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Procedia Engineering 54 (2013) 428 – 439
Procedia Engineering
www.elsevier.com/locate/procedia

The 2nd International Conference on Rehabilitation and Maintenance in Civil Engineering

GFRP Strengthening and Applications of Unreinforced Masonry wall (UMW)

S.Saileysh Sivaraja[a*],T.S.Thandavamoorthy[b], S.Vijayakumar[c], S.Mosesaranganathan[a], P.T.Rathnasheela[d] and A.K.Dasarathy[e]

[a]*Department of Civil Engineering, Dr MGR Educational & Research Institute University, Chennai, India*
[b]*Department of Civil Engineering cum Research Centre, Adhiparasakthi EngineeringCollege, Tamil Nadu, India*
[c]*AATA-OM Saravanabava Developers, Velachery, Chennai, India.*
[d]*Department of Civil Engineering, Anna University, Chennai, India*
.[e]*Department of Civil Engineering, Dr MGR University, Chennai, India*

Abstract

Glass Fiber-Reinforced Polymer (GFRP) composites are more and more used in the building trade for the set up of reinforcing and strengthening applications devices. As known, GFRP composites offer higher strength and Young modulus than traditional steel devices. The majority of these buildings were built before any provisions for earthquake loadings were established. The failures and damages reported in recent earthquakes attest to the need for efficient strengthening procedures. The effectiveness of increasing the shear strength of brick masonry coating with epoxy-bonding by Glass Fiber-Reinforced Polymer (GFRP) overlays to the exterior surfaces was evaluated. Out-of-plane failures are common in unreinforced masonry wall (UMW) constructed in seismic regions. This paper deals with the experimental characterization of the mechanical tensile and shear bond behavior of Glass Fiber-Reinforced Polymer (GFRP) sheets externally glued on masonry wall, in terms of load capacity and stress distribution along the bonded length. A combined experimental program was conducted to study the out-of-plane shear behavior of (i) Burned Clay Brick Masonry Walls and (ii) Strengthened with Glass Fiber Reinforced Polymer (GFRP) over the Burned Clay Brick Masonry Walls surface.

Keywords: unreinforced masonry wall (UMW); GFRP; out-of-plane; specimen; scaled bricks; epoxy.

* Corresponding author.
E-mail address: sivaraja05@gmail.com

doi:10.1016/j.proeng.2013.03.038

1. Introduction

Unreinforced masonry is one of the most popularly used construction materials in the world. It is also unfortunately, the most vulnerable to earthquakes loading. This combined with the widespread use of masonry in earthquake prone regions of the world has resulted in a large number of casualties due to the collapse of this type of structures. This is a serious problem for the societies. Apparently, its solution is straight forward: retrofitting the existing structures. Several methods have been proposed to improve strength, ductility and energy dissipation capacity of masonry structures. However, in developing countries, retrofitting masonry structures should be economic, the retrofitting material accessible, and the workmanship locally available. Considering these points, a new retrofitting technique has been proposed based on the use of GFRP which is commonly utilized for packing and is available all over the world. To evaluate the beneficial effects of the proposed GFRP retrofitting method, out-of-plane tests were carried out on masonry walls with and without retrofitting.

One of the main problems connected with preserving and maintenance of historic buildings and existing dwellings is the need for strengthening and retrofitting of the masonry parts of the structures. For design purposes masonry is considered as homogeneous material but in reality it shows very complex heterogeneous characteristics. Aggressive environment and some natural calamities can cause extensive damage to unreinforced masonry (URM) structures. Many older masonry structures currently in use were designed and constructed with little or no consideration of these aggressive factors. In addition, recent changes in seismic requirements have left many URM buildings in need of strengthening In many cases, these natural effects were not considered in ancient time. Since the advent of modern reinforced masonry construction, URM structures have been viewed as a significant liability when considering strengthening. Borri and Corradi (2004) studied vaults and arches, based on which it has been concluded that the use of FRP inhibits the out-of- plane mechanisms of masonry walls and permits the transfer of stresses to the wall parallel to the direction of seismic action and increases the ductility of the masonry structures. Shrive (2004) GFRP applied on both sides of wall, and found that the flexural strength of walls were increased up to 32 times self weight of wall. The deformation resisting capacity is 14 times that permitted. Ghobarah and Mandooh Galal (2004) strengthened walls which sustained lateral load of the order of five times that of un-strengthened URM walls. The proposed strengthened systems increased the ductility of the walls by approximately 10 fold compared to the un-strengthened walls. A variety of masonry structures are constructed in India using different types of blocks, bricks, stones etc. and different types of mortar such as mud mortar, lime mortar and cement mortar. Though the properties of the constituents of masonry are well known, the information regarding the dynamic behavior of masonry is scant. Masonry walls are known to suffer maximum damage during earthquakes. While such a masonry structure is subjected to lateral inertial loads during an earthquake, the walls develop shear and flexural stresses. The strength of masonry under these conditions often depends on the bond between brick and mortar. A masonry wall can also undergo in-plane shear stresses if the gravity forces are in the plane of the wall. Shear failure in the form of diagonal cracks is observed due to this. The brittle nature of masonry leads to sudden and catastrophic collapse of walls when the wall experiences out-of-plane failure. In this paper the failure pattern of simple masonry elements without any earthquake resistant features and masonry elements with GFRP wrappings subjected to base shock vibrations for out-plane-loadings was studied. The GFRP wrapping is alternative modern technique and is used to strengthen the masonry elements. The GFRP wrapped masonry elements will be compared with conventional masonry elements in terms of first crack load, energy absorption, velocity of impact, cumulative energy, Peak Base Acceleration (PBA), and Peak Response Acceleration (PRA).

