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Structural Analysis of Tirana's Clock Tower in Albania

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ABSTRACT

Preservation of the ancient heritage and old structures for future generations is considered as a fundamental issue in the cultural life of modern societies. The purpose of preserving old monuments is to protect them as enduring landmarks and as testimony of the Albanian's unique, multi ethnic and rich cultural heritage. On the other hand, the repair and conservation of historical buildings and monuments is a complex and challenging discipline.

Watch towers are common in Albania. In many cities these towers are often protected by law as part of the cultural heritage. The main focus of this paper is to investigate and to present a summary of the results of the structural response of the Clock tower of Tirana, including its response under gravity and seismic loads. The stress concentrations at the critical locations are investigated and the analysis results were discussed.

Keywords*: Clock tower, seismic vulnerability, structural behaviour, dynamic analysis*

INTRODUCTION

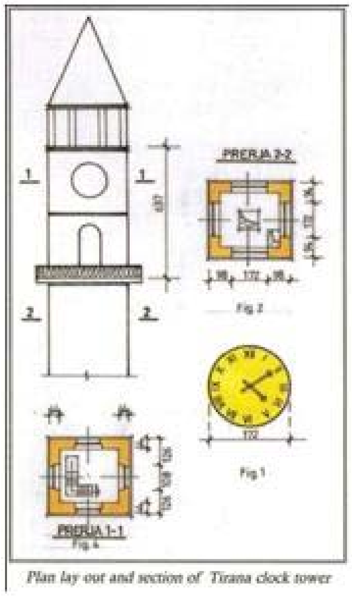
Historical masonry towers are found throughout world, where they characterize a unique aspect of many of its historical centers. It is not well-known that almost all of Albanian urban cities had watch towers. Although for some watch towers there are no information regarding their accurate time of construction, it is widely accepted that they are constructed between 16th - 17th centuries during Ottoman Empire and later in 20th century in modern times.

Usually the watch towers were constructed in the highest peaks of the cities. Thus, they were built on the high grounds of the city near markets with the aim to make people aware of time such that people could open their stores or pray to their beloved God. Outside today's Albanian territory, the Skopje watch tower is the oldest one. It was constructed in 1555. Whereas in the Albanian territory, Kruja watch tower is the oldest one that once used to be the supplement of a church. Kruja watch tower is constructed in 16th - 17th century. Sometime later, Berat watch tower constructed but it got damaged in 1967 and the city of Berat is the only city in Albania without a watch tower. It is said that the Berat watch tower used to be so big such that 16 grown men could be seated inside the tower and its sound could be heard miles away. There are still some old Watch towers in other Albanian cities such as Gjirokaster, Peqin, Kavaje and Elbasan using old mechanism.

Evaluation of the structural safety of historical masonry towers is one of the vital issues in the preservation of the national and international patrimony of architectural heritage in the cultural life of modern societies. Their vertical structure places at significant risk, not only because of the high stresses acting at their foundation, but also due to their great vulnerability to the thermal effects variations and, especially, dynamic actions consequent to events such as earthquakes, the vibrations produced by traffic or the wind.

In this context, Tirana's clock tower has been selected as a case study [Figure 1]. Dating back to the 1820-1821, the tower was initially started and its construction was finished with the help of richest families of Tirana. The tower is about 35 meters in height, with a rectangular cross section of about 4.30 by 4.30 meters. It was built in masonry (granite stones) with dry joints in the corners and mortar joints in the middle of the walls. The walls have, on average, 450 mm. of thickness.

a) Clock Tower of Tirana



b) Plan layout and elevation of the clock tower

Figure 1. Tirana Clock Tower

In the present study, gravity and earthquake analyses have been carried out using response spectrum provided in UBC97 [1] and the results are comparatively given.

ANALYTICAL MODELING

Micro and macro modeling possibilities for masonry structures exist due to various accuracy of the analysis. Macro modeling is preferred in this study. It is preferable in case of necessity compromising between efficiency and accuracy and it is used when the structure has solid walls with large dimensions [2]. Therefore, the tower was assumed to be made of unique material which has a Young modulus E = 2 GPa, a unit weight γ = 20 kN/m^3 and the Poisson ratio ν = 0.2. These values were selected by literature survey and by comparing the properties with similar type structures. A detailed geometrical model of the structure is extracted by using the 3D geometrical modelling software (AutoCAD). After that three-dimensional analysis model is developed by using SAP2000 structural analysis software [3]. The program employs a layered finite element approach and can be used to predict the behaviour of any masonry structure. The tower was modelled by two-dimensional shell elements. Totally, 2810 shell elements were used for the analysis model [Figure 2]. Displacements at the base of the chimney have been considered fixed in vertical direction. No soil-structure interaction or base rotations have been taken into account.

