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Strengthening of adobe houses with arch roofs using tie-bars and polypropylene band mesh

Navaratnarajah Sathiparan [a,b,*], Kimiro Meguro [c]

[a] Department of Civil and Environmental Engineering, University of Ruhuna, Sri Lanka
[b] Institute of Industrial Science, The University of Tokyo, Japan
[c] ICUS, Institute of Industrial Science, The University of Tokyo, Japan

HIGHLIGHTS

- Effects of PP-band and tie-bars retrofitting have been experimentally investigated.
- Arch with only tie-bars was clearly shown a collapse pattern with the thrust force.
- Arch with PP-band retrofitting maintained wall integrity for large deformations.
- Presence of tie-bars in PP-band retrofitting improves this performance of the arch.

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ABSTRACT

The purpose of this study was to compare the effects of strengthening adobe houses with an arch roof using polypropylene band (PP-band) mesh with or without tie-bars. To this end, an experimental analysis was conducted on scale models of adobe houses. In one test, an arch roof was retrofitted with only a PP-band mesh. In the second test, in addition to being retrofitted with PP-band mesh, tie-bars were used for horizontal support at roof level. These two PP-band retrofitted house models and house model with tie-bars only were subjected to sinusoid loading until the point of collapse or the capacity of the shaking table was exceeded. Results collected during the analyses were significant in assessing the capability of these retrofitting methods to support dynamic loads, increasing the collapse load, stiffness and ductility and dissipate energy.

1. Introduction

The results of earthquake damage investigations have revealed that adobe structures collapse within a few seconds during earthquake movement and become a major cause of human fatalities. The collapse of walls, roofs and ceilings and the spread of suffocating dust at the time of collapse are key factors that typically contribute to a wide range of human casualties.

The recent earthquake in the Bam region of the Kerman state in southeast Iran on 26 December 2003 resulted in an estimated 23,000 human casualties. The earthquake demonstrated the effects on adobe materials used in a dome or arch type of roofs and the thick walls traditionally used since ancient times. Buildings of this type can be found not only in Iran, but also throughout countries in the Middle East. Since the olden days, roof design has been influenced by culture and religion. However, the unreinforced adobe structures with arch roofs are generally characterized by weak, brittle materials, weak connections and excessive weight. In order to reduce damage to these adobe buildings during earthquakes, it is important to identify methods for improving and upgrading the earthquake resistance of existing adobe buildings. The failure of arch structures under a given loading condition is generally dependent on the geometry of the arch and on the mechanical characteristics of the materials used in construction. Three possible failure types (Fig. 1) were discussed by Foraboschi [1] and include:

- Failure by crushing.
- Failure by sliding of components.
- Failure by the hinge mechanisms that join the arches.

* Corresponding author at: Department of Civil and Environmental Engineering, University of Ruhuna, Sri Lanka. Tel.: +94 77 4929868; fax: +94 91 2245762.
E-mail address: nsakthiparan@yahoo.com (N. Sathiparan).

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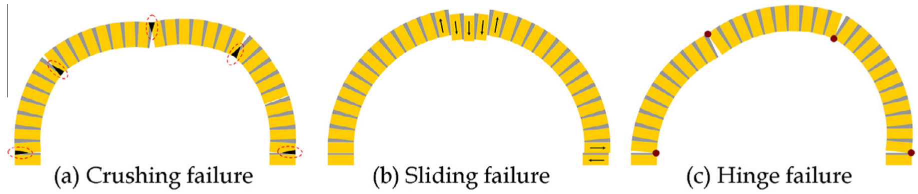

Fig. 1. Arch failure mechanisms.

The failure of crushing is unlikely because the normal cross section can balance even severe external loads [1]. Because adobe has a low tensile strength, the failure of the hinged model likely occurs well before failure from crushing or sliding.

The testing program called for loading a full-scale prototype of an adobe house with an arch roof to the point of failure (Fig. 2). The results of this test have been presented elsewhere [2], only a brief description of the failure pattern is provided here. Initially, the corner of the opening (door and window) and the side parts of the arch type roof cracked when a strong earthquake force was applied. The cracks widened under the thrust of the roof, then fell out of the plane when the wall began to open. A wall dropped sharply, causing the roof to lose support and drop sharply inside the house. When the arch roof lost balance, it crumbled easily. In this type of brittle failure, evacuation is very difficult and dangerous. Therefore, retrofitting these types of adobe structures is a key to earthquake disaster mitigation. Using this type of full-scale model for testing, it is possible to study the seismic behavior of structures during an actual earthquake. The major problem associated with a shaking table test of full-scale models observed by researchers was the cost and capacity of available shaking tables. As a result, most researchers have preferred reduced-scale shaking table tests in recent years. Another important advantage of the reduced-scale models is the ability to test the potential for collapse of masonry models.

