PARAMETRIC STUDY ON DIAGONAL SHEAR AND OUT OF PLANE BEHAVIOR OF MASONRY WALLETTES RETROFITTED BY PP-BAND MESH

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ABSTRACT :

Unreinforced masonry is one of the most popular construction materials in the world. It is also unfortunately, the most vulnerable against earthquakes. Damage to unreinforced masonry buildings has caused huge number of human casualties historically and during recent earthquakes in developing countries. It reveals that development of proper retrofitting technique for masonry buildings, especially existing buildings, is the main challenge to increase seismic safety in those countries. PP-band (Polypropylene band) Technology is a simple, economical and efficient retrofit method developed at International Centre for Urban Safety Engineering (Meguro Lab 2003[1]), Institute of Industrial Science, The University of Tokyo. This technology has been developed considering economical affordability and social acceptability together with technical feasibility for masonry buildings in earthquake prone regions. PP-bands are commonly utilized for packing and it is available at a very low price even in remote areas of the world. In order to verify the suitability of the proposed retrofitting technique, an experimental program was designed and executed. From test results, it could be seen that PP-band mesh retrofitting could improve the overall stability and ductility of the structure.

KEYWORDS: unreinforced masonry, retrofit, polypropylene band, diagonal shear test, residual strength, PP-band mesh retrofit

1. INTRODUCTION

A real scale model test makes possible to obtain data similar to real structures [2]. 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, ¼ scale models was used to investigate the static behavior of masonry walls.

To evaluate the beneficial effects of the proposed PP-band mesh retrofitting method, diagonal shear tests and out-of-plane tests were carried out using masonry wallettes with and without retrofitting. In addition to them, efficiency of different mesh-pitch and effect of looseness in attachment were also examined by diagonal shear tests. 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 uni-axial tensile test as shown in Figure 1 (left). The test was carried out under displacement control method. The results are shown in Figure 2 (right). To calculate the stress in the band, its nominal cross section 15.5×0.6mm^2 was used. As the matter of fact, the band has a corrugated surface and therefore its thickness is not uniform.

All of the bands exhibited a large deformation capacity, with more than 13% axial strain. The stress-strain curve is fairly bilinear with an initial and residual modulus of elasticity of 3.2 GPa and 1.0 GPa, respectively. Given its large deformation capacity, it is expected that it will contribute to improve the structure ductility.

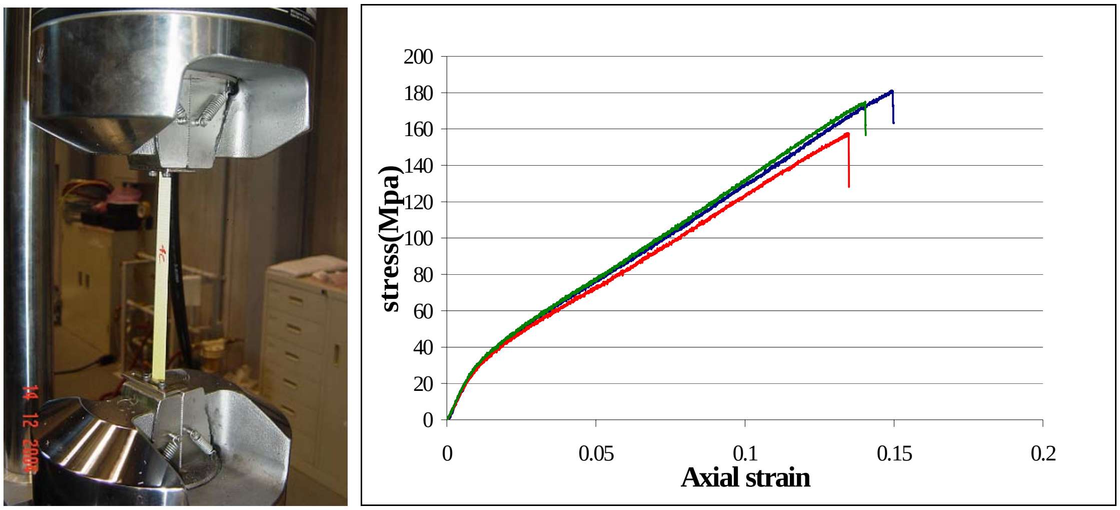

Figure 1 Tensile test setup (left) behavior of PP-band under tension (right)

