Conditional Assessment of Historical Structures: Earthquake Performance of Naziresha Mosque

Enea Mustafaraj[1], Yavuz Yardım[1]

[1]*Department of Civil Engineering, Epoka University, Albania*

ABSTRACT

The Naziresha Mosque is one of the most important historical buildings built during the Ottoman period, still functional in Albania. It is located in Elbasan, a city in the center of Albania. Naziresha mosque was built during 1590s. It has a square plan and a cubic shaped central hall. Though it is a historical monument with unique architectural properties, the current structural condition of the mosque is observed to be severe. Furthermore, the mosque is found in an active seismic area. In this paper, conditional assessment of the mosque and structural behavior is investigated to identify the weak locations of potential failure in the structure. The static behavior and performance under earthquake load of the mosque have been evaluated using the finite element modeling technique, where the behavior of masonry has been taken into account by proper constitutive assumptions. It is believed that the case studies conclusions are applicable to most of Ottoman period mosques in Albania. As a result, significant information on the understanding of the actual structural behavior of historic buildings is presented to provide effective solutions.

INTRODUCTION

The Naziresha Mosque is one of the most important historical buildings built during the Ottoman period, still functional in Albania. It is located in Elbasan, a city in the center of Albania. It was built in 1590s and it is situated in the southern suburb area of the city (Figure 1). It is under the protection of National Institute of Monuments of Albania as a monument of first category (Figure 2).

Figure 1. Satellite view Naziresha Mosque

Figure 2. North facade of Naziresha Mosque

The Mosque of Naziresha was built in Ottoman style. It has a squared 10.70 x 10.70 meters plan and only one cubic shaped central hall. The walls made of stone comprise the main load bearing system of the mosque. They are 1 meter thick and rise until a height of 8.12 meters. The materials used for building of the walls are rough yellowish limestone and red bricks. [1]

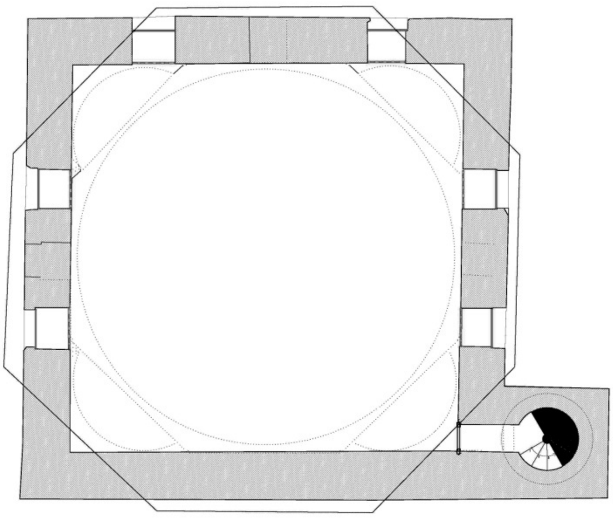

Figure 3 . Plan view of the mosque

Figure 4 . Interior view of the mosque

Transition from the cube to the dome is provided by perndentives. They are covered from outside by triangular shoulders. The dome rises over the pendentives 14 meters above the ground. It was made of bricks and has a thickness of 0.35 meters.

Roofing system is made of baked clay tiles attached to timber frame. Interior of the mosque was newly plastered and painted in white and green. It has a special acoustic system providing the sound to be heard clearly at every corner of the mosque. The minaret is placed at the west corner. It is made of neatly cut blocks combined with three layers of thin red bricks. The minaret is damaged and the upper section is missing.

CONDITIONAL ASSESSMENT

In this paper, conditional assessment of the mosque and structural behavior is investigated to identify the weak locations of potential failure in the structure Methodology for this assessment was based on visible “symptoms” that the loads and stresses have caused throughout the structure in time. Degree of the distresses severity was stated based on possible causes, location and extent of the cracks. The aim was to improve the existing capacity not only for static, but also for possible earthquake loads.

