STRENGTHENING LOAD BEARING MASONRY WALL PANELS USING LOCALLY AVAILABLE MATERIALS

Priyadarshani S.T.A.
Department of Civil and Environmental Engineering, Faculty of Engineering,
University of Ruhuna, Hapugala, Wackwella, Galle
stpanoma@gmail.com

Sanjeewa W.S.M.G.
Department of Civil and Environmental Engineering, Faculty of Engineering,
University of Ruhuna, Hapugala, Wackwella, Galle
sudhira@cee.ruh.ac.lk

De Silva Sudhira
Department of Civil and Environmental Engineering, Faculty of Engineering,
University of Ruhuna, Hapugala, Wackwella, Galle
subashi@cee.ruh.ac.lk

De Silva Subashi
Department of Civil and Environmental Engineering, Faculty of Engineering,
University of Ruhuna, Hapugala, Wackwella, Galle
wsumudumendis@gmail.com

W.S.Wasundara Mendis
Department of Civil and Environmental Engineering, Faculty of Engineering,
University of Ruhuna, Hapugala, Wackwella, Galle

Abstract

In past decades, many thousands of Un-Reinforced Masonry (URM) buildings were fully or partially damaged due to natural disasters such as earthquakes, tsunamis and storm surges, floods, cyclones and landslides. Therefore a considerable amount of studies and researches have been conducted to identify the response of the masonry buildings during natural disasters and to introduce effective and economical retrofitting techniques. In this research work an attempt has been made to investigate feasible and economical retrofitting methods suitable for countries like Sri Lanka.

The laboratory test was carried out to investigate the effectivenes of selected three retrofitted methods against the shear failure of URMs. The test setup was implemented according to ASTM-E-519-02 standard guidelines which are available to investigate the in-plane diogonal shear strength. Test wallets would represent load bearing brick masonry. In order to verify the suitability of the proposed methods, masonry walls, with and without retrofit were subjected to diagonal shear test. Wallets were strengthened using bamboo strips, steel bracing and Poly-Propelene (PP) bands. Axial load and the diagonal deflection were measured during the experiment. From test results, it could be seen that pp-band mesh and bamboo strip mesh could improve in-plane shear capacity and ductiliy of structures together with no brittle collapsing while steel bracing could only improve shear capacity, but lost its stability with brittle failure.

Keywords: *bamboo strips, Poly-Propelene bands (PP-bands), steel bracing, clay brick wall, retrofitting*

1. Introduction

URM buildings can be found in every state because of its durability, fire resistance, its economy, use of local available materials, ability to insulate the variation in temperature, ease of construction and alteration after construction, need of less skilled labor and engineer and also eco-friendly and its architectural character. Therefore, masonry construction is the most popular and suitable for rural housing purposes. In addition, unreinforced masonry has often been the construction material of schools, city halls, central business district buildings, factories, and apartment buildings. However, these unreinforced masonry buildings have a higher probability of failing under natural disasters. In past decades, a thousands of unreinforced masonry buildings were fully or partially damaged due to natural disasters such as earthquakes, tsunamis and storm surges, floods, cyclones and landslides. As a result numerous human lives have been lost (Macabuag, 2008).

Brick masonry fails mainly due to shear failure, bending failure and sliding failure. This research work mainly focuses on shear failure among the three failure types. Previous research studies have identified the shear failure by three mechanisms: Bed joint sliding, Step joint sliding, Diagonal shear cracking. This shear failure of brick masonry is more common during earthquakes. Therefore seismic resistant techniques are essential to minimize the damage. In previous studies, many advanced techniques have been found to control large scale seismic forces and they are used in most vulnerable countries like Japan, New Zealand, China and Iran. The prevailing seismic retrofitting solutions include addition of steel reinforcements, reinforced surface plastering, grouted near surface mounted steel bar insertion (D'Ayala D, 2011).

