



EXPERIMENTAL STUDY OF PP-BAND RETROFITTED MASONRY WALLETTES

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ABSTRACT: Unreinforced masonry is one of the most 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. 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 local available workmanship used. Also simple construction procedure is needed. Considering these points, a new retrofitting technique has been proposed based on the use of polypropylene bands (PP-bands), which are commonly utilized for packing. This material is available at a very low price even in remote areas of the world. To evaluate the beneficial effects of the proposed PP-band mesh retrofitting method, diagonal shear tests and out-of-plane tests were carried out on masonry wallettes with and without retrofitting. In diagonal shear tests, the masonry wallettes were retrofitted with meshes whose borders were connected with either epoxy or just by overlapping to evaluate whether the connection type influences the retrofitting performance. From both tests results, which are highlighted in the paper, it could be seen that PP-band retrofitted masonry wallettes had larger residual strength after the first crack in both in-plane and out-of-plane loading. It was clear that PP-band mesh retrofitting improved the overall stability and ductility of the structure.

Key Words: unreinforced masonry, polypropylene band, diagonal shear test, residual strength, wire connectors, wallettes

INTRODUCTION

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 $\frac{1}{4}$ scale model was used to investigate the static and seismic behavior of masonry walls.

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Diagonal shear tests and out-of-plane tests were carried out on masonry wallettes with and without retrofitting for both burned and unburned bricks to evaluate the beneficial effects of the proposed PP-band mesh retrofitting method. In addition to these, efficiency of different meshes orientations was also examined. The test results are reported in this paper.

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. The test was carried out under displacement control method. The results are shown in **Figure 1**. To calculate the stress in the band, its nominal cross section $15.5 \times 0.6 \text{mm}^2$ was used.

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 3200MPa and 1000MPa, respectively. Given its large deformation capacity, it is expected that it will contribute to improve the structure ductility.

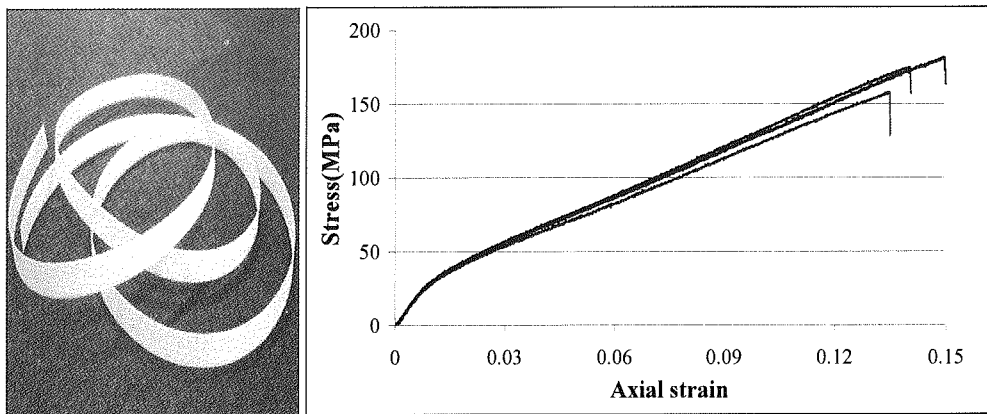


Figure 1. Polypropylene band used for retrofitting (left) and Behavior of PP-band under tension (right)

DIAGONAL SHEAR TEST

To evaluate the beneficial effects of proposed PP-band mesh reinforcement method, diagonal shear tests were carried out on masonry wallettes with and without retrofitting for both burned and unburned units. The wallette dimensions were $292.5 \times 290 \times 50 \text{mm}^3$ for burned and $275 \times 275 \times 50 \text{mm}^3$ for unburned unit and consisted of 7 brick row of 3.5 brick each. The mortar joint thickness was 5mm for both cases. Cement/Water ratios equal 0.14 and 0.33 were used for burned and unburned brick, respectively.

To observe the efficiency of different mesh orientations, two types of PP-band mesh arrangement were considered.

Type-1: PP-band mesh oriented parallel to the masonry joints.

Type-2: PP-band mesh oriented 45° from the masonry joints.

Both had mesh pitch equal to 40mm. A total of 4 wire connectors were used to attach the mesh with the masonry.

The specimens were named according to the following convention: **A-T-O** in which **A** is **B**: Burned or **U**: Unburned; **T** is **NR**: Non-retrofitted, **RE**: Retrofitted by PP-band meshes whose borders were connected with epoxy and wire connectors or **RO**: Retrofitted by just overlapping of PP-band meshes and wire connectors; and **O** is **1**: PP-band mesh oriented parallel to the masonry joints or **2**: PP-band mesh oriented 45° from the masonry joints.