3. DIAGONAL SHEAR TEST

To evaluate the beneficial effects of proposed PP-band mesh retrofitting method, diagonal compression tests were carried out on masonry wallettes with and without retrofitting for both burned and unburned units. The wallette dimensions were 275×275×50 mm^3 and consisted of 7 bricks row of 3.5 bricks each. The mortar joint thickness was 5mm for both cases. Mortar joint material mixing ratio as follows;

- For burned brick model
  Water:Cement:Sand:Lime = 1.00:0.14:2.80:1.11
- For unburned brick model
  Water:Cement:Sand:Lime = 1.00:0.33:2.80:0.92

The specimens were named according to the following convention: **A-T-L-S** in which **A** is masonry unit, **B**: Burned or **U**: Unburned; **T** is retrofitted condition, **NR**: Non-retrofitted, **RE**: Retrofitted by PP-band meshes; **L** is PP-band mesh pitch in mm; and **S** is surface condition, **X**: no surface finishing applied or **P**: surface finishing applied.

Specimens were tested 28 days after construction under displacement control. The loading rate was 0.3mm/min for first 10mm and 2mm/min for remaining loading. The retrofitted wallettes were applied 50mm vertical displacement. Average measured mechanical properties of the masonry at the time of testing are shown in Table 1. Direct compression, direct shear and bond tests were carried out to obtain these properties.

Table 1: Mechanical properties of masonry

	Burned Brick	Unburned brick
Compressive strength (MPa)	21.78	4.45
Shear strength (MPa)	0.075	0.006
Bond strength (MPa)	0.055	0.006

Specimens used in these tests were shown in Figure 2.

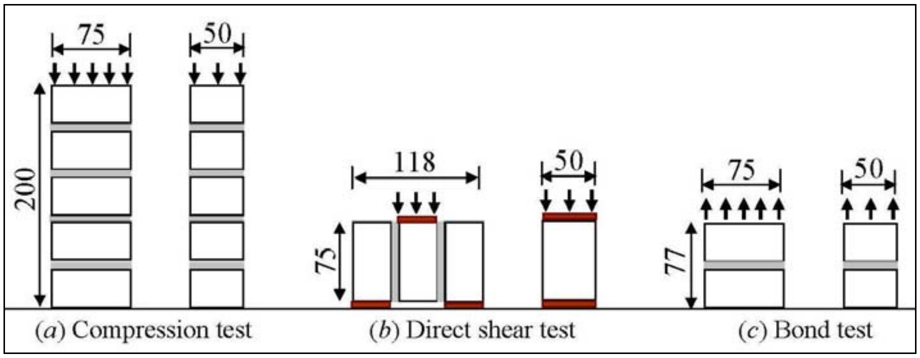

Figure 2 Layout of specimens used for direct compression, direct shear and bond test (unit:mm)

3.1. Behavior of burned brick specimens

Figure 3 shows the non-retrofitted and retrofitted specimens at the end of the test, which corresponded to vertical deformations equal to 0.71mm 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. In the retrofitted case, on the other hand, diagonal cracks appear progressively, each new crack followed by a strength drop. Although the PP-band mesh influence was not observed 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.

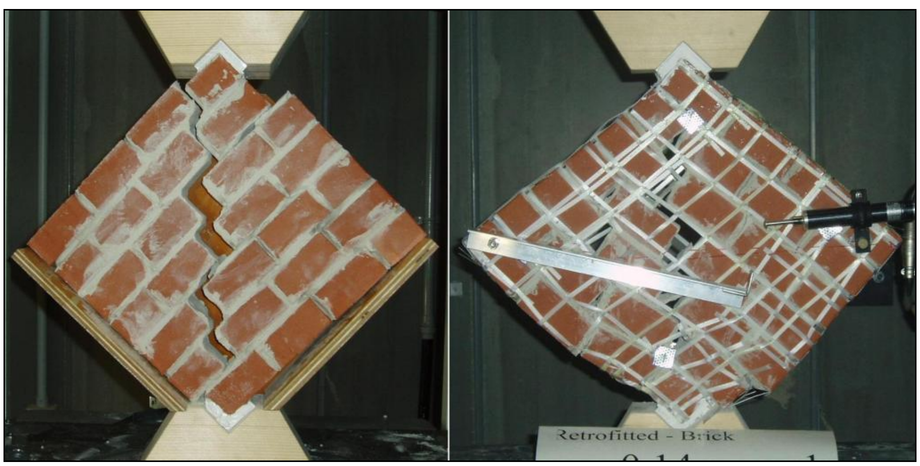

Figure 3 Failure patterns of brick masonry wallettes with retrofitting (left) without retrofitting (right)

