RETROFITTING OF CONFINED MASONRY STRUCTURE WITH FIBER REINFORCED POLYMER (FRP)

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Abstract- The following experiment presents a method for evaluating the earthquake resistance of confined masonry buildings before and after being strengthened using fiber-reinforced polymer (FRP). The results of this research are anticipated to substantially impact future studies' direction and design guidelines' development, contributing to the global understanding of seismic retrofitting in confined masonry structures. A 1:3 scale-down single-story confined masonry structure (CM) constructed by ERRA guidelines was subjected to a novel application of a consistent vertical force and displacement-based reverse cyclic lateral loading up to maximum resistance. The damaged model underwent a retrofit using fiber-reinforced polymer (FRP) and was then tested again until it failed under the same conditions. The efficiency of FRP retrofitting was assessed through a thorough examination of the damage distribution and force-displacement characteristics of the retrofitted confined masonry structure (RCM) compared to the original confined masonry structure (CM). The experimental data, presented as force-deformation parameters, clearly demonstrate the benefits of FRP in improving lateral displacement and deformability.

Keywords: confined Masonry, retrofitting, seismic

1 Introduction

The most admired type of residential structure is masonry. These structures are economical and have good thermal insulation properties, with aesthetic vistas. Three types of masonry structures exist confined masonry (CM), un-reinforced masonry (URM), and masonry infill RC frame structures. After the Kashmir earthquake in October 2005, which resulted in 73000 fatalities and left 70000 people injured, 3.5 million individuals were also displaced from their homes.[1]. Most damaged structures were unreinforced masonry (URM) buildings[2]. Confined masonry (CM) is now extensively utilized for cost-effective building construction, addressing the issues about unreinforced masonry, and this study aims to validate its effectiveness further. The confined masonry structures have also sustained significant damage in previous earthquakes. Now, buildings that have experienced partial damage can be retrofitted or rebuilt. We often lean towards retrofitting as it is more cost-effective and efficient than reconstruction, providing a sense of reassurance and confidence in our approach. Different researchers have analyzed different retrofitting techniques.[3]

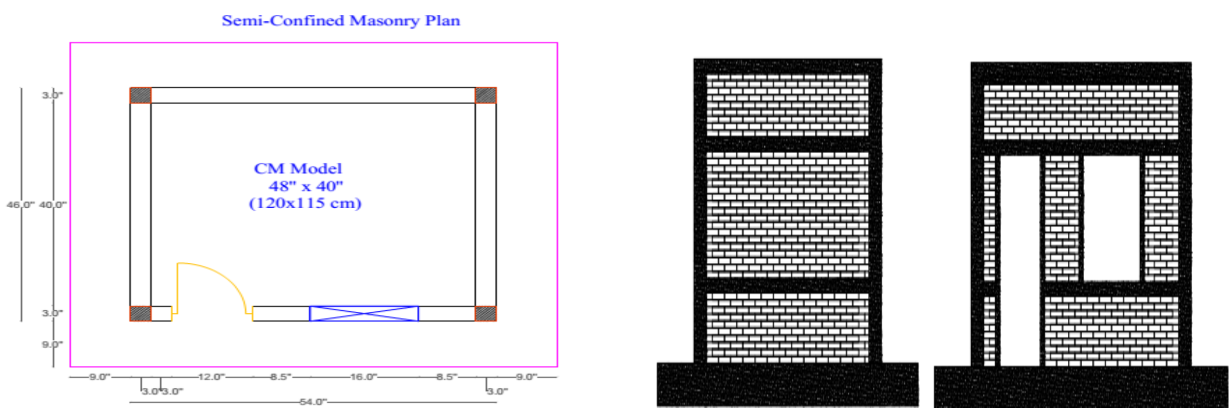
Different researchers have worked on the behavior of FRP-retrofitted masonry walls under seismic forces. Relatively, no study has been seen on an experimental investigation of the influence of FRP on confined masonry structures built according to the ERRA guidelines, which represents the typical building structure found in the northern regions of Pakistan.

