Evaluating dynamic behavior of historical buildings through ambient seismic noise measurement and numerical modelling

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Abstract – **The paper describes integrated geophysical investigations coupled with structural analysis and numerical simulation with the aim of study and evaluate seismic vulnerability of cultural heritage sites. The analysis consists in collecting data with non-invasive portable instruments to characterize local site effects as well as dynamic properties of the structure. We focus investigations on data collected at several locations in the Maltese Archipelago (central Mediterranean) and in some historical buildings located in Catania (Sicily).**

I. INTRODUCTION

In order to improve the knowledge about the seismic risk of cultural heritage several attempt have been made. In this framework, the use of ambient-vibration monitoring represents a useful tool for the monitor and the structural assessment of historical buildings to evaluate their dynamical response. In addition, it can be used in the free-field to constrain the geological/seismic model to be used for site response analysis. In our study the fundamental period of several Maltese Watchtowers (Figure 1) is obtained by computing the ratio between the amplitudes of the Fourier spectrum of horizontal (longitudinal and transverse) components recorded on the top and on the ground floors [1,2,3,4,5]. This method is also known as standard noise spectral ratio (SSNR) technique. A similar work was performed in some historical buildings of Catania (Figure 1), belonging to a total set of 70 buildings distinguished according to their construction typology. The Finite Element (FE) model was employed to assess the seismic vulnerability of the studied buildings.
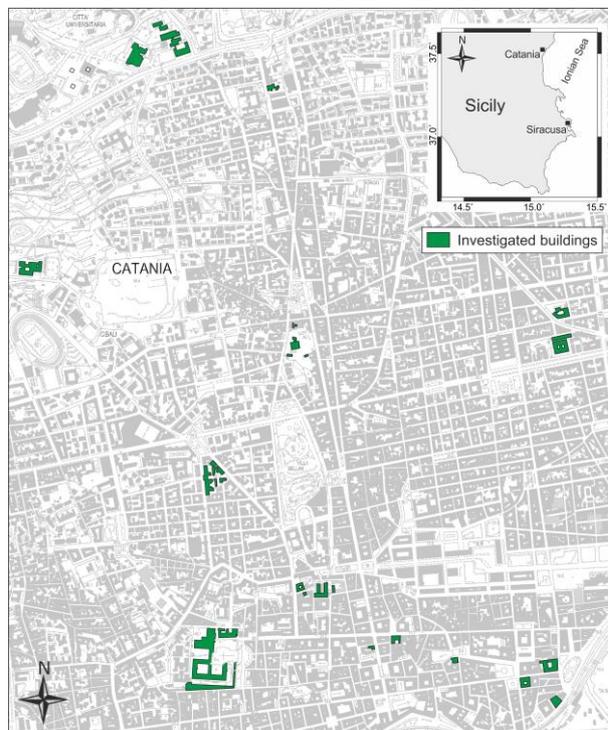
Fig. 1: (top)Location of the investigated buildings in Catania and Malta (bottom)

II. DATA COLLECTION AND PROCESSING

Ambient noise was recorded using a three-component velocimeter, locating it both at the top and at the ground floor, computing the H/V and the SSNR to identify the site and the building fundamental frequencies respectively. In addition, the damping ratio was computed as well using the Random Decrement technique. Since no earthquake recordings were available, numerical modelling were carried out for the investigated site using the code STRATA (https://nees.org/resources/strata). It computes the seismic site response of a 1D soil column using the equivalent-linear analysis method. The analysis was performed considering a horizontally polarized shear wave vertically propagating through horizontal layers. The input stratigraphic sequences were modelled using the elastic parameters of the main outcropping geological formations at the investigated sites. Geological stratigraphy was evaluated using some passive seismic techniques. In particular, joint inversion of array measurements (42 geophones placed in an L- or C-shaped configuration) and H/V data where used in order to derive a 1D velocity model for the investigated sites and subsequently an amplification function has been computed [6,7,8,9,10,11]. The latter has been used to compute synthetic seismograms for the evaluation of seismic vulnerability of the structure. The H/V recordings outside the buildings were used to determine predominant frequencies of the soil and to highlight the existence of potential site-to-structure resonance during a seismic event.

