildings can be performed by different alternative procedures. In all cases the dynamic properties of the building, i.e. the vibrational periods, the amount of damping and the waves propagation within the building, play a crucial role in the evaluation of its seismic response. In these years, the improvement of data acquisition and processing capabilities, has increased the diffusion of experimental campaign based on the dynamic monitoring of the buildings [1, 2].

Dynamic characterization is considered a powerful technique for testing the conservation status of structures as their natural frequency, damping ratio and modal shapes are directly related to their stiffness and integrity [3]. The dynamic monitoring of a sample building requires a wave propagation motion, and, consequently, an accelerations source. The acceleration sources consist in forced vibrations, weak earthquakes and ambient vibrations. The ambient vibrations have been extensively used in these last years [4, 5, 6, 7], since they are always available without requiring any specific effort. They are characterized by low intensities, and therefore the dynamic response of the monitored building can be investigated in the elastic range only. Furthermore, for RC buildings, such response can be even more rigid than the theoretical elastic one, since the cracking limit is hardly achieved [8].

In this work the dynamic monitoring based on ambient vibrations has been applied to an Hospital building located in Sansepolcro (Italy), with a medium seismic hazard (PGA equal to 0.227g for the Severe Damage, *SD*, limit state), i.e. the highest seismicity in Tuscany [9]. The building has been built before the current seismic legislation, so requiring a special attention in terms of seismic reliability, and it has been object of careful investigations. The building, 4 storey height, has rectangular shape and a framed RC structure. Two stations at each level, one at the foundation, and further three ones at the top of the three adjacent buildings have been adopted in the analysis, for a global number of 9 stations. The location of the stations at each storey has been carefully evaluated, in order collect meaningful data, and to check the possible interaction between the examined structure and the next ones. The recording phase had a duration of about 20 hours; the long time recording interval has allowed to check the stability of the vibrations and to get robust average values of the frequency response. An automatic identification procedure via Enhanced Frequency Domain Decomposition (EFDD) [10, 11, 12] has been used to evaluate the modal parameters and to remove any user interaction.

The dynamic information provided by the experimental monitoring analysis have been compared to the one found by performing an analytical analysis. To this purpose a structural model has been built, by representing all the major geometrical and mechanical properties of the building, by using the Seismostruct [13] software. A modal analysis has been performed, and the elastic vibrational periods, together with the corresponding modal shapes, have been found.

The comparison between experimental and analytical data have evidenced some differences between the two analyses. The first one is about the stiffness found for the building: the experimental campaign provides a n higher estimation of the building stiffness, since it is based on a completely elastic response, due to the low intensity of the adopted acceleration source, and to the contribution of some non-structural components, like partitions, and architectural finishing, not included in the analytical model. The second difference is about some of the modal shapes, which are conditioned by the buildings adjacent to the checked one, which are not included in the analytical model.

2 THE CASE STUDY

The Hospital complex, shown in Fig. 1, is made by 18 independent buildings, differing for age, material and number of storeys. The buildings shown in Fig. 1 have been classified during the assessment analysis made in the jointed agreement between the University of Florence and the Regional Government [14]. The examined building, named 07 in Fig. 1b, adjoins three other ones, along three of its sides, as can be seen even by views shown in Fig. 2. It has a rectangular plan, of sides of 30.15 m and 18.90 m respectively. The RC structure is made by 10 transversal frames along the E-W direction, and by three RC frames along the N-S direction. Figs 3 and 4 show, respectively, the standard plan and two 3D views and cross sections of the building.

Figure 1: Hospital complex of Sansepolcro a) Air view b) General plan

Figure 2: The examined building.

