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Experimental diagonal tension (shear) test of Un-Reinforced Masonry (URM) walls strengthened with textile reinforced mortar (TRM)

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HIGHLIGHTS

- The effectiveness of shear strengthening of URM walls using TRM was considered.
- Ten brick wall panels were tested under diagonal tension test method.
- TRM is an efficient strengthening method for URM walls, if it is applied on both faces.
- Out-of-plane failure is an issue for masonry walls strengthened on one face.

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ABSTRACT

The presented study is part of ongoing experimental program on Un-Reinforced Masonry (URM) walls strengthened with Textile reinforced mortars (TRM). Ten walls were tested under diagonal tension (shear) test method in order to consider the effect of strengthening system on the behavior of brick walls. One plain wall was tested as reference. Two walls were overlaid with 15 and 25 mm thick of high strength mortar on one face without any textile sheet. Another seven walls were externally strengthened with 15 and 25 mm thick of AR-Glass Textile Reinforced Mortar (TRM) on one or both faces. Results confirmed the efficient possibility of shear strengthening of existing URM walls using TRM, especially for those strengthened on both faces. On the other hand, one face strengthened walls were sensitive to the applied load and can buckle or experience out-of-plane deformations. TRM extremely improved diagonal load carrying capacity and deformation capacity, which caused the strengthened walls fail in a ductile manner. The governing failure mode was out-of-plane deformation for one face strengthened walls, and failure of both faces strengthened walls was controlled by initiation of substrate toe crushing in compression continued by diagonal crashing. Results showed that for masonry walls strengthened on both faces, during pure in-plane diagonal load, there is no need to mechanical connection between TRM and masonry substrate. However, out-of-plane failure is an important issue for masonry walls, especially for those strengthened on one face. Therefore, connectors must be designed for out-of-plane lateral force to ensure that masonry wall and TRM reinforcement layer work together properly.

1. Introduction

Un-reinforced Masonry (URM) is widely used as a building technique throughout the world, such as seismically active regions [1–4]. The design philosophies of these structures are focused on the gravity loading and many URM buildings are potentially earthquake vulnerable [1,2,4–8]. Due to the existence of a large number of buildings constructed by URM brick walls, reconstruction is not the most appropriate solution. This indicates the necessity for seismic assessment and considering appropriate strengthening techniques for these structures [2,5,9–11]. Several conventional techniques are presented for retrofitting of masonry structures [2,8,10,12]. These methods can be classified to: surface treatment (Ferrocement, shotcrete, fiber reinforced polymer (FRP) and textile reinforced mortar (TRM)), grout and epoxy injection, external reinforcement, confining, and post-tensioning [4,13–21].

The presented experimental study is a part of experimental program considering different retrofitting methodologies in the strengthening of URM buildings and especially URM School Buildings in Iran, with the financial and technical aid from the “Organization for Development, Research and Equipping Schools of I.R. Iran”. The objective of this research project is to develop a practical instruction for seismic rehabilitation of URM school buildings, as

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an alternative for the traditional retrofitting method of URM walls using shotcrete.

Recently, new materials such as fiber reinforced plaster (FRP) and textile reinforced mortar (TRM) were exploited for retrofitting solutions. FRP composite is one of the most popular strengthening methods mainly due to their lightweight and ease of use [3,13,22]. However, using of FRPs as strengthening materials of masonry structures associated with some limitations, especially debonding of the composite sheets from substrate when they are externally used [2,3,13]. Inability to install FRP on damp substrate, poor behavior of the usual resins at high and low temperatures, relatively high cost of epoxies, potential hazards for the manual worker, lack of vapor permeability (which may cause damage to the substrate), incompatibility of epoxy resins and some substrate materials (large stiffness difference between masonry and FRP), and difficulty to conduct post-earthquake assessment of the damage suffered by the masonry behind the FRP are some of the drawbacks of using FRP [2–4,11,13]. Because of these problems, there has been considerable research on alternative reinforcing methods and materials. Among various presented methods, substituting the resins with inorganic matrices, such as cement-based mortars is beneficial because of its better compatibility with the masonry substrate [23]. In this approach, fabric meshes are made of fiber roving in at least two orthogonal directions. The amount and the spacing between roving in each direction control the mechanical characteristics of the textile and the level of penetration of the mortar through the mesh openings [13]. This approach was introduced in previous studies [2–4,13,24–27] under various terms, namely: textile reinforced mortar (TRM), textile reinforced concrete (TRC), fabric-reinforced cementitious matrix (FRCM), cementitious matrix-grid (CMG), or inorganic matrix-grid (IMG) composite. At first, TRM was developed for applying on strengthening reinforced concrete structures but soon was used for strengthening masonry structures [4,11,13,24,27,28].