2. Dynamics of Masonry Buildings

There are three kinds of building behaviour as described below.

1. Quasi-static behaviour (displacement sensitive): The fundamental frequency of the building is below the range of ground motion frequencies. Under such conditions the mass of the building does not experience sufficient acceleration and thus remains relatively stationary. The behaviour is illustrated in Fig.1(a).

2. Resonant behaviour (velocity sensitive): The fundamental frequency and other higher frequencies of building are within the range of frequencies of ground motions. This behaviour illustrated in Fig. 1(b).

3. Inertial behaviour (acceleration sensitive): The fundamental frequency is above the range of ground frequencies leading to a rigid structure; (Fig. 1(c)). Here the entire structure responds as a rigid body and thus the acceleration experienced by the structure is equal to the ground acceleration. This behaviour is illustrated in Fig. 1(c).

3. Construction of Scaled Masonry Elements without GFRP

The original size of masonry elements considered is 3m x 3m x 0.30m and 3mx3.75mx0.30m. The 1/3 scaled size of masonry elements are 1m x 1m x 0.092m and 1mx1.25mx0.092m. The scaled masonry elements are constructed by using mortar ratio 1(cement):5(sand) as given in Fig. (2). The low strength mortar is used to offer a low flexural strength in the element which is required to limit the lateral load. First two courses of the masonry elements were constructed using rich C.M. mix 1:2 to avoid base shear cracks. Types of load tests are out-of-plane loading. Slenderness ratio is varied by varying height in another two set of elements same tests are followed. The two masonry elements were constructed for each type of testing. Two elements, in size 1m x 1m x 0.092m (one without wrapping and another one with GFRP wrapping) are subjected to out of plane loadings. Two elements, in size 1m x 1.25m x 0.092m (one without wrapping and another one with GFRP wrapping) are subjected to out of plane loadings.

4. Upgrading of the Masonry Elements with GFRP Wrap

The application of the wrap material is a simple and rapid operation. The surface was roughened by grinding, cleaned with high air pressure. It was then coated with a thin layer of two component epoxies, Sikadur-30 and hy-551 mixed in a ratio of 3:1 by weight. First coat of epoxy resin was applied and cured. Second coat of epoxy resin was applied and GFRP wraps were applied on the elements. They were applied by hand and pressed with a roller as shown in Figs. 3 and 4. Again third coat of epoxy resin was applied and cured.

5. Experiment Details

A simple version of shaking table is a shock table shown in Figs. 5a and b which is a horizontal table over which masonry elements can be built and subjected to base shock vibration. The shock table can be used to simulate the effects of ground motion by subjecting it to series of base impacts. Using a pendulum impact device it is possible to control the magnitude of base shock vibration. This helps in reproducing the masonry elements failure modes. Also, after each shock it is possible to study the progress of failure in masonry elements. The walls were instrumented with data acquisition systems.

6. Base Impact Test

The base impact test is very much useful system, used to simulate the effects of lateral ground motion in the building. In this experiment pendulum impact device is used for base shock. The input energy is controlled by varying height of release (h). The pendulums weight of 50 kg is used for testing. The chord length for the release of pendulum is varied from 30 cm to 75cm. The weight of the hammer is calculated as 10% of the total weight of the shock table and the masonry element, ie., un-reinforced masonry elements and GFRP wrapped masonry elements. The above two types of masonry elements are subjected to base shock vibrations. (Out-of-plane loading shown in Fig. 8). The amount of energy imparted during each shockis calculated by knowing the velocity (v) of the impact and mass of the pendulum (m) ass hown in Table 1 to Table 4, $E= (1/2)\ mv^2$, where, $v= (2gh)^{1/2}$, g-acceleration (m/sec^2).Vibrations of the base impacts were recorded for unreinforced masonry elements and GFRP reinforced masonry elements by using data acquisition systems. The test setup is shown in Fig. 7a and data acquisition systems are shown in Figs. 7b and c. The failure patterns of the both elements were noted.

