Consolidation a Mud-Brick Tomb against the earthquake: An Experience from Ardakan, Iran

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ABSTRACT

Mud-brick has been used as a building material in the urban and rural fabrics of many of the hot and dry climate zones of the world. In the architecture of the Central Plateau of Iran, mud-brick has many applications due to its appropriate compatibility, economic benefits, ease, and speed in preparation. An important issue with most mud-brick buildings is their earthquake instability. Recent earthquakes have shown that, in general, unreinforced masonry structures are vulnerable to tensile loads and need to be consolidated. The purpose of this study is to introduce the measures taken to consolidate a historic mud-brick tomb in the city of Ardakan (Iran). This tomb dates back to about 100 years ago and is the burial place of one of a famous cleric's family. The measures taken to conserve this mud-brick building are important because it has been done in full compliance with the construction techniques and materials characteristics of traditional Iranian architecture. These solutions include consolidating mud-brick walls and ceilings with natural date palm fibers and strengthening the structure with wooden beams, which has improved the performance of the building against tensile loads.

Keywords: Consolidation, Tombs, Mud-brick, Earthquake

1 INTRODUCTION

The use of mud-brick materials in the construction of buildings has been common in Iran for centuries and in many cities and most rural areas located in hot and dry areas, mud-brick buildings are the majority of buildings [1]. Experiences gained from past earthquakes have shown the improper and destructive behavior of mud-brick buildings as a result of the earthquake [2].
Ardakan city is located near Yazd-Ardakan fault with an approximate length of 60 km. This fault starts from the north of Yazd city and extends to the north of Ardakan city [3]. According to the historical evidence, the Yazd-Ardakan plain is considered relatively calm from a regional tectonic point of view [4]. However, there is a possibility of an earthquake in this area.
This study aims to introduce conducted measures that have been done to consolidate a mud-brick dome from the experimental point of view. These measures could be considered as examples for similar mud-brick buildings.

2 CASE STUDY

Ardakan 'Fig. 1' is one of the cities of Yazd province in central Iran and with 23,478 km^2 is the largest city in the province. Ardakan city is located at 53◦ 48' E longitude and 32◦ 20' N latitude and the average altitude of this city is 1234 meters above sea level [5].

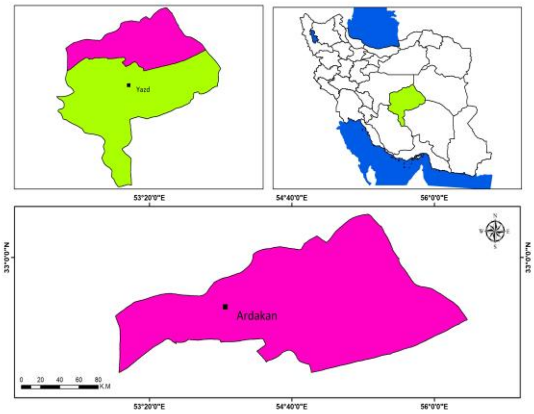

Figure 1. Location of Ardakan in Iran

The studied mud-brick tomb 'Fig. 2' is the burial place of Katami's family, a famous cleric of Ardakan, and it has been built about 100 years ago. The tomb is located in the west of Ardekan cemetery.

Figure 2. Location of the tomb in Ardakan cemetery

2 BUILDING PATHOLOGY

2.1 Foundation

Based on the stratigraphy of the basement of the building, it was revealed that the building does not have a solid limy or stone foundation. Its main reason was the existence of many graves adjacent to the tomb. Since the presence of lime accelerated the corruption of corpses and is not correct according to Islamic law, the architect had to not use the lime. Furthermore, the columns of the building were located on old graves which has led to the looseness and emptiness of the soil under the columns.

2.2 Structure

As shown in 'Fig. 3', the main columns have drifted due to the lack of a tensile element or backing in two positions, including west and southwest. In other words, the western side has projected more than 10 cm. This drift has caused vertical cracks in the legs of the arches on the north and south sides and dome as shown in 'Fig. 4'. Controlling this drift and correcting the geometry should be one of the priorities of the consolidation plan.

