Dynamic identification of a historical masonry building: the case study of palazzo Rosciano

DYNAMIC IDENTIFICATION OF A HISTORICAL MASONRY BUILDING: THE CASE STUDY OF PALAZZO ROSCIANO

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Abstract

This paper focuses on the dynamic characterization of a historical building located in the port city of Livorno (Italy), Palazzo Rosciano. It is a masonry structure built in the second half of the 1600 and fully renovated in the nineties to accommodate the offices of the North Tyrrhenian Sea Port Authority. The research was carried out starting from a preliminary inspection and a historical-critical analysis. Then, a detailed geometric survey was carried out using a 3D laser scanner. To define the mechanical properties of materials a series of minor destructive tests, i.e., flat jacks, shove test, and penetrometer, were performed. A structural health monitoring campaign was also carried out under ambient vibrations using a wireless sensor network. The acquired data was processed to characterize the dynamics of the structure by means of two different output-only techniques, the frequency domain decomposition, and the stochastic subspace identification.

Keywords: Historical masonry building, Materials testing, Structural Health Monitoring, Ambient Vibration Test, Operational Modal Analysis, Structural Dynamic Identification.

1 INTRODUCTION

Traditional masonry buildings have an extensive and prominent heritage in Europe, especially in Italy. It is crucial to preserve this built heritage in historic cities, above all those that are located in seismically active regions. In fact, the recent earthquakes in Italy have highlighted the necessity of comprehensive monitoring and safety evaluation of the built environment.

Structural Health Monitoring (SHM), a tool of particular relevance that allows for the analysis and estimation of the state of health of civil works with the goal of determining their safety, represents a reliable support that professionals and researchers may rely on [1, 6].

The inspection and testing campaign carried out on the historic building "Palazzo Rosciano" will be examined in the following paragraphs, starting with the historical-critical analysis, and ending with the dynamic identification, by way of the in-situ testing and investigation.

2 GENERAL OVERVIEW

Located in the Venezia Nuova district (Livorno, Italy), the building under study is a branch of the Port System Authority of the Northern Tyrrhenian Sea. It is a historic building built in the early decades of the 1600s, part of a larger masonry aggregates (Figure 1).

The building has four floors above ground and a basement, with a pseudo-rectangular shape. The load-bearing structure consists of masonry walls of various thicknesses, that widen below the ground level to shape the foundations system. The above ground floors are one-way timber-concrete composite slabs, while the ground floor consists of masonry vaults.

In Figure 2 the architectural plan of the ground floor is shown.

Figure 1 – Google Earth view

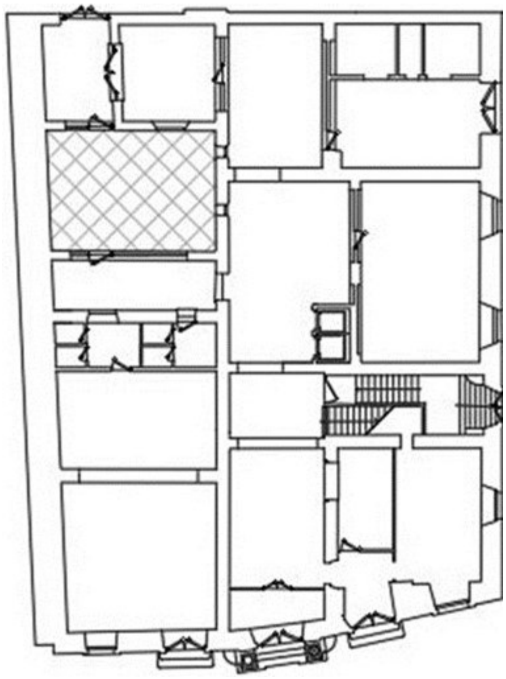

Figure 2 – Architectural plan of the ground floor

3 HISTORICAL-CRITICAL ANALYSIS

Despite being a city with an important historical past, Livorno has seen its cultural heritage greatly reduced following the devastation caused by war events and an invasive reconstruction plan. However, there were several urban redevelopment projects that have affected the Venezia Nuova district and, consequently, Palazzo Rosciano after the first half of the 1900s. The building was built between 1580 and 1620. Originally, only the construction of a warehouse for remittances of port equipment had been planned and, only later, the above floors were built. After its construction, the building underwent many transformations mainly due to the bombings that devastated the city during World War II. Ignored for several years, it regained its splendor thanks to the 1989 restoration.