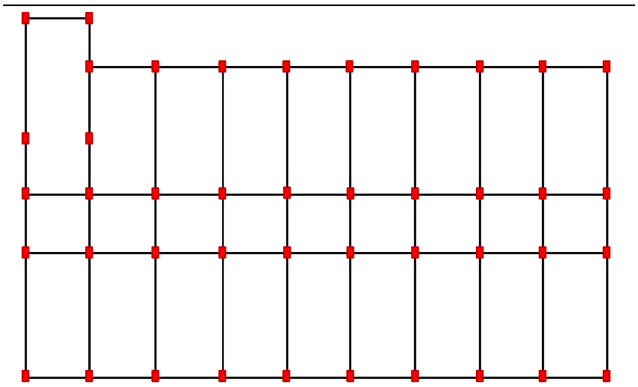


Figure 3: Plan of the building

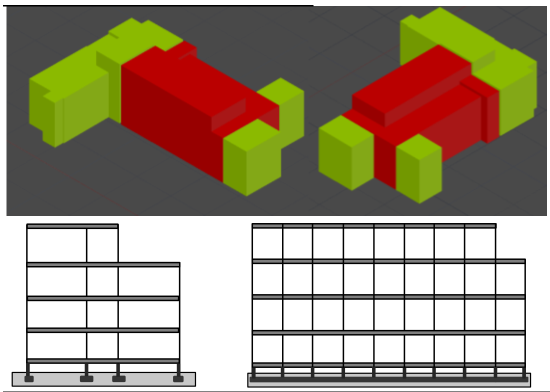


Figure 4: 3D views and sections of the building

The columns have different sections at each storey, ranging between 30x50 cm at the first level, and 30x35 cm at the top one. The transversal beams (EW direction), which sustain the floors, have a section of 30x60 cm, with the exception of some beams on the external wall, which have a special S shape to sustain the infill panels. The longitudinal beams (NS direction) have a lower depth at the first level, whilst they have the same dimensions of the transversal ones (30x60cm) at the upper storeys. The ceiling is made of two different floors, next each other, while the flat roofs includes 1m long cantilever along the entire perimeter. More details about the building can be found in [14].

3 THE DYNAMIC MONITORING

Ambient vibration measurements were performed for 20 hours from 23 to 24 April 2015 with 9 seismic stations (Fig. 5). Each seismic station was equipped with 3-component seismometers; more precisely, six stations were made by Lennartz 3D/5s (sensitivity 400 V/m/s and flat transfer function up to 5 s); one station by Guralp CMG-6T seismometer (sensitivity 2400 V/m/s and flat transfer function up to 10 s), one station by Guralp CMG-40T seismometer (sensitivity 800 V/m/s and flat transfer function up to 30 s) and one station by Trilium Compact 120s model (sensitivity 750 V/m/s and flat transfer function up to 120 s). All the seismometers were digitized by with a 24 bit Guralp CMG24 Digitizer at 100 Hz, and the time synchronization between stations was achieved using GPS.

The F01 station, located on the foundations of the building, has been used as reference station, while two stations were installed at each floor in the opposite corner (Fig. 5).