Specimens were tested 28 days after construction under displacement control. The loading rate was 0.3mm/min and 2mm/min for the non-retrofitted and retrofitted cases, respectively. 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 carried out to obtaining these characteristic properties were similar to that shown in **Figure 2**.

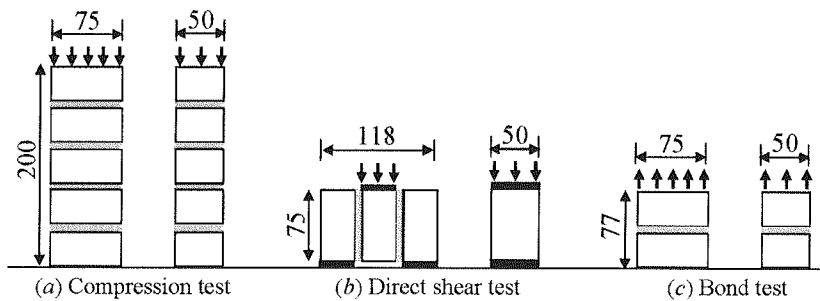


Figure 2. Layout of specimens used for direct compression, direct shear and bond test (unit:mm)

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

Behavior of retrofitted masonry

Initially retrofitting was done with PP-band meshes whose borders were connected with epoxy and wire connectors, in order to evaluate the beneficial effects of the proposed PP-band mesh reinforcement method. In the following sections, a brief discussion of diagonal shear test results of burned and unburned unit specimens is presented.

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 wallets did not lose stability.

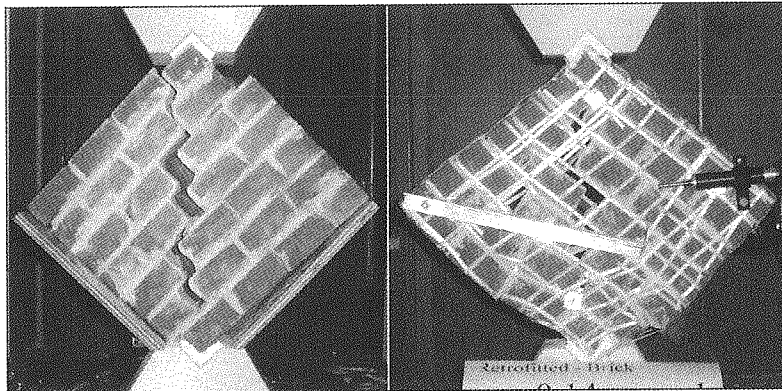


Figure 3. Failure patterns of brick masonry wallets with and without retrofitting by PP-band mesh.

Figure 4 shows the diagonal shear 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.

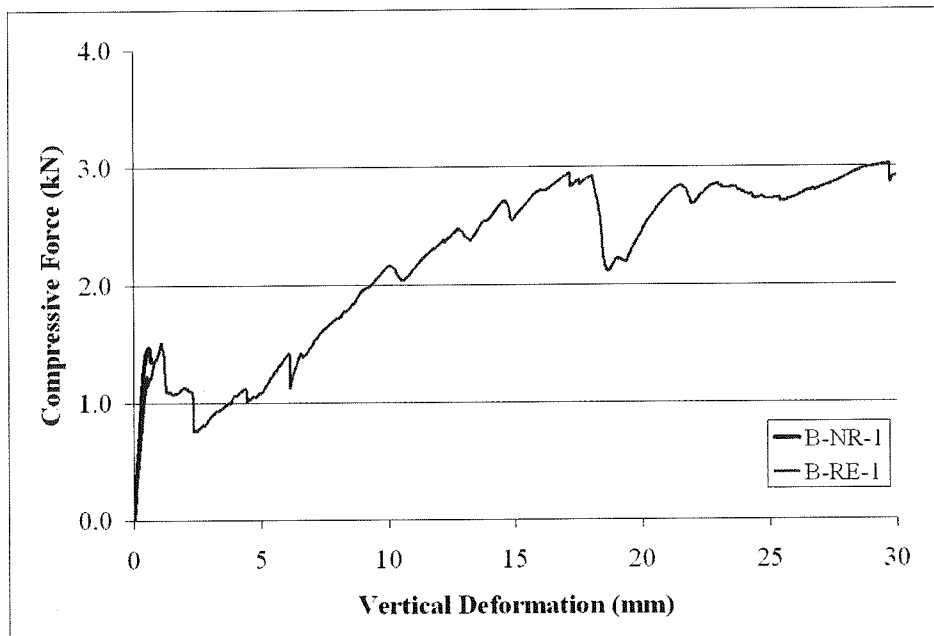


Figure 4. Force vs. vertical deformation for burned brick masonry wall specimen with and without retrofitting.

