Modelling the structure of Carol I Mosque Minaret taken into account the seismic evaluation

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Abstract. The paper aims to analyze the behavior of seismic actions of minaret – structural components characteristic of mosque. As it is known, the characteristics of this construction are governed by the slenderness and the distribution of the constituent materials by height. An important component is the most real quantification of the characteristics resistances as well as the impact of other loads in operation. The paper presents the case study – the minaret of the Carol I Mosque from Constanta, an emblematic historical monument of Constanta made by Eng. Gogu Constantinescu 110 years ago.

1. Introduction

The minaret is a very important component in the composition of a mosque, being defined as a high tower attached to the building, which has at the top a balcony from where, the muezzin calls the people for praying. Also, the minaret has an important role due to its height, being observed from a distance by the visitors of those lands, which thus symbolizes the presence of Muslim people.

A special worship place for the Muslim community in Dobrogea is the Carol I Mosque, which was built between 1910-1913 by the Romanian state during the leading by King Carol I, this being the reason that the mosque received his name, but is also known like the royal mosque. The architect Victor Stefanescu, one of the famous architects of the time, and the engineer Gogu Constantinescu, an exceptional inventor in the field of reinforced concrete, who used it in the construction of the dome and minaret of royal mosque, were engaged to build the project (figure 1).

It is a minaret that reaches a height of over 40m, so its behavior under the action of destructive environmental factors becomes a special concern for specialists, for this important component of the mosque that is a historical monument. So, in this paper are presented the efforts and displacements that appear in the minaret under the seismic action force, the structure being modelled in the automatic calculation program Scia Engineer.

It is necessary to know the critical point of this type of construction in order to combat the serious damages that may occur under the seismic action. We can thus refer to the minarets of other mosques in Dobrogea that have suffered very important degradations that have led to the need for significant repair works. For example, at the minaret of the Esmahan Sultan mosque from Mangalia, built in 1573 year, whose structure is made of limestone masonry, in 2008 year were carried out on this structure, which was partially demolished and rebuilt with the original materials left intact. The cause of the need for work on this minaret was the fact that the structure was tilted to one side and its resistance was severely damaged. It is also mentioning that the minaret at the beginning of the building had a height twice as high as the current one according to an image made around 1828. [1]
Another example can be the mosque from Cernavoda built in 1756, and built of stone masonry. Its minaret has tilted over time and it was necessary to carry out works to consolidate the minaret in critical areas. Also the mosque from Medgidia, built between 1856-1861 years, the minaret was in same situation like in Cernavoda.

![Figure 1. Carol I Mosque.](image)

2. **Methodology**

In this paper the following methodology was applied to obtain the results: comprehensive analysis of the references, field survey and seismic behavior analysis with Scia Engineer.

In the first stage, was studied the history of the mosque, if was some restoration or repairing process at this building. The aim was also to determine the characteristics of the materials used to build the minaret, and to identify the architectural elements.

The field study was performed to verify the information obtained from the documentation, about the dimensions and materials used for minaret building. An analysis of the degradations in the minaret structure was also performed through a photographic analysis.

In the third stage we performed the modelling of the minaret structure in the automatic calculation program Scia Engineer, whose shape was obtained as seen below (figure 2).

The outer body of the minaret was introduced into the program using the “Predefined shapes” function. The outer part is defined as a wall, its shape being like a cone trunk. In the middle of the minaret was inserted the central pillar, which like the outer wall has the shape of a cone trunk. The helical staircase is defined as concrete slabs connected in the outer wall and in the central pillar.

The following emplacement characteristics were used for the automatic calculation:
- \( a_g = 0.2\, g \);
- \( T_c = 0.7\, s \).

The structure fit into class II of importance – exposure because the height of the structure exceeds 28m, and the importance factor \( \gamma \) is 1.2. The behavior factor \( q \) is 2, because the minaret has a medium ductility class, having the shape of an inverted pendulum type.
After structural modelling were introduced load cases defined in table 1, that acting on structure.

