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MODEL UPDATING THROUGH IDENTIFIED FREQUENCIES OF AN HISTORICAL STOCKY STRUCTURE BUILDING WITH WOODEN FLOORS

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Abstract. *The scope of the paper is to present the analysis of an important historical building the "San James" theater actually used as the Municipality House in the city of Corfù (Greece). The building, that is located in the center of the city, is characterized by an extremely stocky shape, and by the presence of wooden floors. Moreover, the upper part of the building has been realized many years after the end of the works of the main part of the building. The aforementioned considerations do not allow to be sure about the "box" behavior of the building and makes the dynamic analysis and tests of great importance for the exactly comprehension of its structural behavior. With this aim an extensive experimental campaign has been performed: in detail 18 accelerometers with high sensitivity have been installed and the ambient vibrations of building have been recorded. In the present paper the performed experimental tests and the analysis of the experimental data are discussed and compared with a finite element model of the examined building. At this aim an important task of the present research is related to the consideration that all the floors are made by wood and so, the analysis of the experimental data and the dynamical identification could be influenced by the presence of local modes. This problem has been tackled by introducing a 'single wall analysis'strategy for demonstrating the global behavior of the estimated experimental modes that may be used for updating the building FE model.*

1 INTRODUCTION

The recent seismic events have demonstrated the high vulnerability of the architectural heritage. The main reasons of such behavior are: the circumstance that such structures have been designed considering only the gravitational loads, and in some cases the lack of maintenance/retrofitting interventions. This problem is particularly felt in such countries in which the architectural heritage is richer as in Greece.

The major problems related with the study of the mechanical behavior of historical buildings are related to the difficulties in defining an analytical model that is able to describe the behavior of the examined structure. In fact, usually the available technical documentation is not exhaustive and all the interventions occurred during the years are not described. Moreover, commonly only no-destructive tests and/or a limited number of destructive ones can be performed on such buildings, due to their historical importance and to the necessity of guaranteeing the ordinary service state (in fact generally these structures are devoted to public service, i.e. municipalities, museums, religion activities, etc.). To overcome these problems, many no-destructive tests have been proposed (i.e. using radar in [1-2]) but only dynamic tests can give information on global behavior of the structure and not only on local properties.

In the field of the dynamic tests, the ones that make use of the environmental actions are the most utilized as they are easily to perfume and cost effective, in fact such tests do not request actuators and sensors for recording the forces acting on the structure, moreover they can be performed in the ordinary conditions of service only by guaranteeing the integrity of the sensors and the cables. Consequently, a wide class of applications of such tests and the development of the procedures for the analysis of the recoded data are available in the last years [i.e. 3-12] and also the authors used this techniques in other recent studies [3-4, 6-12] . In the aforementioned papers, the structural details related to the connections between orthogonal vertical walls or between vertical walls and floors, suggest that the structure is characterized by a "global" behavior and subsequently the estimated natural frequencies are due to "global" modes. However, in some cases the dynamical response of masonry buildings may be dominated by local modes instead of global ones, due e.g. to the existence of deformability floors and/or ineffective connections. In these cases only an attempt analysis of the dynamical tests can underline such behavior and give information for defining the analytical model of the structure. In the present paper a masonry building "San James" in Corfù (Greece), characterized by wooden floors, is investigated with the aim of evaluating its dynamical behavior and its local or global modes. In particular, the experimental tests and the preliminary analysis of a finite element model of the "San James" building are discussed and a strategy for identifying the first five global modes is presented and applied to the experimental data.

2 THE SAN JAMES BUILDING

The public building "San James" is the unique example of structure construct from carves stones inside the city of Corfu, Greece (Fig. 1). It is also characterized from excellent construction quality.

The structure was started to build in 1663 but it stopped for a period, probably due to financial problems. The works started again in 1687 and the construction was completed at 1693. Initially, the structure was built as lodge for the nobles and was known with the name "Loggia", only in 1720 it was renamed as "San James" like the close catholic Cathedral and was converted into a theater. At the end in 1903 it was converted into a City Hall when the insertion at the front part of the building was dismantled and one more floor at the center was built.

Figure 1: Main entrance of San James building in Corfù (Greece).

The building is rectangular and absolutely symmetric, with dimensions 24.75 m and 14 m, and height 9 m. Five domes in a row at the two small sides and two symmetric rectangle windows in each narrow side characterize the structure.

