STRENGTHENING OF UNREINFORCED MASONRY STRUCTURE WITH FIBER-REINFORCED POLYMER

[a] Ahmad Suboor* and [b] Samiullah Qazi

a: Department of Civil Engineering, University of Engineering and Technology Peshawar, Pakistan.
ahamadsuboor.civ@uetpeshawar.edu.pk
b: Department of Civil Engineering, University of Engineering and Technology Peshawar, Pakistan.
samiullah.qazi@uetpeshawar.edu.pk

Abstract- This study investigates the effect of carbon fibre-reinforced polymer (CFRP) in improving the seismic capacity of rural masonry structures prevalent in central Asia, where an overwhelming majority of masonry buildings lack reinforcement, rendering them susceptible to seismic events. Considering the situation, it is essential to reinforce these buildings using an efficient, cost-effective, and practical approach. CFRP partial bonding has been more economical compared to full jacketing; though, it comes with potential challenges such as interface delamination. As a result, this study utilizes the partial bonding method coupled with a CFRP anchorage system applied on the exterior of the structure. Two one-third scale unreinforced masonry structures (URM), designed to replicate typical village rooms, were constructed and subjected to displacement-controlled lateral loading and a constant normal load. The specimen reinforced with CFRP exhibited satisfactory performance in terms of observed failure modes and load response curves compared to the URM structure. In addition, the strengthening technique resulted in keeping the masonry structure intact over large drift ratios.

Keywords- Carbon fiber reinforced polymer (CFRP), CFRP anchorage, Masonry Structures, Seismic performance.

1 Introduction

Brick masonry is widely utilized in the construction industry around the world thanks to its practical application, local availability, heat insulation property, and affordable price. These structures are constructed either following engineering guidelines, referred to as confined masonry (CM), or without the use of confining elements, known as unreinforced masonry (URM). In Pakistan, however, a substantial 62% of the overall building stock is composed of brick masonry structures [1]. While unreinforced masonry (URM) structures exhibit satisfactory performance under gravity loads, their seismic resilience is limited, with the potential to withstand only minor earthquakes, rendering them susceptible to damage even in the case of moderate seismic events. The assessment conducted after the 2005 Kashmir earthquake revealed that the majority of the damaged or collapsed buildings were URM structures [2]. Moreover, URM structures suffered substantial damage in the 2015 Nepal earthquake and the 2016 Italy earthquake [3], [4]. Based on the occurrence of recent catastrophic seismic events and post-earthquake assessments, there is a crucial need for further research to enhance the seismic capacity of URM structures. Conventional seismic strengthening techniques, such as post-tensioning, member confinement, the centre core method, surface treatment, etc., have been explored to enhance the capacity of URM structures. Nevertheless, these techniques are accompanied by certain drawbacks such as mass increase, labour-intensive processes, and time consumption. On the contrary, Fibre-reinforced polymer (FRP) has captured the interest of researchers due to its inherent properties, such as its lightweight nature, high tensile strength, ease of application, corrosion resistance, and minimal alteration to the geometry of structural elements [5]. Many researchers have focused on strengthening of URM structural components such as walls, piers, or spandrels using FRP composites. Mustafaraj and Yardim [6] explored the effect of the diagonal compression test on brick masonry panels and reported a 27% increase in shear strength, a 645% increase in shear modulus, and an 1100% increase in ductility compared to that of the control specimen. Hernoune et al. [7] reinforced masonry panels constructed from hollow bricks using various carbon fibre-reinforced polymer (CFRP) configurations. The specimens strengthened with FRP showed a 3 to 4 times increase in shear strength and up to an 88% increase in ductility. Although numerous studies have concentrated on strengthening individual components (pier, spandrel, or wall) of the URM structure, limited literature is available regarding the global response of FRP-strengthened masonry structures under seismic loading. Moon et al. [8] conducted tests on a two-storey unreinforced masonry (URM) structure both before and after retrofitting with fibre-reinforced polymer (FRP). The primary objective of the composite repair was not to strengthen the structure but rather to maintain the damaged structure intact over significant displacement. Notably, the FRP was not anchored to the masonry. However, no research has so far been conducted on the seismic performance of the typical village room structure that is typically constructed in rural areas of developing countries. In this type of structure mainly the outer wall is also used as a boundary wall whereas door and window openings are made in the parallel wall—open to in-house courtyards. Therefore, this research work presents the seismic performance of the URM structure that is prevalent in rural areas of developing countries and explores the effect of FRP reinforcement on the strengthening of such structures. Apart from that to improve the bonded CFRP strips two types of CFRP anchors are used.

