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Experimental Studies on Strengthening of Masonry Walls with GFRP Subjected to Lateral Loads

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Abstract: Masonry building remains as one of the best known and the widest spread constructions. Recent earthquakes have shown the vulnerability of such Unreinforced Masonry (URM) walls, which leads to an urgent need in developing effective and affordable retrofitting techniques to upgrade the strength of the existing masonry walls to resist lateral forces. The paper presents the experimental studies conducted to investigate the effects and efficiency of utilizing surface mounted Glass Fiber Reinforced Polymer (GFRP) strips to strengthen the Unreinforced Masonry (URM) walls with openings against lateral loads. URM walls were tested against lateral loads for different percentages of openings retrofitted and strengthened by GFRP strips horizontally, vertically and diagonally around the opening. The ultimate lateral load carrying capacity of the URM walls and their crack patterns were studied. The GFRP strengthening system can increase the ductility, load carrying capacity of URM walls and thereby improving the performance of walls mainly for lateral loads.
Keywords: Unreinforced Masonry, GFRP, Strengthened Masonry Walls, Lateral Loads.

1. Introduction:

Masonry, which can be stressed relatively high in compression, is not a suitable material for carrying bending and shear. URM buildings which found seismically deficient, as assessed by today's normal engineering procedures have survived earthquakes with or without minor damages. When subjected to earthquakes, at times the resulting damage is severe and often collapses the buildings. Load bearing walls of building are usually built with openings for doors and windows which weaken the walls to resist lateral forces during an earthquake. Hence, it is mandatory to strengthen these URM walls with new retrofitting techniques which must be an effective methods and means to carry lateral loads.

The weak load carrying capacity of masonry structures against lateral loads are due to the results of their non-homogenous, brittle material properties and geometry. Masonry walls consist of uniformly dispersed units connected by a regular array of bed and head mortar joints. The mortar joints contribute to the material non-linearity which significantly influences the lateral load carrying capacity of the masonry structure. The nonlinear characteristics of the mortar joints initially result from the nonlinear deformation characteristics of the joints due to in-plane plane failure modes because of lateral loads on URM walls. The in-plane failures are [Figure 1] (a) Shear failure, (b) Sliding failure, and (c) Rocking failure or Slip of the joints.

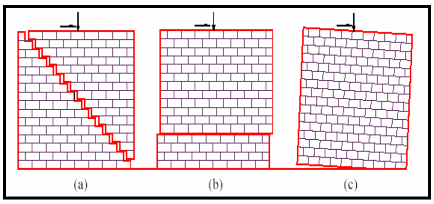


Figure 1 – In-Plane Failure modes

Extensive studies on strengthening of URM walls were using GFRP. The externally applied fiber reinforced polymers are effective in increasing the load carrying capacity of URM walls that are subjected to flexural loads. GFRP materials were selected due to its high-strength, low modulus of elasticity and high tensile strength[4]. The mid span deflection response was characterized by separating into two phases**.** The first phase is non linear and represents the stiffness contribution of the masonry materials and second phase is linear and represents the stiffness contribution from the fiber reinforcement [3].

The present paper describes the lateral load carrying capacity of URM walls with openings strengthened with GFRP strips. The GFRP strips were near surface mounted on both sides of the wall, which is done by embedding GFRP strips in pre-cut grooves along the mortar joints and then plastering the walls.

2. Experimental Study:

2.1 Test Setup

The dimension of the wall was 1000 mm long x 1000 mm high x 230 mm wide (11 courses high and 4 and a half bricks in each course). The wall was constructed on top of a concrete foundation beam to simulate the house footing effects. The Walls were fixed at the bottom and lateral in-plane loads were applied upon by hand operated hydraulic jack of 500kN capacity. The load by the hydraulic jack was applied at the top most brick (39mm from top surface of brick wall). Dial gauges for measuring deflections were fixed at the top [δ_2] (39mm from top surface of brick) and one-third points [δ_2 (500mm from top surface of brick) to measure corresponding deflections.

2.2 Properties of Bricks:

Brick are the main constituent in masonry. The nominal size of brick is 230 x 115 x 77mm (Tamil Nadu, India – Average of 3000Bricks).

