研　究　速　報

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Experimental Study on In-plane and Out-of-plane Behavior of Masonry Wallettes Retrofitted by PP-Band Meshes

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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.

To evaluate the beneficial effects of the proposed PP-band mesh retrofitting method, diagonal compression tests and out-of-plane tests were carried out using masonry wallettes with and without retrofitting.

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

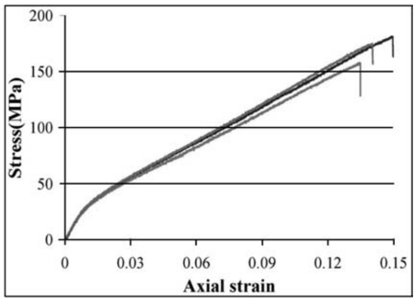

Fig. 1 (a) Polypropylene band used for retrofitting (left)
(b) Behavior of PP-band under tension (right)

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.

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 burned brick. The wallette dimensions were $292.5 \times 290 \times 50\text{mm}^3$ and consisted of 7 brick rows of 3.5 brick each. The mortar joint thickness was 5 mm for both cases. A Cement/Water ratio equal to 0.14 was used.

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.

The pitch of both meshes was 40 mm. 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-O. A** indicated the brick type, **B** in case burned bricks

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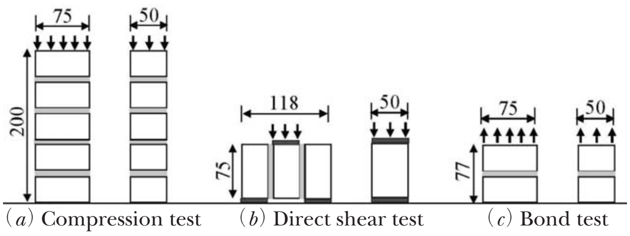

Fig. 2 Direct compression, direct shear and bond test specimens（all dimensions are in mm）

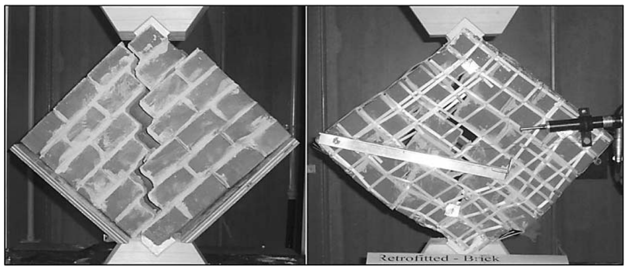

Fig. 3 Failure patterns of brick masonry wallettes with and without retrofitting by PP-band mesh

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. **O** is the type of the mesh, **1** in case the PP-band mesh oriented parallel to the masonry joints and **2** for PP-band mesh oriented 45° from the masonry joints.

Specimens were tested 28 days after construction under displacement control. The loading rates were 0.3 mm/min and 2 mm/min for the non-retrofitted and retrofitted cases, respectively. The retrofitted wallettes were applied 50 mm 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 : 21.78 MPa
Shear strength : 0.0075 MPa
Bond strength : 0.0055 MPa

Behavior of retrofitted masonry

Figure 3 shows the non-retrofitted and retrofitted specimens at the end of the test, which corresponded to vertical deformations equal to 0.71 and 50 mm, respectively. Initially retrofitting was done with PP-band meshes whose borders were connected with epoxy and wire connectors. 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.

Figure 4 shows the diagonal compression strength variation with vertical deformation for the non-retrofitted and retrofitted burned brick specimens. In the non-retrofitted case, the average initial strength was 1.5 kN and there was no residual strength after the first crack. In the retrofitted case, although the initial cracking was

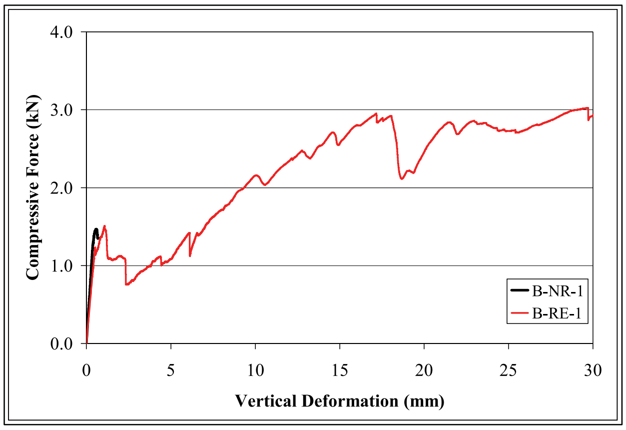

Fig. 4 Force vs. vertical deformation for masonry wall specimen with and without retrofitting

followed by a sharp drop, at least 60% of the peak strength remained. Subsequent drops were associated with new cracks like the one observed at the deformation of 2.5 mm. After this, the strength was regained by readjusting and packing by PP-band mesh. When the strength exceeded 2.9 kN individual PP-bands started to fail. However, this did not reduce considerably strength of the specimen, because stresses were redistributed to other PP-bands. The specimen quickly recovered its strength. The final strength of the specimen was equal to 3.0 kN much higher than initial strength of 1.5 kN.