III. DISCUSSION AND CONCLUSIONS

The dynamic properties of a building are usually described through its natural frequency and the damping ratio. The latter parameter represents the energy loss of an oscillating system that can be either internal (material damping) or due to another system (radiated damping). The damping ratio is important in seismic design since it allows one to evaluate the ability of a structure to dissipate the vibration energy during an earthquake. Such energy causes a structure to have the highest amplitude of response at its fundamental frequency, which depends on the structure's mass and stiffness. Therefore, the damping level, as well as the knowledge of the fundamental period (T) of the building are particularly important for estimating the seismic base shear force F in designing earthquake resistant structures. The fundamental frequency of the investigated structure has been obtained using two or more sensors monitoring the motion at different locations in the building (usually top level and basement) and using ambient vibrations.
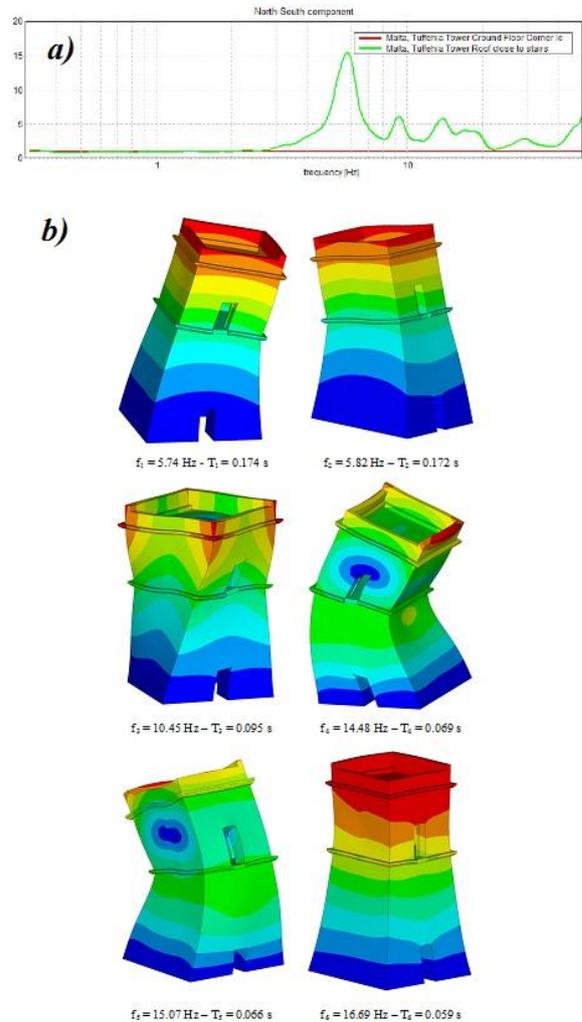

Fig. 2. a) H/V graph for the Ghajn Tuffieha. Watchtower (Malta). b) Mode shapes and natural frequencies

Using the SSNR technique, the seismometer was

placed on the top floor in a point assumed to be coincident with the center of mass of the floor in order to minimize vertical modes of beams or floors. The fundamental frequencies observed for these towers ranges between 5 – 6 Hz. Figure 2a gives an example of the computed H/V. Using ANSYS [12, 13] the modal analysis was performed to evaluate the first 10 vibration modes with the aim to check the activation of the modal masses. Several numerical mode shapes of Maltese towers were obtained with the identified numerical model. An example for one of the Maltese watchtowers is reported in Figure 2b. The first two computed are bending modes (almost pure translations) along the two main directions of the tower, the third mode is a torsional mode, while higher modes are superior bending modes. To this aim, linear time-history (TH) and nonlinear static (pushover) analyses were performed in order to predict the capacity diagrams of the masonry building along with extension and type of damage. In particular, during this process the computed site effects have been used and have been incorporated in the computation of synthetic seismograms [14, 15].

For the buildings investigated in Sicily, the SSNR results set into evidence the complex dynamic behavior of the investigated buildings. Thus it was not possible to identify a single natural frequency but several oscillation modes have been observed; an example is given in Figure 3. These results can be interpreted in terms of several factors such as the structural complexity of the whole edifice (masonry building with the presence of reinforced concrete elements), irregular plan shape and the presence
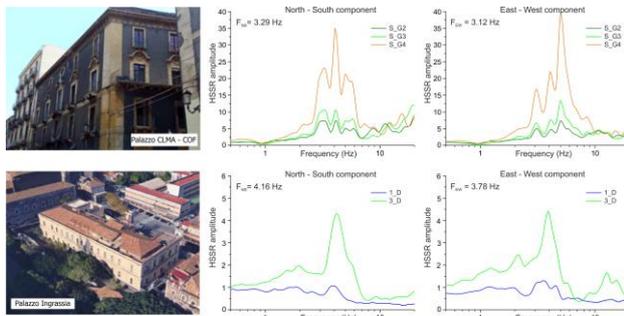

Fig. 3: Example of SSNR results in two investigated buildings

of adjacent structures. The damping values obtained through a weak motion input (ambient noise) must be handled with caution, but significant information can be gained. In our study it appears evident a variability linked to the different rigidity of the considered buildings as a function of the longitudinal or transversal orientation of its main structural elements.

In conclusion, he used approaches highlight how the structural complexity and the local seismic response play an important role on building damage. The achieved findings can represent useful clues for further numerical modelling and to finalize additional engineering investigations aiming at reducing the seismic risk.

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