The retrofitting history of the building has been extracted from technical reports and geological surveys and used to develop the FEM model of the building.

A program of investigations and testing has been planned, as described in the following paragraphs, to confirm the accuracy of the information acquired from the historical-critical analysis and collect the extra information.

4 IN-SITU TESTING AND INVESTIGATION CAMPAIGN

First, visual investigations were conducted, allowing for the analysis of the cracking pattern, the texture of the walls and their degree of interlocking. Based on these findings, a set of *minor-destructive tests (MDT)* were planned to evaluate the mechanical properties of the constituent materials, such as single and double flat jacks, shove test, and penetrometer [1, 2, 3, 4].

Regarding the geometric survey of the building, the BLK360 3D laser scanner produced by Leica was used. The point cloud (Figure 3) acquired in such a way can be used to create a future BIM model.

Figure 3 – Point cloud

5 DYNAMIC IDENTIFICATION

5.1 SHM acquisition system

The TRITON model of the LUNITEK data gathering and processing system was employed. An integrated Force Balance triaxial accelerometric sensor is part of the system. The 24-bit resolution A/D conversion device was configured with synchronous sampling at a sampling rate of 250 samples/second per channel. The device has a microSD memory that you may use to manage a ring-buffer for prolonged continuous recordings and a GPS receiver for absolute time synchronization. A local network connection (cable or WiFi) or a UMTS/HSPA modem can be used to connect to the instrument and enable remote control of its operation. The system has an internal battery (LiPo) that ensures continuous operation for more than 30 hours and is powered by an external network [1, 2, 3, 4].

5.2 Sensors setup

The accelerometers were placed on the extrados of the slabs to carry out the recordings. The different configurations of accelerometers have all been oriented in accordance to a single global reference system (N,E,Z). Figure 4 represents a setup example used during the building's dynamic characterization tests.

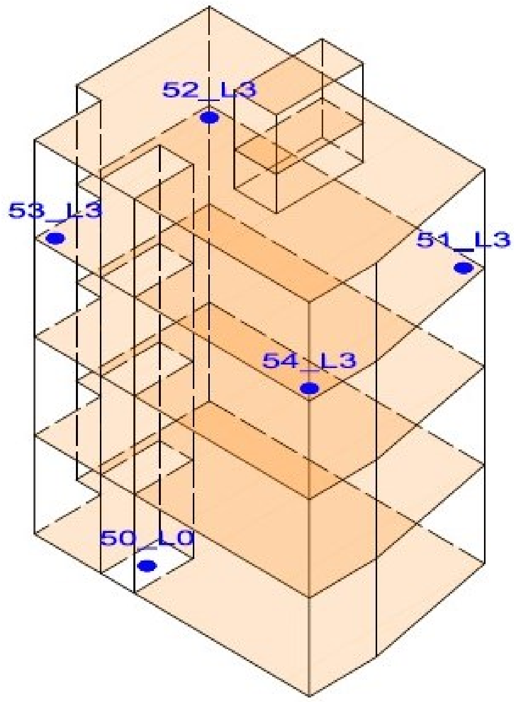

Figure 4 – Example of sensors setup

5.3 Ambient Vibration Test (AVT)

Ambient Vibration Tests (AVT) were performed on the structure in compliance with operational modal analysis to identify its modal properties (natural frequencies and mode shapes).

The sensors' data consists of acceleration time histories. A "clean" sub-window, which is one that is free of anomalous peaks caused by bumps, for example, and can therefore be recognized as white noise, was then obtained within the actual recording window [1, 5, 7].