7. Vibrations

Vibrations of the base impacts were recorded for unreinforced masonry elements and GFRP reinforced masonry elements by using data acquisition system. The records of the data acquisition system are given in Fig. 10

8. Summary and Concluding Remarks

In this investigation an attempt has been made to simulate the out-of-plane failure of masonry elements as those observed in the event of a strong earthquake. Shock Table tests of 1/3rd scale masonry elements were carried out to simulate such failure. The peak accelerations were recorded for each shock. The scaled bricks were prepared by proper cutting of locally available bricks using special tools. The amount of energy imparted during each shock has been calculated by knowing the velocity of impact and mass of the pendulum. Two elements of size 1m x 1m x 0.092 m of two numbers and 1m x 1.25m x0.092m of two numbers have been tested for out-of -plane loading. It can be seen that the total energy imparted to the element size of 1m x 1m x 0.092 m of without GFRP is 380.60 Nm before its total collapse and the element size of 1m x 1m x 0.092 m with GFRP was capable of withstanding a total energy of 6722.76 Nm before its total collapse, which is about 17.66 times greater than the without GFRP masonry elements. Similarly the total energy imparted to the element size of 1m x 1.25m x 0.092 m of without GFRP is 326.26 Nm before its total collapse and the element size of 1m x 1.25 m x 0.092 m with GFRP was capable of withstanding a total energy of 7826.72 Nm before its total collapse, which is about 23.99 times greater than the without GFRP masonry elements. This reveals that the failure modes seem to suggest that the simulation of the impact test for earthquake is reasonable.

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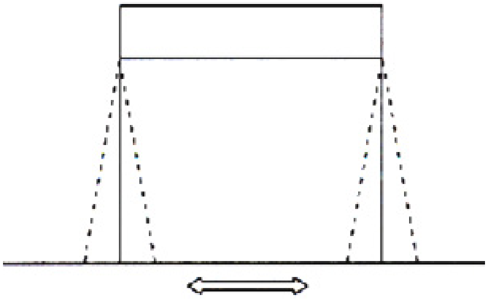
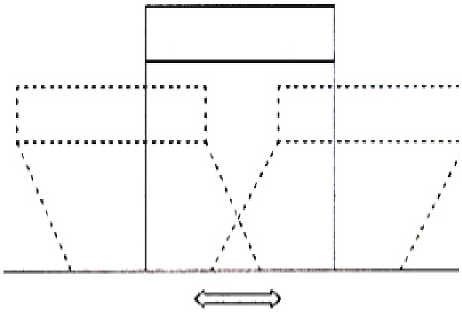
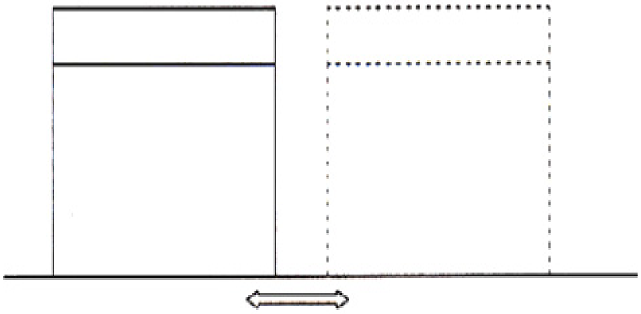
Figures and Tables



