

Effect of different retrofitting techniques on in-plane behavior of masonry wallettes

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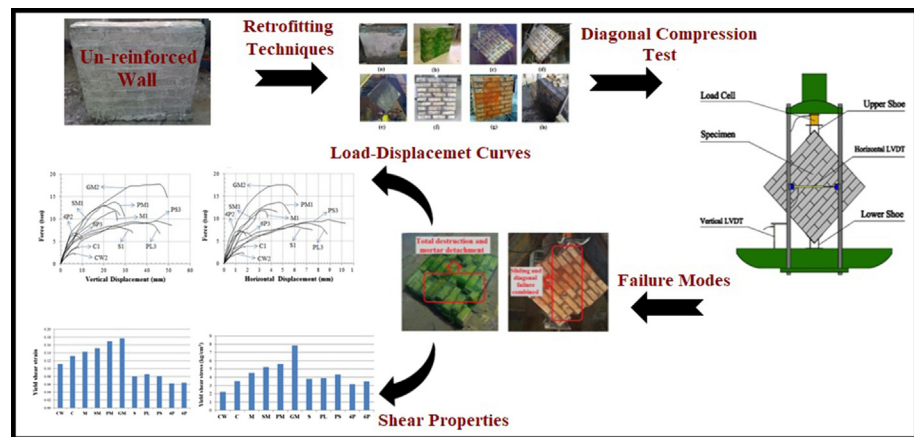
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HIGHLIGHTS

- In-plane behavior of various retrofitted URM walls is investigated.
- Un-reinforced and reinforced mortar coating, mesh reinforcement, and PP-band were used for retrofitting.
- Failure modes, elastic characteristics, and shear stress and strain were studied.
- The dominant failure mode of the wallettes entailed diagonal shear cracks.
- Wallettes retrofitted with GFRP mesh mortar-coated performed much better in most characteristics.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper presents the results of diagonal compression tests conducted on a series of un-reinforced and reinforced masonry specimens. Reinforced specimens were strengthened by using three types of mortar coating (with and without inner reinforcement), mesh reinforcement, and PP-band reinforcement. In particular, four different reinforcement methods with mortar coating (bare mortar coating, coating with steel mesh, coating with polymer reinforcement, and coating with GFRP mesh reinforcement), three different mesh-only reinforcement (steel mesh, polymer mesh with larger grids, and polymer mesh with smaller grids), and 2 different arrangements of PP-bands (4×4 and 6×6) were tested. Also, two different un-reinforced specimens (with and without mortar between bricks in a row) were tested to observe the effect of this matter. Each reinforcement method was tested with three wallettes and the effectiveness of each reinforcement method was observed in terms of both loading capability and ductility (especially the GFRP mesh reinforcement with mortar coating) because of the low resistance of the un-reinforced specimens. Shear stresses and strains and the elastic characteristics of each method are also presented in this paper.

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1. Introduction

Despite modern building design methods, there are a number of seismic regions around the world in which the masonry buildings have not been designed to withstand the appropriate seismic loads; retrofitting these buildings so that they can withstand local expected seismic load is a priority [1,2]. Masonry walls have two main modes of failure: (a) in-plane, and (b) out-of-plane [2–4]. When the joint between adjacent walls is strong enough, when subjected to high lateral forces, mobilized walls suffer in-plane shear resistance and in-plane failures. The in-plane failure modes of unreinforced masonry (URM) walls fall into the following four categories: (a) shear failure, (b) sliding failure, (c) rocking failure, and (d) toe crushing [5,6]. There are no current internationally accepted guidelines available to assist engineers in deciding which methods to use when retrofitting masonry walls; a thorough investigation of methods used to retrofit masonry walls is, therefore, required [1,7]. This paper reviews and demonstrates the result of the common methods to retrofit masonry walls in in-plate shear static tests.

Recent earthquakes have highlighted the need to improve the seismic performance of URM walls that are present in historical and important buildings through the use of new retrofitting methods [8–10]. One method treats the wall surface with mortar alone or with both mortar and different kinds of mesh such as steel, plastic and fiber-reinforced polymer (FRP). While this method improves the seismic performance of a wall, the extra weight of the mortar means that a wall that has been retrofitted in this way is more vulnerable to damage from lateral earthquake forces. Gattesco et al. [11] carried out a series of diagonal tests on a range of masonry wall types that were constructed with a mortar coating that had been reinforced with glass fiber reinforced polymers (GFRPs). When compared to URM, Gattesco et al. observed that reinforced masonry (RM) underwent a much larger deformation (>50%) of the peak value at a compression strain and an almost double maximum resistance. Reinhorn et al. [12] tested shotcrete retrofitted walls that had been reinforced with steel mesh under a diagonal compression jack. Two failure modes were observed: (a) diagonal tension failure (ductile) and (b) bond failure (brittle). Bond anchors between the wall masonry and coating had a large effect on the development of each failure mode. The strength and ductility of coated walls are almost double those of uncoated walls, regardless of mesh size. Many previous studies investigate the use of FRP materials and polymer nets to retrofit masonry walls.

