THE CONTRIBUTION OF WOODEN RING BEAMS TO THE RESPONSE OF ADOBE STRUCTURES

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Earthen structures made of adobe bricks are complex systems making the calculation of their behavior difficult, especially when they have to sustain lateral forces such as seismic. This paper presents a numerical investigation for the assessment of the structural response of unreinforced adobe masonry structures and how the installation of wooden ring beams contributes to their resistance. In the framework of the numerical investigation, finite element models were created to simulate the response of an adobe building with and without the implementation of wooden ring beams. The test building is located in Cyprus, in the South Eastern Mediterranean region which is a seismic area. The models were subjected to various earthquakes performing time history analyses for the calculation of pertinent displacements and stresses. The results show that the installation of the wooden ring beams vastly changes the response of the building not only in terms of the magnitude of the displacements and stresses but also their distribution pattern.

Keywords: Traditional buildings, Adobe masonry, Structural modeling, Finite element.

1 INTRODUCTION

Most of the structural systems for historical buildings consist of adobe, stone and wooden elements as well as mortar. Earthquake is a major hazard for old earth masonry buildings (including monuments) found in areas of moderate and high seismicity, due to their limited tolerance in lateral forces such as those caused by earthquakes. An effective intervention on an adobe building requires a clear understanding of its response under static and/or dynamic loads. Therefore, an architect/engineer participating in the process of restoring a historical structure by evaluating its structural capacity, faces the challenging task of inspecting and designing the structure for sufficient capacity to sustain future actions, within specified damage limits, while at the same time considering the characteristics and values that make a structure unique and deserving of special attention.

Constructions of adobe or stone are traditionally more massive than the buildings of today and their behavior during an earthquake is difficult to define. Adobe masonry buildings have an anisotropic behavior and therefore there is a lot to be done to the level of expertise in terms of accurate modelling. Effective modelling of a typical stone or adobe structure is a basic criterion for the appropriate analysis and design of its resistance against earthquakes.

The aim of this paper is to investigate the contribution of wooden ring beams to the capacity of a building and justify their importance in the overall behavior during an earthquake. The paper presents simulations of an adobe building which is situated in Cyprus and is subjected to earthquake forces. The finite element models simulate the behavior with and without the installation of
wooden ring beams. The comparison of the results show that the wooden ring beams affect the overall response of the structure and contribute to the effective resistance of the whole system.

2 BEHAVIOR OF ADOBE STRUCTURES

Adobe walls are constructed with adobe masonry blocks and are normally founded on stone strips of 0.50 – 1.00m in height. A traditional technique includes the installation of wooden beams at the corners or on the perimeter of the buildings as a ring, spaced every 0.60 – 1.00m in height of the wall (Figure 1) which enable the structure to behave as a unit (box frame entity) increasing its structural resistance against dynamic loads in earthquake-prone areas.

![Figure 1. Adobe construction a) Adobe masonry on stone foundation, b) Installation of wooden ring beams.](image)

The wooden ring beams provide physical boundaries along the height of the walls, interrupting the flow of the stresses, therefore, any potential cracks are confined between the layers of the wooden ring beams and do not extend over the entire surface of the wall. A very important condition is the effective interlocking of the walls at the corners either through the installation of the ring beams or by the rearrangement of the adobe bricks, to prevent the separation of the walls due to the applied load. It is important to note that weak connections i.e., the use of round branches or poor-quality wood damaged by the binding nails, hinder the ability of the structure to behave as a single unit.

Normally the roof of the traditional buildings consists of a timber support construction consisting of individual beams or trusses which is covered with clay tiles or sometimes metal sheeting. The floor is made of earthen materials or cast plaster (screed). The roof and the floors are supported on the adobe masonry load bearing walls for which they provide a lateral connection between them. The quality of the connection of the roof and floors to the supporting walls is essential as it provides diaphragmatic behavior. The effectiveness of the connection and the in-plane stiffness of the roof and floors dictate the level of the diaphragmatic behavior and affect the overall structural response when the building is subjected to lateral loads.