Figure 4 shows the diagonal compression strength variation with vertical deformation for the non-retrofitted and retrofitted specimens. In the non-retrofitted case, the average initial strength was 1.5kN and there was no residual strength after the first crack. However, in the retrofitted case, although the initial cracking was followed by a sharp drop, at least 50% of the peak strength remained. Subsequent drops were associated with new cracks like the one observed at the deformation of 4mm. After this, the strength was regained by readjusting and packing by PP-band mesh. When the strength exceeded 3.0kN individual PP-bands started to fail. However, this did not reduce considerably strength of the specimen, because stresses redistributed to other PP-bands. The specimen quickly recovered its strength. The final strength of the specimen was equal to 3.0kN relatively higher than initial strength of 1.5kN.

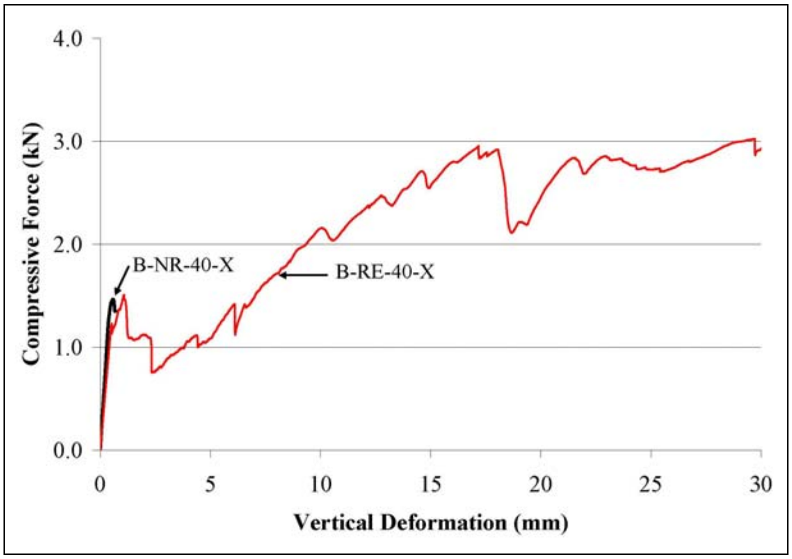

Figure 4 Force vs. vertical deformation for burned brick masonry wallette

3.2 Behavior of unburned brick (adobe) specimens

Figure 5 shows the diagonal compression strength variation with vertical deformation for the non-retrofitted and retrofitted specimens. In the non-retrofitted case, the initial strength was 0.89kN 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. As expected, the initial strength of unburned brick (adobe) specimens was relatively lower than that of the burned brick one.

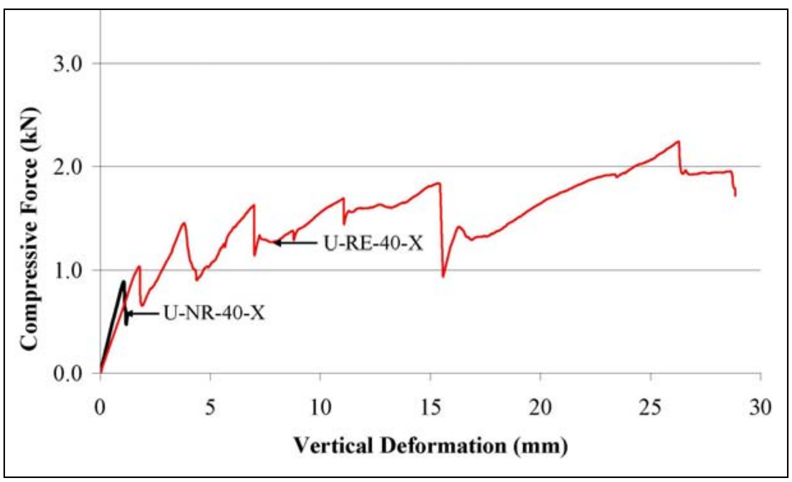

Figure 5 Force vs. vertical deformation for unburned brick (adobe) masonry wallette

3.4 Effect of PP-band mesh pitch

For retrofitted specimen, four cases varying PP-band mesh pitches of 33mm, 40mm, 50mm, 66mm were used for retrofitting keeping other parameters same. To easy compare the behavior of retrofitted masonry wallettes; the behavior idealized as shown in Figure 6. Initial strength (Vo) and Initial stiffness (Ko) were mainly depending on the masonry properties. Residual strength after initial crack (Vr) and residual stiffness (Kr) mainly depend on

PP-band properties and PP-band density.