Alternative methods to retrofit walls include the use of steel and plastic mesh without mortar, and to apply more fixing points to the wall. The use of mesh without mortar is expected to offer improved strength as well as a lighter wall compared to the use of more fixing points.

Cracked walls can be retrofitted by injecting epoxy into the cracks in order to restore uniformity; the same outcome can be achieved using steel ties and mortar [1,13]. Injecting epoxy into cracks can increase both strength and stiffness, but strength increases with higher rate. The widespread use of this method is aided by its low cost, ease of use and wide availability of the required materials.

Reinforced tie columns (or steel columns) at corners can be used to retrofit masonry walls as well as in new constructions [5,13]. Paikara and Rai [14] investigated this kind of wall under conditions of cyclic loading, and they found an improvement in in-plane deformability and energy dissipation. A diagonal compressive strut was shaped in these samples under conditions of lateral loading.

Another method is to use PP-bands (polypropylene bands) with different arrangements. These kinds of bands are mainly used in

the packaging industry, and they also can be pre-stressed. Sathiparan et al. [15] carried out diagonal compression (in-plane) and also out-of-plane tests on wallettes retrofitted with pp-bands with two arrangements. Large residual strength was observed after the formation of the first diagonal shear cracks (i.e., usually considered the plastic phase). Retrofitting with PP-bands increased the strength up to 250% and caused a deformation 45 times larger than non-retrofitted wallettes did.

One of the innovative and relatively new materials used for constructing new structures and retrofitting existing structures such as masonry walls is Fiber-Reinforced-Polymers (FRPs) [16,17]. The advantages of this product are: (a) high strength-to-weight ratio, (b) high stiffness-to-weight ratio, (c) good fatigue properties, (d) ease of handling, and (d) resistance to corrosion [18,19]. These factors have made the FRP composites an appropriate material for use in constructional application [20,21]. The seismic retrofitting of URM walls can be accomplished in the use of: (a) FRP sheets, (b) meshes, and (c) near-surface mounted (NSM) FRP bars. Mahmood and Ingham [22] conducted diagonal compression on wallettes retrofitted with GFRP fabrics, pullulated CFRP plates, and NSM rectangular bars. A large increase in shear strength was achieved (i.e., up to 325%) in wallettes that were retrofitted with one sided FRP fabrics. There was a nonsignificant change observed in stiffness with FRP. Also, there was a linear relationship between increase in shear strength and the product of horizontal reinforcement ratio and FRP modulus of elasticity.

Ismail et al. [23] studied the behavior of URM wallettes, which were strengthened with the use of near surface mounted twisted steel to restrain diagonal cracking failure in a diagonal compression test. The observed improvement in shear strength ranged from 114% to 189%, except for those where horizontal bars were used, and the shear strength decreased. Use of the vertical bars increased ultimate displacement in order to support larger loads [24].

Since very little experimental studied are available on the diagonal compression behavior of masonry walls retrofitted using various kinds of meshes with different implementation, this study presents a comprehensive experimental study to investigate the effect of mesh type, mesh size, and its implementation. Moreover, tests were conducted with walls, which were retrofitted with the use of other traditional material, in order to determine the advantages of the presented method in regard to the costs and weight reduction factors.

2. Experimental program

2.1. Materials characteristics

It is known that the mortar strength and masonry unit (brick) play a key role in in-plane resistance of un-reinforced masonry (URM) walls. To obtain the properties of mortar and see if they meet minimum limits of the current codes, tests have been conducted on five 50 mm cubes. Mortar was made with a water-to-cement ratio of 0.5, with proportions of sand to cement being 0.25. This test was based on ASTM C109 [25]. The average characters and properties of five mortar samples, tested simultaneously, are given in Table 1. The mortar is classified as middle-strength mortar.

Compression tests also were carried out on 10 randomly selected bricks based on ASTM C67-00 [26]. In Table 2, dimensions, weights, and ultimate compression strengths for each brick, and the average value of each of the above, are given.

PP band properties are shown in Table 3. Table 4 also shows the characteristics of steel, polymer, and GFRP meshes provided by their manufacturer used in this study. For all mortar coating wallettes, tests were carried out after 28 days of curing.

2.2. Test setup

Diagonal compression tests, based on ASTM E519-02 [27], were carried out on a total number of 33 wallettes to evaluate the behavior and properties of masonry walls with and without retrofitting. The load was applied using two high strength

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