(a) Quasi-static



(b) resonant



(c) Inertial

Figure. 1 (a,b,c). Dynamic response of building during earthquakes

Figure.2. Masonry wall

Figure3. Wrapping work

Figure.4. GFRP wrapped wall

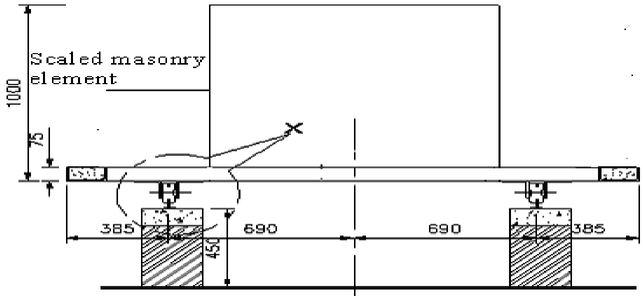


Figure 5a. Details of shock table – out of plane loading

Figure 5b. Shock table

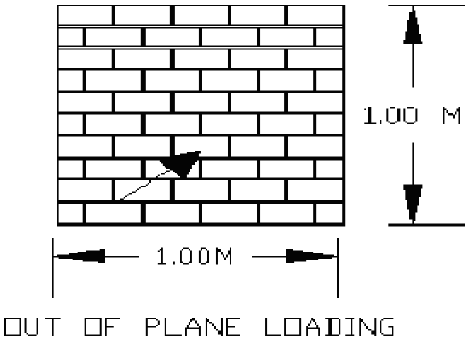


Figure 6. Out of plane loading

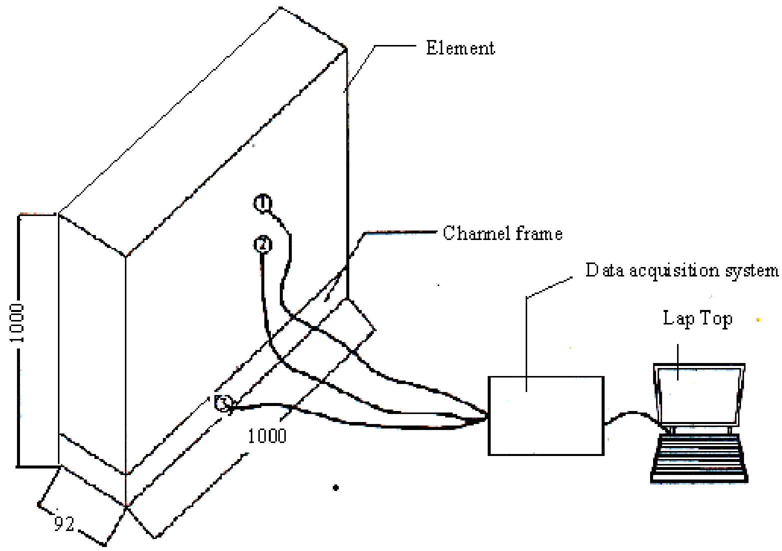


Figure7a.Test setup

Figure 7b. Data acquisition system

Figure 7c. Piezo electric accelerometer

Figure 8. Out of plane loading

Figure 9a. Wall collapsed

Figure 9b. Delamination and worn out

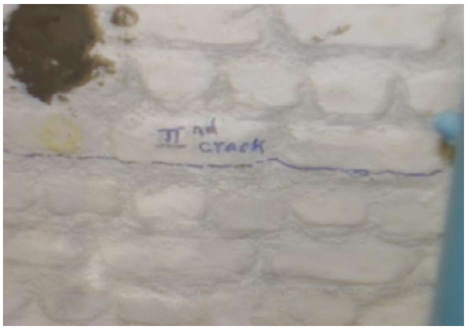
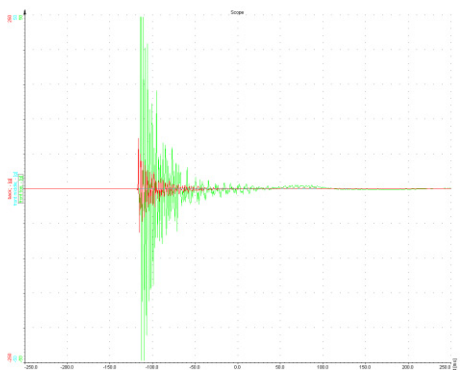


Figure 9c. Second crack

(a) 1mx1mx0.092mwithout GFRP wrap1st



(b) 1 mx1 mx0.092 m with GFRP wrap

Figure 10 . Vibration records

Table 1 Details of base impact test conducted on masonry element size 1.00mx1.00mx0.092m without GFRP under out of plane loading

Impact No	**Velocity of Impact (m/s)**	**Cumulative energy (Nm)**	**PBA m/s^2**	**PRM (T) m/s^2**	**PRM (M) m/s^2**	**Remarks**
1	0.88	19.36	30.34	34.25	#	Mass of pendulum is 50 kg. Pendulum released from 30cm. No visible cracks.
11	1.33	121.66	42.77	33.55	15.20	Pendulum released from 45cm.Horizontal crack (I) developed at 40 cm from bottom on east side
12	1.33	165.88	52.77	28.28	22.16	Horizontal crack (II) developed at 39 cm from bottom on west side.
14	0.88	204.60	31.67	16.34	#	Pendulum released from 30cm.Horizontalcrack (III) developed at 40 cm from bottom on south side.
16	1.77	302.28	*	*	*	Pendulum released from 60cm.Horizontal crack (IV) developed at 18 cm from bottom on west side.
17	1.77	**380.60**	*	*	*	Element collapsed (Fig. 9a)