In this context, a 1:3 scale-down CM single-story structure was built and placed to a quasi-static lateral load test. The damaged building underwent retrofitting with FRP before being retested to assess the repair approach's effectiveness. The experimental results regarding lateral deformation and deformability were compared and discussed.

2 Research Methodology

2.1 Test Specimen

A typical 1/3 reduced-scale confined masonry structure was built at UET Peshawar. First, the test specimen was constructed on a substantial reinforced concrete raft footing of dimension 72"x64"x6" (length x width x height)), reinforced with 12mm bars placed at 4-inch intervals in both directions, all vertical confinement elements (3"x3") rebar were extended from the foundation to the RCC slab, were cast. The building was erected upon the pad using handmade burnt clay brick units till sill band. Then, the openings (a door and window) were provided, which were confined horizontally and vertically with the seismic band and lintel band, having a cross-section of 2"x3" (depth x width), reinforced with four longitudinal bars of 3/24" diameter and stirrups of 3/24" diameter spaced at 12" c/c. Similarly the construction was continuous up to lintel band. Finally, the construction of specimens was completed by casting 3" thick RC slab. Details of the room are shown in Figure 1.



a) b)

Figure 1: Test Specimen, a. Plan view of the Model, and b. Elevation view of the model

2.2 Testing

The upper part of the specimens was clear to enable unrestricted movement in all directions while keeping the lower part immobile. A constant vertical load of 735 kg was imposed by placing steel plates of known weights above the specimen. The structure was subjected to lateral load with the help of a hydraulic jack. Horizontal displacement was recorded by connecting twelve LVDTs. The load cell and LVDTs were connected to the UCAM-70A data logger to record the induced load and resulting displacement and strains at various locations.

The structure was placed to displacement control horizontal loading with a constant vertical load at the roof level. Each cycle of displacement is comprised of two (negative and positive) amplitudes, with similar loading conditions in both directions. Starting from 0.25mm, all displacement cycles were repeated three times. After every cycle, the appeared cracked marked with marker and prepare short note from load and displacement. This load cycle procedure was in progress until the load decreased by 20% of the maximum load because, in this stage, the structure could be retrofitted.

3 Retrofitting Technique

3.1 Retrofitting with FRP

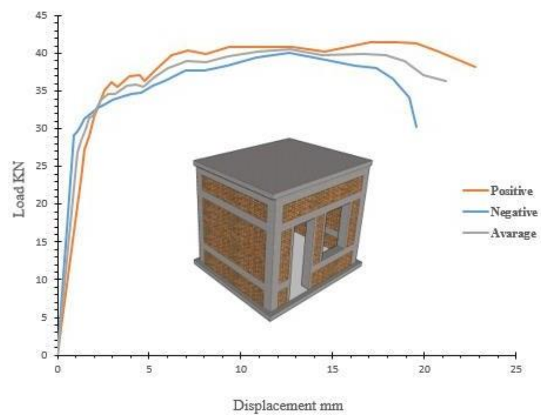
The cracks and overall structure were cleaned with a brush, and loose mortars were replaced with fresh mortar. Then, injection ports or nozzles made of plastic, each with a diameter of 6 mm, were placed into pre-drilled holes located at intervals of about 150 mm along the cracks. The surface cracks were sealed using cement mortar and left to cure for seven days. Before grout injection, the air was directed through nozzles to eliminate any dust inside the cracks and to inspect the connection between the nozzles. Grout was pumped under high pressure of over 0.6 MPa from the lower to the upper nozzles against the force of gravity. The CFRP's woven structure was unidirectional. The FRP strips, which have a width of 3 inches, were bonded in the vertical direction on the coated surface, and then, The FRP strips received an additional layer of epoxy coating.CHEMDUR-52 LP of components A and B with 2:1 was used as epoxy resin. Anchors were installed to prevent FRP strip detachment and to improve the bond performance between the FRP and masonry substrate. The FRP strips received a final epoxy coat to avoid the detachment of the FRP strips and improve the bonding performance between the FRP and the masonry substrate anchors during testing. The Retrofitted CM structure (CFRP-Retrofitted masonry) was subjected to the same loading condition and test procedure as the control specimen.