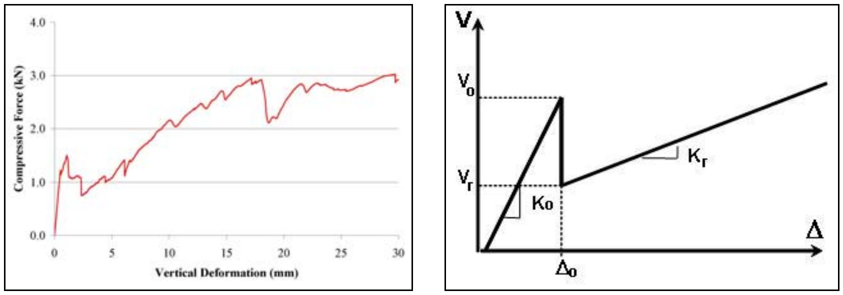

Figure 6 Real (left) and ideal (right) behavior of PP-band mesh retrofitted wallette.

Figure 7(a) shows the residual strength/initial strength (Vr/Vo) variation with number of PP-band per one side of the masonry wallette. From the experiment it was found that there is a significant role of PP-band pitch in behavior of masonry wallettes.

In general residual strength after crack initiation and residual stiffness of masonry wall with PP-band mesh retrofitting are directly proportional to PP-band density up to some value. But when it exceeds the optimum value, improvement ratio of residual strength after crack initiation and residual stiffness are not increase with amount of the PP-band density.

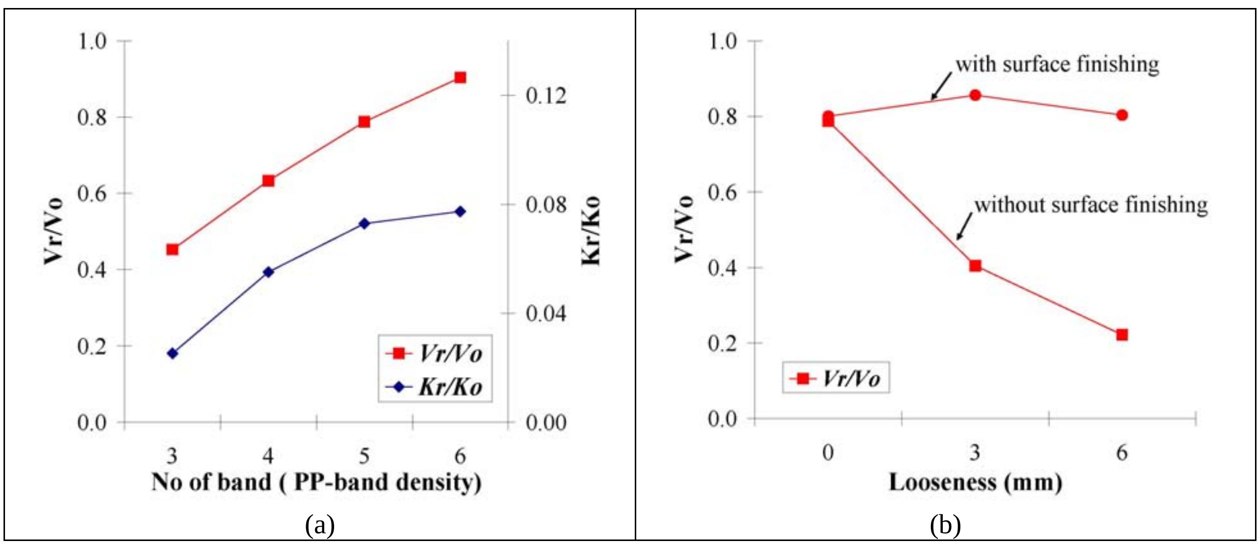

Figure 7 (a) Effect of PP-band density (b) Effect of looseness between wallette and PP-band mesh

3.5. Effect of attachment condition between PP-band mesh and masonry wallette

To verify the effect of looseness of the retrofitting attachment on retrofitted specimen, 0mm (fully fixed), 3mm and 6mm of gap between PP-band mesh and wallette were provided. Figure 7(b) shows the residual strength/initial strength (Vr/Vo) variation with looseness of attachment between PP-band mesh and masonry wallettes. The result shows that; when there is looseness, it does dramatically reduce the residual strength of the masonry wallettes after initial crack. Bet when we applied the surface finishing above the masonry wallette, because to surface paste fill the gap between PP-band mesh and masonry wallette; even after the initial crack, at least 80% of the initial strength remained.