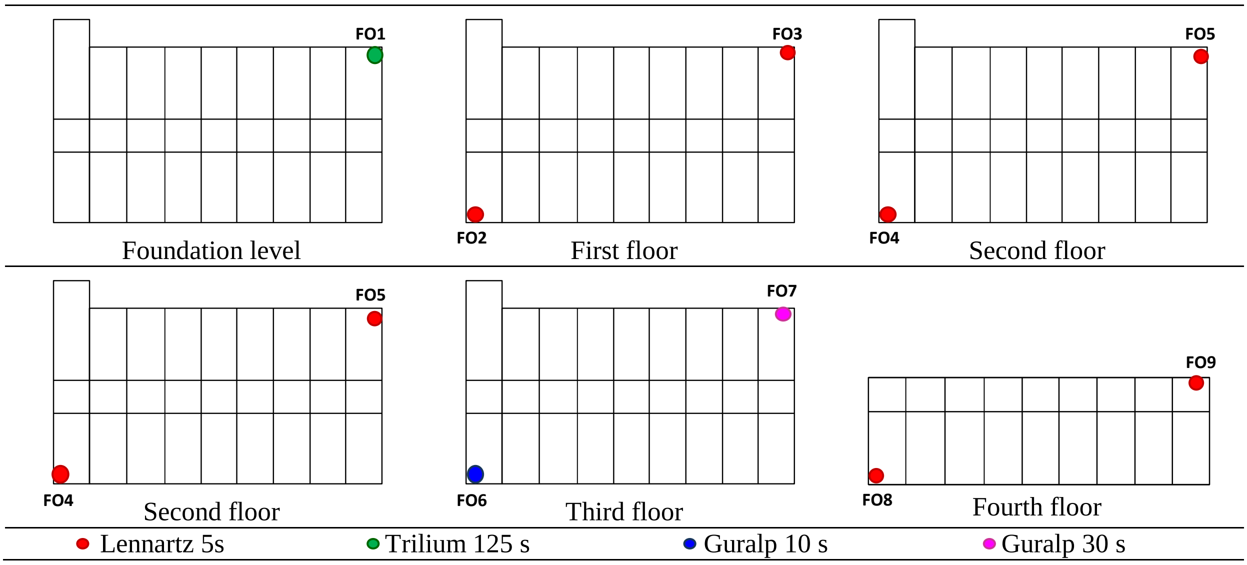
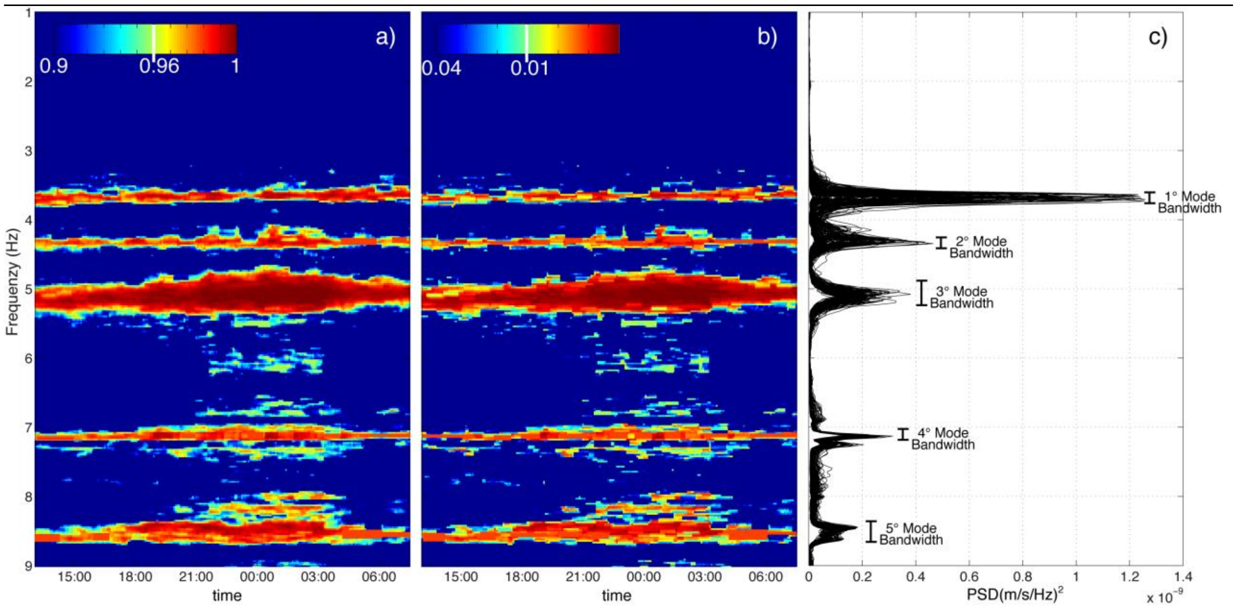


Figure 5: Position of the nine stations used to measure the effects of the ambient motion.

In order to apply the operational modal analysis, the 20 hours long record has been divided into times windows of 300 s and the data have been first deconvolved for the instrument response function and then filtered to frequencies above 0.1 Hz. The time window of 300 s is long enough with respect to the Brincker criterion [10], which requires time series ~1000 times longer than the fundamental oscillation period (~0.3 s in our case). An automatic identification procedure via Enhanced Frequency Domain Decomposition (EFDD) [15] has been used to calculate the modal parameters (frequency, damping and modal shape).

The EFDD is a frequency domain technique for operational modal analysis of structures, whose theoretical background is described in numerous papers [15, 16, 17]. The EFDD is an extension of the Basic Frequency Domain technique (BFD), often called Peak-picking method, which is based on the Singular Value Decomposition (SVD) of the Power Spectral Density (PSD) matrix $G_{yy}(\omega)$**,** where ω_i are the single angular frequency. The modal shapes are automatically found within the modal domain (or modal bandwidth) using the modal coherence [14, 16, 12]. The latter is evaluated between each frequency line of two first singular vectors calculated for two consecutive records 300 s length.