4 Results

4.1 *Before retrofitting*

A cyclic horizontal load was performed on the model. The damage scheme is shown in Figure 2. A. The primary type of failure observed was a step crack that traversed mortar joints and a diagonal shear crack in the confined vertical column at the joint where the slab corner meets. The experiment was halted when reaching a maximum displacement of 19 millimeters, resulting in moderate damage. Figure 2. b illustrates the envelope curve of the CM structure. The structure reached its high lateral load-resisting capacity (40.50 KN) at 18mm displacement, after which strength degradation started.

a)



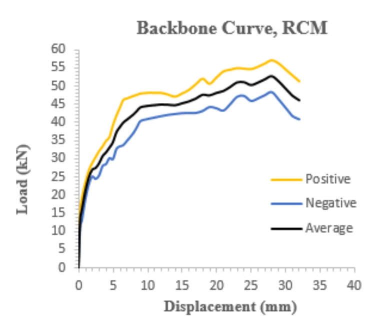
b)

Figure 2: CM results, a. Failure of confined vertical column b. Envelope curve

4.2 *After retrofitting*

Similar to the CM structure, a shear crack at an angle appeared in the tie column near the corner joint of the slab, which was wide enough to be visible during testing, and the FRP was ruptured at that point, as shown in Figure 3. a. The test was then stopped. Figure 3. b shows hysteresis loops of retrofitted confined masonry structures. The structure's highest resistance was 57KN, reached at a displacement of 28mm, following which there was a gradual decrease in strength.

a)



b)

Figure 3: Retrofitted CM results, a. Failure of retrofitted confined tie column b. Envelope curve

4.3 Force-deformation parameters comparison

A comparison of the force deformation parameters is shown in Table 1.

The estimated maximum load, Vu, is calculated using the formula Vu=0.9Vmax. The effective stiffness, Keff, is determined by dividing 0.75Vu by the displacement on the envelope curve that corresponds to it. The displacement at yield is determined by the formula Δy=Vu/Keff. The maximum displacement occurs at a location corresponding to 0.8 times the ultimate shear strength in the envelope curve. Once these values have been calculated, the displacement ductility, represented by μ, is defined as the ultimate displacement divided by the yield displacement, or μD = Δu/Δy[4]. The response modification factor (R) and the displacement amplification factor (Cd) were computed using equations 4.1 and 4.2, respectively.

$$R = \sqrt{2\mu - 1} \quad \text{eq.4.1} \qquad\qquad C_d = \frac{\mu}{\sqrt{2\mu-1}} \quad \text{eq.4.2}$$

Table 1 Force-deformation parameters

Parameters	CM specimen	CFRP-retrofitted Specimen	Ratio (CFRP-retrofitted/CM)
Maximum load Vu (kN)	36.45	51.30	1.40
Elastic Stiffness (kN/mm)	18.22	6.41	0.35
Yield Displacement (Δy) (mm)	2.00	8.00	4.00
Ultimate Displacement (Δu) (mm)	19.00	32.00	1.68
Displacement Ductility μ	9.5	4.00	0.42
Response modification factor (R)	4.24	2.64	0.62
Displacement amplification factor (Cd)	2.23	1.51	0.67

5 Conclusion

The following conclusions can be drawn from the conducted study:

1 Externally bonded CFRP strips are an effective retrofitting system for enhancing the seismic performance of CM buildings.
2 After retrofitting, the structure's lateral load capacity increased from 40.50 kN to 57 kN, 40.7 % higher.
3 Formability experienced a substantial decrease of 0.42.
4 The modification factor R and the displacement-amplification factor Cd were determined based on the idealized bilinear curves for the cases before and after retrofitting. The values for R and Cd were 34.24 and 2.23 for the original buildings and 2.64 and 1.51 for the retrofitted structure, respectively. Values for consideration in the development of seismic design guidelines are recommended.

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