研　究　速　報

Experimental Study on Unburned Brick Masonry Wallettes Retrofitted by PP-Band Meshes

Navaratnarajah SATHIPARAN*, Paola MAYORCA**, Kourosh NASROLLAHZADEH NESHALI**,***, Ramesh GURAGAIN**** and Kimiro MEGURO*****

1. Introduction

Unreinforced masonry is one of the most popularly used construction materials in the world. It is also unfortunately, the most vulnerable during earthquakes. 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 capability 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 polypropylene band (PP-band) meshes. PP-band is commonly utilized for packing and it is available all over the world at a very low price.

In order to verify the suitability of the proposed retrofitting technique, an experimental program was designed and executed. A real scale model test makes possible to obtain data similar to real structures. However, it requires large size testing facilities and large amount research funds, so it is difficult to execute parametric tests by using full scaled models. Recently, structural tests of scaled models become well-known as the overall behavior of the system can be also understood from scaled model. In this experimental program 1/4 scale models was used to investigate the static behavior of masonry walls.

*Doctor Course Student, Institute of Industrial Science, The University of Tokyo
**Post-Doctoral Research Fellow, Institute of Industrial Science, The University of Tokyo
***Assistant Professor, Department of Civil Engineering, University of Tehran, Iran
****Master Course Student, Institute of Industrial Science, The University of Tokyo
*****Professor, International Center for Urban Safety Engineering, Institute of Industrial Science, The University of Tokyo

Diagonal compression tests and out-of-plane tests were carried out on masonry wallettes with and without retrofitting for unburned bricks to evaluate the beneficial effects of the proposed PP-band mesh retrofitting method. The test results are reported in this paper.

2. Axial tensile test of polypropylene bands

Preliminary testing of the PP-band was carried out to check its deformational properties and strength. To determine the modulus of elasticity and ultimate strain, 3 bands were tested under uniaxial tensile condition with constant rate deformation. The results are shown in Fig. 1. To calculate the stress in the band, its nominal cross section $15.5 \times 0.6\text{mm}^2$ was used. As the matter of fact, the band has a corrugated surface and therefore its thickness is not uniform. The stress-strain curve is fairly bilinear with an initial and residual modulus of elasticity of 3.2 GPa and 1.0 GPa, respectively. Considering its large deformation capacity, it is expected that the PP-band mesh will improve the structure ductility.

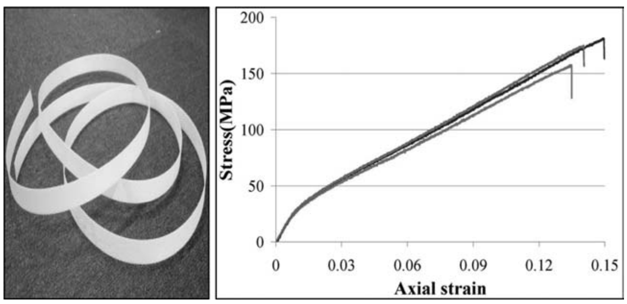

Fig. 1 (a) Polypropylene band used for retrofitting (left)
(b) Behavior of PP-band under tension (right)

3. Diagonal compression test

Test setup

To evaluate the beneficial effects of the proposed PP-band mesh reinforcement method, diagonal compression tests were carried out using masonry wallettes with and without retrofitting for unburned brick. The wallette dimensions were 292.5 × 290 × 50mm^3 and consisted of 7 brick rows of 3.5 brick each. The mortar joint thickness was 5mm for both cases. A Cement/Water ratio equal to 0.33 was used.

The pitch of meshes was 40mm. Four wire connectors were used to link the meshes attached from both surfaces of the wallette.

The specimens were named according to the following convention: **A-T. A** indicated the brick type, **U** in case unburned bricks are used. T shows with or without retrofitting by PP-band meshes: **NR**: Non-retrofitted, **RE**: Retrofitted by PP-band meshes whose borders were connected with epoxy and wire connectors, and **RO**: Retrofitted by just overlapping of PP-band meshes and wire connectors.

Specimens were tested 28 days after construction under displacement control. The loading rates were 0.3mm/min and 2mm/min for the non-retrofitted and retrofitted cases, respectively. The retrofitted wallettes were applied 50mm vertical displacement.

Direct compression, direct shear and bond tests were carried out to obtain masonry mechanical properties, as shown in Fig. 2.