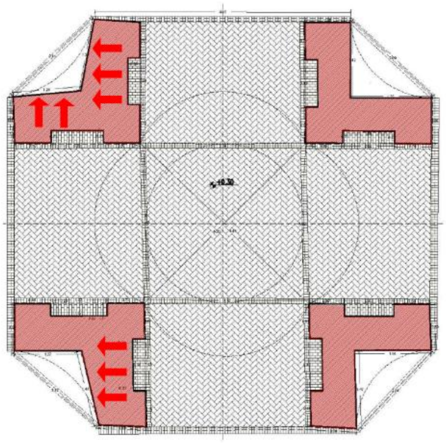

Figure 3. Drift diagram and

Figure 4. Cracks in the legs of the arches and under the dome

Hollow spandrels (Konu) have been broken due to drift. They should be removed from the arch surface and reassembled.

2.3 Materials

Most surfaces of the building are covered by a cob layer that has been spoiled in many places due to the presence of termites. This issue has caused the possibility of falling off the eaves on the north as shown in 'Fig. 5'.

Figure 5. Possibility of falling off the eaves on the north

The exterior of the building has a 20 cm plinth of brick, which is executed in the form of a porcelain vein brick, and from the inside, square bricks have been added later. The plinth inside the building is very weak and has been damaged in different places as shown in 'Fig. 6'.

Figure 6. External and internal plinth

3 PROPOSED CONSOLIDATION PLAN

As mentioned earlier, this building has no foundation. For preventing further subsidence, it is necessary to use vertical wooden piles that connect the structure to the ground. According to 'Figs 7 and 8', eight grooves were created in the eight corners of the building.

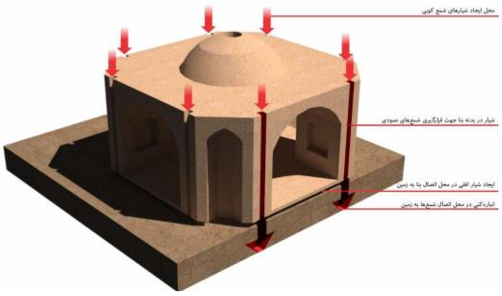

Figure 7. Simulation of vertical load path

Figure 8. Wall grooving

As seen in 'Fig. 9', posts were embedded in the eight grooves and dipped into the ground at a depth of 1 meter. Also, a hole for each pier foundation was dug and they were filled with lime mortar. Old electric poles that have high resistance to rot and termites were used as the post. To control the drift, the posts should be jointed in two parallel rings, a plinth beam on the floor level and a tie beam on the roof using wooden beams. This type of joint acts like a tie. Date palm fibers were wrapped around the posts and beams so that they have a better connection with the structure and the joinery, as shown in 'Fig. 10'.

Figure 9. Simulation of lateral load path

Figure 10. Embedding the posts in the grooves and jointing them to the beams

The hollow spandrels have been removed from the arch surface and reassembled as shown in 'Fig. 11'.

Figure 11. Removing the hollow spandrels and reassembling them

Due to the subsidence, structural cracks had been created in the dome of the tomb. Thus, the dome had to be removed. A new dome was rebuilt with the remaining mud-bricks as shown in 'Fig. 12'.

Figure 12. Removing the old dome and rebuilding the new one

In order to integrate the building components, the roof was covered with a net of date palm fibers as seen in 'Fig. 13'.

Figure 13. Removing the old dome and rebuilding the new one

To kill the termites, holes were dug into the floor and walls, and then poison was injected into the holes as shown in 'Fig. 14'.

Figure 14. Making the holes and injecting the poison

As seen in 'Fig. 15', 60 cm plinth was executed using bricks inside and outside the tomb.

Figure 15. Executing plinth inside and outside the tomb

4 Conclusion

This paper was devoted to the conducted measures for consolidating a mud-brick tomb against the earthquake in Ardakan, Iran. Initially, a pathology was carried out to determine the foundation, structure, and material issues. Then, some solutions were considered in response to the problems in accordance with the character of the building as below:

- Using vertical wooden piles to connect the structure to the ground;
- Digging a hole for each pier foundation and filling them with lime mortar;
- Jointing posts in two parallel rings using wooden beams to control the drift;
- Removing the hollow spandrels and reassembling them;
- Removing the old dome and rebuilding the new one;
- Covering the roof with a net of date palm fibers to integrate the building components;
- Making the holes and injecting the poison into the floor and wall to kill the termites;
- Executing plinth inside and outside the tomb.

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