When consider the situation in Sri Lanka, floods, strong winds, landslides and ground shakings have frequently occurred in different regions. In addition, a large amount of masonry buildings were damaged due to Tsunami in 2004 (Maheshwari, 2005). Recently, there were some ground shakings in Ampara, Hambanthota, Badulla and Matara. As a result, masonry buildings have damaged since there have not been any control technique had been applied. Most of the existing masonry buildings in Sri Lanka have not been designed to resist seismic forces. Consequently, they can usually collapse during earthquakes. However, if the service life of the building can be improved in a way that it will give sufficient clues for occupant to escape then the deaths and life damages can be minimized.

This research study was carried out to improve the strength of domestic buildings in Sri Lanka by selected convenient retrofitting techniques using low cost materials. Bamboo, PP bands and steel bars were used as materials for implementation of selected retrofitting techniques to strengthen the URM walls against in-plane forces induced by natural disasters (Sathiparan et al.,, 2008).

2. Methodology

In this research work, few retrofitting solutions were optimized using low cost materials. Laboratory test was carried out to investigate the effectiveness of bamboo mesh reinforcement, steel diagonal bracings and PP-band mesh reinforcement as retrofitting methods for URM walls for improving the in-plane performance for a better in-plane resistance. The test setup was implemented according to ASTM-E-519-02 standard guidelines which are available to investigate the in plane diagonal shear strength.

2.1. Specimen preparation

Test wallets representing load bearing brick masonry were cast. Each wallet was 225 mm thick, 570 mm wide and 570 mm high and consisted 7 layers of burned clay bricks (Figure 1). The mortar joint thickness was 10 mm and its material mixing ratios of cement: sand were 1:6 and 1:5 for mortar joints and plaster layer, respectively. The English bond type was used in construction of wallet. The dimensions of the used brick were 215 mm x 100 mm x 75mm and the other important properties are listed in Table 1.

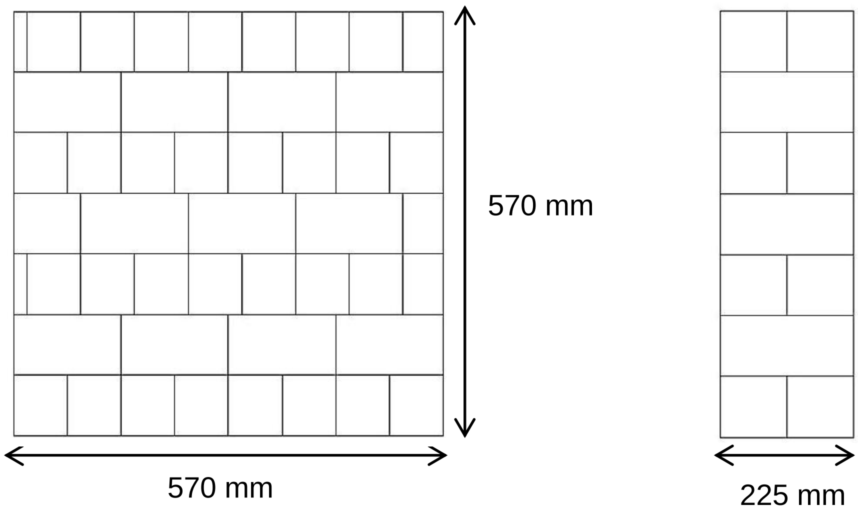


Figure 1: Wall geometry and masonry bond pattern

Table 1: Properties of bricks and mortar

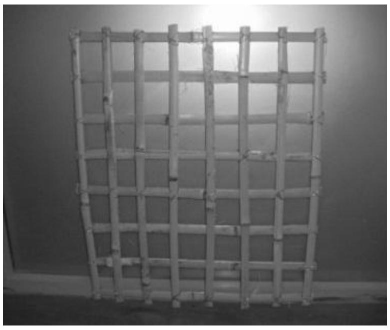
Material	Property	Value
Burned clay brick	*Mean compression strength (N/ mm^2)*	*3.1*
	Dry density (g/cm^3)	*> 2.5*
	Water absorption (percent by mass)	*> 15*
1:5 mortar (Plaster)	*Mean compressive strength (N/mm^2)*	*8.5*
1:6 mortar (Mortar bed joints)	*Mean compressive strength (N/mm^2)*	*7.9*

The test walls were cast on timber planks and a thin polythene sheet was layed on timber plank to produce no connection between the wall and timber plank. The wallets were kept for about 28 days to achieve the full strength.

