NATURAL AND ANTHROPOGENIC HAZARDS OF A BELL-TOWER LOCATED IN CENTRAL GREECE

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ABSTRACT

The bell-tower under study is located at Artesiano village, at a distance of 35 km from Meteora monasteries. The bell-tower is one of the four in Central Greece that share a unique feature: the base’s masonry is made of stone while the upper levels’ masonry is made of bricks.

Concerning the damage caused by anthropogenic hazards, the abandonment of the monument resulted an extend damage of its construction materials. Moreover, several applied interventions and decorative additions are observed. Although they have been applied arbitrarily, they indicate respect and interest for the monument. The local authorities have undertaken the maintenance work, which is not unusual at Greek province.

Concerning the damage caused by natural hazards, several cracks are observed at base’s parts and especially at openings. A strong earthquake, occurred in 1954, is possibly the reason for the observed cracks. Analysis is carried out and the results are compared to the present state of the structure.

INTRODUCTION

Natural and anthropogenic hazards are responsible for the collapse of many masonry bell–towers in Greece. Initially the paper describes general architectural characteristics of bell-towers, located in Central Greece and particularly the ones of the monument under study. In addition, observed damage, caused by the absence of maintenance work, such as detachment, erosion and biological colonization, is pointed out. Moreover, the human interventions and the decorative additions to the monument are highlighted, as they constitute a common practice, applied often at the monuments of the Orthodox faith. Finally, the vulnerable parts of the construction are mentioned and an analysis of the structure is carried out, in order to verify observed cracks caused by earthquakes.

DESCRIPTION OF THE BELL-TOWER OF SAINT THEODORE CHURCH

The bell-tower is an important individual or embedded part of the Hellenic Orthodox church. The appearance of a bell-tower in an area is a sign of establishment of the Orthodox Faith. Therefore, the bell-towers were erected in central Greece just after the Turkish rule, the last decade of the 19th century (“Early years of the Nation” era).

Since bell-towers are considered as landmarks of the Orthodox Faith, the requirements of the architectural design are high due to the symbolic context of the building. Additionally, their morphological characteristics should be in harmony with the facades of the church. Moreover, structure’s slenderness and the type of available materials at the time, make their structural design a challenging issue, especially in terms of required earthquake resistance [1]. All the above parameters raise the expectations for shape, details and structural adequacy of the particular building.

An historical, typical bell-tower located in central Greece, consists of the base, the main part and the roof. The main part is divided into two or three levels and the masonry walls are formed with
openings. Although mostly, the bell-towers are constructed entirely of stone, in a few cases, a second structural material, the solid brick, is used especially in the construction of vaults, domes and arches.

However, there are also few unique bell-towers, where the base’s masonry is made of stone and the levels’ masonry is made of solid bricks. The above construction technique is applied at only four bell-towers in Central Greece.

The bell-tower under study is one of these four bell-towers. It belongs at the Saint Theodore church, which is located in Artesiano village, 35 km away from Meteora monasteries. The monument, erected in 1888, constitutes the central entrance at the churchyard, separated from the church (Figure 1), which was constructed in 1899.

![General view of the bell-tower](image)

**Figure 1:** General view of the bell-tower

**GEOMETRY OF THE BELL-TOWER UNDER STUDY**

The bell-tower of Saint Theodore church, is divided into base and two upper levels. The first level is accessible via a metallic staircase. The bells are suspended between the first and the second level and the structure is covered by a dome. The basic architectural plans are presented in Figure 2 and the dimensions of the basic parts of the structure are the following:

- Total height = 13.20 m
- Plan area = 3.60 x 3.60 m
- Dome’s internal diameter = 2.75 m
- Dome’s internal height = 1.00 m
- Unit of brick = 115 x 50 x 30 mm (length x width x height)
- Average unit of stone = 700 x 200 x 300 mm
- Average width of mortar joints = 10 mm
- Tie’s cross section = 40x5 mm
Four openings of the base provide access to the churchyard. The morphological characteristics are notable and plenty of details of the base’s structure indicate a tentative architectural treatment. The base’s masonry consists of ashlars, with strips of solid bricks intervening in between (Figure 3). The vault and the arches at the openings are also constructed of solid bricks, while pieces of stone are put only at the exterior façade. Pilasters with capitals appear on the sides of the central opening frame at the base. The lintel is decorative by a bas-relief where a face like form is raised, a classic theme of traditional art [2] (Figure 4).

At the upper levels, the piers are constructed with a unique way, which results in a sculptural form.
of the external surfaces. The particular shape of piers copies the equivalent shape of stone construction. It should be noted that the dimensions of basic structural parts like piers and openings, remain the same as if the construction was made of stone (Figure 5). At the second level, the construction of masonry is even more refined with round decorative patterns at the corners. For masonry’s reinforcing and linking, ties are applied at openings, installed where the arches begin. It is also observed that the dimensions of the piers are slightly reduced from the first level to the second one.