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 and consisted of 6 bricks row of 6 bricks each. The mortar joint thickness was 5mm. A total of 6 wire connectors were used to attach the meshes with masonry wallettes. Considering the stability of the specimens, for mortar joint following mixing ratio were used;

- For burned brick model
  Water:Cement:Sand:Lime = 1.00:0.25:2.80:1.00
- For unburned brick model
  Water:Cement:Sand:Lime = 1.00:0.45:2.80:0.80

Bond tests were performed to characterize the engineering properties of the material used in the investigation. The average tensile strength of burned brick and unburned brick masonry obtained from bond test were 0.162MPa and 0.006MPa, respectively.

The specimens were named according to the following convention: **M-T** in which **M** is brick type, **B**: Burned or **U**: Unburned; **T** is retrofitted condition, **NR**: Non-retrofitted or **RE**: Retrofitted by 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 mid-span of the wallettes. The loading rate was 0.05mm/min for the non-retrofitted case. For the retrofitted case, it was also 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 Figure 8.

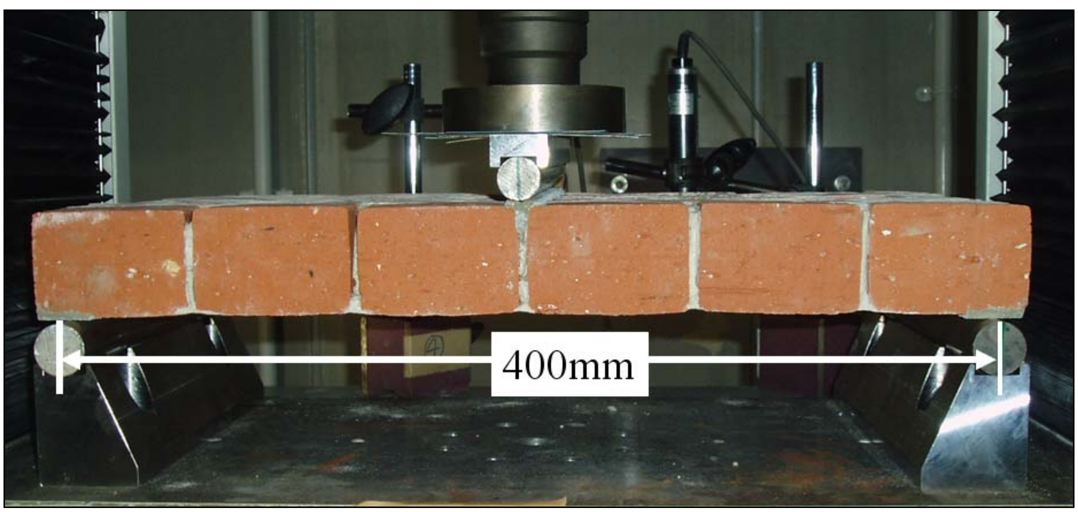

Figure 8 Out-of-plane test setup

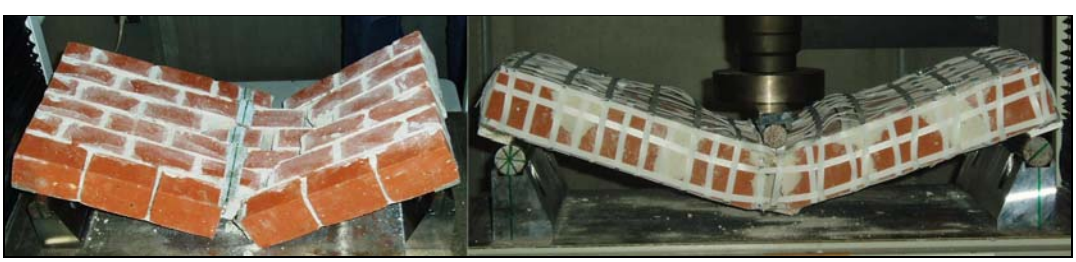

Figure 9 Failure patterns of brick masonry wallettes with and without retrofitting by PP-band mesh.