The building is composed by a semi-basement level with a height of 3.30 m, a first level that is partially covered by a wooden horizontal floor, up to which the second level is located, and by wooden trusses. The second level is protected by wooden trusses that have been utilized to avoid horizontal forces on the top of the masonry vertical structures (Fig. 2).

The masonry walls are made by natural limestone blocks, and have a thickness of about 1 m at the semi-basement level, that becomes equal to 0.75 m at the first level and remains constant up to the top of the building. The building is characterized by wooden horizontal floors, and shows no significant signs of inclinations or cracks.

Figure 2: Vertical section of San James building in Corfù (Greece).

3 THE FINITE LEMENT MODEL

The main aim of the present study is to define an analytical model that is able to describe with good accuracy the mechanical behavior of the San James building. Consequently, as a first step, all the drawings and the documentation of the San James building has been examined, and a visual inspection and a metric survey have been performed.

The available information have been utilized for the definition of the geometrical model of the building. Since, no reliable documentation related to the mechanical behavior of the masonry walls was available, three core samples have been extracted from the perimetral masonry walls and tested in the Laboratory ‘M. Salvati’ of the Department of Sciences of the Civil Engineering and Architecture of the Technical University of Bari, Italy. The Table 1 shows the experimental results on the three core samples, it must be underlined that it was not possible to evaluate the Young’s modulus on the third sample.

Table 1: Unitary weight and Young’s modulus of the three core samples extracted from the perimetral masonry walls of San James.

n. sample	Unitary weight [kg/m^3]	Young’s modulus [MPa]
1	2563	73850
2	2571	75246
3	2529	-

On the basis of the aforementioned experimental results, the finite element model of the Sn James building has been defined using the Sap 2000 Nonlinear commercial software [13]; in detail, the masonry walls have been modelled by means of thick-shell elements of constant characteristics along the transversal direction while the masonry has been modelled as isotropic material with density of about 2200 kg/m^3 (the unitary weights of table 1 have been reduced for taking into account the presence of the mortar) and Young’s modulus of 7000 MPa, i.e. the 10% of the experimental Young’s modulus of the natural limestone (see table 1). Moreover, the wooden floors have been modeled by means of shell elements with 0.25 m thickness that simulate the wooden beam and the wooden deck platform. The building has been considered fixed at the base and in correspondence of the connections between the semi-basement and the outside roads. The source of mass of the building has been considered the weights of the structural elements and the 30% of the live loads acting on the floors, that have been assumed equal to 2 kN/m^2.

The frequency values related to the first three global modes are shown in table 2, while in figure 3 the first three mode shapes are plotted.

Table 2: Frequency values of the first three natural global modes of the finite element model of San Giacomo building.

Mode	Frequency (Hz)	Classification
1	8.49	Bending
2	10.671	Bending
3	12.922	Torsion

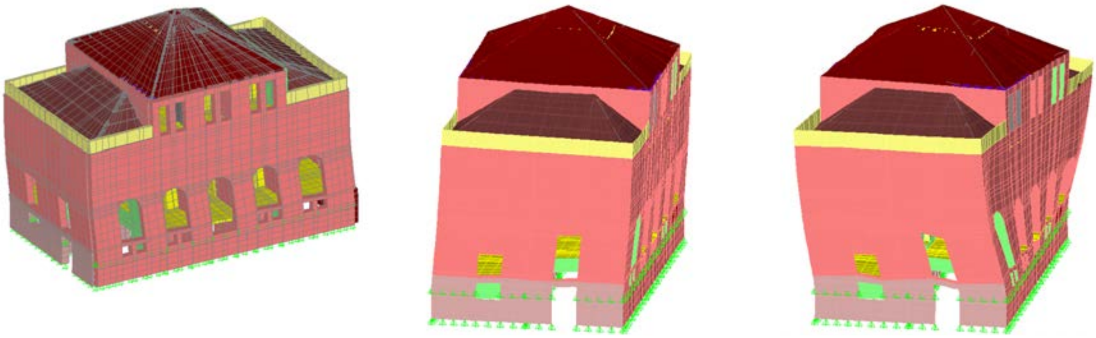


Figure 3: First three global mode shapes of the finite element model of the San James building in Corfù . (a) Fist mode, bendig, (b) Second mode, bendig, (c) Third mode, torsion