Average measured mechanical properties of the masonry at the time of testing are shown below;

Compressive strength	: 4.45 MPa
Shear strength	: 0.0061 MPa
Bond strength	: 0.0056 MPa

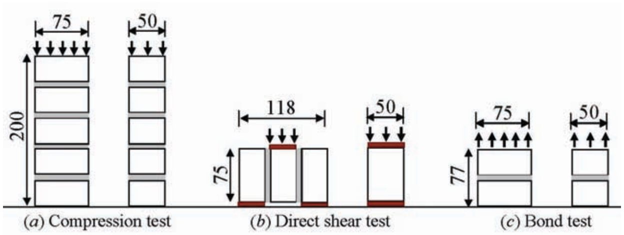

Fig. 2 Direct compression, direct shear and bond test specimens (all dimensions are in mm)

Behavior of retrofitted masonry

Initially retrofitting was done with PP-band meshes whose borders were connected with epoxy and wire connectors. Figure 3

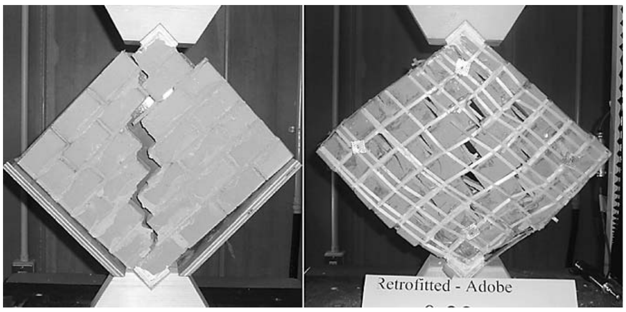

Fig. 3 Failure patterns of brick masonry wallettes with and without retrofitting by PP-band mesh

shows the non-retrofitted and retrofitted specimens at the end of the test, which corresponded to vertical deformations equal to 1mm and 50mm, respectively. In the non-retrofitted case, the specimens split in two pieces after the first diagonal crack occurred and no residual strength was left while in the retrofitted case, diagonal cracks appear progressively, each new crack followed by a strength drop. Although the PP-band mesh influence was not obvious before the first cracking, after it, each strength drop was quickly regained due to the PP-band mesh effect. Although at the end of the test, almost all the mortar joints were cracked, the retrofitted wallettes did not lose stability.

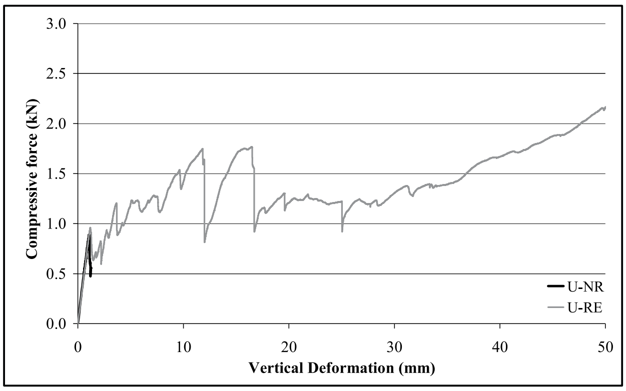

Fig. 4 Force vs. vertical deformation for masonry wall specimen with and without retrofitting

Figure 4 shows the diagonal compression strength variation with vertical deformation for the non-retrofitted and retrofitted unburned brick specimens. In the non-retrofitted case, the average initial strength was 0.88kN and there was no residual strength after the first crack. In the retrofitted case, although the initial cracking was followed by a sharp drop, at least 70 % of the peak strength remained. Subsequent drops were associated with new cracks like the one observed at the deformation of 2.2mm. After this, the strength was regained by readjusting and packing by PP-band mesh.

The final strength of the specimen was equal to 2.16kN much higher than initial strength of 0.88kN.

Effect of mesh edge connection

Figure 5 compares the diagonal compression behavior of retrofitted masonry wallettes with mesh whose borders were connected with epoxy and retrofitted by just overlapping of PP-band meshes.

Within the 3mm vertical deformation, similar performance was observed. However, because PP-band slip was observed along the specimen borders, compression strength of wallettes without epoxy was considerably reduced. It could also be observed that close to the connectors, there was almost no mesh slip, i.e., the connectors could effectively link two meshes. On the