The test results of simple earthquake simulator test on small scale masonry building by Tomazevic et al. [3] indicate that reliable information on global seismic behavior and failure mechanisms can be obtained by testing small-scale models on simple earthquake simulators. Several studies have assessed the effectiveness of retrofitting unreinforced masonry structures with carbon fiber reinforced polymer (CFRP) laminates, geogrid, PP-band mesh, bamboo mesh and fiber-reinforced polymer by reduced-scale shaking table tests. These tests provided valuable information on the seismic performance of masonry buildings and the components of masonry.

2. Available retrofitting methods for masonry arches

2.1. Strengthening of tie-bars

If the walls contain large arches, steel tie-bars should be installed across them at or slightly above springing levels by drilling holes on both sides and securing the ends of the rods with grout. In arches, tie-bars play a decisive role in the control of horizontal thrust produced by both permanent and seismic loads. For example, they can avoid or at least reduce the possibility of out-of-plane failure. For these reasons, tie-rods are still used widely used as a reliable technique for the reinforcement of masonry buildings [4]. As shown in Fig. 3(b), tie-bars minimize the displacement of springing arches, thereby inhibiting the formation of hinge collapse mechanisms. In addition, there is a possibility of failure as shown in Fig. 3(a) or local failure closer to the tie-bar anchors. Arches with tie-bar can increase their effectiveness by creating buttresses or engaged piers. Buttresses might have to contribute to prevent from failure mechanisms related to lateral deformation and avoided the tie-rod anchorage problem. Buttresses originally built as part of the entire original construction may be very efficient. However, if the buttresses are built as later additions, may show limited efficiency due to lack of satisfactory interlocking or differential settlements separating them from the

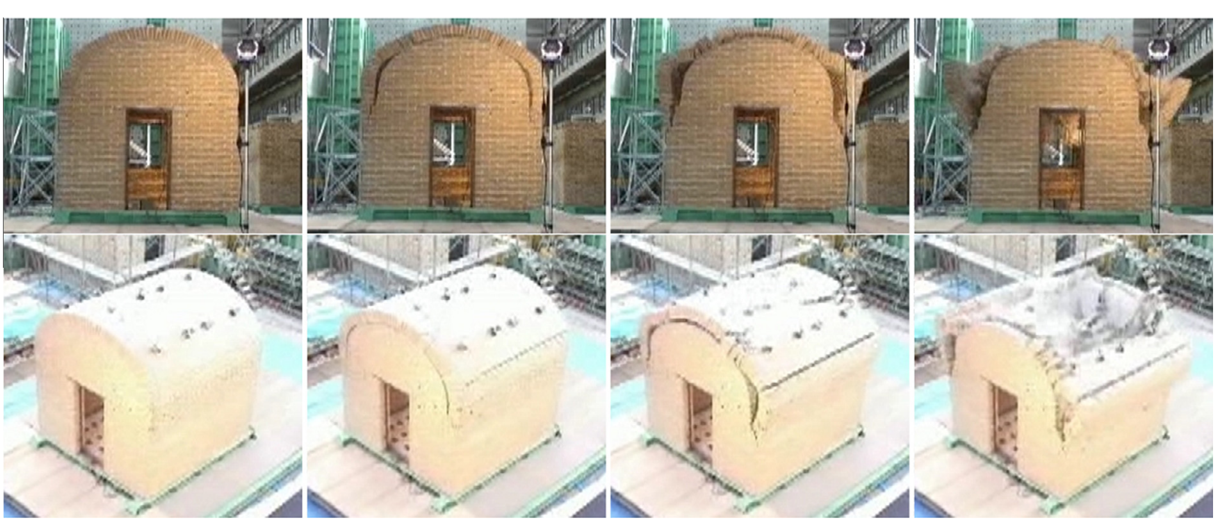

Fig. 2. Failure pattern of full scale non-retrofitted house model with arch roof.