Experimental Evaluation of the Out-of-Plane Performance of Clay Block Masonry Infill Walls Using a Composite Retrofitting System

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Abstract

Clay block masonry infill walls are among the most nonstructural components in reinforced concrete (RC) frames. During earthquakes, particularly under out-of-plane loading, these walls are susceptible to brittle failure and sudden collapse, which can result in loss of life and property damage. This study experimentally investigates the effect of retrofitting clay block masonry infill walls using alkali-resistant (AR) glass fiber mesh strips on their out-of-plane behavior within RC frames under quasi-static loading. For this purpose, two RC frame specimens with masonry infill walls, comprising one non-retrofitted specimen and one retrofitted specimen, were constructed at a 1:2 scale and subjected to out-of-plane cyclic loading. The retrofitted specimen incorporated a composite retrofitting system consisting of AR glass fiber mesh strips, a sand-cement mortar coating, and steel anchorage components. The performance of the specimens was evaluated in terms of load-bearing capacity, stiffness, ultimate displacement, ductility, crack patterns, failure mechanisms, and infill wall collapse behavior. The results showed that, compared with the non-retrofitted specimen, the composite retrofitting system increased the out-of-plane load-bearing capacity by approximately 173%, the ultimate displacement by 75%, and the effective stiffness by approximately 125%. Furthermore, the retrofitted specimen exhibited more gradual crack propagation, better preservation of infill wall integrity, and a more gradual failure process than the non-retrofitted specimen. Based on the results obtained from the tested specimens, the proposed composite retrofitting system can be considered an effective approach for improving the out-of-plane performance of clay block masonry infill walls and reducing the risks associated with their collapse during earthquakes.

Keywords: Clay block infill; alkali-resistant glass fiber; out-of-plane loading; seismic performance; retrofitting.

1. Introduction

Masonry infill walls are widely used as nonstructural components in reinforced concrete (RC) buildings. Although they are often disregarded in the primary structural design, their interaction with the surrounding frame can significantly influence the overall stiffness, lateral resistance, force distribution, and seismic damage patterns of the structure [1, 2]. One of the major concerns regarding these walls is their susceptibility to out-of-plane failure under earthquake-induced inertia forces acting perpendicular to their surfaces. Such failure can result in the detachment or collapse of masonry units [3, 4] , posing a serious threat to occupants and causing substantial property damage, even when the primary structural system remains intact.

Previous experimental and analytical studies have investigated the out-of-plane response of masonry infill walls, with particular attention to the effects of boundary conditions, prior damage, and strengthening techniques [1]. Among the proposed strengthening approaches, textile-reinforced mortar (TRM) and other composite systems have attracted attention because of their potential to enhance wall integrity and improve out-of-plane resistance [5, 6].

Glass-fiber meshes and mechanically anchored overlays have also been investigated for strengthening masonry walls and RC frame infills [6]. However, experimental evidence regarding the combined use of alkali-resistant (AR) glass fiber mesh strips, a sand–cement mortar overlay, and steel anchorage components in clay block infill walls subjected to cyclic out-of-plane loading remains limited.

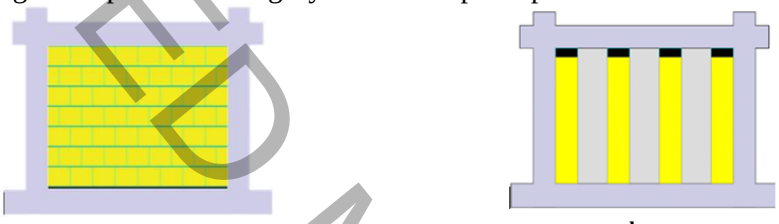
To address this research gap, the present study conducts a comparative experimental investigation of two half-scale RC frames with clay block masonry infill walls, one non-retrofitted and the other strengthened using the proposed composite system. The main objective is to evaluate the overall

effectiveness of this strengthening system in improving the out-of-plane performance of the infill walls, rather than to examine the individual contribution of each component.

2. Experimental Program

Two geometrically identical reinforced concrete (RC) frame specimens were constructed at a 1:2 scale. The first specimen contained a non-retrofitted clay block masonry infill wall and was designated IFM-OOP, whereas the second specimen, designated SIFM-OOP, incorporated the proposed composite strengthening system, Fig. 1. The RC frames were designed and detailed in accordance with ACI 318-19. The infill walls were constructed using hollow clay blocks and sand–cement mortar with a sand-to-cement ratio of 3:1. The mortar joints were approximately 10 mm thick. The mechanical properties of the concrete, reinforcing bars, clay blocks, mortar, and alkali-resistant (AR) glass fiber mesh were determined through relevant experimental procedures in accordance with the applicable standards, including ASTM A370, ASTM C67, ASTM C109, and ASTM E2098 [7-10].