Furthermore, the city of Elbasan is found in one of the highly active seismic zones of Albania (Aliaj, Adams et. Al.,2004) with a rate density of 6.3 [2]. Though it is a historical monument with unique architectural properties, the current structural condition of the mosque is observed to be severe. Some of the main structural problems are listed below:

Dome and pendentives

Dome structural conditions are not adequate to carry static load. There are structural cracks found on it. It is very difficult to be seen from the interior, as it was recently re-plastered. Tiles on the roof are broken. There is found vegetation over them. Drainage system is not functional. Rainwater is not collected, but it leaks over the roof and over the walls being a potential agent for damaging the facade and structure of the walls. The lantern hanged at the top of the dome after the construction had caused extra stresses on the dome. However, as the dome has been recently plastered and old lantern replaced, cracks cannot be seen with naked eye (Figure 5).

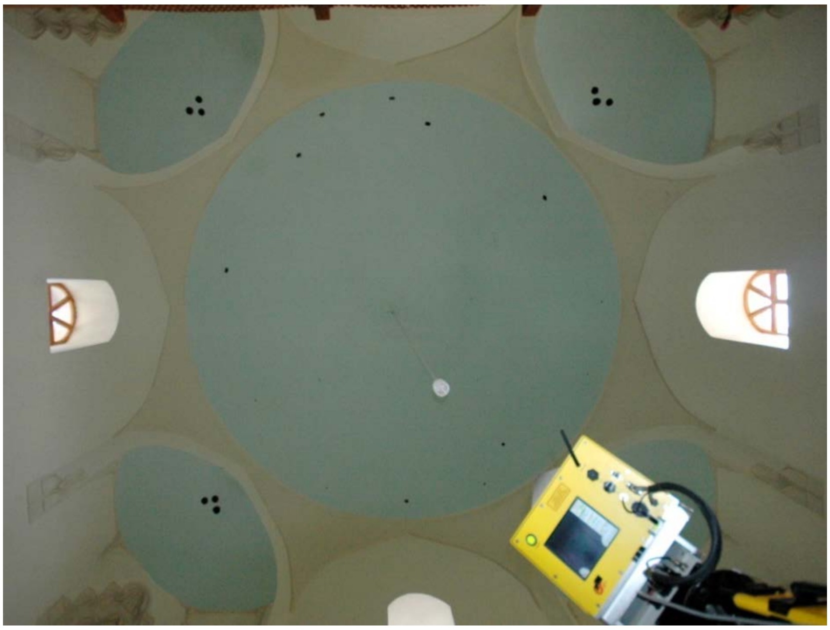

Figure 5. Interior of the dome

Load bearing walls

Assessment results have shown that load bearing walls are the ones suffering the most by structural problems. Serious cracks have been observed. The cause of these cracks are excessive stress concentrations such as: compressive stress caused by vertical loads (static), shear stress caused by lateral loads (earthquakes) and propagation of cracks due to successive earthquakes and amortization during centuries. [3]

Figure 6. Structural cracks in the north façade

Propagation of structural cracks from the dome to the load bearing walls was observed at all outer facades of the structure as shown on Figure 6. Some massive cracks were observed on the north façade (Figure 6). It is believed that cracks were caused by combined effects of improper modification of the entrance of the mosque and amortization.

Figure 7. Structural cracks in the interior of the mosque

In the walls containing openings, a different crack pattern is observed. Stresses are concentrated at the edge of the openings, thus every window is cracked at the bottom corners of it frame. Structural cracks propagate diagonally from top windows to the lower ones in the same way (Figure 7). This is very dangerous for overall stability of the wall as it may cause in-plane failure and trigger the collapse mechanism of the entire mosque.

FINITE ELEMENT MODELLING

In order to define and locate the most critical regions where the maximum stress concentrations are found, a computer based linear analysis was conducted using Sap2000 v.15 software. The mosque's model consists of 9604 joints and 9563 shell elements. Material properties are taken from literature [4].

The characteristic properties of stone and masonry bricks are: Young modulus E = 1740 MPa and 2100 MPa; tangential elasticity modulus G = 290 MPa and 350 MPa; poisson ratio υ = 0.2 and υ = 0.2; unit weight γ = 18 kN/m^3 and 21 kN/m^3, compression strength σ_c = 2.5 MPa and masonry brick σ_c = 3 MPa , tensile strength σ_t = 0.12 MPa and σ_t = 0.12 MPa respectively .