2.2. Strengthening methods

2.2.1. Strengthening of wall with bamboo strips

Two meshes were prepared with 20 mm wide bamboo strips and the strips were placed in 50 mm intervals (Figure 2(a)). The strips of mesh were connected at their intersecting points using binding wires. After construction of clay brick wall, this bamboo meshes were installed on both side of the wall. The meshes were easily attached to the wall surface using steel wire inserted through straws kept at pre-requisite places within the wall during its construction as shown in Figure 2(b). Then the both sides of the wall were plastered.



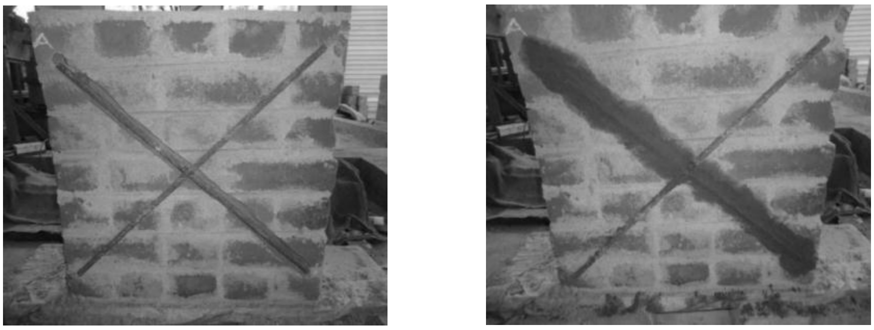
(a)

(b) ***(b)***

Figure 2: Installation of bamboo mesh on the wall surface

2.2.2. Strengthening of wall using steel bars

In this method, diagonally arranged two twisted steel bars, with12 mm diameter, were installed on both sides of the wall by inserting them into grooves made on wall surface (Figure 3). The grooves were cut along the diagonal directions and then cleaned and dust was removed using an air blower. The cutting grooves were 16 mm deep and 20 mm wide. An approximately 10 mm thick grout bed was injected into grooves before placing the steel bars. Then twisted steel bars were inserted into the grooves (Figure 3(a)) with the help of the fingers and finally grooves with steel bars were filled with grout (Figure 3(b) and after that, the specimen was plastered using 1:5 cement :sand mortar.



(a) *(b)*

Figure 3: Installation of steel bracings on the wall surface

2.2.3. Strengthening of wall using Poly-Propylene bands (PP-bands)

PP- bands are available in worldwide for packing and anyone can get these bands easily at a lower cost. The PP-bands were arranged in a mesh pattern by placing them at an interval of 50 mm and connected at their intersecting points by gluing (Figure 4). Then the wall to be retrofitted was wrapped by this mesh and two ends were connected tightly (Figure 4). Finally, the wall was plastered after applying a thin cement grout layer. This cement grout was applied to create a better bond between PP-band mesh and the plaster.

Figure 4: Use of PP-bands for retrofitting of wall

2.3. Laboratory experiments

The Figure 5 shows the schematic diagram of experimental set up including test specimen used in the laboratory to observe the shear failure as well as the effectiveness of selected retrofitting methods against shear failure. The four types of wall panels were tested.

1. Normal clay brick wall without plastering (as reference specimen)
2. Clay brick wall strengthened using external vertical and horizontal bamboo strip mesh
3. Clay brick wall strengthened by near surface mounting of diagonal steel bars

4. Clay brick wall strengthened using external vertical and horizontal PP-bands

Two steel plates were used to bolt the specimens to the loading frame or hydraulic actuator. A plaster of paris layer of 5 mm thickness was applied on both steel plates and one of steel plates was fitted to hydraulic actuator and other one was placed on a support below the actuaor. Then, the specimen was carefully installated into actuater and the specimen was leveled using a plumb bob. The media of plaster of paris between wallet and steel plate is crucial to carry out a better load tranformation to the wallett.