The modal coherence is equal to 1 for stationary signals and allows to define the modal domain due to the structural modes. A *mean* value over 0.96 (Fig. 6a) and a *standard deviation* below 0.01 (Fig. 6b), calculated for a set of 10 consecutive modal coherences, are used to reduce the noise and to identify the modal domain. This procedure is repeated for the entire record every 300 s. Within each modal bandwidth, the maximum amplitude of the first singular value indicates the modal frequency. For such frequency peak, the corresponding first singular vector provides the modal shape every 300 s long data set. The application of the EFDD method has allowed to automatically identify the first five bandwidth modes of the checked building (Fig. 6c).



a) *mean* of modal coherence evaluated during the observation time on 10 consecutive records, the white line on the color bar indicates the threshold (>0.96) used for the identification of the mode bandwidth;
b) *standard deviation* of the modal coherence evaluated on 10 consecutive records, the white line on the color bar indicates the threshold (<0.01) used for identification of the mode bandwidth;
c) 240 first singular values calculated for all the observation time (20 hours).

Figure 6: Modal coherence found by the analysis.

An example of the five modal shapes calculated following the EFDD procedure during 300 s time window relative to the 15:00 to 15:05 interval is illustrated in Fig 7, which shows the first five modal shapes found from the analysis. As can be seen by the plots, the first mode is translational and occurs along the X direction (Fig. 7a), with a frequency of 3.71 Hz (T_1 = 0,27 s) and a damping ratio of 1.3 %, whereas the second mode shape is still translational, but along the Y direction (Fig. 7b) with a frequency of 4.32 Hz (T_2 = 0,23 s) and damping ration of 1.4 %. The third mode has a torsional modal shape with a frequency of 5.08 Hz (T_3 = 0,20 s) and damping ratio of 1.61%, while the fourth and fifth modes have a frequency of 7.12 Hz (T_4 = 0,14 s) and 8.54 Hz (T_4 = 0,12 s) and a damping ratios of 0.5% and 0.7% respectively.

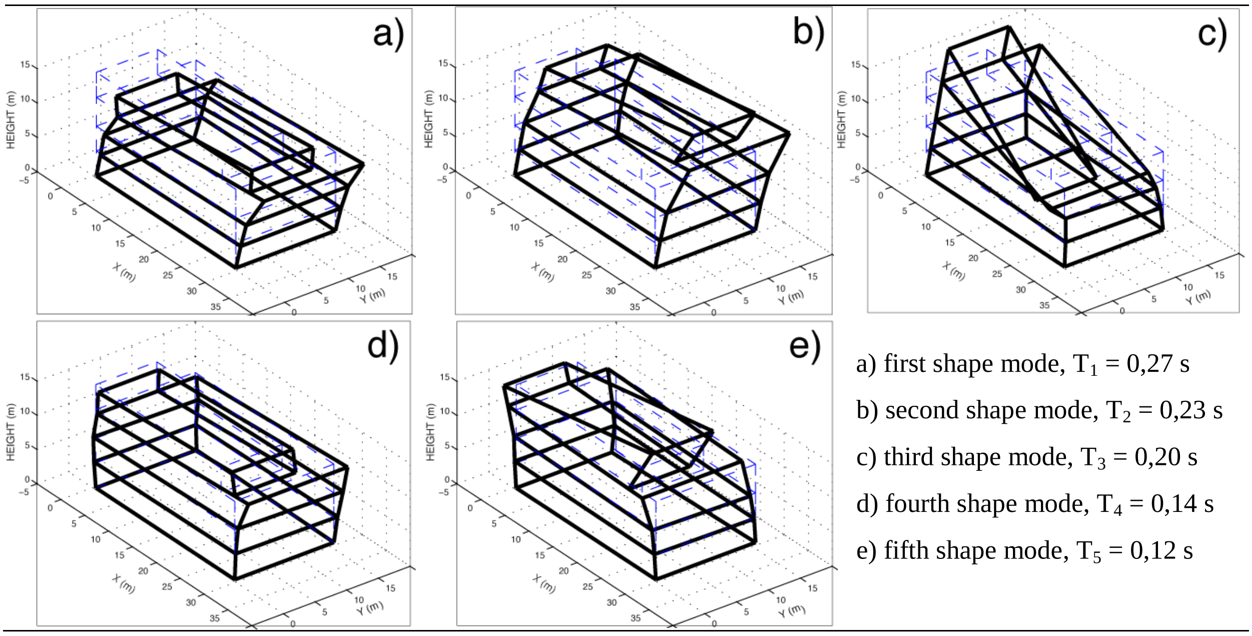


Figure 7: Tri-dimensional representation of the first five modes.