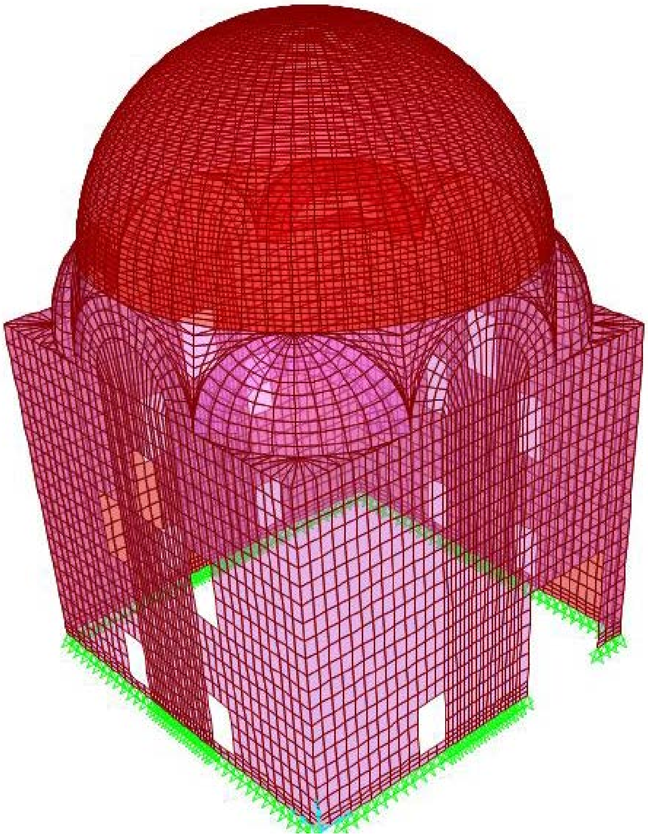

Figure 8. Finite Element Model in Sap2000

Table 2. Material Properties of the main structural elements of the mosque

	Thickness (cm)	Material	E (MPa)	γ (kN/m^3)
Dome	35	Brick	2100	18
Semidome	30	Brick	2100	18
Pendentive	20	Brick	2100	18
Arches	45	Stone	1740	21
Walls	100	Stone	1740	21

Linear static and dynamic analyses have been performed. In static analysis the model was subjected to the vertical loads coming from its own weight and loads from the roof. In dynamic analysis, response of the structure under seismic loads is investigated.

Static Analysis

In the static analysis, the following linear equation system is used by SAP2000 to calculate deformations:

$$[K] * \{u\} = \{R\} \quad (1)$$

Where [K] is the stiffness matrix; {u} is the displacement vector; and {R} is the vector of the applied loads. The global stiffness matrix would be calculated by using equilibrium and compatibility equations. [5]

It should be stated that the deformations predicted by the model above are the ones that would occur if the system experienced a homogeneous linear elastic behavior under its own weight. Useful information that can be derived from static analysis is the stress distribution.

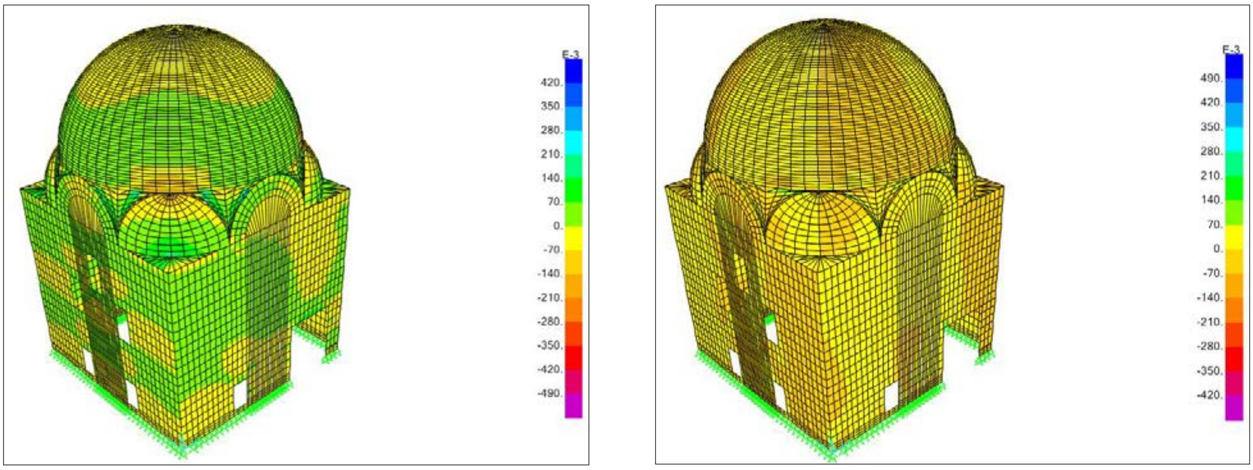

Figure 9. S11 (-0.566 to 0.567 MPa) and S12 (-0.396 to 0.399 MPa) stress distribution.