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.

Behavior of unburned brick specimens

Figure 5 shows the diagonal shear strength variation with vertical deformation for the non-retrofitted and retrofitted specimens.

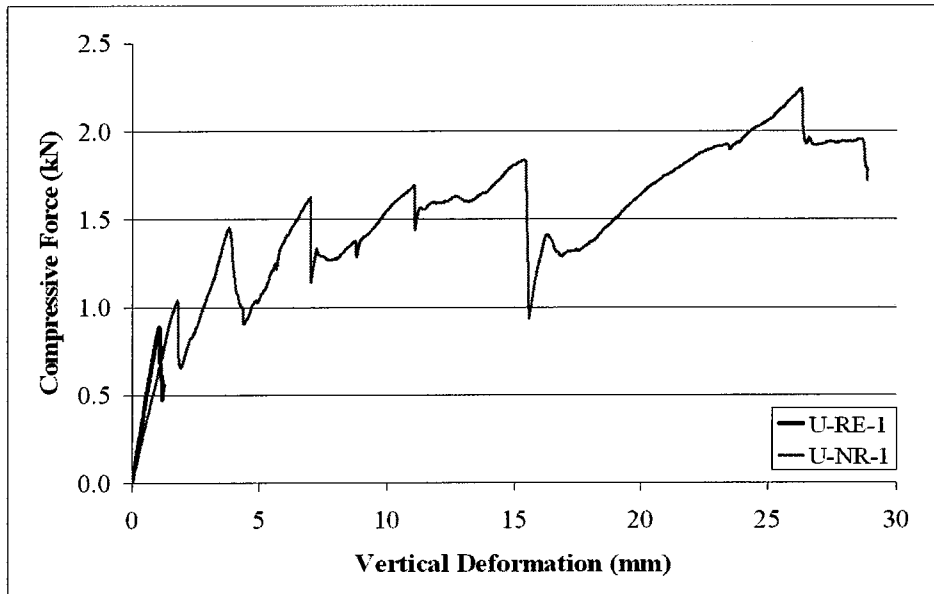


Figure 5. Force vs. vertical deformation for unburned brick masonry wall specimen with and without retrofitting.

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 specimens was relatively lower than that of the burned brick one.

Efficiency of mesh orientation

Figure 6 compares the diagonal shear strength of retrofitted masonry wallettes with different mesh orientation:

Type 1 is PP-band mesh oriented parallel to the masonry joints.

Type 2 is PP-band mesh oriented 45° from the masonry joints.

Generally Type 2 mesh provided larger strength than Type 1 mesh arrangement. This was expected because the confining effect on the masonry wall is larger in the former case. Cracks become gradually wider as the vertical deformation increased. In this condition, the reinforcement oriented

perpendicular to the crack. i.e. Type 2 worked under optimum conditions. The results of B-RE-1 and B-RE-2 were compared; the maximum strength difference was 30% at a vertical deformation of 17 mm. Although the mesh Type 1 did not fully use the mesh capacity, it improved the wallette behavior to a degree which can be considered enough for the purpose of earthquake damage mitigation. In addition to this, the mesh Type 1 is easier to manufacture and install. Therefore, it was selected as the proper solution for retrofitting.

