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Investigation of Different Methods of Connecting GFRP Sheets to Ductility and In-Plane Behavior of Masonry Walls

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1. Introduction

Masonry has been used as structural system of many constructions all around the world since ancient times; thus, unreinforced masonry constructions, including primeval and cultural buildings, are spread out in a large number all over the world. The study of past seismic occurrences proves the structural vulnerability as well as high amount of casualties in this kind of structures. As a load carrying member, masonry walls have a highly important role in masonry buildings. These walls are made of brick units and similar materials (concrete blocks, rocks, and adobes), which are known to have reasonable compressive bearing capacity but not to act so well under shear or tension as a result of their brittle manner in normal conditions. Generally, the failure mechanism of masonry walls can be classified in two categories called in-plane and out-of-plane failures. Typical, failure modes of unreinforced masonry walls under in-plane loadings include the bed joint sliding, diagonal splitting, rocking or uplift along with crushing at toe. Failure mechanism is strongly affected by wall dimension, supporting condition and lateral and vertical loadings as well as properties of bricks and mortar.

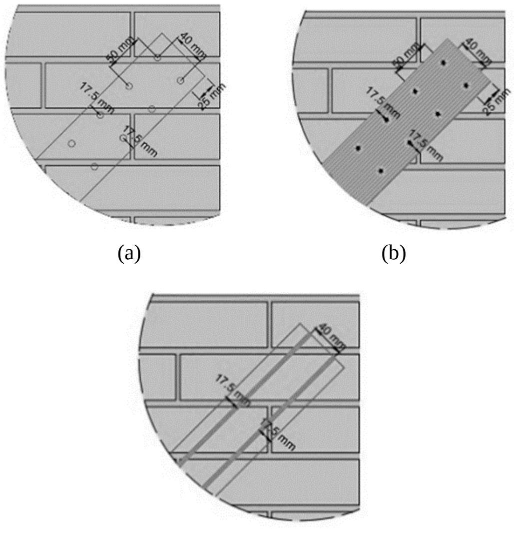
Seismic rehabilitation of unreinforced masonry walls is followed by several methods including the use of steel bracings, galvanized hexagonal wire mesh, shotcrete, concrete shear walls and mortar injection. The fact is that typical methods of rehabilitation usually result in lowering useful spaces of the building and increasing the total mass as well as destroying the structure facade; as a solution, the use of FRP in seismic strengthening, negates most of the difficulties associated with other methods. FRP composites are used in the form of rebar, strapping, and sheets.

The studies signify the fact that the use of FRP as reinforcement on masonry walls results in remarkable increase of bearing capacity and ductility of the walls. In addition, it is reported that the failure in masonry walls reinforced with FRP under in-plane loading is a bending failure (generally one-sided reinforced walls) while the shear failure is related to FRP rupture or debonding.

This study investigates the effects of various types of GFRP plate mounting methods on stopping or delaying the debonding issue. The surface preparation work including boring, boring with nailing, and grooving are the mounting methods used in this study. According to the existing studies, amongst various patterns of FRP reinforcements on masonry walls, the diagonal type has been proved to yield better responses; thus, such a pattern has been used in this study on masonry panels. It is also worthwhile to mention that according to ASTM E 519 (2002), the tests on masonry walls have been done by using uniform loading (diagonal tension).

2. Experimental Procedure

In this study, 17 unreinforced masonry walls with -870×870×100 mm dimensions have been constructed and undergone the diagonal compressive loading. 11 masonry walls have been constructed and categorized into 6 groups. Group one consists of 4 unreinforced masonry walls without any external strengthening. The outcomes of this group has been chosen as reference responses for other groups to be compared with. In every other five groups, one mounting method of FRP reinforcement in diagonal pattern has been studied as how it affects the bearing capacity and ductility of masonry walls. Group two includes 2 masonry walls reinforced with GFRP without surface preparation (by using the wearing surface (WS) method). Group three includes one masonry walls reinforced with GFRP by using surface preparation method EBR. Group four consists of 2 masonry walls reinforced using boring method. The diameter and depth of the holes are 8 and 7 mm, respectively; and they are located in two rows with 22 holes each. The longitudinal and latitudinal distances between punched holes in the wall surface are 50 and 40 mm, respectively. Each of the groups 5 and 6, consists of one masonry walls reinforced using nailing (steel nails) and grooving installation techniques. Width and depth of the groovs are 4 mm and 7 mm, respectively. The general design of the tested samples in this research are presented in Table 1 and Fig. 1.