5.4 Frequency Domain Decomposition (FDD)

Frequency Domain Decomposition (FDD), a dynamic identification approach, was used. It works in the frequency domain and is based on the *Power Spectral Density (PSD)* matrix's singular value decomposition algorithm.

It is possible to determine the spectral density eigenfunctions corresponding to each mode of the system and, consequently, to estimate the modal shape at each peak, from the assessment of the *Singular Values - SV* (Figure 5) that are returned in the output [7, 8].

5.5 Stochastic Subspace Identification (SSI)

The dynamic identification method known as *Stochastic Subspace Identification (SSI)*, that operates in the time domain, was then used. These kinds of methods are considered as a robust output-only identification approach, compared to other methods currently available.

A stochastic state-space model of the structure is found through *SSI* algorithms. The final model can then be converted into a more practical structural model form for the results' engineering interpretation. Both the modal model and the *Finite Element (FE)* model formulations can be related to the state-space model.

In practice, once the analysis has been performed, the output will be determined by stabilization diagrams (Figure 6) which align the distribution of the values obtained in the frequency peaks, identifying the modes of vibration of the system [9, 10]

Figure 5 – Example of SV-frequency diagram

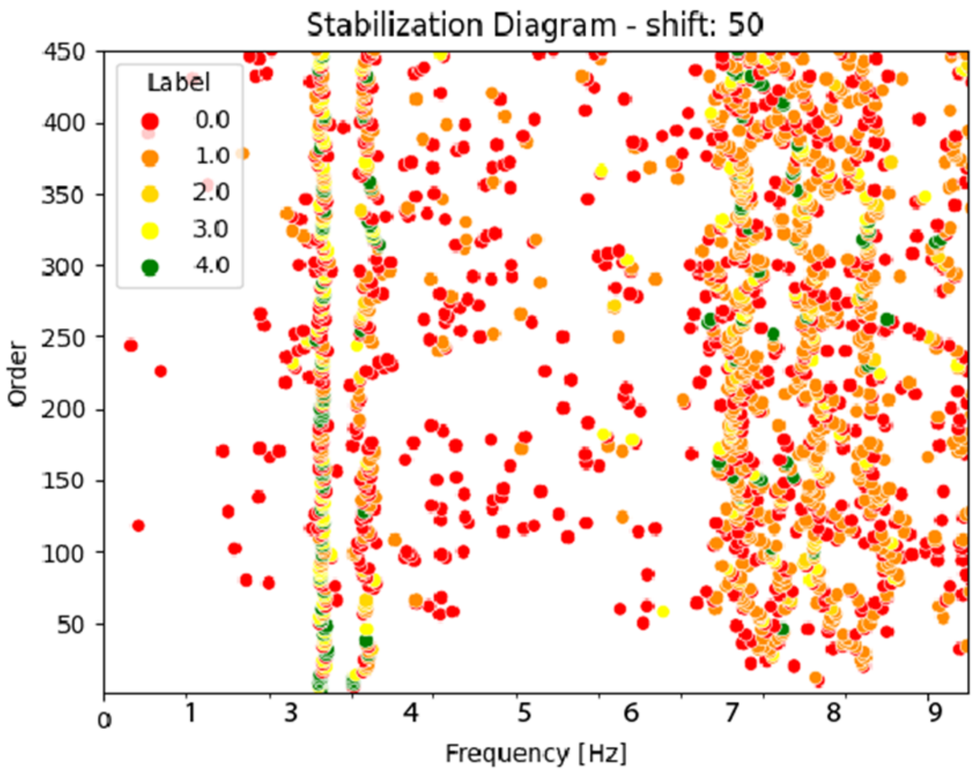

Figure 6 – Example of stabilization diagram

5.6 Results

The *FDD* algorithm has led to the identification of a single mode shape of the structure. In fact, considering the results for all the different sensors setups, it was possible to identify a natural frequency corresponding to the identified mode equal to 3.24Hz. While, the stabilization diagram obtained with the *SSI* technique has returned a distribution of remarkable values around 3.21 Hz. By performing a final comparison between the outputs of the two analyzes performed, with the necessary approximations, the procedure and the obtained results have been validated.