- No vibration record

* - Accelerometers removed

PBA - Peak Base Acceleration (m/s^2)

PRM (T) - Peak Response Acceleration at Top of Model (m/s^2)

PRM (M) - Peak Response Acceleration at Middle of Model (m/s^2)

Table 2 Details of base impact test conducted on masonry element size 1.00mx1.00mx0.092m with GFRP ubnder out-of-plane loading

Impact No	**Velocity of Impact (m/s)**	**Cumulative Energy (Nm)**	**PBA m/s^2**	**PRM (T) m/s^2**	**PRM (M) m/s^2**	**Remarks**
1	0.88	19.36	31.80	28.89	24.49	Mass of pendulum is 50 kg. Pendulum released from 30cm. No visible cracks
8	1.33	179.74	70.07	49.45	0.00	Pendulum released from 45cm. No visible cracks
	1.33	1019.92	114.49	49.45	48.40	Pendulum released from 45cm. De-lamination occurred at 80 cm from bottom on west side (Fig. 9b).
51	1.33	2081.20	108.19	49.45	48.40	Pendulum released from 45cm. De-lamination occurred at 20 cm from bottom on east side.
117	1.33	4999.72	142.33	40.43	48.40	Pendulum released from 45cm. Base cracks start.
130	1.77	5782.92	*	*	*	Pendulum released from 60cm. Element tilted due to weakened base.
142	1.77	**6722.76**	*	*	*	Due to base failure, element fell down.

- No vibration record

* - Accelerometers removed

PBA - Peak Base Acceleration (m/s^2)

PRM (T) - Peak Response Acceleration at Top of Model (m/s^2)

PRM (M) - Peak Response Acceleration at Middle of Model (m/s^2)

Table 3. Details of base impact test conducted on masonry element size1.00mx1.25mx0.092m without GFRP under out of plane loading

Impact No	**Velocity of Impact (m/s)**	**Cumulative Energy (Nm)**	**PBA m/s^2**	**PRM (T) m/s^2**	**PRM (M) m/s^2**	**Remarks**
1	0.88	19.36	31.79	9.63	7.65	Mass of pendulum is 50 kg. Pendulum released from 30cm. No visible cracks.
8	0.88	154.88	101.77	31.42	13.56	Pendulum released from 30cm.Horizontal crack (I) developed at 54 cm from bottom on east side.
9	0.88	174.24	80.97	32.63	13.25	Pendulum released from 30cm.Horizontal crack (II) developed at 60 cm from bottom on west side (Fig. 9c).
11	1.33	237.82	*	*	*	Pendulum released from 45cm.Horizontal crack developed around the element and base crack developed.
12	1.33	282.04	*	*	*	Element cracks widened.
13	1.33	**326.26**	*	*	*	Element collapsed

* - Accelerometers removed

PBA - Peak Base Acceleration (m/s^2)

PRM (T) - Peak Response Acceleration at Top of Model (m/s^2)

PRM (M) - Peak Response Acceleration at Middle of Model (m/s^2)

Table 4. Details of base impact test conducted on masonry element size 1.00mx1.25mx0.092m with GFRP under out of plane loading

Impact No	Velocity of Impact (m/s)	Cumulative Energy (Nm)	PBA m/s^2	PRM (T) m/s^2	PRM (M) m/s	Remarks
1	0.88	19.36	142.16	49.45	#	Mass of pendulum is 50 kg. Pendulum released from 30cm. No visible cracks.
11	1.33	237.82	146.86	49.45	#	Pendulum released from 45cm. No visible cracks
17	1.33	503.14	140.11	49.45	#	Delamination occurred at 46 cm from bottom on east side.
28	1.33	989.56	158.16	49.45	#	Delamination occurred at 17th impact developed.
35	1.33	1299.10	177.32	49.45	#	Delamination occurred at 1m from bottom on west side.
133	1.77	6416.96	246.31	49.45	#	More delamination occurred on east side.
140	1.77	6965.20	*	*	*	Element cement mortar fallen from north side. Base crack developed
151	1.77	**7826.72**	*	*	*	Due to base failure, element fell down.

#	-No vibration record
*	-Accelerometers removed
PBA	- Peak Base Acceleration (m/s^2)
PRM (T)	- Peak Response Acceleration at Top of Model (m/s^2)
PRM (M)	- Peak Response Acceleration at Middle of Model (m/s^2)