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Determination of structural behavior of a unreinforced masonry Clock Tower using FEM analysis

Enea Mustafaraj[1], Yavuz Yardım[1,2],
[1](Department of Civil Engineering, Epoka University, Albania)
[2](Department of Civil Engineering, University of Nizwa, Oman)

ABSTRACT :*In this paper it is presented the structural assessment of the Clock Tower found in the castle of Preza, an old historical landmark built during the beginning of 15th century. The structural behavior is analyzed using FEM modeling in order to examine at what extent the structural defects endanger the stability of the tower also considering the geotechnical properties of the soil under the basement of the tower. The geometrical data are acquired by means of terrestrial laser scanner (TLS). Mechanical properties of the constituents were defined through experimental tests on stone samples extracted from the tower. As a result, a better overview of the structural conditions is established and improvement techniques are suggested in order to enhance the performance under both static and dynamic loads.*

Keywords –*finite element modelling, heritage buildings, structural assessment, TSL, unreinforced masonry*

I. INTRODUCTION

Masonry is one the most used construction materials in the history of mankind used in various forms as a basic construction material for public and residential buildings, closely associated with the earliest civilization about 10 000 years ago. Unreinforced masonry (URM) buildings are the most common construction type around the world, as well as in Southern Europe and around the Mediterranean basin. Although these regions are characterized with medium-to-high levels of seismic hazard, the URM buildings are vulnerable as they have been designed (often not designed at all) to only resist gravitational loads and have been realized by rules of common practice. Many of those structures have suffered from the combined effects of inadequate construction techniques, seismic and wind loads, foundation settlements and deterioration of construction materials [1].

In Albania, there are found many cultural heritage buildings made of unreinforced masonry that carry a significant importance due to their unique, cultural, historical and architectural values. Many of those buildings due to the decay and degradation of construction material, aggressive environmental conditions, frequent seismic activity and various geological phenomena, as well as the lack of maintenance, are found to be in a very bad condition. The large number of historical structures highlights the need for preserving this cultural heritage group as one of the most immediate issues to be resolved [2].

It is believed that the suggested assessment method as well as the retrofitting strategies, could be applicable also to other similar heritage buildings that belong to the same period of construction.

II. MATERIALS AND METHODS

Assessment of seismic vulnerability of historic masonry constructions is a very challenging task due to several uncertainties regarding a material's mechanical properties and geometric characteristics of the structure. Recent earthquakes around the world have shown that most masonry towers are susceptible to structural damage and collapse. There have been many attempts from researchers all over the world to model, analyze and retrofit various heritage building structures that are prone to natural disasters. Vicarious Palace in Pescia is an example of seismic vulnerability assessment where a FEM analysis was applied. The comparison of the expected seismic demand versus capacity of that palace emphasized the insufficient resistive capacity of this building against earthquake forces [3]. Lourenço et al., 2001, with the aid of geometric simplifications, carried out an assessment seismic behavior of a basilica church defining the most vulnerable parts and identifying the possible failure mechanisms [4].

In Albania, there have not been any organized large scale attempts to assess current cultural heritage inventory. In 2012, five Ottoman mosques in Albania were analyzed and assessed based on visible "symptoms" that the structural defects or distresses had caused throughout the structures. After the analysis process, strengthening strategies were suggested [5].

2.2 Description of the structure

The Clock Tower is found in the castle of Preza located 15 km away from the capital, Tirana. It has an irregular pentagon plan which measures roughly 80 by 50 meters. The form is largely dictated by the shape of the hilltop. The eastern tower of the castle, which was turned into a Clock Tower in 1852, has a height of 14.5 meters and stands on a 4.2 x 4.2-meter-plan. It has two stories, separated by timber floors. The second story is accessible through internal ladders (Fig.1).

Figure 1. Clock tower: the past (a) and present condition (b)

The tower had a large rosette window, on the outside executed in brick work, in Ottoman style. Nowadays, the top of the tower has been modified and the clock and window are missing. However, it should be mentioned that during its existence the tower has been damaged and repaired several times, mostly due to earthquakes (Fig.1) [6].

2.2 Methodology

The methodology used for this study is based on the in-situ assessment of visible “symptoms” that structural defects and distresses had caused throughout the structure. Visual inspection was followed by a finite element model (FEM) analysis of was conducted in SAP2000 in order to examine the behavior of the tower under static and dynamic loads, as well as to identify the weak locations of potential failure in the structure. The input data related to mechanical properties of the stones were defined after conducting material tests according to ASTM, C170-90 which describes the standard test method for compressive strength of dimension stone. This test method covers the sampling, preparation of specimens, and determination of the compressive strength of dimension stone (Fig.2) [7].