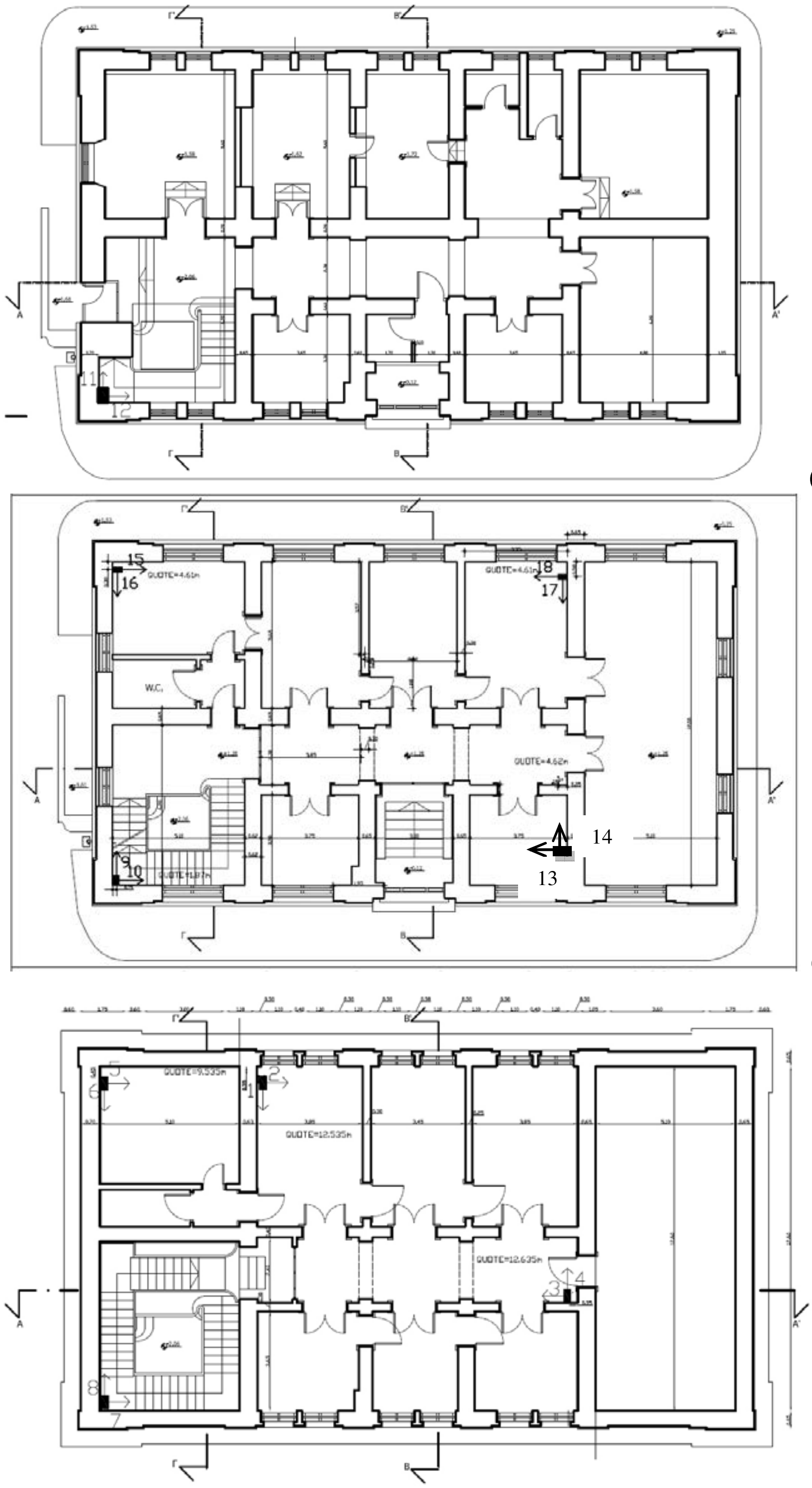
4 THE EXPERIMENTAL SETUP

After the survey, the monitoring phase has been performed on 10th and 11th of July 2013. The monitoring system consists of several elements properly connected: 18 seismic accelerometers ICP PCB 393B31 with a sensitivity of about 10 V/g; the data acquisition system or DAQs positioned at each level monitored; the laptop with an acquisition software; the cables that connect all elements each other.

Nine points of the building have been monitored by installing in each point two accelerometers on appropriate rectangular blocks (see Figure 4) in order to ensure the orthogonality of the couple of sensors.