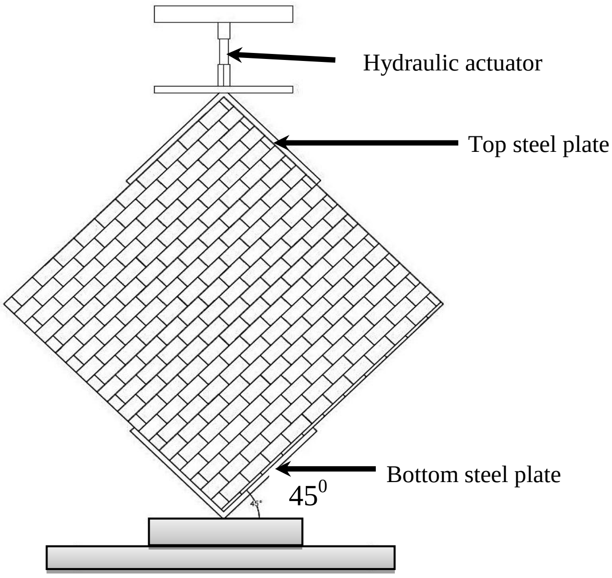
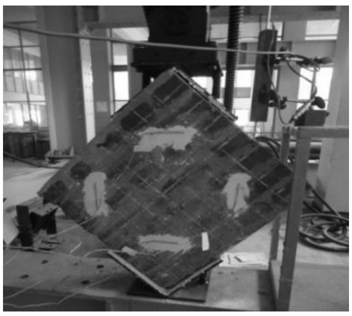
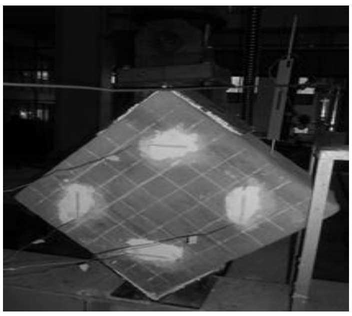


Figure 5: Schematic of specimen in the test setup

The specimens were subjected to diagonal shear test under displacement control loading rate of 0.1 mm/s. The load was applied centrally by a 200 kN hydraulic jack and linear variable displacement transducer (LVDT) was set at wall to measure the deflection of the specimen. Figure 6 shows the non-retrofitted specimen and retrofitted specimen with external bamboo mesh at the test set up before loading.



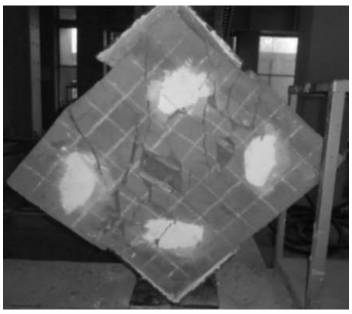


(a) *(b)*

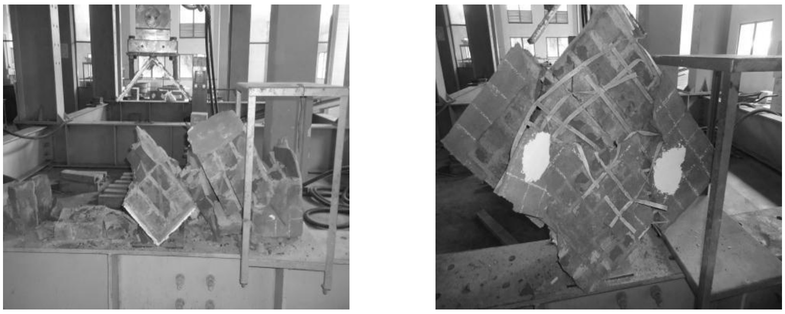
Figure 6: Test set up of (a) non-retrofitted and (b) fully-retrofitted specimens

3. Results and Discussion

Full scaled models were used in this experimental program in order to investigate the static behavior of masonry walls. To evaluate the beneficial effects of proposed external bamboo mesh retrofitting method, steel bracing method and external PP-bands retrofitting method the diagonal compressive test was carried out on masonry wallets with and without retrofitting. Figure 7 shows the failure patterns of non-retrofitted (Figure 7 (a) and retrofitted specimens (Figures (b), (c) and (d)). Non-retrofitted specimen displayed brittle failure and collapse where the specimens retrofitted with external bamboo mesh and PP-bands continued to maintain the structural integrity after initial cracking of the masonry plaster.