Figure 7 shows the comparison between the normalized modal shapes obtained with *FDD* (dash-dotted line) and *SSI* (solid line). The first mode of vibration of the structure is a flexural type mode shape in the global east direction, the only free angle of the structure.

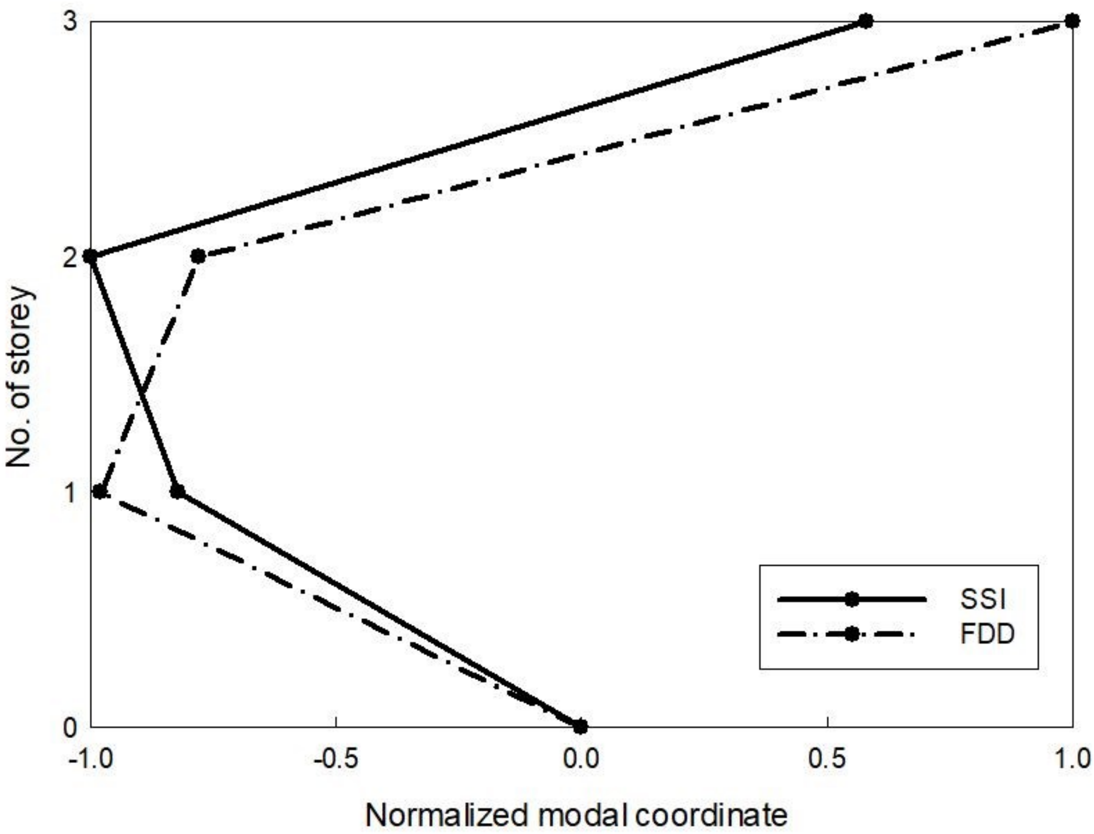

Figure 7 – Comparison of mode shapes

6 CONCLUSION

The aim of the present paper is to assess the dynamic behavior of the Palazzo Rosciano, a historical masonry building located in the port city of Livorno (Italy).

At first, a preliminary inspection and a historical-critical analysis were carried out to obtain as much information as possible. Secondly, a detailed geometric survey was conducted using a 3D laser scanner at the same time. Then, test campaign, which included a series of *minor destructive tests (MDT)*, was carried out to evaluate the mechanical properties of materials.

Finally, an ambient vibration modal identification campaign was carried out to detect the dynamic characteristics of the structure. Two different output-only techniques, frequency domain decomposition and stochastic subspace identification, provide reliable and comparable results. The latter could be the starting point for the development and calibration of future numerical models.

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