4 THE MODAL ANALYSIS

An analytical model has been made through the computer code Seismostruct [13] to achieve an analytical representation of the seismic response of the building. A detailed representation of the building geometry has been achieved, by tracing the original architectural and structural drawings. The mechanical properties of the materials have been carefully checked during the knowledge process, but in the current analysis only the concrete Young modulus is adopted, which is assumed to be equal to 27000 MPa.

A fiber model has been adopted to describe the cross sections; the Mander *et al*. model [18] has been assumed for the core concrete, a three-linear model has been assumed for the unconfined concrete, and a bilinear model has been assumed for the reinforcement steel. Contribution of floor slabs has been considered by introducing a rigid diaphragm. The model only represents the structural system of the building, neglecting the non-structural components, like the internal partitions and the architectural accessories. In the same way, in this first approach to the numerical representation of the seismic response of the building, the possible interaction with the adjacent buildings has been neglected. Fig. 8 shows two views of the model adopted in the analysis.

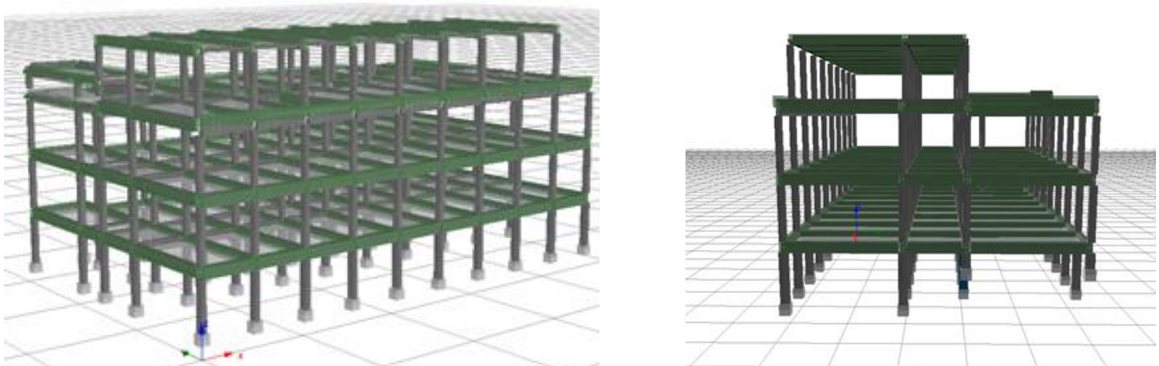
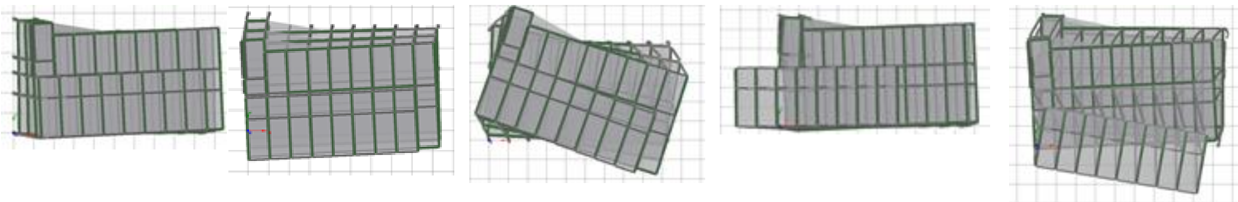


Figure 8. Views of the structural model.

The modal analysis has been performed by assuming an elastic behavior of the structure. Tab. 1 shows the main information (period and percentage of the total mass activate by each motion) of the first modal shapes, while Fig. 9 shows the corresponding modal shapes.

Table 1. Modal shapes found by the numerical analysis

Mode	Period (sec)	% of participation mass		
		Ux	Uy	Rz
1	0.462	80.23%	0.16%	2.30%
2	0.377	0.33%	78.14%	2.90%
3	0.333	1.94%	1.91%	73.07%
4	0.179	5.81%	0.00%	0.26%
5	0.128	0.51%	8.02%	0.03%



1st shape | 2nd shape | 3rd shape | 4th shape | 5th shape

Figure 9. Modal shape found through the modal analysis.

