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Shear strengthening of unreinforced masonry wall with different fiber reinforced mortar jacketing

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HIGHLIGHTS

- We tested 12 masonry wall panels under diagonal shear load.
- Three different fiber reinforced mortar used four different ways to strengthening.
- Application of fiber reinforced mortar improves shear strength of the wall panels.
- Ferrocement and polypropylene reinforcement improved shear strength significantly.
- The strengthening techniques need connection to utilize benefit of the reinforcement.

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ABSTRACT

This study presents the comparison of different strengthening techniques for unreinforced masonry walls. Three materials are considered in four different ways for strengthening URM walls, textile reinforced mortars (TRM) plastering, applied on one and both faces of the wall, polypropylene fiber reinforced mortar plastering (PP-FRM), and ferrocement reinforced mortar plastering. Shear performance of the strengthened walls were tested under diagonal compression test method. Changes of shear performance of strengthened walls were determined by comparison of before and after the application of the reinforcements. The walls reinforced with ferrocement and polypropylene mortar plaster exhibited a significant improvement in shear strength capacity of up to 412% when compared to the control specimen. The results indicate a good increase of shear strength for all selected strengthening techniques, while stiffness change and failure mode are more varied.

1. Introduction

Masonry walls are composed of bricks and mortars, which have distinct properties. The adhesion provided by mortar between these constituents is responsible for the behavior of masonry under lateral loads. Therefore, masonry is very vulnerable when subjected to earthquake loads. Unreinforced masonry (URM) buildings are constructed with thick bearing masonry walls in box-like structures form. These walls are main load carrying elements which can safely carry vertical loads without damages. However the shear response of masonry walls is more complex and depends on composite nature of mortar and bricks. Furthermore, the stocky nature of URM walls and the zero tensile strength of the material, makes masonry very brittle and with low ductility [1].

The Darfield and Christchurch earthquakes that stroke New Zealand provide a vast amount of examples of damages to URM from earthquakes. The damages are categorized as non-structural and structural. The non-structural damages include chimney and parapet failure, veneer peel-off, gable wall out-of-plane failure. The structural damages include out-of-plane wall failure, and in-plane wall failure. The in-plane wall failures observed were the diagonal shear cracking in piers, spandrels and walls; sliding shear on mortar bed joints or between stories; and in-plane rocking or toe crushing [2,3]. Most of the URM buildings were built based on experience and construction practice of the time it was built. Moreover many of them were designed and built before any code or provisions for seismic load were required. Therefore URM buildings need strengthening to satisfy today codes requirements and engineering understanding of URM.

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Due to the huge building stock of URM throughout the world and weak characteristic under seismic loads, strengthening techniques for masonry have evolved significantly last two decades. Originally, the techniques used for RC structures were adopted for masonry structures as well. These comprise bracing, shear wall addition, secondary moment or bracing frames (RC or steel) [4]. Typical masonry strengthening techniques comprise restoration techniques such as grout injection, crack stitching and repointing [5]. New techniques have risen the recent years, such as post-tensioning, base-isolation, shotcreting and jacketing [6]. While the classical solutions such as bracing and shear wall addition are appropriate when the structural system presents deficiencies; grouting, and stitching can only close cracks and restore the wall capacity at a certain degree, jacketing is a local strengthening technique that seems very promising.

The development of new materials such as fiber polymers has made jacketing a solution for strengthening structural elements. Fiber reinforced polymer (FRP) wrapping of masonry walls has been tested in a variety of configurations. Besides for the conventional form of FRP used in strengthening of RC element, textile reinforced mortar (TRM) has been developed specifically for masonry. It consists of glass fibers pre-embedded in epoxy, and woven in the form of mesh. It has lower modulus of elasticity than CFRP, therefore is more adequate for the strengthening of masonry walls [7]. The application of TRM increases the shear strength of masonry walls. It also affects the stiffness and ductility, and improves the failure mode. The walls have a gradual prolonged failure, which is highly desirable in earthquake prone areas [8]. The application of TRM on one side of the wall, due to the asymmetry of the section and mix failure mode, has resulted less satisfactory. The plain side has excessive deformations. This strengthening technique not always results in increase in stiffness of the walls [9].