Bricks were tested and following parameters were observed. (Average of 25Bricks)

Water absorption	= 7.89% (By weight)
Young's Modulus	= 22430 N/mm^2
Compressive Strength	= 7.92 N/mm^2
Tensile Strength	= 1.88 N/mm^2

2.3 Properties of Mortar Joints

Mortar has an important role to play and to bind the units together into one mass, in order that masonry may effectively perform its functions. It is the most important ingredient as its characteristics have a strong influence on the strength and durability of masonry assemblage. It is also that the ingredient is most liable to site problems related to mixing and batching. The properties of mortar joints usually dominate the behaviour of URM structures. Proper modeling and studies on the behaviour of these mortar joints is critical. The properties of these mortar joints were to be determined not only on the material properties of mortar units but also on the interaction between bricks and mortar joints.

The mortar proportion varies from 1:8 to 1:3 improving strength and workability with increase in proportion of cement. Cement mortar of thickness 10 mm was adopted throughout the construction of wall along bed and head joints.

Mix Proportion	= 1:4(H1)
Young's Modulus	= 7400N/mm^2
Poisson's ratio	= 0.3
Compressive Strength	= 6.7 N/mm^2
Tensile Strength	= 1.15 N/mm^2(Head Joint)
	1.15 N/mm^2(Bed Joint)

2.4 Properties of GFRP Laminates

GFRP composite laminates are assemblies of layers of fibrous composite materials which can be joined to provide required engineering properties, including in-plane stiffness, bending stiffness, strength, and coefficient of thermal expansion. Epoxy resins are used to connect the layers of laminates. Externally bonded GFRP reinforcement is an efficient technique that can be applied for a wide range of structures and materials. Claims have been made that up to 5% glass fiber by volume has been used successfully in sand-cement mortar without balling.[4]

Tensile Strength = $2.69 N/mm^2$
Young's Modulus = $83.1 N/mm^2$

2.5 Experimental program:

Unreinforced brick masonry 13 walls each of size 1000 mm x 1000 mm x 230 mm were built using cement mortar of ratio 1:4 with different percentage of opening(by Area).

Figure 2 – Experimental Setup of URM Wall

Various specimens are listed in Table 1.

Table 1 – Description of URM Wall Test Specimens

S.No	URM Wall Specimen	Description
1	A	Control Specimen
2	B	URM Wall - 15% Opening (Opening Size 387 x 387 mm)
3	B1	URM Wall - 15% Opening - Wall Strengthened with GFRP Laminates – Horizontally
4	B2	URM Wall - 15% Opening - Wall Strengthened with GFRP Laminates – Vertically
5	B3	URM Wall - 15% Opening - Wall Strengthened with GFRP Laminates – Diagonally
6	C	URM Wall - 20% Opening (Opening Size 447 x 447 mm)
7	C1	URM Wall - 20% Opening - Wall Strengthened with GFRP Laminates – Horizontally
8	C2	URM Wall - 20% Opening - Wall Strengthened with GFRP Laminates – Vertically
9	C3	URM Wall - 20% Opening - Wall Strengthened with GFRP Laminates – Diagonally
10	D	URM Wall - 25% Opening (Opening Size 500 x 500 mm)
11	D1	URM Wall - 25% Opening - Wall Strengthened with GFRP Laminates – Horizontally
12	D2	URM Wall - 25% Opening - Wall Strengthened with GFRP Laminates – Vertically
13	D3	URM Wall - 25% Opening - Wall Strengthened with GFRP Laminates – Diagonally

4. Results

4.1 Experimental Results

The URM wall specimens were loaded up to failure. The maximum lateral loads and corresponding deflections of the respective specimen for different percentage of openings are detailed in Table 2. The specimens tested showed brittle failure controlled by the loss of bond between mortar and the masonry units with split cracking following the head and bed joints. The specimens also showed sliding failure along the bed joints.

The increase in the horizontal displacement leads to crack widening and failure of the wall because of bond failure between mortar and masonry units ultimately.