5 COMPARISON BETWEEN EXPERIMENTAL AND ANALYTICAL DYNAMICAL RESPONSE

Before proceeding to the comparison between the numerical results and those provided by the experimental campaign, some observations should be made. The dynamic response of buildings related to ambient vibrations is largely affected by all the non-structural components that, at the increasing of the dynamic intensity, lose their entirety, and, consequently, their influence on the building response. The checked building is separated by the adjacent ones through seismic joints: at the occurring of an earthquake, therefore, it should experience an independent dynamic response, resulting not affected by their behavior. Under ambient vibration, instead, the seismic joints have not lost their entirety, and therefore the dynamic response of the case- study found through the experimental test is affected by the dynamic properties of the next buildings. Moreover, the internal partition and the perimeter infill walls are known to largely affect the initial stiffness of the building, before they become ineffective due to the amount of the experienced stress.

The analytical model used in this work is very simple: it only considers the structural elements of the building and the mass distribution, and therefore it can be assumed to be a first attempt to represent the dynamic response of the case-study. The effects of the adjacent buildings is not taken into account, and the non-structural components have been neglected. Therefore, a more deformable system should be foreseen, and only the first shapes can be expected to be comparable, since the torsional behavior of the building is certainly affected by the contribution of the neglected aspects. In the following, therefore, only the first two modes, which represent the translational response of the building along the two main directions, have been discussed.

As regards the elastic periods of the first two modes, it should be noted that the numerical model provides values about 40% larger than the ones obtained by the experimental campaign. The amount of this increase is compatible to more general studies [19] referred to the contribution of the non-structural components on the dynamic response of RC structures.

Fig. 10 shows the comparison of the modal shape found for the first (translational) two modes through the two approaches. The shapes have been normalized to the maximum response along the main direction.

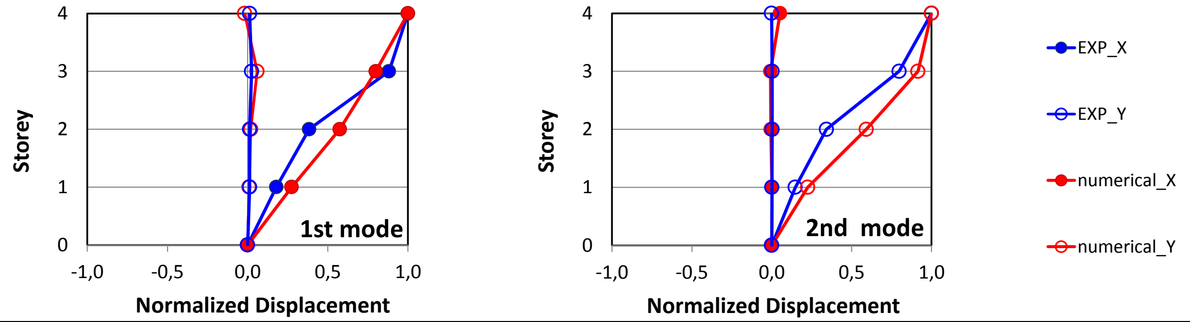


Figure 10: comparison between the first two modes of the dynamic response of the case-study.

6 CONCLUSIONS

In this work a dynamic monitoring based on ambient vibrations has been applied to an Hospital building located in Sansepolcro (Italy). Nine seismic stations, consisting in 3-component seismometers, have been placed in the building, checking every floor, included the foundation level. The recording phase had a duration of about 20 hours, and an automatic identification procedure via Enhanced Frequency Domain Decomposition (EFDD) has been performed on the obtained data to evaluate the modal parameters, i.e. frequency, damping and corresponding modal shape.

The dynamic response found through the experimental campaign has been numerically simulated by representing the building by means of a simplified model. The model represents a first attempt to describe the dynamic response of the building, since it does not take into account the non-structural components, or the possible interaction between the building itself and the adjacent structures. It has been prepared through the platform Seismostruct, and takes into account the effective geometry of the building, and its main dynamical properties, like the mass and the stiffness distribution.

The fundamental periods provided by the numerical model for the building are about 40% larger than the ones provided by the experimental campaign, whilst the two first (translational) modal shapes are very similar with each other. A more detailed model of the building should be made in order to check the effects related to the experimental campaign, like the continuity between the case-study and the adjacent buildings and the effects of the non-structural components.

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