Papanicolaou et al. [4,13] presented TRM as a strong promising solution for the strengthening of masonry members subjected to in-plane and out-of-plane loading conditions in terms of shear capacity and pseudo-ductility. Parisi et al. [29] and Prota et al. [30] conducted experimental studies on tuff masonry externally strengthened using TRM under diagonal tension (shear). According to their experimental results, retrofitted walls reached higher shear strength and pseudo-ductility. Babaeidarabad et al. [31] tested clay brick masonry walls strengthened with carbon textile reinforcement under diagonal tension (shear) loading. Retrofitted walls revealed considerable increments in terms of strength and pseudo-ductility. Bernat et al. [11] during an experimental program on full scale brick masonry walls consider the effectiveness of TRM for the strengthening of masonry walls. Besides considering the influence of different mortar and fiber types, they study the effectively of using anchors for improving the connection between the reinforcement and substrate. According to their results, applying of TRM results in an increase of initial load bearing capacity under eccentric axial load and a stiffer and more homogeneous behavior were provided. Moreover, no connectors were required in the strengthening of the walls. According to Blanksvärd [32] study, again no TRM de-bonding problems were observed, compared with the FRP de-bonding failures. In contrast, Bernat et al. [8] by testing 12 masonry wall panels under diagonal shear load with three different fiber reinforced mortar and four different ways for strengthening, showed that application of fiber reinforced mortar improved shear strength of the walls. They also show that, the connection of strengthening system to the substrate is necessary in order to better using of the reinforcement.

Although previous studies provided valuable information on the strengthening of URM walls using TRM system, some parameters such as the sufficiency of strengthening of wall on one face with TRM, its effect on the failure mechanisms and the interaction between reinforcements and masonry material need more investigations. This paper presents an experimental program where URM walls were externally retrofitted with Alkali Resistant (AR)-Glass fabrics and subjected to diagonal tension (shear) loading according to ASTM E519-15 [33] in the structural laboratory of Building and Housing Research Center (B.H.R.C), Tehran, Iran. The behavior and ductility of walls, the effect of fabric mesh, failure modes and load deformation diagram of the tested specimens are investigated.

2. Experimental program

2.1. Test specimens

The investigation was performed on ten URM walls, 1200 by 1200 by 110 mm [33] (Fig. 1). The specimens were built using brick clay masonry units and normal mortar that were tested under diagonal tension (shear) test method. All of the specimens were built by a professional mason in order to make them similar to the practice.

One plain wall was tested as reference. Two walls were overlaid with 15 and 25 mm thick of high strength mortar on one face without any textile sheet. Another Four walls were externally strengthened with 15 and 25 mm thick of AR-Glass Textile Reinforced Mortar (TRM) covering one or both faces. After conducting the experiment of aforementioned specimens, in order to validate the results of the specimens, three more specimens with the same detail as previous tested specimens were constructed and the experiment were repeated (word "repeated" in Table 1 denotes specimens that their experiment were repeated). Two major parameters were considered in the investigation, namely the thickness of reinforcement layer and the number of reinforcement layers (on one or both sides of the specimen). The series of ten aforementioned walls was built with the properties given in the Table 1. TRM overlay sprayed manually.

Specimens are given the notation $AGRW_n^N$, where "A" denotes the faces of the specimen that are strengthened (1 means one face and 2 means both faces), "G" denotes the type of textile used (G for AR-Glass fabrics), subscript "n" denotes the thickness of reinforcement layer and the superscript "N" denotes the condition of anchoring of the TRM layer to the masonry. "RW" is used to distinguish the control specimens and the ones receiving reinforcement.

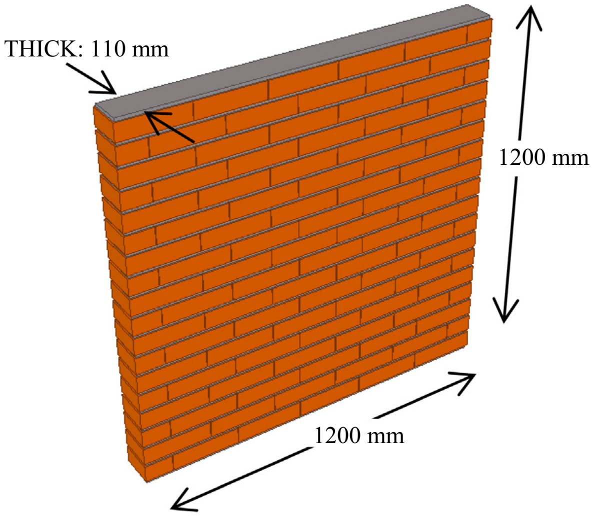

Fig. 1. Geometry of masonry panels.