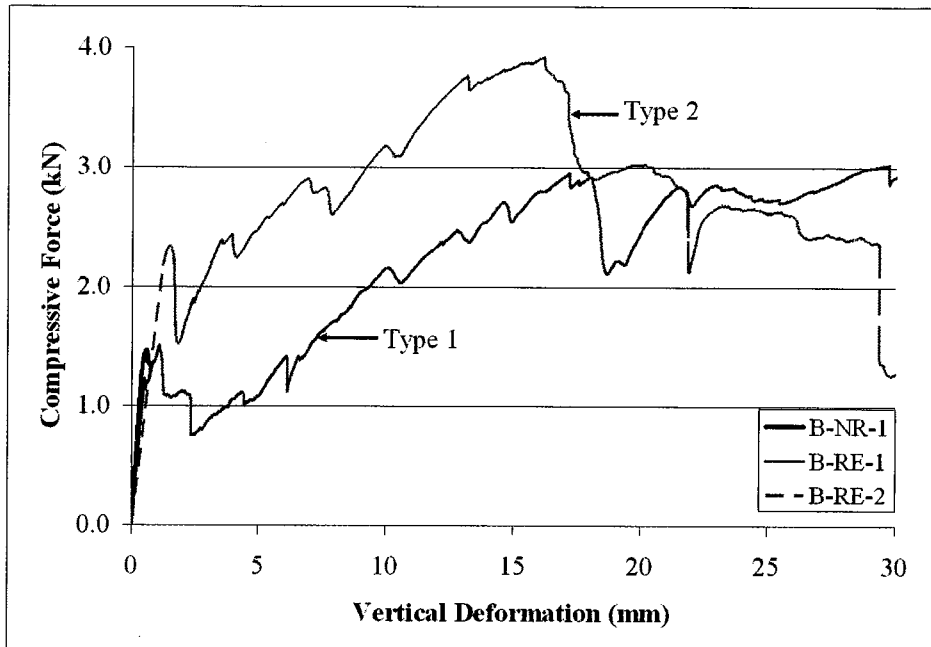


Figure 6. Comparison between masonry wallettes retrofitted by different orientation meshes: Type 1 is PP-band mesh oriented parallel to the masonry joints. Type 2 is PP-band mesh oriented 45° from the masonry joints.

Effect of mesh edge connection

Figure 7 shows comparison of the diagonal shear behavior of retrofitted masonry wallettes with mesh whose borders were connected with epoxy and retrofitted by just overlapping of PP-band meshes for burned masonry wallettes.

In case of burned masonry wallettes, within the 10mm vertical deformation, similar performance was observed in both cases. However at larger vertical deformation, because of PP-band slip was observed along the specimen borders, compression strength of wallettes without epoxy was considerably reduced. Also it could be observed that close to the connectors there was almost no mesh slip, ie the connectors could effectively attach two meshes. On the other hand, the bands located far from the connectors experienced considerable slip. This was not observed in the meshes connected with epoxy. As mentioned before for vertical deformation smaller than 10mm, which corresponds to 15 times the working strain, the behavior of both edge connections was almost the same.

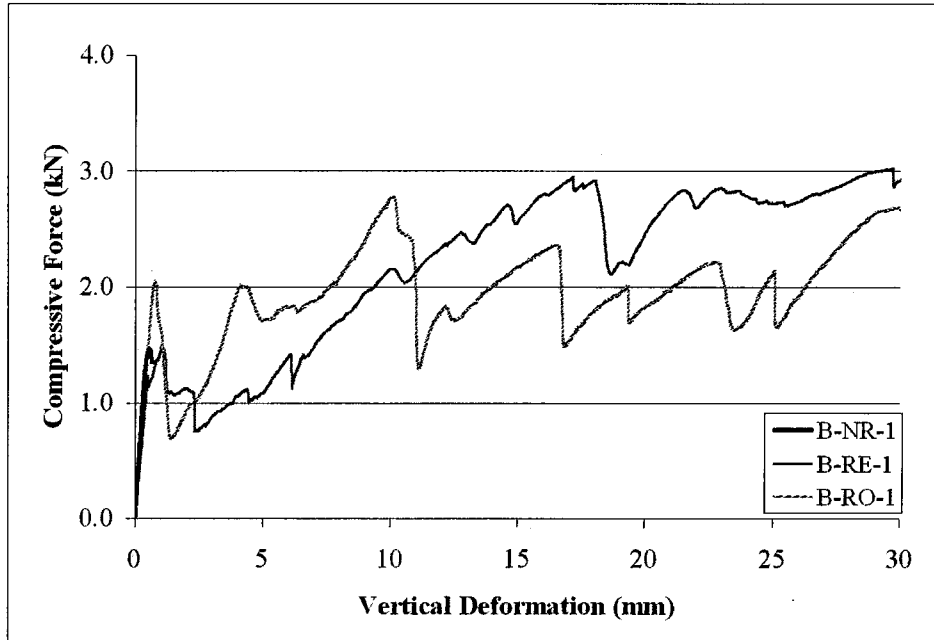


Figure 7. Behavior of masonry wallettes with mesh edges fully or partially connected

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 attach the meshes with masonry wallettes. Considering the stability of the specimens, Cement/Water ratios equal 0.25 and 0.45 were used for burned and unburned brick, respectively.

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 **B**: Burned or **U**: Unburned; **T** is **NR**: Non-retrofitted or **RO**: Retrofitted 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 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**.