### Table 1. Load Cases

| Name | Description | Spec  | Action type | Load type |
|------|-------------|-------|-------------|-----------|
| LC1  | Self weight | Permanent | Self weight |
| LC2  | Useful weight | Variable | Static |
| LC3  | Snow | Standard | Variable |
| LC4  | Seismicity | Seism X | Dynamic |
| LC5  | Seismicity | Seism Y | Variable |

Thus, after the introduction of the loads, the load combinations were generated in order to perform the calculation for determining the efforts and displacements, in order to verify the resistance and stability conditions at SLS and ULS.

### 3. Results

In the first stage, was obtained information about the materials used to build the mosque, which are as follows: for the foundations of the mosque: limestone; for the walls of the mosque: brick masonry, and for the dome and the minaret: reinforced concrete. The type of concrete used is C 6/8 (figure 3).

The shape of the minaret is tronconical, with a size of 3.9 m at the base, and 2 m at the top. The thickness of the minaret walls is 20 cm, and the height to the top reaches 40 m. At the top of the minaret is the balcony, which is accessed by the helical staircase inside the minaret, a staircase that consists of 140 steps. In the middle of the minaret is the central column which has the size at the base 1.5m and at the top 0.8m (figure 4). The amount of material used in the construction of the minaret can be found below in table 2.
Figure 3. Plan Carol I Mosque, side view.

Table 2 Material used for minaret building.

| Material  | Mass [kg]   | Surface [m²] | Volume [m³] |
|-----------|-------------|--------------|-------------|
| Concrete  | 249973.9    | 511.737      | 100         |
| Total     | 249973.9    | 511.737      | 100         |

Figure 4. Minaret plan.

During the field study we noticed some degradations on the minaret inside at the finishes due to the water penetrations through the windows, and in front of the balcony door. But also, in this stage we didn’t notice large cracks in the minaret structure (figure 5).
In Scia Engineer are obtained the 3D deformed shape of the minaret, the maximum displacement, and the values of the efforts in the walls of the minaret and in the central column, values of bending moments and axial efforts (figure 6, 7, 8).

After obtaining the results from Scia Engineer, are checked the conditions:

Resistance conditions

\[ E_d \leq R_d \]  

where:

\[ E_d = \frac{1}{q} \cdot E_e^* + E_g \]  

- \( E_d \) – total calculation effort;
- \( E_e^* \) - seismic actions effort;
- \( E_g \) – non-seismic actions effort;
- \( q \) – behaviour factor;

**Figure 5.** Degradations inside the minaret.

**Figure 6.** Deformed shape of the minaret
**Figure 7.** Maximum bending moment in central column.

$$E_d = \frac{1}{2} \cdot 1018 + 1004.58 = 1513.58 \text{ kN}$$

$$R_d = 2816 \text{ kN for } v = 0.4$$

$$\Rightarrow E_d \leq R_d$$

(3)

(4)

(5)

Stability conditions:

$$SLS - d_s = v \cdot q \cdot d_e \leq d_{ia}$$

$$SLS - d_s = 0.5 \cdot q \cdot 46.7 = 46.7 \text{ mm}$$

$$d_{ia} = 0.005 \cdot h = 150 \text{ mm}$$

$$\Rightarrow d_s \leq d_{ia}$$

(6)

(7)

(8)

(9)

$$SLU - d_s = c \cdot q \cdot d_e \leq d_{ia}$$

$$SLU - d_s = 0.89 \cdot q \cdot 46.7 = 84 \text{ mm}$$

$$d_{ia} = 0.025 \cdot h = 750 \text{ mm}$$

$$\Rightarrow d_s \leq d_{ia}$$

(10)

(11)

(12)

(13)

4. Conclusions

Historical monuments present a very important objective for the country. This construction is very important also for Constanta being a point of attraction for tourists as well. This monument attracts a significant number of visitors, so knowing the critical points of the minaret under the seismic action is particularly important.
From the point of view of structural behavior under the action of seismic force the minaret shows very good stability, although it has not undergone any consolidation process, from the edification to the present day.

It is visible the need to perform repair works on the finishes, such as painting inside the minaret, achieving a proper sealing at the windows so that it cannot penetrate the humidity. The reparations process that are used to ensure the stability of this kind of structure, must not affect its originality.

The modelling of this minaret represents a first step towards the modelling of the other minarets of the mosques on the territory of Dobrogea, framed as historical monuments, so that the serious damages on these constructions can be combated.

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