Ferrocement jacketing has also been tested in masonry walls. This strengthening technique results in considerable increase in stiffness. Studies have indicated that strengthening of predamaged masonry walls with ferrocement jacketing can restore the original capacity and original stiffness of the wall. In the case of ferrocement jacketing, a key point in the success of the strengthening is the use of anchorages to fix the jacket and prevent it from delamination [10]. Ferrocement has high flexural and shear strength, and can control the crack formation. Therefore it gives good results when used as a strengthening technique for masonry. Masonry columns have been confined with ferrocement layers, which has restored and/or increased the capacity of the column [11,12]. Further studies have tested the effectiveness of ferrocement for the confinement of masonry walls. The jacket increases the strength and improves the ductility and failure mode of the walls [13]. A comparative study on the shear strength of masonry walls retrofitted with various techniques, including ferrocement shows that it increases the shear strength and the stiffness of the wall considerably [14]. Other advantages in the use of ferrocement as strengthening material are the availability of the galvanized steel wire mesh and the unskilled workmanship required to install it.

Strengthening masonry walls with fiber reinforced mortars (FRM), which are microfibers embedded in mortar, is a technique needs to be study. The microfibers can be of different composition: steel, glass, synthetic fibers (acrylic, aramid, carbon, nylon, polyester, polyethylene, and polypropylene) and natural fibers (straw, coconut, bamboo). The addition of these fibers to concrete/mortar affects its flexural and shear properties, the energy absorption capacity and delays cracking [15]. Polypropylene fibers are chemically inert fibers that bond mechanically with the mortar through the contact area. In order to obtain good bonding between the fibers and the mortar smaller diameter fibers are produced. The dimensions of the fibers range between 7 and 77 mm, and the aspect ratios are in the range 20–100. These fibers are usually used to plaster tunnel walls, due to the high resistance to impact loads and the good cracking behavior. The most usage of polypropylene for strengthening masonry walls is in the form of meshes. The research on this topic has shown that polypropylene meshes plastered to masonry walls improve their post crack behavior, and restore the capacity of damaged walls [16]. Other studies found out that polypropylene meshes do not enhance the shear strength of the walls [17]. Affect of polypropylene microfibers to mortars is known to increase the energy absorption and toughness, limits cracking due to the spread of the fibers, which hold the matrix together, improves the flexural and shear strength, but does not affect the compressive strength of mortars [14]. Mortar mix with the polypropylene microfibers, ferrocement and TRM one and two sides plaster are used in this study to strength unreinforced masonry walls. Comparison of different strengthening technique is carried out by diagonal shear test.

2. Materials and methods

The critical seismic strength for masonry is the shear strength. Usually, masonry sections do not present problems for axial loads, but have limited capacity in shear. To investigate the behavior of strengthened walls under lateral loading, the diagonal shear test, standardized by ASTM 519 [15] was used. For the study, 12 walls were constructed, 2 in full scale, as defined by ASTM 519, and the rest as half-scale. The size of standard walls was 1.2 × 1.2 m while the size of half-scale walls was 0.65 × 0.65 m. The thickness for all walls was 0.25 cm.

Two layers of wire mesh are used for each side of the wall. The two layers are tied together by means of a thin wire. Surface preparation is required in order to install the steel wire meshes. The anchors used, were normal threaded bolts of diameter 6 mm .Welded steel wire mesh of opening size 12.7 mm 12.7 mm with an average wire diameter of 1.1 mm was used.

The test setup consisted of the loading frame, two steel loading shoes, a hydraulic jack and two dial gauges for the small and half-scale walls. Since the standard size walls were too big to be moved with ease, a modification was done to the test setup. Instead of the loading frame, the two loading shoes were fixed by means of 4 steel rods, riveted on both ends (Fig. 1a). The load was applied by means of the hydraulic jack at small increments to allow for the detection of cracks prior to failure. Fig. 1 shows the ASTM test setup, and the adopted setups for the standard size and half-scale specimens (Fig. 1b).

In this study, the 2 full size walls were tested plain, with no strengthening or any form of plaster. From the half-scale walls specimens, 2 were tested plain, 2 were strengthened with TRM jacketing in only one side, 2 were strengthened with TRM on both sides, 2 were strengthened with ferrocement jacketing, and 2 were strengthened with polypropylene FRM jacket. The specimens are named as PL (plain-large), PS (plain-small), TI (TRM-one side), TII (TRM-two sides), FC (ferrocement) and PP (polypropylene).

The shear strength and shear modulus of the specimens were calculated using ASTM [18] recommended Equations

$$S_n = \frac{0.707P}{A_n} \quad (1)$$

(a) standard size specimen setup **(b) half-scale specimen setup**

Fig. 1. Test setup for diagonal shear test.