3 SIMULATION OF THE CASE STUDY

The case study consists of an adobe masonry building of 1960 which is located in Cyprus. To investigate the contribution of the wooden ring beams to the structural response of the building, two finite elements models were developed, one with and the other without the installation of wooden ring beams.
Figure 2 shows the case study. There are three interior spaces enclosed by load bearing adobe walls and a patio with two columns supporting the roof. The area of the two smaller spaces is 6.40m x 4.25m and the area of the larger space is 3.10m x 10.60m. The walls are 0.50m thick, 3.20m high and are founded on a strip of sandstone 0.60m in height as shown on the figure. The façade in the south side incorporates two window openings with dimensions of 1.20m x 1.00m and a balcony door with dimensions of 2.60m x 1.20m which are typical for this type of structures. Similar type and size of openings are found on the other sides of the structures. The roof consists of a wooden truss which is supported on the walls and the columns, covered with clay tiles as shown on the Figure 2. The dimensions of the wooden ring beams which are spaced every 0.80m are 0.50 x 0.10m.

Following a macro-modelling approach, the adobe and sandstone masonry walls were simulated using shell elements incorporating the Mindlin formulation, to account for the shear deformations across the thickness of the elements. The wooden elements (ring beams and roof truss) were also modeled using shell elements for better interfacial connection between the two materials. The boundary conditions of the walls were considered as pinned (Figure 3).

Table 1 shows the mechanical properties used in the analysis. These properties were found in the literature and are based on experimental results from local materials (Illampas et al. 2011, Zhu et al. 2016, Salman et al. 2020).
Table 1. Mechanical properties of the structural materials.

<table>
<thead>
<tr>
<th>Property Type</th>
<th>Adobe</th>
<th>Sandstone</th>
<th>Cypress</th>
<th>Clay Tiles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m$^3$)</td>
<td>1.275,00</td>
<td>2.340,00</td>
<td>500,00</td>
<td>1.400,00</td>
</tr>
<tr>
<td>Modulus of Elasticity (KN/m$^3$)</td>
<td>135.000,00</td>
<td>20.000.000,00</td>
<td>10985000,00</td>
<td>14.000.000,00</td>
</tr>
<tr>
<td>Poisson ratio, $\nu$</td>
<td>0.35</td>
<td>0.23</td>
<td>0.18</td>
<td>0.20</td>
</tr>
<tr>
<td>Shear Modulus, $G$ (KN/m$^3$)</td>
<td>50.000,00</td>
<td>4.545.455,00</td>
<td>4654661,00</td>
<td>5.833.333,00</td>
</tr>
</tbody>
</table>

4 RESULTS OF THE DYNAMIC ANALYSIS

The response was simulated in SAP2000 using the time history of a recent earthquake in Cyprus (Figure 4).

![Event Famagusta, 21 Jan 2021](image)

Figure 4. Time – acceleration graph (Geological Survey Department, 2021).

The fundamental period of the model without the wooden ring beams is 0.29s. The application of the dynamic load on the x-x axis shows compressive stresses on the top left and bottom right of the window (Figure 5); tensile stresses are observed on the other two corners of the openings as expected. In addition, the stresses along the tensile diagonal of the openings range between 10 to 14KPa whereas the compressive range between -2.5 to -4KPa. The inter-storey drift is 0.0004m.

![No wooden ring beams, Smax (x-x).](image)

Figure 5. No wooden ring beams, Smax (x-x).
The fundamental period of the model with the wooden ring beams included is 0.21s. The stress distribution pattern is now different than the above (Figure 6). The stresses now follow the direction of the ring beams and their values are comparatively smaller ranging from 0.4 to +7 KPa which amounts to about 50% reduction. The inter-storey drift is significantly smaller, 0.00025m which is a reduction of about 62.5%.

Figure 6. Wooden ring beams included, Smax (x-x).

5 CONCLUSION

The resistance of adobe masonry structures to lateral loads is highly dependent on their ability to maintain their integrity and subsequently respond as a consistent unit, often referred to as “box entity”. This behavior is dictated by the interlocking of the walls at the corners which prevents the separation and overturning. The installation of ring beams (often constructed with wood) ensures the interlocking of the walls and prevents separation. The ring beams also confine the external walls enabling them to act as a unit while at the same time contributing to the overall capacity of the structure not only because of their inherent ability to resist axial forces but also by altering the distribution of the stresses which eventually are considerably smaller compared to those developed in the structures without the installation of ring beams. This study exemplified these differences and showed the great contribution of the ring beams to the overall resistance of earth masonry structures to lateral loads. Further research concentrates on the modelling of various retrofitting techniques and the development of pertinent fragility curves for this type of structures.

References