(a) *(b)*



(c) *(d)*

Figure 7: (a) Non-retrofitted retrofitted specimen (b) with bamboo mesh (c) with steel bracing and (d) with PP-bands at the end of the test

Figure 8(a) shows the initial crack pattern of non-retrofitted masonry wallet. It proves that, cracks were initiated through mortar joints between two rows of bricks and did not harm the bricks. Figure 8(b) shows the crack initiation on plastering layer of retrofitted wallet with bamboo mesh. It could be observed that, cracks were propagated in wider area on plastering layer of retrofitted wallet instead of concentration the few major cracks into specific area as in control non-retrofitted specimen. During loading, the mesh acted to maintain panel integrity allowing the load to be redistributed throughout the mesh and masonry (shown by the formation of further cracks upon continued loading) and the bricks have not been damaged at failure and bricks have been separated due to the failure of mortar joints. A similar behavior was showed by the wall retrofitted with PP-bands (Figure 8(d)) too. In case of using steel bars, few cracks were appeared near to the loading point and propagated to center area. And at the end, a brittle failure could be observed and a considerable amount of bricks have been damaged at the failure (Figure 7(c)).

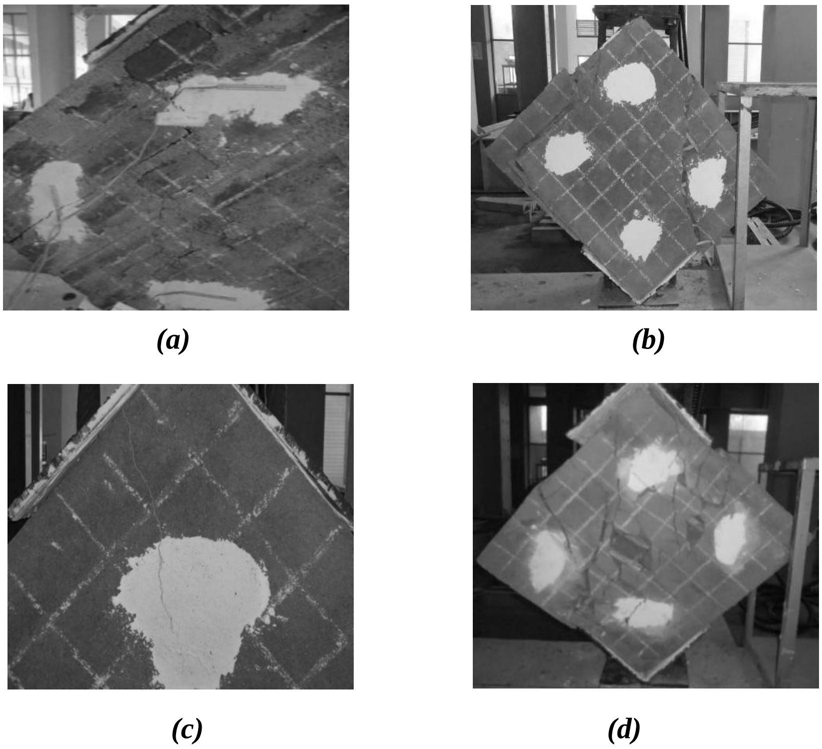


Figure 8: Crack formation on (a) non-retrofitted wallet and on plastering layer of fully retrofitted wallet (b) with bamboo mesh (c) steel bracing and (d) PP-bands