2 Research Methodology

2.1 Specimens Preparation

The construction of the models is carried out in two stages. In the first stage, two one-third-scale unreinforced brick masonry room models are constructed. The decision to scale down the specimens is made based on the limitations in instrumentation and project funds. The geometric configuration of the model is such that it has one perforated wall and three solid walls. The model dimensions are 122 cm x 102 cm x 130 cm (length x width x height) with 7.5 cm thick walls laid in English bond. Each room model is constructed over a 15 cm reinforced concrete (RC) raft to ensure they do not incur any damage during transportation to and placement inside the steel reaction frame. After construction and a curing period, one of the specimens is whitewashed and positioned within the straining frame. Its base is securely fastened to the underlying steel girders through a nut and bolt connection. The model is then subjected to the displacement-controlled cyclic load and a constant vertical load.

In the second stage, the uncracked model is confined with unidirectional CFRP strips. In solid walls, all vertical strips running throughout the specimen are 7.5 cm in width, while the vertical strips, on the sides of the openings (door and window) in the perforated wall, are 5 cm in width. The horizontal strips and the vertical strips running up to the sill level are both 5 cm in width. The CFRP pattern and strip width are determined based on both local and global failures observed in the control specimen, as well as previous studies on CFRP-strengthened masonry walls. To minimize the occurrence of premature failure, 90-degree and 180-degree FRP anchor spikes are employed to anchor the CFRP strips to the masonry walls, RC slab, and raft foundation. The FRP strips were bonded to the masonry substrate using Chemdur 300 epoxy resin and were allowed to cure for 7 days before undergoing testing. The materials used in the preparation of the test specimens and the mixed proportions of mortar and concrete are kept similar to those of the study area. The specifications of CFRP reinforcement, as provided by the manufacturer, are illustrated in Table 1.

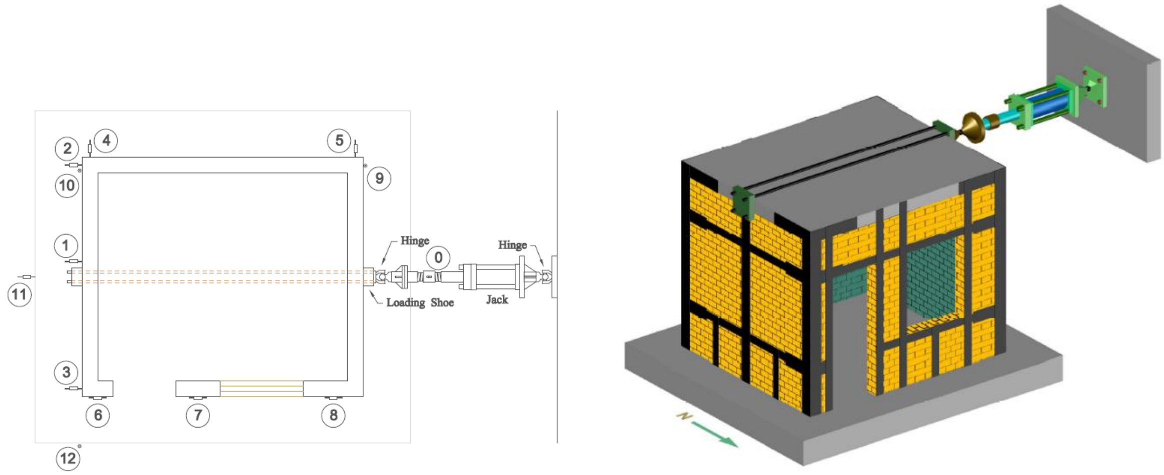
Table 1 Specifications of CFRP fabric

Fibre Type	**Areal Weight**	**Tensile Strength of Fibres**	**Tensile E-modulus of Fibres**	**Strain at Break of Fibres**
High-strength carbon fibres	220 $g/m^2 \pm 10\ g/m^2$	4100 N/mm^2	231000 N/mm^2	1.7%