Figure 3 -Cracks of URM Walls

Figure 4 -Displacements of Bricks

Table 2 – Tabulation of Maximum Lateral Load carrying capacity and maximum deflections

S.No	URM Wall Specimen	Max. Lateral Load (kN)	Deflections (mm)	S.No	URM Wall Specimen	Max. Lateral Load (kN)	Deflections (mm)
1	A	18	14.83	8	C2	6.9	7.21
2	B	4.56	9.35	9	C3	8.05	7.23
3	B1	6.20	9.31	10	D	2	5.52
4	B2	8.75	9.25	11	D1	2.01	4.89
5	B3	9.5	8.23	12	D2	2.35	5.65
6	C	3.55	7.5	13	D3	2.89	5.56
7	C1	6.01	7.78				

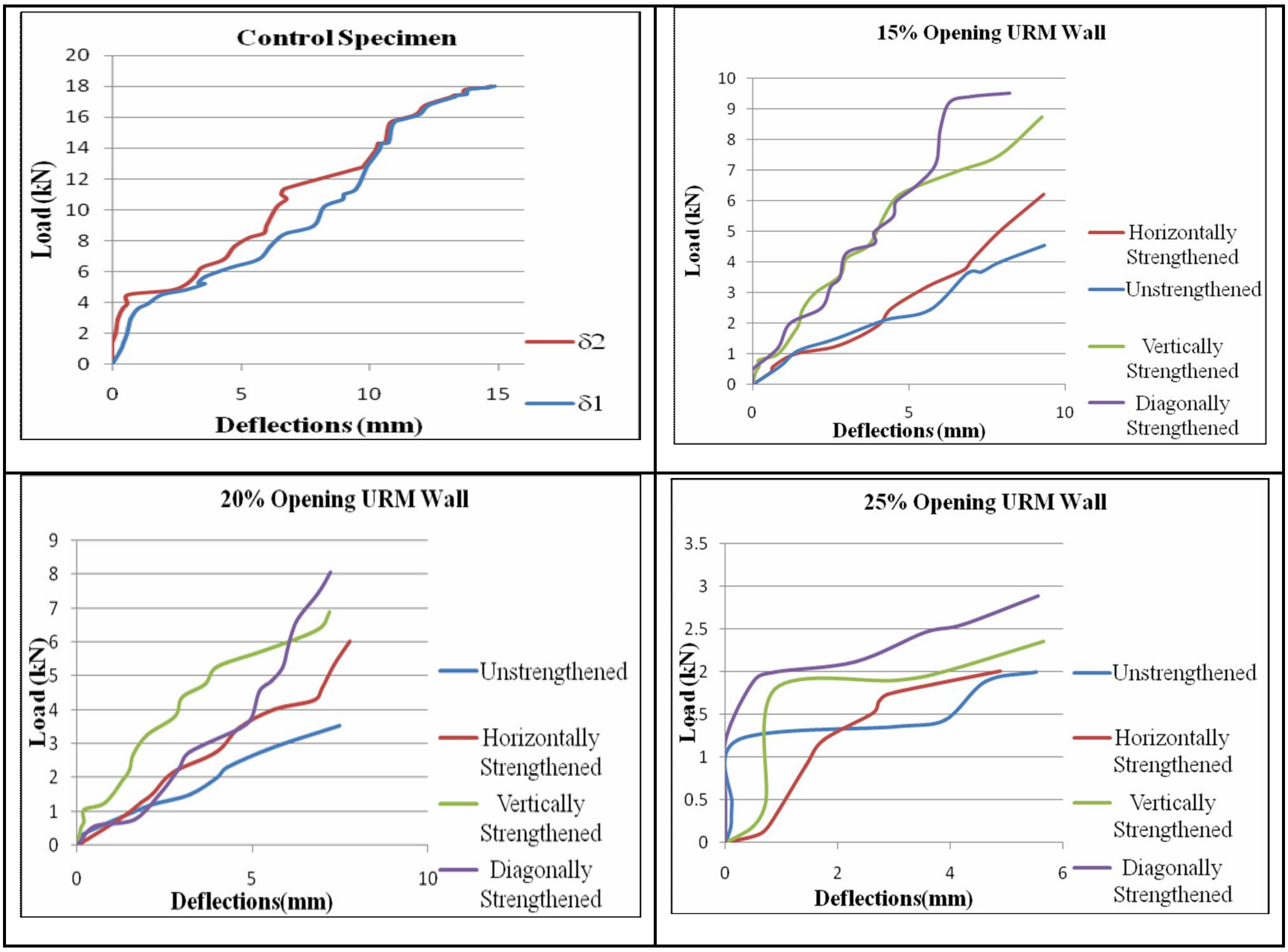
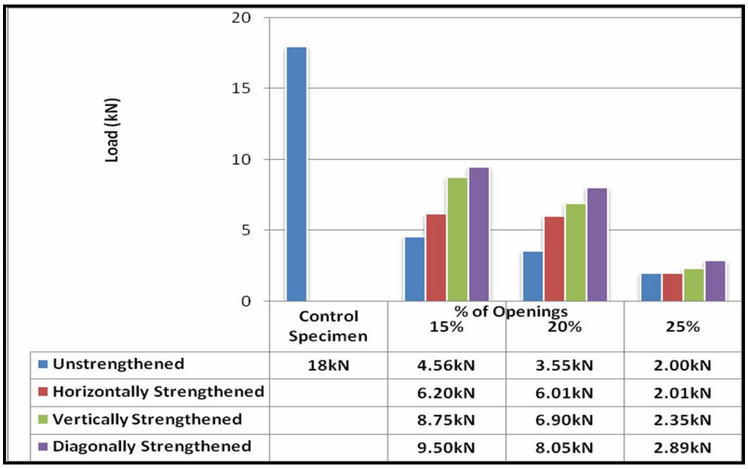