Figure 9 shows the non-retrofitted and retrofitted masonry wallettes at the end of the test, which corresponded to a mid-span net deformation equal to 2.8mm 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, although 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 10 shows the out-of-plane load variation in terms of net vertical deformation for the non-retrofitted and retrofitted wallettes in the mid-span. For burned brick, in the non-retrofitted case, the initial strength was 0.63 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. In the retrofitted case, although the initial cracking was followed by a sharp drop, at least 45% of the peak strength remained.

As expected, the initial strength of the burned brick was relatively higher than that of unburned brick (adobe). Even higher cement/water ratio was used for unburned brick (adobe), the poor bonding between mortar and unburned brick (adobe) led to separation along the brick and mortar. On the other hand, in the burned brick case, failure occurred within the mortar. This behavior highly influenced the initial strength of the specimens.

After the initial drop in strength, the mesh presence positively influenced the wallette behavior. Both types of retrofitted brick wallettes showed similar behavior in strength up to a vertical deformation equal to 8mm. At the point, brick crushing was observed in the unburned brick case. Due to that, the overall strength of the unburned brick wallettes was considerably smaller than that of burned brick wallettes. There after, if two types of bricks are compared, almost 40% difference in strength was observed.

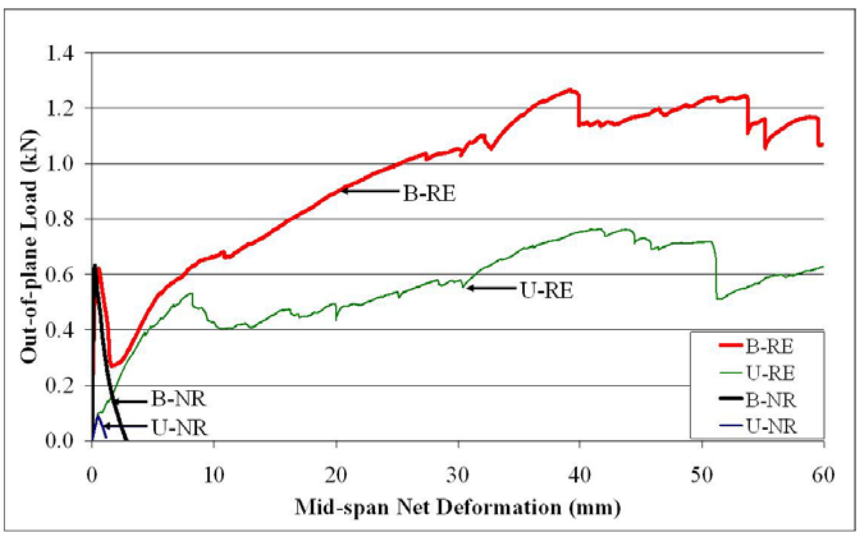

Figure 10 Out-of-plane load variation in terms of net vertical deformation

5. CONCLUSIONS

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. Masonry wallette without PP-band mesh would loose the entire load bearing capacity immediately after crack appeared,
2. Masonry wallette with PP-band mesh retrofitting loose some of load bearing capacity immediately after

the crack-initiation, but with the effect of the PP-band meshes, it could regain the load bearing capacity and recover immediately, and its strength and deformability improves.

3. Residual strength after crack initiation and residual stiffness of masonry wall with PP-band mesh retrofitting are directly proportional to PP-band density up to some value. But when it exceeds the optimum value, improvement ratio of residual strength after crack initiation and residual stiffness are not increase with amount of the PP-band density.
4. Looseness of the PP-band attachment with specimen reduces the residual strength after crack initiation of the specimen. But application of surface finishing makes beneficial effect in residual strength.

The out-of-plane tests showed that;

1. In case of out-of-plane tests, the mesh effect was not observed before the wall cracking. After cracking, the mesh presence positively influenced the wallette behavior.
2. In case of burned brick, the retrofitted wallettes achieved strengths twice greater and deformations 60 times larger than the non-retrofitted wallettes strength.
3. Although the overall strength of burned retrofitted wallettes was higher than that of the unburned (adobe) ones, the ratio maximum strength/cracking strength in the latter was larger.

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

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