2.2 Test Setup and Procedure

The instrumentation and isometric view of the test specimen are illustrated in Figure 1(a) and Figure 1(b) respectively. The displacement cycles are applied using a 500 kN capacity hydraulic jack fixed to the steel reaction frame and connected to the specimen at the roof slab. For brevity, the four walls of the structure are referred to as Wall A, Wall B, Wall 1, and Wall 2. Wall A and Wall B represent the perforated and solid in-plane walls, respectively. Wall 1 designates the out-of-plane wall where the load cell is attached, while Wall 2 signifies its parallel out-of-plane wall. To measure the displacement at various points of the structure, twelve Linear Variable Displacement Transducers (LVDT) are installed on steel reference frames and connected to the structure at various locations of interest through flexible steel wires. Each displacement cycle encompasses two amplitudes, one negative and one positive, with identical loading conditions applied in both directions.

Starting from 0.25mm, all displacement cycles are repeated three times. The test is continued till the structure fails or is excessively damaged.



a) b)

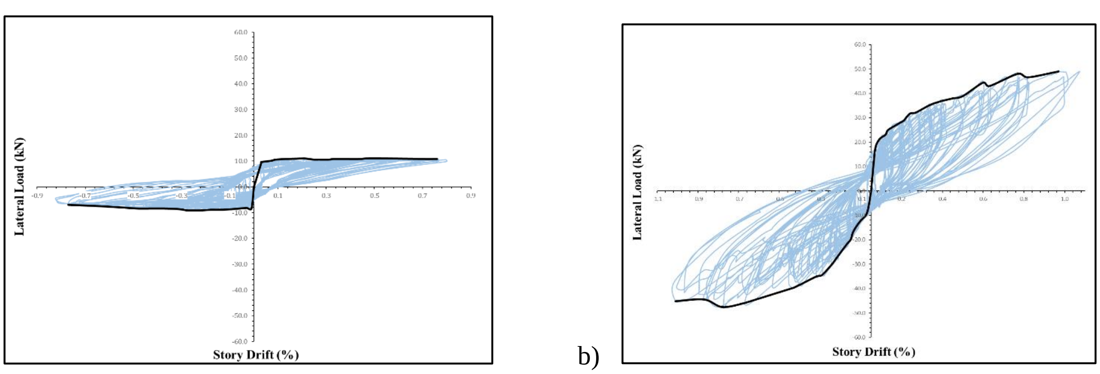
Figure 1: Test specimen, a. instrumentation setup, and b. N-E isometric view

3 Results

3.1 Hysteresis Loops

In the URM specimen, a tight loop was formed at the initial displacement cycle corresponding to 0.02% drift. Beyond this drift, wide loops were observed. Tight loops show small energy dissipation while wide loops are an indication of higher energy dissipation. Rapid stiffness degradation occurred at 0.02% drift and reached almost zero at 0.15% story drift. This rapid stiffness degradation could be attributed to the brittle behaviour of unreinforced masonry. During the initial displacement cycles, wall B (solid in-plane wall) was undergoing sliding failure while wall A underwent diagonal shear failure. However, during the final displacement cycles, the failure mode of wall B altered to rocking while the existent diagonal cracks in wall A continued to widen.