Figure 4: Accelerometers installed in three different points of the San Giacomo building in Corfù (Greece).

The monitored points are sketched in figure 5. Each data acquisition was carried out by 10 minutes recordings with a sampling frequency of 1024 Hz, which has been subsequently decimated by a factor equal to 4 to have a sampling frequency of 256 Hz in the considered data.



(a)

(b)

(c)

Figure 5: the plan views of the San Giacomo building in Corfù (Greece); the arrows indicate the acquisition direction of each accelerometer: a) semi-basement level; b) first level; c) second level.

A preliminary analysis of the accelerometers time histories is shown in [10] where a detailed description of the experimental setup is also shown.

5 THE DATA PROCESSING

The recorded data have been processed to identified the natural frequencies and the modal shapes of the San James building by using the specialized Artemis software [15]. At this proposal a spatial model of the building and of the position of the accelerometers has been created as shown in Fig.6.

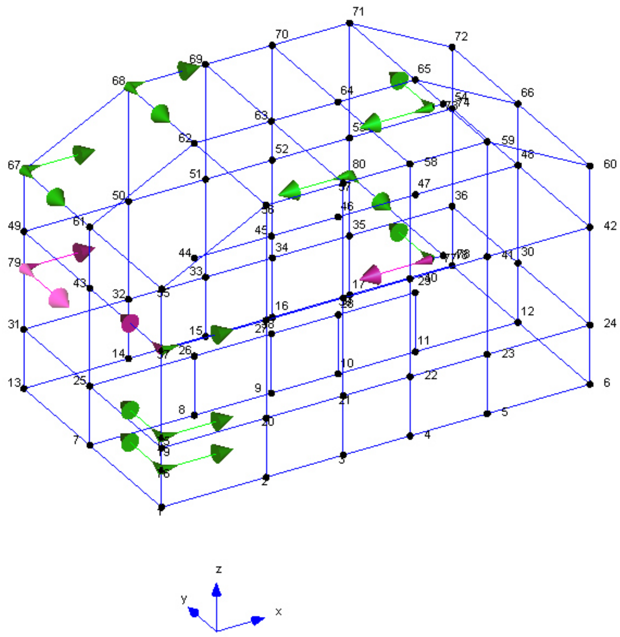
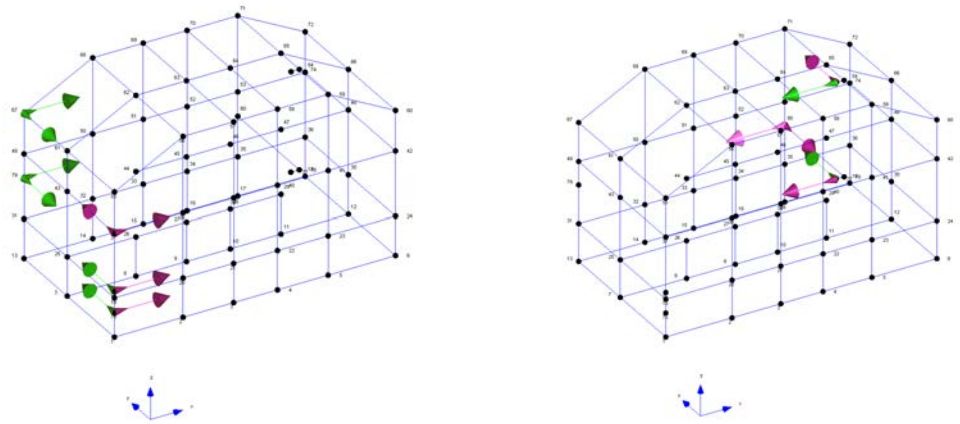


Figure 6: Artemis model of the San Giacomo building in Corfù (Greece); the arrows indicate the acquisition direction of the 18 used accelerometers.

As shown in [10], the acquired signals in environmental conditions have a very low amplitude, due to the very squat profile of the structure and for the large walls. For this reason, as demonstrated in [16], only the Stochastic Subspace Identification (SSI) method [17-18] essentially based on fitting to dynamic response discrete-time data and more robust for low significant data, has been used for performing the Operational Modal Analysis in this case.