Figure 4 – Load Vs Deflection of Various Specimens



	Control Specimen	15%	20%	25%
Unstrengthened	18kN	4.56kN	3.55kN	2.00kN
Horizontally Strengthened		6.20kN	6.01kN	2.01kN
Vertically Strengthened		8.75kN	6.90kN	2.35kN
Diagonally Strengthened		9.50kN	8.05kN	2.89kN

Figure 6 – Comparison of Max. Load Carrying Capacity of Specimen

4.2 Discussion:

The GFRP strengthening system was much simpler than using steel reinforcement and can be applied to walls that have been already damaged without the need of repairing cracked mortar joints.

Framing of opening with GFRP reduces the negative effects of openings on the lateral load carrying capacity thereby improving the performance of the walls and increasing the ductility of the wall compared to the unstrengthened walls. Strengthened walls exhibit much better ductility and are much more stable after failure reducing the risk of partial or total collapse. It can be concluded from the experimental study that GFRP composites are efficient in improving the overall performance of URM walls.

i. The URM wall significantly carried higher loads when strengthened diagonally compared to other means of strengthening.
ii. The plain wall with no opening significantly carried much higher loads in order of two times when compared to 15% opening and order of six times when compared to 25% opening.
iii. The lateral load carrying capacity decrease with increase in percentage of opening, with no significant changes in deflection.
iv. In case of 15% opening the load carrying capacity was increased from 4.56kN when it was unstrengthened to 9.5kN when it was diagonally strengthened, increasing the load carrying capacity by 52%.
v. In case of 20% opening the load carrying capacity was increased from 3.55kN when it was unstrengthened to 8.05kN when it was diagonally strengthened, increasing the load carrying capacity by 56%.
vi. In case of 25% opening the load carrying capacity was increased from 2kN when it was unstrengthened to 2.89kN when it was diagonally strengthened, increasing the load carrying capacity by 31%.

5. Conclusion

i. The GFRP strengthening system can increase the ductility, load carrying capacity of URM walls and thereby improving the performance of walls mainly for lateral loads.
ii. Diagonal GFRP Strengthening is more effective in load carrying capacity and minimizing the deflections compared to horizontal and vertical GFRP strengthening.
iii. The GFRP composites much more stable after failure, potentially reducing the risk of partial or total collapse.
iv. The proposed model is capable of capturing some basic mechanisms that characterize the behaviour of the masonry walls, namely tensile cracking failure of the mortar joints, shear sliding of the mortar joints as well as fracturing of the masonry units due to high friction in joints.
v. Seismic retrofitting of unreinforced masonry walls with GFRP proved to be an effective and reliable strengthening alternative.
vi. GFRP strengthening technique is effective in significantly increasing the lateral load carrying capacity and stiffness of URM walls there by reducing the lateral deflections.
vii. With increase in percentage of opening the load carrying capacity of the wall decreased with change or no change in deflection irrespective of the methods of strengthening.
viii. The load carrying capacity of the walls strengthened with diagonal bars (B3, C3) carried lateral loads higher than that of the unstrengthened wall by 51% and 56%, respectively.

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