In the case of the CFRP-confined specimen, Rapid stiffness degradation was observed till 0.1% story drift and thereafter continued to gradually decrease till the ultimate displacement cycle. FRP rupture initiated at 0.77% story drift followed by gradual failure of the composite at various locations. During the initial displacement cycles, fewer cracks were observed in the CFRP-strengthened specimen as compared to the URM specimen because the introduction of CFRP enhanced the stiffness of the structure. However, during the final displacement cycles, more cracks were propagated in the strengthened specimen as opposed to the URM specimen. Figure 2 illustrates the hysteresis loops and envelope curves of URM and CFRP-strengthened specimens.

a) 

b)

Figure 2: Hysteresis loops, a. URM specimen, and b. CFRP-Strengthened specimen

3.2 Backbone envelope

The peak load and its corresponding displacement in each displacement cycle, for both positive and negative amplitudes, were joined to obtain the backbone curve for URM and CFRP-strengthened specimens. Initially, both control and strengthened models exhibited stiff behaviour. However, the stiffness of the URM specimen decreased substantially during the initial displacement cycles while the CFRP-strengthened specimen showed a gradual decrease in stiffness till the ultimate displacement cycle. URM specimen reached its maximum capacity of 9.98 kN at 0.19% story drift whereas the CFRP-strengthened specimen reached its ultimate capacity of 47.09 kN at a drift ratio of 0.7. The CFRP confinement dramatically enhanced the lateral resistance of the URM structure by a factor of 4.72. This was achieved as a result of the proper anchorage of CFRP strips to the masonry walls, RC slab, and raft foundation. A parametric comparison of URM and CFRP-strengthened Masonry is presented in Table 2.

Table 2 URM and CFRP-Strengthened Masonry Specimens Parametric Comparison

Parameters	**Control Specimen**	**CFRP-Confined Specimen**	**Percent Increase due to CFRP Application**
Peak Resistance (kN)	9.98	47.09	372%
Drift at Peak resistance (%)	0.19	0.7	268%
Ultimate Displacement (mm)	10	12	20%

4 Practical Implementation

Based on the experimental findings, the adopted strengthening technique can be used to enhance the seismic performance of non-engineered rural area masonry structures that do not satisfy the local building code's seismic requirements without displacing their occupants and in a shorter period as compared to conventional strengthening techniques.

5 Conclusions

- The adopted CFRP strengthening configuration improved the URM structure's seismic performance significantly.
- The CFRP bonding technique improved the strength of the URM structure by 372%.
- The adopted technique also improved the ultimate displacement of the structure by 20%.
- The adopted anchorage technique proved to be effective in preventing the delamination of CFRP strips from masonry, RC slab, and foundation.

References

[1] M. Ahmed, S. Lodi, M. Rafi, and N. Alam, "Transforming Census Data in Pakistan into Spatial Database for Earthquake Loss Estimation Models," *Lisb. Sn*, 2012.
[2] M. Javed, "Seismic risk assessment of unreinforced brick masonry buildings system of Northern Pakistan," *Civ. Eng. Dep.*, 2009.
[3] D. Dizhur, R. P. Dhakal, J. Bothara, and J. M. Ingham, "Building typologies and failure modes observed in the 2015 Gorkha (Nepal) earthquake," *Bull. N. Z. Soc. Earthq. Eng.*, vol. 49, no. 2, pp. 211–232, 2016.
[4] M. Çelebi *et al.*, "Recorded motions of the 6 April 2009 Mw 6.3 L'Aquila, Italy, earthquake and implications for building structural damage: overview," *Earthq. Spectra*, vol. 26, no. 3, pp. 651–684, 2010.
[5] A. Ahmed and V. Kodur, "The experimental behavior of FRP-strengthened RC beams subjected to design fire exposure," *Eng. Struct.*, vol. 33, no. 7, pp. 2201–2211, 2011.
[6] E. Mustafaraj and Y. Yardim, "In-plane shear strengthening of unreinforced masonry walls using GFRP jacketing," *Period. Polytech. Civ. Eng.*, vol. 62, no. 2, pp. 330–336, 2018.
[7] H. Hernoune, B. Benabed, M. Alshugaa, R. Abousnina, and A. Guettala, "Strengthening of masonry walls with CFRP composite: experiments and numerical modeling," *Ép. Online*, no. 1, pp. 2–11, 2020.
[8] F. L. Moon, T. Yi, R. T. Leon, and L. F. Kahn, "Testing of a full-scale unreinforced masonry building following seismic strengthening," *J. Struct. Eng.*, vol. 133, no. 9, pp. 1215–1226, 2007.