The diagonal compressive strength variations with vertical deformation for the non-retrofitted and retrofitted specimens are shown in Figure 9. The influence of bamboo mesh and PP-bands on strengthen could be observed even before the first cracking (Figure 9). The critical crack formation (i.e., peak strength) of non-retrofitted specimen was at 23.73 kN and 80.4% of peak strength was remained. However, there was no regaining of strength again and no residual strength left after two or three cracks appeared in non-retrofitted wallet. In retrofitted wallets with bamboo strips and PP-bands, initial cracking was followed by a sharp drop with remaining of 55.2% and 29.86% of its peak strength, respectively. After it, subsequent strength drop was quickly regained due to the elastic behavior of bamboo and PP-bands. At the end of the test regarding to both of these two techniques, the plaster layer was almost lost but the retrofitted wallets did not lose its stability.

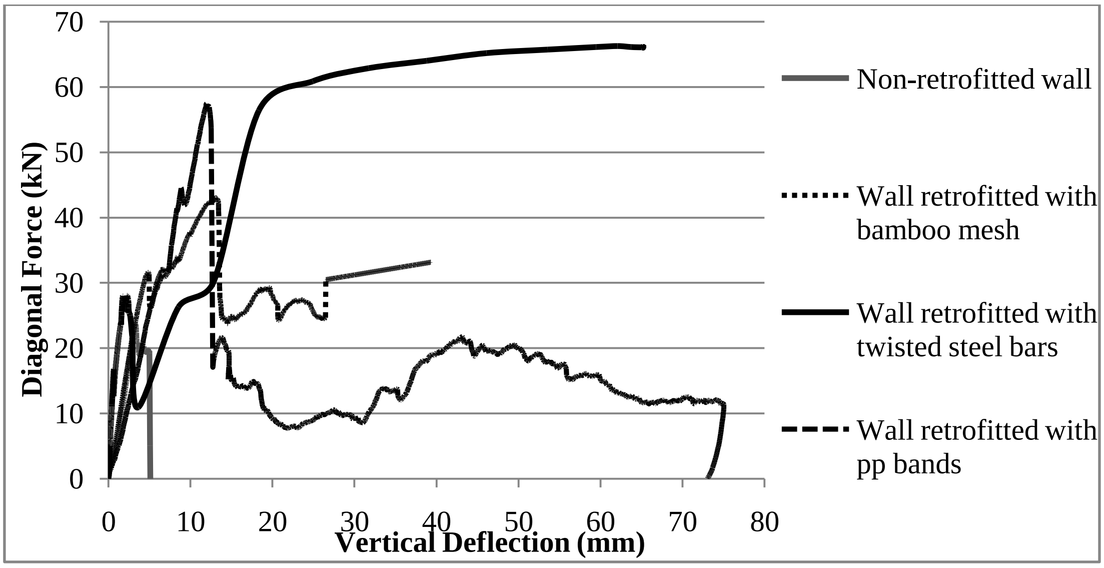


Figure 9: Load vs. vertical deformation for different test specimens

When consider the test wallet retrofitted with twisted steel bars (Figure 9) it could be observed that the wallet resisted a considerably higher load than the walls retrofitted with bamboo strips and PP-bands. But there was no any strength regain after cracking and only a very few amount of cracks could be observed at peak load. The highest peak load could be observed in the wallet due to the high compressive and tensile strength of inserted steel bars.

Figure 10 shows the load variation with the time. The wall retrofitted with bamboo strips has failed after a considerable time period. Even after around 6.5 minutes from load application the bricks did not separate from wallet (Figure 7 (b)). The control wall failed after 50 seconds and walls retrofitted with steel bars and PP-bands failed after 4.7 minutes and 3.8 minutes, respectively.