Figure 2. Testing the samples in laboratory

Obtaining the geometrical data was done by using a calibrated high-resolution digital camera (Nikon D90) firmly mounted onto the terrestrial laser scanner Optech ILRIS (3D Intelligent Laser Ranging and Imaging System) together with Topcon GPT 3007 Total Station that provided a combination of scan data and image data. The laser scanner facilitates the procedure of measurements. It enables a field view of 360º along horizontal and a 60º view in vertical plane. In this way, a full panoramic view could be generated. The generated point cloud provided accurate details of the surface pattern of the structure and mapping coordinate system of the volume the structure covered. The structure surface was scanned using the laser scanner with high resolution. A laser beam is used to obtain the geometric coordinates (x,y,z) of points at regular intervals on the visible surface of the structure. Then a point cloud is obtained based on the adjustment and sensitivity of used equipment. A total of 120.000 cloud points were obtained. A color imaging device such as 3D camera used together with the scanner to projecting structure’s geometric data onto obtained image for each scanned point.

The second stage of the geometric data representation with TSL is carried out in the office. Obtained data were merged using the PolyWorks commercial software. The software allows the input data to be accurately purified. The produced triangular meshes control model details. Finally, three-dimensional digital models were obtained (Fig.3).

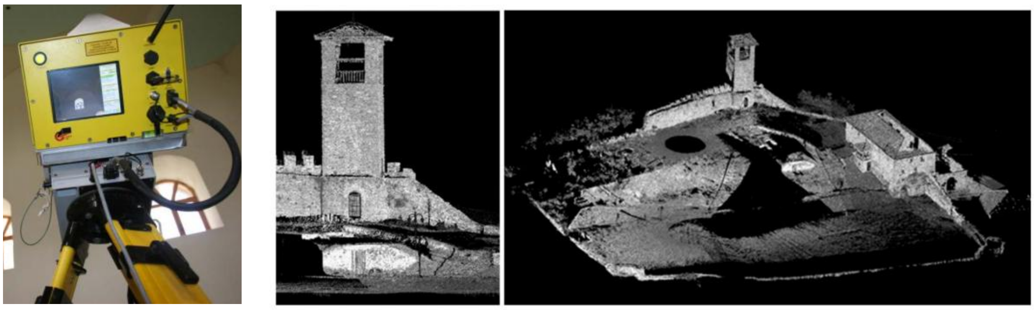

Figure 3. (a) Laser scanner used, (b) point cloud of the tower, (c) point cloud of the whole area of the castle

In order to have a better understanding of the structural behavior, the geotechnical properties of the soil under the tower have been investigated. It is composed of two layers; clayey sand and clayey gravels. The bearing capacity of the first layer, σ, is about 1.8 kg/cm^2, whereas the second one is 5 kg/cm^2. The results showed that the properties were classified as good to very good. The underground water table was found to be below 15 meters. These data clearly indicated that the soil does not have an important role in formation of the cracks in the structure.

A FEM modeling was carried out to demonstrate the behavior of the structure based on rough shapeand more accurate shape. The analysis was carried out using SAP2000 v.15.0 software [8] based on Eurocode 8 [9] (EN1998-1) with consideration of local earthquake code, KTP-N2-89 [10]. The elements and material were chosen to obtain the most realistic simulation of the structure's behavior.

The Clock Tower was modelled in SAP2000 using macro-modelling (masonry units and mortar layers are considered as a continuum, where masonry is isotropic, homogeneous and shows elastic behavior) with shell elements. The analysis would define and locate the most critical regions where the maximum stress concentrations are found. Moreover, distribution of secondary stresses and the behavior of the undamaged model under static and dynamic load was investigated.

The model consists of 2644 joints and 2568 shell elements. Material properties of the model are: unit weight, γ = 20 kN/m^3, modulus of elasticity, E = 1800 MPa, Poisson's ratioυ = 0.2[11], tensile strength, f_t = 1.42 MPa [3] and compressive strength of the stone masonry, f_c = 15 MPa.

Response spectrum analysis was conducted in order to analyze the effects of the ground motion excitations on the structure. The peak ground acceleration based on the obtained soil data and the location of the site, was taken as 0.25*g*. "Type 1" spectral acceleration curve was chosen from Eurocode 8 [9]. Response spectrum analysis predicted the maximum likely response of the structure for a possible earthquake with a magnitude of 5.5 with a 10% likelihood of occurrence and a return period of 475 years [8]. In order to validate the assumption accuracy results, the modal frequencies were compared with previous studies. The most difficult part in modeling a historical monument is obtaining the right material characteristics. Uncertainties related its construction and maintenance and obtaining required number of samples to test are the main obstacle to achieving accurate material properties.

III. RESULTS AND DISCUSSION

The results of the damage survey showed that there is a need for intervention in order to improve its structural performance under cyclic loads. There are a diffuse series of visible cracks are present in all façades of the tower (Fig.4). It is seen the propagation of cracks from top until the bottom of the tower. It is believed that seismic loads are one of the main causes of these cracks.

Moreover, from the archive, it was stated that the tower has been repaired several times. The materials used for repair might have had different properties than the original ones, thus many of the surface cracks could have been formed.

After the visual inspection, FE analysis was carried out. The laser scanner data was transferred to AutoCAD and Sap2000 software to figure out a detailed representation of the geometric model.

Figure 4. Structural cracks found on the main façade.

As expected, the tower exhibits higher displacements at the top. The stresses under dead load are seen to be below the ultimate resistive capacity of materials. In other words, maximum stress values for all the elements do not exceed the allowable limits.