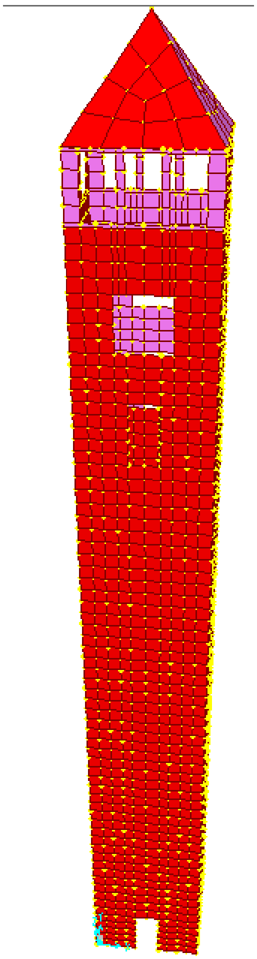


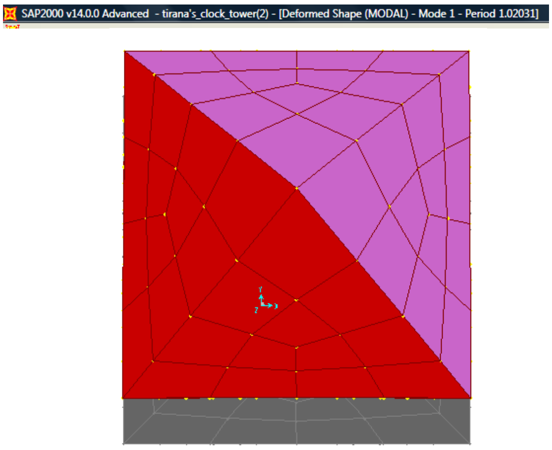
Figure 2. Structural analysis model

It is important to employ reasonable number of finite elements to capture the response of the structure having acceptable level of accuracy. Using large number of elements may give results where the global behavior of the building can be difficult to extract. On the other hand, very small number of elements is not able to obtain the behavior of the structure with sufficient level of accuracy. Some minor simplifications are carried out in order to avoid geometrical complexity of the tower structure. The model is elaborated until obtaining the response of the structure with reasonable accuracy.

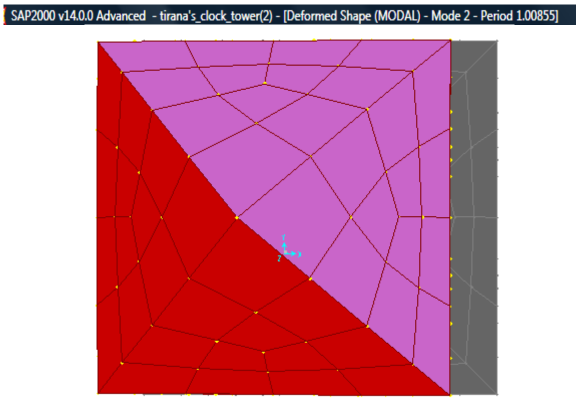
Self-weight and earthquake analyses

The dynamic behaviour of these towers is related to their modal characteristics such as natural frequencies, mode shapes, and damping ratios. Free vibration and spectral earthquake analyses are employed so as to determine the structural response and the stress variation of the tower. Analyses are performed under the assumptions of linearly elastic material as it has been applied generally in solid masonry structures in order to obtain overall response.

Free vibration analysis is performed and the natural periods of the building are obtained. The first two mode shapes of the tower occur in the two orthogonal directions [Figure 3]. First and second natural periods are close, which represents the mass participating ratios of these first two modes and structural rigidity of the both directions are approximately equal to each other [4].



(a)



(b)

Figure 3. Mode Shapes; a) First mode shape, b) Second mode shape

Variation of the normal stress due to the self-weight is presented in Figure 4. As expected, vertical compressive stresses increases downwards and it reaches up to 0.65 MPa at the lowest level of the tower. As seen in the figure, stress concentrations occur in the vicinity of the openings and the stress at the edges of the lower openings increases up to 0.20 MPa.