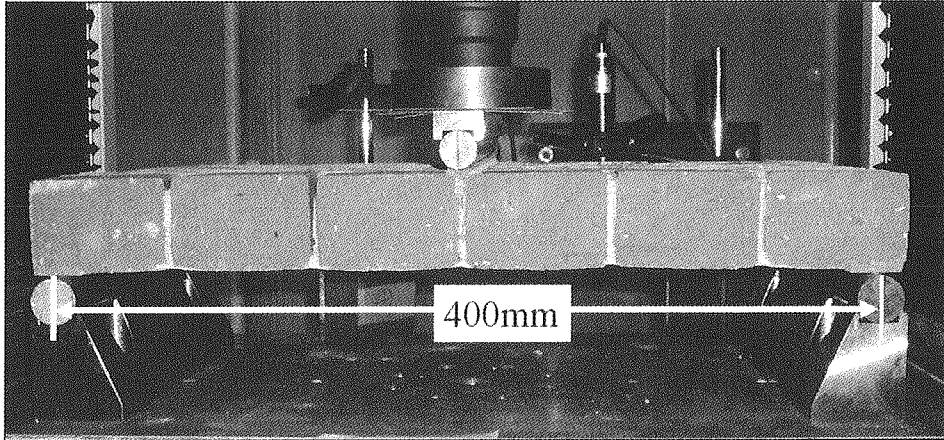


Figure 8. Out-of-plane test setup

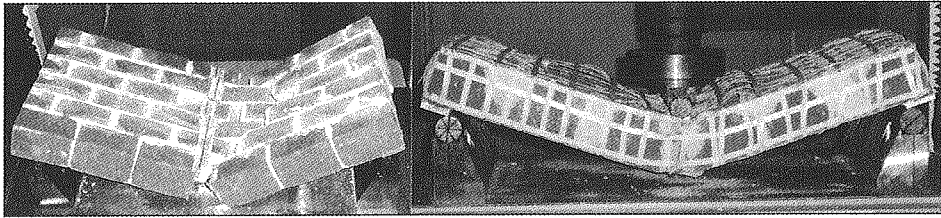


Figure 9. Failure patterns of brick masonry wallettes with and without retrofitting by PP-band mesh.

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 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. Even higher cement/water ratio was used for unburned brick, the poor bonding between mortar and unburned brick 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.

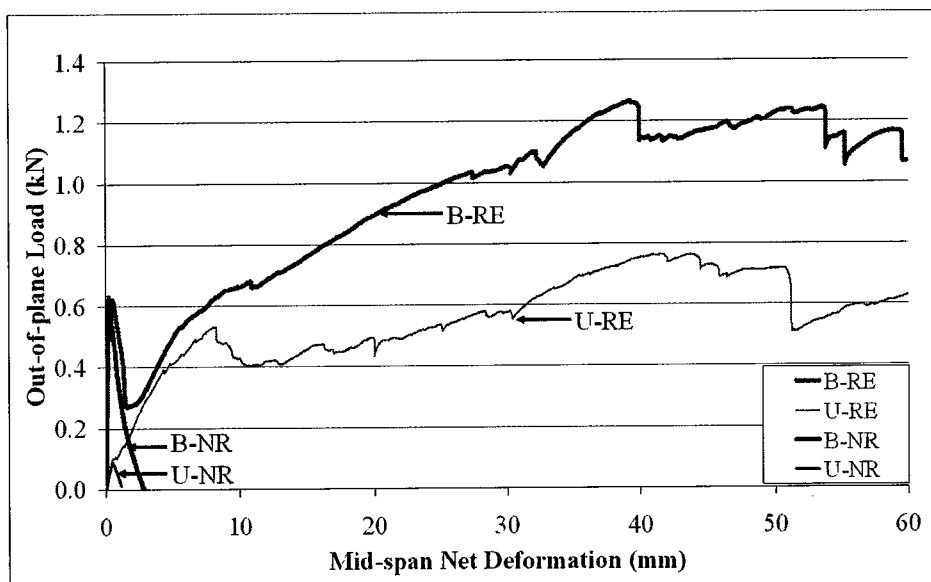


Figure 10. Out-of-plane load variation in terms of net vertical deformation

CONCLUSIONS

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

The diagonal shear tests showed that:

- (1) When appropriately set, no epoxy failure was observed before 2.9kN.
- (2) 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 higher strength than the initial cracking strength.
- (3) Mesh Type 1, in which PP band mesh is oriented parallel to the masonry joints, improved the wallette behavior to a degree which can be considered enough for the purpose of earthquake damage mitigation. In addition to this, Type 1 is easier to manufacture and install. Therefore, we consider mesh Type 1 is better for retrofitting.
- (4) For vertical deformation smaller than 10mm, similar performance between wallettes, with mesh edges fully and partially connected was observed.

The out-of-plane tests showed that:

- (1) In 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) The retrofitted wallettes achieved strengths 2 times greater and deformations 60 times larger than the non-retrofitted wallettes.
- (3) Although the overall strength of burned retrofitted wallettes was higher than that of the unburned 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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