Moreover, in order to verify the contribution of local modes on the dynamic response of the examined building, the following strategy has been proposed: the data have been analysed taking into account only the accelerometers positioned on the same wall. So, two groups of accelerometers have been considered; the first composed by the accelerometers (named by the numbers as indicated in Fig.5) 5,6,7,8,9,10,11,12,15,16 related to the perimeter wall parallel to the y axis (Fig.6) on the left part of the building. The second composed by the accelerometers 3,4,13,14,17,18 related to an internal wall parallel to the same *y* axis on the right part of the building. In Fig. 7, the two groups considered indicated directly on the Artemis model neglecting the presence of the other sensors.

The SSI method has been applied on ten different acquisitions in such a way to have a statistical identification; a sample of the SSI application (first group of accelerometers, test 1) with maximum order 100 is shown in Fig.8. The SSI diagram in Figure 8 demonstrates that the peaks corresponding to the frequencies are not well highlighted, probably due to the very squat and fixed shape of the structure. Anyway, a certain number of frequencies may be identified; considering the repeatability of the frequencies all over the ten considered acquisitions, the frequency repeated over the 50% of the tests have been considered for the following analysis. In Table 3, the average value on the ten tests and the standard deviation of the first five identified frequency by SSI method for the two considered groups of accelerometers.



a) b)

Figure 7: the two groups of accelerometers separately considered: a) first group; b) second group.

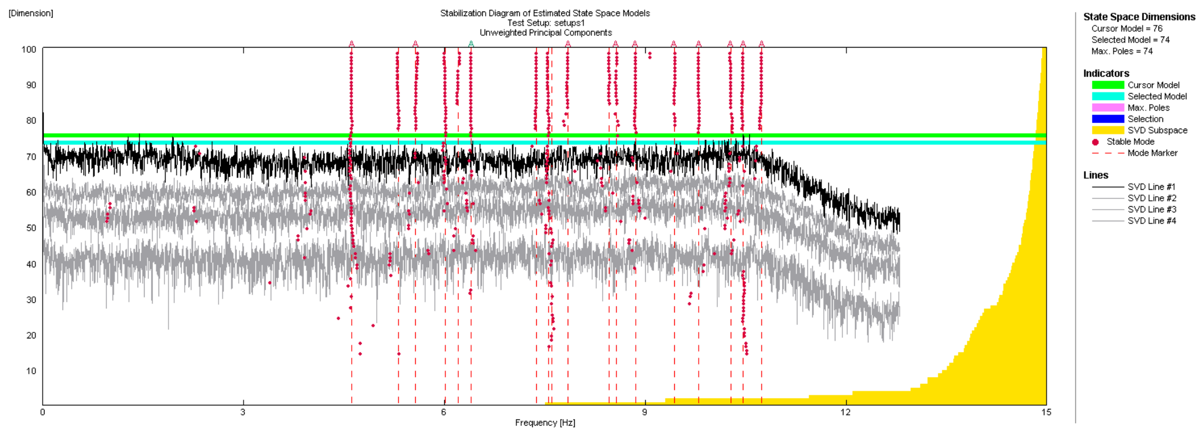


Figure 8: Results of SSI methods for the first test of the first group of accelerometers.

Table 3: Statistical characteristic of the first five identified frequencies with SSI method for the two groups on ten tests.

n. identified frequency	Average value for the first group [Hz]	Standard deviation for the first group	Average value for the second group [Hz]	Standard deviation for the second group
1	4.69	0.044	4.68	0.017
2	5.74	0.065	5.73	0.028
3	6.51	0.053	6.50	0.036
4	7.60	0.049	7.66	0.040
5	8.88	0.036	8.87	0.064

The results in Table 3 clearly demonstrate that the identified frequencies are very repeatable and stable for both the groups showing a very low standard deviation on the 10 experimental tests. Moreover, the frequency values are practically coincident for the examined groups, consequently such frequencies can be reasonably considered as related to "global" modes. This information is very important for a subsequent phase of model validation and updating.

The actual differences between the identified frequencies and the numerical ones may be due to some hypothesis regarding the total mass of the building and the mechanical characteristics of the masonry, but the entities of such differences make confident of the updating procedure of the finite element model.

6 CONCLUSIONS

The present paper describes the study of an important historical building characterized by a squat profile, large walls and wooden floors. The dynamical identification using accelerometers has been carried out estimating the first five frequencies of the structure and analyzing their global character; the identification accuracy has been guaranteed by considering several experimental data referred to consecutive acquisitions. In this sense, a statistical approach has been performed. These results will further increase the accuracy of the realized FE model.

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