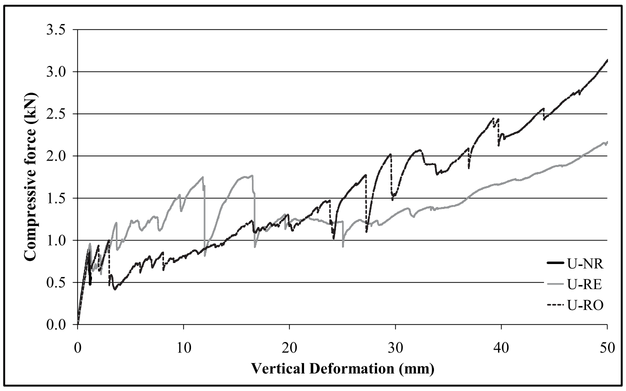

Fig. 5 Behavior of masonry wallettes with mesh edges fully or partially connected

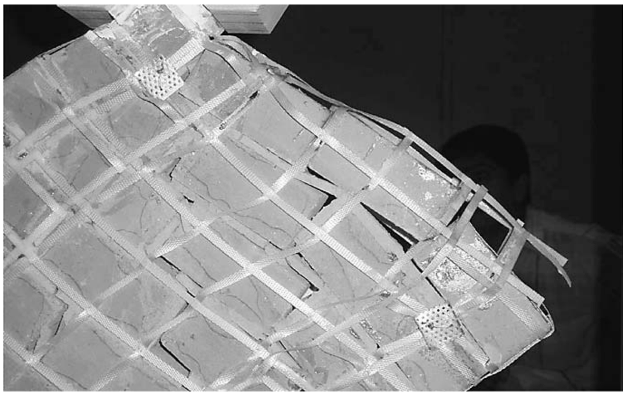

Fig. 6 Epoxy failure at top edge

other hand, the bands located far from the connectors experienced considerable slip. This was not observed in the meshes connected with epoxy.

In specimen with epoxy paste, failure epoxy paste failure at the top edge was observed at deformations of 12mm and 16.7mm as shown in Figure 6. Due to tension relaxation in the PP-band, PP-band effectiveness was not fully utilized in this specimen. But in the specimen without epoxy joints this behavior was not observed, because the wire connectors prevented the top and bottom side PP-band relaxation.

4. Out-of-plane test

Out-of-plane tests were carried out in order to investigate the PP-band mesh effectiveness in walls exhibiting arching action. The nominal dimensions of these walls were 475mm by 235mm; their thickness was 50mm. The PP-band mesh edges were partially connected, i.e. no epoxy was utilized. A total of 6 wire connectors were used to link the meshes installed on both sides of wallettes.

The Cement/Water ratio was 0.45, considering the stability of the specimens. Direct shear and bond tests were carried out to obtain masonry mechanical properties. Average measured mechanical properties of the masonry at the time of testing are

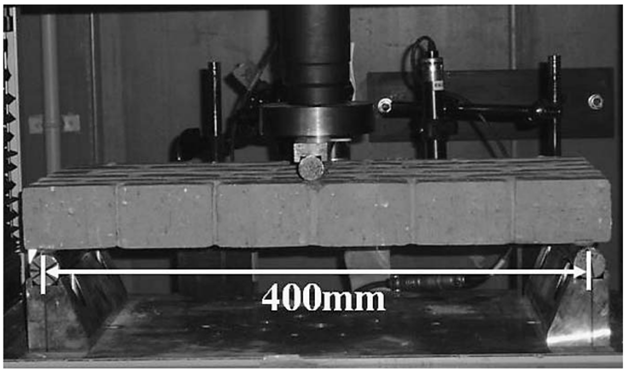

Fig. 7 Out-of-plane test setup

shown below;

Shear strength : 0.0072 MPa

Bond strength : 0.0080 MPa

The specimens were named according to the following convention: **M-T. M** is the type of brick, **B** in case burned bricks are used. **T** shows with or without retrofitting by PP-band meshes, **NR** for non-retrofitted and **RO** for retrofitting by overlapping of PP-band meshes and wire connectors.

Specimens were tested 28 days after construction under displacement control. The wallettes were simply supported with a 440mm span. Steel rods were used to support the wallettes at the two ends. The masonry wallettes were tested under a line load which was applied by a 20mm diameter steel rod at the wallette mid-span. The loading rate was 0.05mm/min for the non-retrofitted case. For the retrofitted case, it was 0.05mm/min for the first 30mm vertical deflection, and then it was increased to 2mm/min for the remaining test period. The retrofitted wallettes were applied up to 70mm vertical displacement. The test setup is shown in Fig. 7.

Figure 8 shows the non-retrofitted and retrofitted masonry wallettes at the end of the test, which corresponded to a mid-span net deformation equal to 1.2mm and 70.0mm, respectively. In the non-retrofitted case, the specimens split in two pieces just after the first crack occurred at mid-span, and no residual strength was left. In the retrofitted case, on the other hand, PP-band mesh influence was not observed before the first cracking. After it, strength was regained progressively due to the PP-band mesh effect.