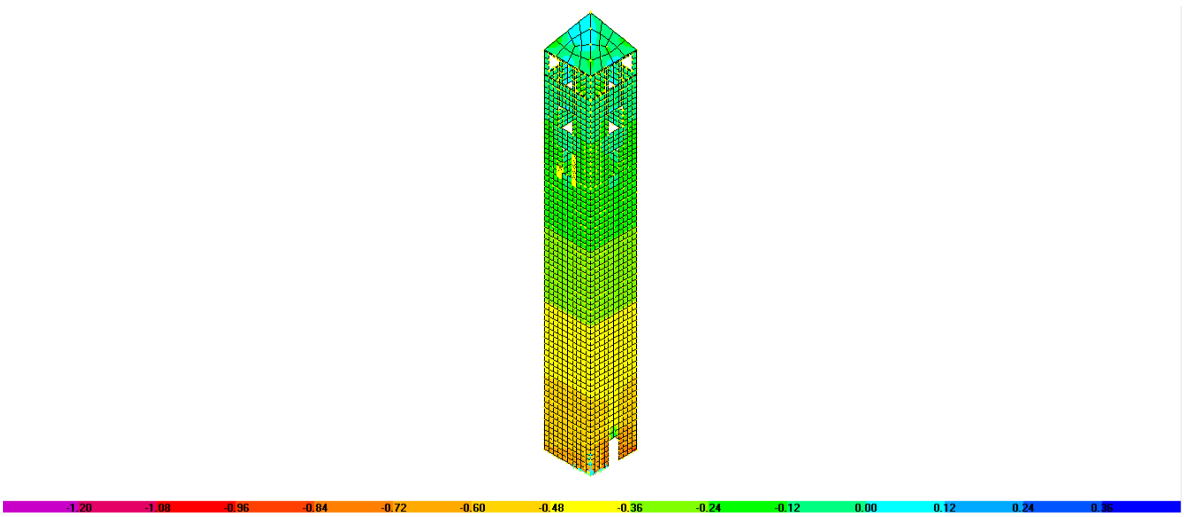


Figure 4. Self-weight analysis – Vertical normal stresses (N/mm^2)

Spectral earthquake analysis has been employed by using the spectra defined provided in UBC-97 [1]. The response spectrum in UBC-97 is related to the site specific values of C_a, C_v which is given in Table 1. Soil type C is considered in this analysis for the case study tower.

Table 1. The values of C_a, C_v according to the soil type (UBC-97)

Soil type	**Soil profile name/ Generic description**	**Shear wave velocity (m/sec)**	C_a	C_v
S_A	Hard rock	> 1500	0.32	0.32
S_B	Rock	760 – 1500	0.40	0.40
S_C	Very dense soil and soft rock	360 – 760	0.40	0.56
S_D	Stiff soil profile	180 – 360	0.44	0.64
S_E	Soft soil profile	< 180	0.36	0.96

The result of the spectrum analysis is given in Figure 5. Stress concentrations occur at the corners, around the opening of the walls under the self weight and the earthquake loading. The maximum normal stress in the structure is around 2 MPa in compression and 1 MPa in tension. Stress concentrations are formed at the edges and around the openings (Figure 5).

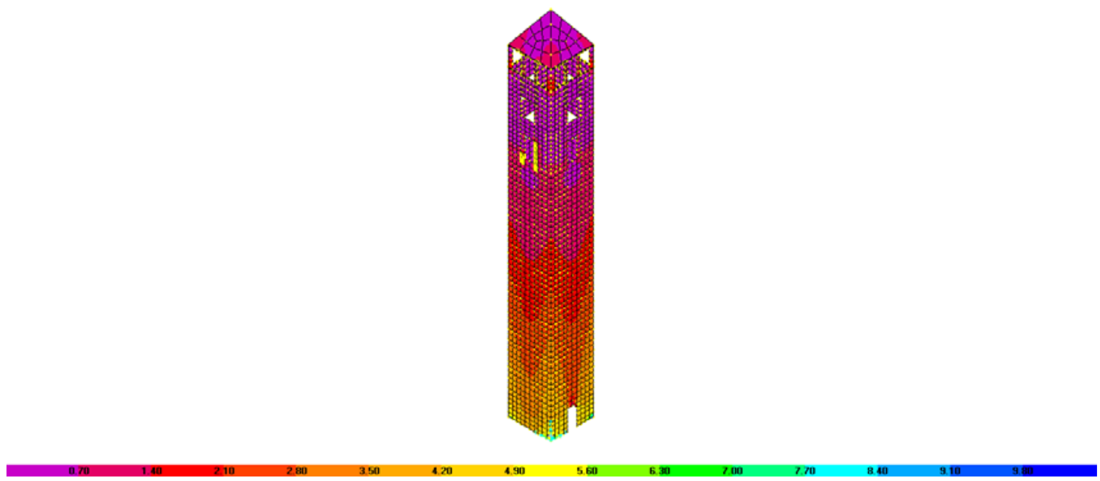


Figure 5. Vertical normal stresses for the N – S earthquake directions (UBC-97 Spectrum) (N/mm^2)

CONCLUSION

Masonry construction consists of masonry units and mortars among them. Analyzing of these structures can be done by two analytical methods. Macro modelling is used here since; the building has solid walls with large dimensions for necessity of compromising between efficiency and accuracy. It is shown that, overall structural behaviour of the building can be obtained by using a reasonable number of finite elements. The first two mode shapes of the building come into being as a result of lateral displacements and occur in two orthogonal directions. Historical structures are expected to undergo larger earthquake forces compared to the ordinary structures. In the numerical analysis, UBC97 earthquake spectra are employed. As expected, stress concentration occurs around the edge of the openings. Small tensile stresses are formed at the top wall levels. Under the self weight and the earthquake loading, stress concentrations occur at the corners, around the openings of the wall. The maximum stress varies around 2 MPa in compression and 1 MPa in tension under spectral analysis.

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