(a) (b)

(C)

Fig.1 Configurations of different retrofits: a) Boring method (HM); b) Boring with Nailing (N); c) Grooving Method (GM)

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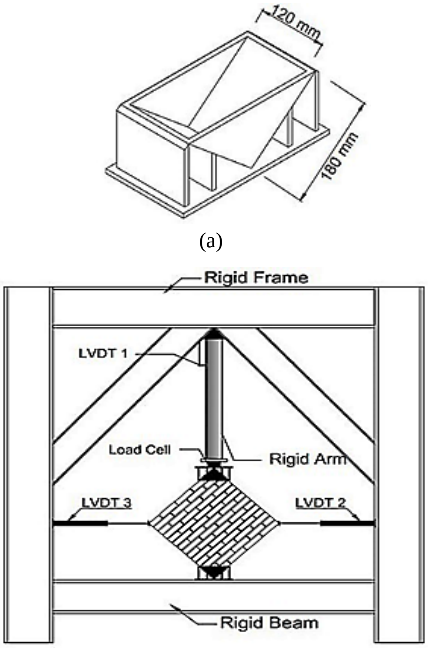
As mentioned before, in this study the masonry walls tested under diagonal compressive loading. In order to do so, according to ASTM E 519 (2002), the steel sections called loading shoes, are constructed (see Fig. 2(a)). The testing machine is composed of a load-bearing frame, a vertical loading jack with a capacity of 2500 kN, one two-parted shaft, and a hydraulic system.



(a)

(b)

Fig.2 Test layout of diagonal compressive loading on the wall: a) loading shoe b) Location of load and displacement measuring tools

According to ASTM E519 (2002), in order to find the value of shear stress, it is required to divide the horizontal component of acting load by section's area (Eq. 1)

$$\tau = \frac{P\cos\theta}{A_0} \quad (1)$$

In which, P is the load exerted on the wall is the angle between mortar band and horizon, and A_o is the pure section area of the wall. According to ASTM E519 (2002), the shear strain is simply acquirable as follows:

$$\gamma = \frac{\Delta V + \Delta H}{g} \quad (2)$$

In which, ΔV and ΔH are shortening in the direction parallel to loading and extension in the direction perpendicular to loading, respectively; also g is gage length in the direction parallel to loading. Test results of each masonry group are discussed in this section in terms of maximum and ultimate bearing capacity, ductility, the ability to dissipate energy, failure type, and displacement capacity of tensile and compressive diagonals related to the maximum and ultimate loads.

3. Conclusion

Some important outcomes of diagonal compression tests on the reinforced and unreinforced masonry walls have been pointed out as follows:

- Two failure modes; sliding in horizontal bed joints and diagonal splitting; are the main failure modes observed in unreinforced masonry walls.
- Bearing capacity of reinforced specimens is affected by the occurred failure mode; as sliding mode of failure yields much lower ultimate bearing capacity compared to diagonal splitting mode.
- Using FRP as reinforcement would increse the bearing capacity of the specimens with sliding mode of failure, considerably; however, it has no tangible increase on bearing capacity of the specimens with diagonal splitting failure mode.
- Use of boring along with nailing method in mounting FRP reinforcements would increase the ductility factors of masonry walls; hence the ductility, energy dissipation, and ultimate strain in these specimens increased by 23, 43 and 27 percent, respectively, as compared to the specimens reinforced without using surface preparation methods.
- Use of grooving method with 4 mm width and 7 mm depth on the wall surface to mount the GFRP reinforcement as a substitution for surface preparation methods is very effective in increasing the ductility factors of the wall. As a result, the obtained values for ductility, energy dissipation, and ultimate strain were 21.3, 33, and 21.2 percent greater than their peer values in the specimens reinforced without surface preparation methods.
- Boring method of mounting FRP reinforcements, not only results in increasing strength and ductility, but also has much less environmental pollution effects as compared with other methods of surface preparation.