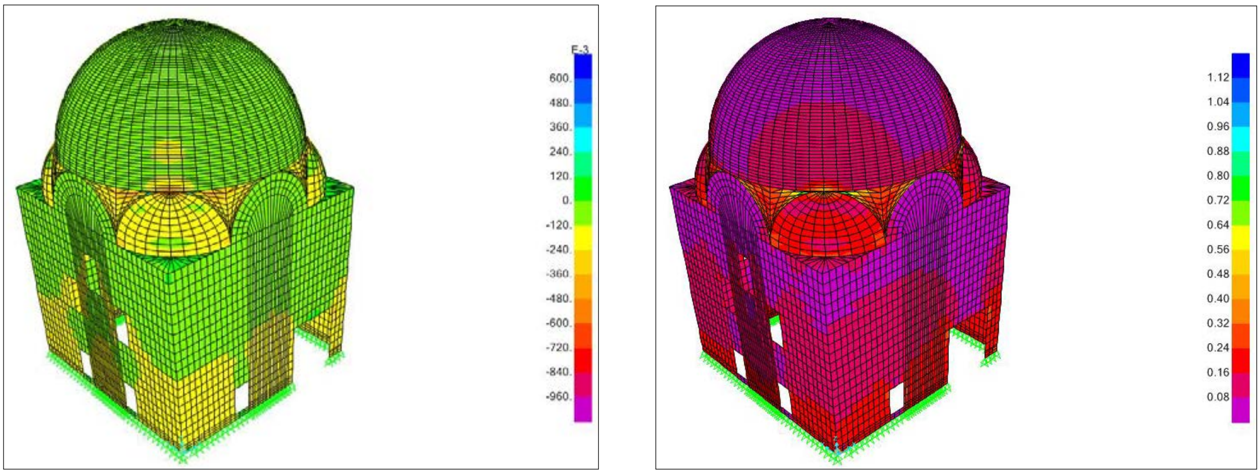

Figure 10. S22 (-0.945 to 0.595 MPa) and SVM (0.002 to 0.946 MPa) stress distributions

Analysis results have shown that maximum stresses under dead load exceed maximum allowable stresses of both of the materials which are 0.12 MPa in tension.

Stresses in the dome are spread over the middle part, and tension stresses occur around the middle part of the dome in circumferential direction. Maximum values for compressive and tensile stresses are 0.946 MPa and 0.945 MPa.

<u>Dynamic Analysis</u>

To study the behavior of the mosque under lateral loads, a linear dynamic analysis is performed. The period and frequencies and mode shapes are obtained using Sap2000 Eigen-vale analysis.