Figure 5: The pier located in first level

PATHOLOGY DUE TO ANTHROPOGENIC HAZARDS

The total absence of scientific conservation work resulted in intense damage of structural materials. Consequently, gradual dislocation of masonry occurred as time passed by. Mortar’s erosion, destroyed masonry’s cohesion and several bricks have been detached especially at the second level. Moreover, a great quantity of mortar has collapsed at the base’s vault. Abandonment has also allowed external factors like rain and ground water to penetrate into the structure and deteriorate masonry’s condition. Plants have eventually colonized places where rainwater is accessible, like the lower parts of piers, extending roots into joints. As the roots have grown, they have also contributed to dampness and other vegetal organisms like lichen have grown as well. Actually, there are many parts of the monument covered by lichen and this can be due not only to abandonment, but also to pollutants derived from heavy vehicle pollution. Furthermore, problems are observed on ties condition and conjunction, as rust has affected the iron. Due to abandonment, some anchors are also missing and as a result, the ties have lost their function.

Beside the absence of maintenance work, human activity has also deteriorated the monument [3]. Given that the monument faces the main road (Figure 1), heavy traffic vibrates the bell-tower and atmospheric pollution deteriorates even more the quality of its materials. Plenty of human deliverable interventions at structural parts of the tower are also observed. For instance, cement of several layers covers the internal surface of the dome (Figure 6). The first level’s floor has been replaced by a concrete slab, while a cement ring belays the masonry at the second level. Possibly the above alterations are due to soil consolidation, since deviation from the vertical axis is obvious. It can be assumed that the above interventions aimed at preventing or at least delaying an imminent failure.

Plenty of additions applied to decorate the bell-tower, are also noticed. For instance, headlamps hang in the interior of the first level. Additional lighting features are applied at the facades and power supply cables are suspended or nailed to the masonry. Base’s floor paving prevents rainwater from infiltration and therefore capillary moisture caused by the prevention of rainwater from infiltration, is observed at the lower units of stone. Furthermore, there are parts covered by plasterwork, in order to decorate the south facade at the churchyard (Figure 7). New metallic
elements are also observed like the railing at first level between the four piers and the two metallic beams based on ties, so as to carry the bell’s load at the same floor. The external staircase for access to the first level is also based on metallic features, which are nailed to the external elevation and a metallic gate is added at base’s main opening. Finally, inappropriate additions surround the monument, such as the low sidewall made by cement tiles, the planting contacted to the structure and the dustbin put at a very close distance. It is obvious that the above human activity does not rely with monument’s historical value and construction’s materials and is applied arbitrarily.

Figure 6: Cement of several levels at the internal surface of the dome

Figure 7: Decorative additions

PATHOLOGY DUE TO NATURAL HAZARDS
Several cracks can be seen on the masonry surface. The most extensive damage appears at the piers of the base’s central opening. Localized failures like the fracture at the capital of the right pier and the partial detachment of the lintel can be discern at the north’s elevation central opening. There is also a deep and long crack at the same opening between the pier and the masonry (Figure 8). Beside the vertical cracks caused by high local compressive stresses, base’s masonry has suffered short diagonal cracks caused by shear stresses.
Figure 8: The long crack at base’s opening

It is interesting to observe that the piers made of bricks at the upper levels, are not split or crashed. However, cracks are observed at the other parts of brickwork like the dome and the base’s vault. It can be assumed that the bearing walls made of bricks, do not face structural damage and the curved surfaces are considered as the vulnerable parts of brickwork.

The mentioned cracks can be caused due to weathering, flaws in stone or stability problems. They can also have been induced by vibrations caused by an earthquake that occurred in 1954 (M 6.7) in central Greece. This earthquake caused the collapse of 1200 masonry buildings among which several churches in the broader area [4]. The bell-tower of Saint Theodore is situated close to the earthquake’s epicenter at Sofades, a city in 30 km distance from Artesiano village. In order to verify the source of the observed cracks, a structural analysis was carried out based on the finite element method and the current recommendations for masonry [5], [6].

The results of the analysis indicate vulnerable parts of the construction and it is verified that they coincide with parts where cracks are observed (Figure 9, Figure 10 and Figure 11). According to the results, the primary stresses are mainly appeared at the lowest parts of the piers and at the openings. Furthermore, the base of the bell-tower is the part of the building that suffers the most.

Figure 9: Compressive stresses

Figure 10: Tensile stresses
CONCLUSIONS
Based on careful observation of the monument, we reached the following conclusions:

Plenty of human interventions and additions have been imposed, since local authorities have undertaken maintenance work at the monument. Unfortunately, this seems to be a common practice in Greek province. The bell-tower is considered as a monument of high sentimental value and the local authorities have been often interested in “protecting” and “preserving” it. The applied practice indicates respect and care for the monument. Nevertheless, the maintenance work is usually applied without scientific guidance.

The bell-tower of Saint Theodore resisted the hit of an earthquake in 1954. The sustained damage caused by natural hazards to the construction, can be estimated by a finite element analysis, since the results indicate the vulnerable parts of the structure.

The bell-tower of Saint Theodore church belongs to a unique architectural category and it is considered as a landmark for the particular area. Its architectural and structural characteristics are notable. It is recommended the required maintenance work to be carried out by a team of specialists and not to be left only to the local society. Fortunately, the mentioned interventions at the Saint Theodore bell-tower are reversible and there is a chance for the monument’s preservation. The restoration work can involve the removal of rough additions that spoil its form and style, so that the initial architectural synthesis will be enhanced. The damages can be repaired taking into account the analysis of the structure. Finally, the above interventions should be followed by conservation work on a permanent basis under scientific consultation.

REFERENCES


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