In the strengthened specimen, eight AR glass fiber mesh strips, each 250 mm wide, were installed on the two faces of the infill wall, with four strips on each face. The mesh had an opening size of 5 × 5 mm, and the strips were arranged vertically at approximately 333 mm intervals. At the top of the wall, the strips were mechanically anchored beneath a steel angle connected to the RC frame, while their lower ends were secured beneath a steel strap. Subsequently, an approximately 10 mm-thick sand–cement mortar overlay was applied to the wall surfaces to embed the mesh strips. Accordingly, the proposed strengthening system integrated distributed surface reinforcement, a cementitious overlay, and mechanical anchorage to improve the integrity and out-of-plane performance of the masonry infill wall.



a. b.

Figure 1. Schematic configuration of the test specimens: (a) IFM-OOP specimen; (b) SIFM-OOP specimen.

3. Results and Discussion

The non-retrofitted specimen exhibited relatively brittle behavior. Initial damage involved the local displacement of a clay block near a loading shoe, followed by the progressive development of horizontal and vertical cracks, mainly along the mortar joints. Although an arching mechanism developed at approximately 15 mm displacement, localized failures at 20 mm disrupted this mechanism, leading to a considerable reduction in stiffness and load-carrying capacity. The test continued until an ultimate displacement of 40 mm was recorded.

In contrast, the strengthened specimen showed limited visible damage at the initial loading stages. Diagonal cracks first appeared in the mortar overlay at approximately 20 mm displacement, followed by further cracking and localized crushing of the blocks and mortar. Nevertheless, the mesh and anchorage system maintained the overall integrity of the infill wall. Despite limited mesh rupture and local overlay damage at the final stages, the specimen sustained loading up to an ultimate displacement of 70 mm and exhibited more gradual damage progression and strength degradation.

Compared with the non-retrofitted specimen, the strengthened specimen showed a 173% increase in peak resistance (from 17 to 46.4 kN), a 75% increase in ultimate displacement (from 40 to 70 mm), and a 125% increase in effective stiffness (from 1.04 to 2.34 kN/mm). Energy dissipation also increased by approximately 223%, from 357.4 to 1,155.7 J. The main first-cycle response parameters are summarized in Table 1.

Table 1. First-cycle out-of-plane response parameters of the tested specimens.

Specimen	P_{max} *(kN)*	d_{max} *(mm)*	d_u *(mm)*	K_i *(kN/mm)*	K_e *(kN/mm)*	E_i *(J)*
IFM-OOP	**17.0**	**20**	**40**	**1.10**	**1.04**	**357.4**
SIFM-OOP	**46.4**	**20**	**70**	**1.70**	**2.30**	**1155.7**

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The comparison of the two loading cycles revealed reductions in several response parameters during the second cycle, indicating the effects of accumulated damage. However, the strengthened specimen maintained higher peak resistance, stiffness, and energy dissipation in both cycles. The observed response also suggested a more stable arching contribution in the strengthened wall. Nevertheless, since strains, crack widths, and force distributions were not directly measured, this interpretation could not be independently verified quantitatively.

The findings should be considered in light of the experimental limitations. Since only one specimen was tested for each condition, the observed improvements cannot establish statistical repeatability or the variability of similar specimens. Furthermore, the individual contributions of the mesh, mortar overlay, and steel anchors could not be isolated because they were evaluated as a combined system. The cost and constructability of the proposed retrofitting method were also beyond the scope of this study.

4. Conclusion

A quasi-static cyclic experimental investigation was conducted to evaluate the out-of-plane performance of clay-block masonry infill walls in RC frames, comparing a non-retrofitted specimen with one strengthened using AR glass fiber mesh strips, a sand–cement mortar overlay, and steel anchorage. The proposed composite system increased peak resistance by approximately 173%, ultimate displacement by 75%, effective stiffness by 125%, and dissipated energy by 223%. It also delayed damage development, limited crack propagation and local disintegration, and helped maintain wall integrity at larger displacements. These findings demonstrate the potential of the proposed system to mitigate the risk of sudden out-of-plane collapse. However, further experimental investigations involving repeated specimens and individual assessment of the strengthening components are necessary to verify the findings and establish their broader applicability.

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