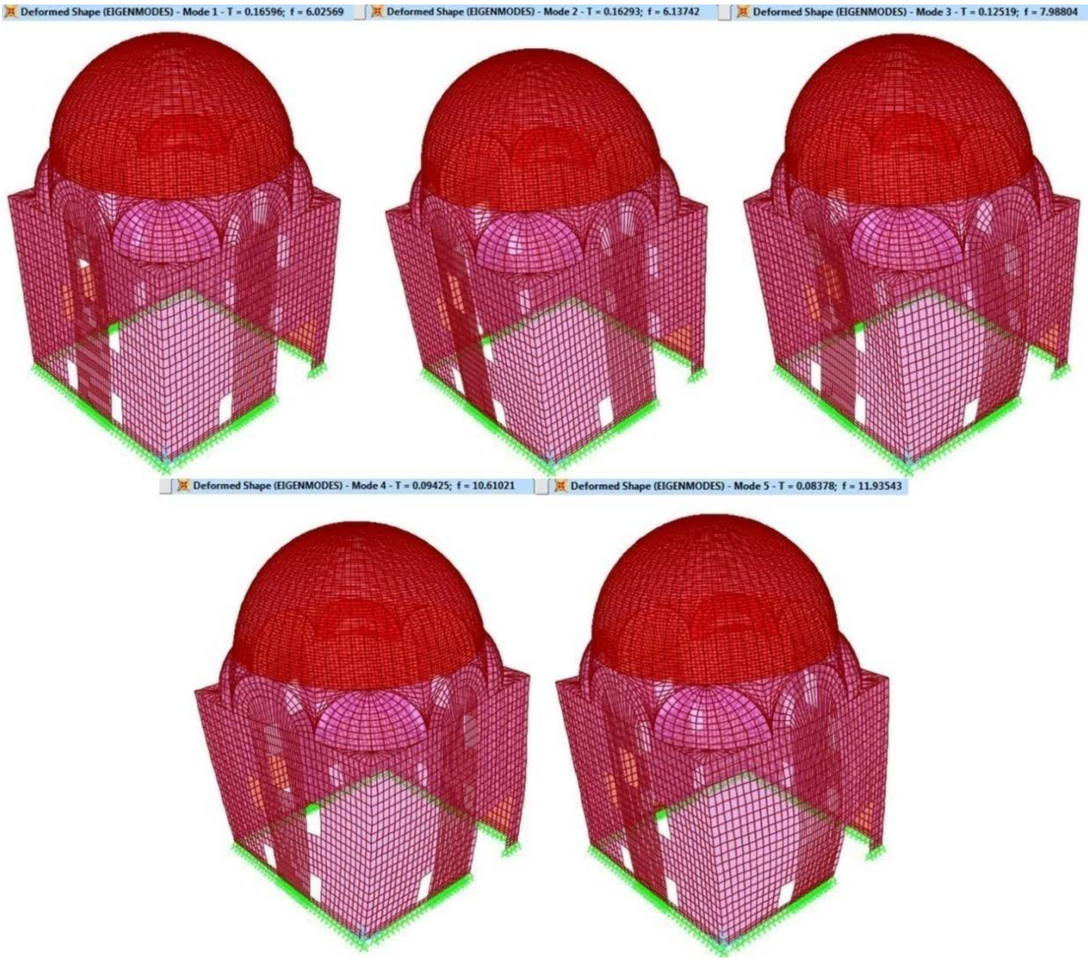

Figure 11. Mode shapes of deformation under modal analysis

Table 3. Shape modes and modal periods

Modes	Period (seconds)	Modal Shapes
Mode 1	0.144	N-S lateral
Mode 2	0.142	E-W lateral
Mode 3	0.110	Squeezing
Mode 4	0.083	Torsional
Mode 5	0.078	Breathing

In order to study the effects of the ground motion excitations on the structure it is necessary to measure the intensity of the motion. Hence, response spectrum analysis is performed based on a 0,35g acceleration and Eurocode 8 spectral acceleration curve.

Dynamic analysis results have shown that:

S11 (hoop stress) maximum stresses develop at the main dome. Compression stresses develop at the middle part and tensile stresses are observed in circumferential direction along the middle part of the dome. Maximum value of S11 is 1.058 MPa, whereas minimum value of S11 is 0.531 MPa which is more than allowable tensile capacity of the material. Maximum and minimum values of S22 (radial stress) are 1,382 MPa and -0,527 MPa respectively.

Maximum and minimum of S12 (in-plane shear stresses) are 0.931 MPa and -0.304 MPa. Results have shown that maximum displacement of the dome is observed to be in x-direction and is 2,82 mm.

CONCLUSIONS

The static behavior and performance under earthquake load of the mosque have been evaluated using the finite element modeling technique, where the behavior of masonry has been taken into account by proper constitutive assumptions. Results have shown that the Naziresha's Mosque structural conditions are not adequate to carry static and dynamic loads.

The tensile stresses at the dome exceed the dome resisting capacity under static load. This may be caused by undersigned load of the lantern or under estimation of material capacity. It is believed that the case studies conclusions are applicable to most of Ottoman period mosques in Albania. Therefore the structure requires strengthening work. Further studies need to be done by micro modeling with real values of the material capacities.

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