The hoop stress (S11) on the walls varies from -0.274 to 0.244 MPa. S22 ranges between -1.368 to 0.34 MPa. Maximum concentrations are located at the bottom parts of the load bearing walls (Fig.6).

The response spectrum analysis results of the undamaged model have shown that the effect of the seismic loads is felt the same in both directions as the structure has a squared plan and with no irregularities. The maximum displacement is 5.4 mm at the top of the tower.

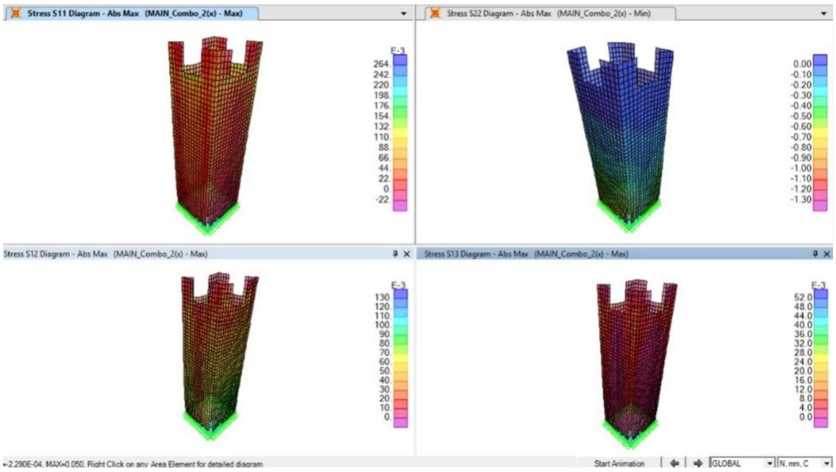

Figure 6. Example of stress distribution after analysis.

IV. CONCLUSION

As it was seen from the assessment result, this structure suffers from cracks and material deterioration. The load bearing walls of the tower exhibit both visible surface degradation as well as structural cracks. Thus, the intervention procedure should consist on reducing the shear and tensile stresses on the walls by adding additional tensile and shear resisting elements where necessary. One of the objectives to be achieved is that connections should be flexible rather than rigid to avoid stress concentrations and guarantee the durability of the structure [12].

Injection is suggested to be used in areas where non-structural cracks less than 10 mm wide are found. The most useful feature is the increase of continuity of masonry. Furthermore, neither aesthetics nor architectural features of the mosques will be altered when applied.

In order to increase ductility of the structure, it is suggested to insert longitudinal FRP bars bonded with epoxy resin or mortar at different levels. Additionally, local reconstruction “cucci scucci” technique is suggested to be used in the places sanding phenomenon is seen and where massive loss of building units is observed. The substituting units must have to the same architectural features, and should be compatible with original facades.

It is believed that the above mentioned strategies would improve the structural performance of the tower under both static and dynamic loads.

REFERENCES

[1] Faella C., Martinelli E., Nigro E., Paciello S., (2010). Shear capacity of masonry walls externally strengthened by a cement-based composite material: An experimental campaign Construction and Building Materials 24 84–93.

[2] Mustafaraj, E., Yardım, Y. (2013). Repair and Strengthening of Historical Structures: Naziresha's Mosque in Elbasan,3rd Annual International Conference on Civil Engineering, 10-13 June 2013, Athens, Greece.

[3] Betti, M., & Galano, L. (2012). Seismic analysis of historic masonry buildings: The Vicarius Palace in Pescia (Italy), Buildings.

[4] Lourenço, P.B. (2005). Assessment, diagnosis and strengthening of Outerio church, Portugal. Construction and Building Materials, 19(8) 634-645.

[5] Mustafaraj, E. (2014). Assessment of Historical Structures, A case study of five Ottoman Mosques in Albania, LAP Lambert Academic Publishing, Saarbrucken, Germany.

[6] Mustafraj, E. and Yardim, Y. Sructural assessment of Preza Clock Tower, Albania, ICESA 2014-International Civil Engineering & Architecture Symposium for Academicians 2014, 17-20 May 2014, Side, Turkey.

[7] ASTM Standard C 170 – 90, (1999). Standard Test Method for Compressive Strength of Dimension Stone, USA.

[8] CSI: SAP2000 v-15.0 (2013): Integrated finite element analysis and design of structures basic analysis reference manual, Computers and Structures Inc, Berkeley, California, USA.

[9] EN 1998-1, (2004): European seismic design code, design of structures for earthquake resistance, Part 1: General rules seismic actions and rules for buildings.

[10] KTP-N2-89: Albanian seismic design code, 1989.

[11] Faella, C., Martinelli, E., Nigro, E. & Paciello S. (2004). Tuff masonry walls strengthened with a new kind of C-FRP sheet: Experimental tests and analysis, 13thWorld Conference on Earthquake Engineering, Vancouver, Canada.

[12] Anzoni, A., Binda, L., Carpinteri, A., Invarnizzi, S. & Lacidogna, G. (2009). A multilevel approach for the damage assessment of historic masonry towers. J. of Cultural Heritage. 11, 459-470.