Structural performance of timber pillared mosques under extreme actions: special case of earthquakes

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Abstract Seismic performances of historical monuments are an important topic for the architectural and engineering community. Such valuable architectural heritage should be preserved and strengthened for the future generations. For this purpose, in this paper a full 3-D finite element analysis of Ahi Elvan Mosque is performed to assess its structural behavior and seismic vulnerability. Structural analysis of Ahi Elvan Mosque presented useful findings concerning structural interaction between rigid stone masonry walls and the timber framed inner structure.

Keywords mosque, natural disaster, earthquake, timber structures

1. INTRODUCTION

In this study, timber pillared historical Ahi Elvan Mosque is analyzed in order to assess its structural behavior and seismic vulnerability. For this purpose, a full 3-D finite element analysis is performed in order to obtain a first insight into its structural performance.

2. THE AHI ELVAN MOSQUE

The Ahi Elvan Mosque is a typical timber pillared Seljukid mosque located in citadel of Ankara, was built by Ahi Elvan Mehmet Bey (1331- 1389) in the year of 1382. It has an almost rectangular plan covering 396m2 area. The 1m thick masonry walls are the main load bearing element surrounding four sides were supported by 12 timber pillars. Although the roof was first covered with traditional flat-roof made with mud, it was replaced with pitched timber roofing in later periods. As in many of the other timber mosques it has a timber balcony, used by women *(kadınlar mahfeli)* added later. The pillars supporting the balcony have special parts both on upper and bottom sides. The only opening in the north façade is the door of the women's balcony. The supporting walls made up of brick and adobe have stone foundations. The minaret is on the northwest corner of the building. The twelve pillars are set in three rows perpendicular to mihrap. Pillars sit on base and heading connected to each other with massive wooden lintels.

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3. FINITE ELEMENT MODEL AND ANALYSIS OF AHI ELVAN MOSQUE

Finite Element Model of Ahi Elvan Mosque was prepared according to the modeling properties and rules of SAP2000 software. Modeling and analysis parameters are described below:

- The 1 meter thick outer peripheral walls of the building were modeled with shell elements. Given the large thickness of these walls, THICK SHELL option is selected in the modeling process.
- Timber columns, primary and secondary beams were modeled with frame elements.
- In the absence of material sampling and testing from the actual building, material properties for the structural elements are obtained from Turkish Earthquake Code and similar studies in the international scientific literature.
- In the selection of the modulus of elasticity and unit weight for the masonry elements, it was assumed that stone and mortar act as a homogenous material.
- Two separate loading scenarios were applied to the model. The first scenario included the effect of gravity loads (G) while the second also included the effect of the ground motion defined by earthquake spectrum (EQx and EQy). The spectrum data was applied in two perpendicular directions defined as G + EQx and G + EQy.

5. THE EVALUATION OF THE ANALYSIS RESULTS

Following observations are made on the behavior of the structural elements of the building:

- The structural system of Ahi Elvan Mosque has high rigidity. At the roof level, under combined gravity and spectral loading (G+EQx) in x direction, largest displacements (Δx) in the x direction is observed as Δx=23 mm; under combined gravity and spectral loading (G+EQy) in y direction, largest displacements (Δy) in the y direction is observed as Δy=19 mm. Considering that this level is 10m above ground, the relative displacement ratio is 0,002 which is within acceptable limits. In this displacement interval there is a small likelihood of non-structural crack formation.
- The finite element analysis of Ahi Elvan Mosque has demonstrated that Turkish Earthquake Code's allowable compressive or shear stress levels for masonry materials were not exceeded anywhere under the applied load cases.
- Allowable tensile stress levels were only locally exceeded near the corners of the openings and lower corners of the walls. Such local stresses are expected and allowable due to the mesh structure of the finite elements and used support conditions.
- The obtained maximum stress levels are well within safety intervals, it is very unlikely that Ahi Elvan Mosque will be subjected to major damage during an earthquake.

6. CONCLUSION

The continuous frame behavior of the timber beams supported by the masonry peripheral walls render the timber pillars into structural elements which carry primarily axial loads. No significant lateral structural weakness is observed in the timber pillared mosques due to the above mentioned interaction between rigid masonry peripheral walls and light timber frame structure. The simple geometry of the timber frame system is a positive factor in both the vertical and lateral resistance of the structure.