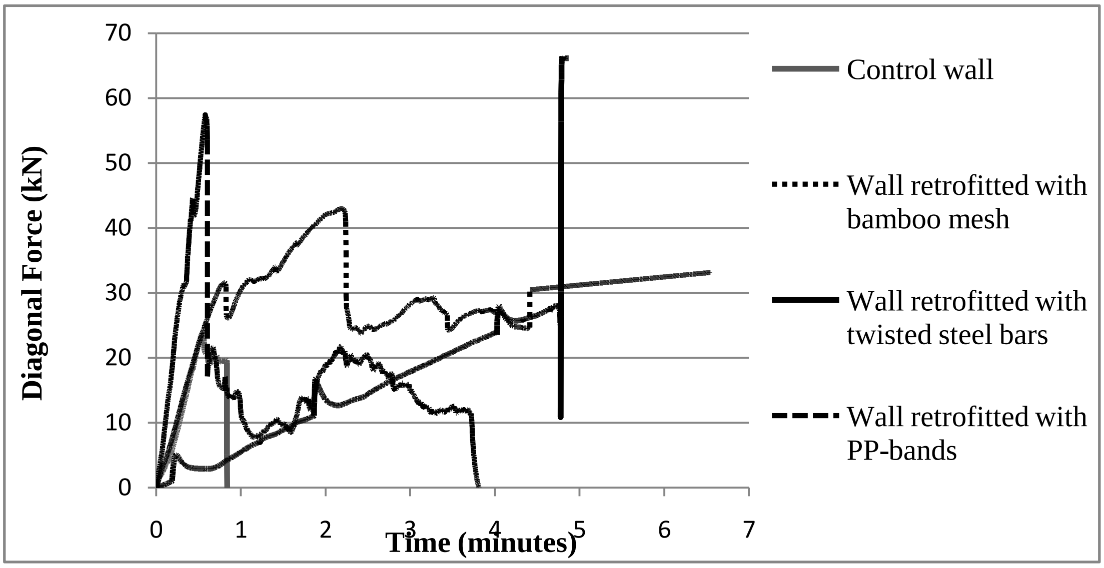


Figure 10: Variation of applied load with the time for different test specimens

The wall retrofitted with bamboo strips and PP-bands lasted for considerable time before fail even after cracking (Table 2) due to the regaining of strength. But the wall strengthened with steel bars was collapsed as soon as cracks were initiated. However the peak load has increased for all three methods.

Table 2: Time difference between peak load and point of failure and the percentage increment of peak load

Test specimen	*Increment of Peak load with respect to control wall (%)*	*Time difference from peak load to point of failure (min)*
Control wall	~	*0.3*
Wall retrofitted with bamboo strips	*81.22*	*4.8*
Wall retrofitted with steel bars	*179.92*	*≈ 0*
Wall retrofitted with PP-bands	*141.93*	*3.2*

However, when using bamboo for retrofitting purpose, it is important to apply a chemical preservative treatment to resist insect attack for long life period of reinforcement. For this purpose, a typical preservative can be prepared to be mixed in the tank in the following proportions: Copper sulphate 4%, Sodium Dichromate 4%, Boric Acid 2% and Water 90%. The materials should preferably be freshly harvested, but dry ones can also be treated. Bamboo battens and mats are to be first soaked in water for at least 24 hours and then dried. They are then to be immersed completely in the chemical preservative solution for 24 hours. Then they are to be dried in an open shaded space for 1-2 days and then in sunlight for 3-4 days. It is also important to consider durability of steel bracings due to its corrosion by various factors. Using galvanized steel is one solution for this problem.

4. Conclusions

This paper presented the methodology of installation three retrofitting techniques :external bamboo mesh (vertical and horizontal) reinforcement, external diagonal twisted steel bracings and external PP-band mesh (vertical and horizontal) reinforcement that can be used to strengthen the URM walls. A series of diagonal compressive tests were carried out using non-retrofitted and retrofitted wallets.

Non-retrofitted wall and the wall with steel bars showed a sudden catastrophic failure and were unable to maintain further load. This brittle failure is that poses significant danger to building occupants during earthquakes. Both the walls retrofitted with external bamboo mesh and PP-band mesh allowed specimens to maintain, regained and redistributed load after initial failure of the masonry and prevented the brittle failure by allowing occupants to identify the damage level and especially to escape from buildings. Both bamboo-mesh and PP-bands technologies may potentially be used to delay brittle collapse of URM structures under seismic loading due to its effective behavior as well as low cost, high availability and relative simplicity of the technique.

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