Figure 9 shows the out-of-plane load variation in terms of mid-span net vertical deformation for the non-retrofitted and retrofitted wallettes. In the non-retrofitted case, the initial strength was 0.08 kN and there was some residual strength remaining for further small amount of deformation after the first crack. This behavior was observed due to interlocking between bricks and also the application of load under displacement control method.

After this, the strength was regained by readjusting and packing

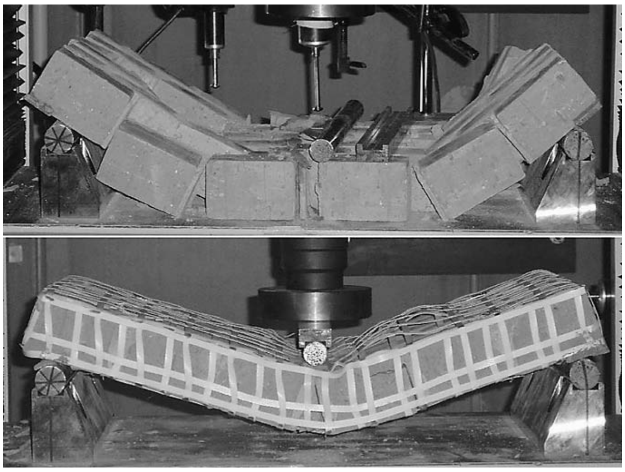

Fig. 8 Failure patterns of brick masonry wallettes with and without retrofitting by PP-band mesh

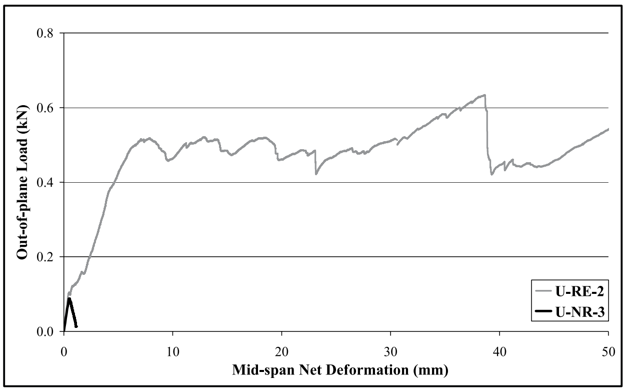

Fig. 9 Out-of-plane load variation in terms of net vertical deformation

by PP-band mesh. The final strength of the specimen was equal to 0.54kN much higher than initial strength of 0.08 kN.

5. Conclusion

This paper discusses the results of a series of diagonal compression tests and out-of-plane tests that were carried out using non-retrofitted and retrofitted wallettes by PP-band meshes. The diagonal compression tests showed that:

(1) In the retrofitted case, larger residual strength after the formation of the first diagonal shear cracks was observed. Furthermore, as deformation increased, the wallette achieved strength higher than the initial cracking strength.

(2) The retrofitted wallettes achieved 2.5 times larger strengths and 50 times larger deformations than the non-retrofitted wallettes did.

(3) Except small range of vertical deformations, similar performance between wallettes, retrofitted with mesh whose borders were connected with epoxy and by just overlapping of PP-band meshes, was observed

The out-of-plane tests showed that;

(1) In out-of-plane tests, the mesh effect was not observed before the wall cracked. After cracking, the mesh presence positively influenced the wallette behavior.

(2) The retrofitted wallettes achieved 7 times larger strengths and 60 times larger deformations than the non-retrofitted wallettes did.

Considering the overall performance of the specimens, it can be concluded that PP-band meshes can effectively increase the seismic capacity of masonry houses.

(Manuscript received, March 17, 2006)

References

1) Sathiparan, N., 2005. *Experimental Study of Retrofit of Masonry Buildings by PP-band Mesh,* M. Eng. Dissertation, University of Tokyo, Japan.

2) Mayorca, P., 2003. *Strengthening of Unreinforced Masonry Structures in Earthquake Prone Regions*, Ph.D. Dissertation, University of Tokyo, Japan.

3) Galati, N., Tumialan, J.G., Nanni, A., Tegola, A. La., *Influence of Arching Mechanism in Masonry Walls Strengthening with FRP Laminates*, University of Missouri, Rolla, Italy.

4) ASTM, E72, 1997. *Standard Test Methods of Conducting Strength Tests of Panels for Building Construction*, American Society for Testing and Materials, Philadelphia, Pa.