Efficiency of mesh orientation

Figure 5 compares the diagonal compression strength of retrofitted masonry wallettes with Type 1 and Type 2 meshes. Generally, Type 2 mesh provided larger strength than Type 1 mesh arrangement did. 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 this study. In addition to this, the mesh Type 1 is easier to

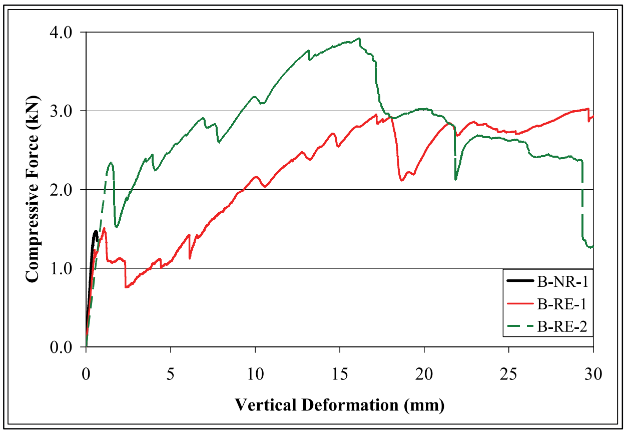

Fig. 5 Comparison between masonry wallettes retrofitted by Type 1 and Type 2 PP-band meshes

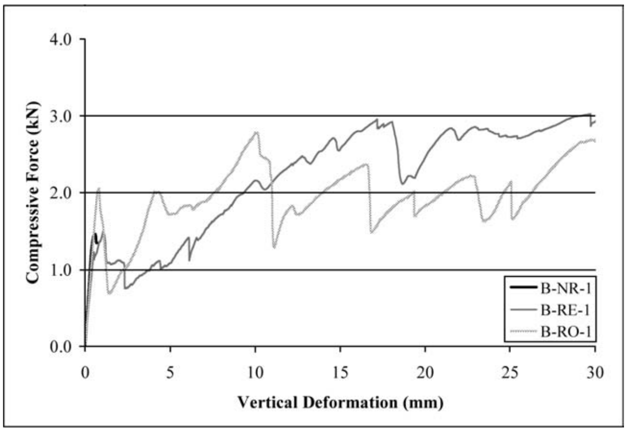

Fig. 6 Behavior of masonry wallettes with mesh edges fully or partially connected

manufacture and install and therefore it was selected as the optimum solution for retrofitting.

Effect of mesh edge connection

Figure 6 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 10mm vertical deformation, similar performance was observed. However, at larger vertical deformation, 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 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.

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 0.25, considering the stability of the specimens.

Bond tests were performed to characterize the properties of the material used in the investigation. The average tensile strength of burned brick masonry obtained from bond test was 0.162MPa.

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

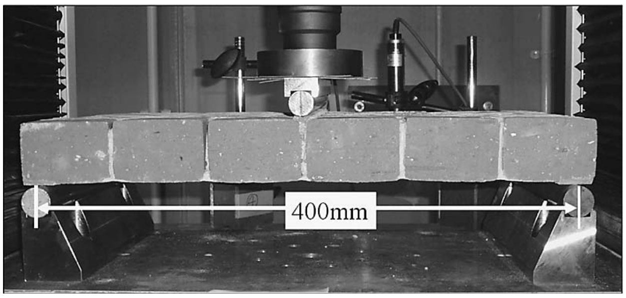

Fig. 7 Out-of-plane test setup

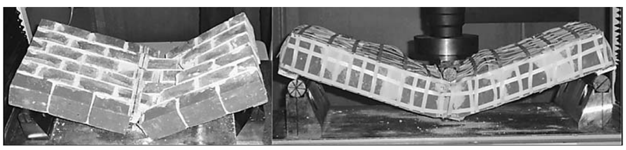

Fig. 8 Failure patterns of brick masonry wallettes with and without retrofitting by PP-band mesh

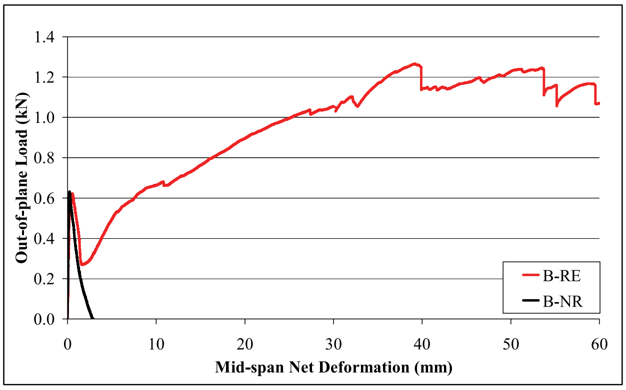

Fig. 9 Out-of-plane load variation in terms of net vertical deformation

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, 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 net vertical deformation for the non-retrofitted and retrofitted wallettes in the mid-span. 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. After this, the strength was regained by readjusting and packing by PP-band mesh. The final strength of the specimen was equal to 1.2 kN much higher than initial strength of 0.6 kN.

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) 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 45 times larger deformations than the non-retrofitted wallettes did.

(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 this study. In addition to this, Type 1 is easier to manufacture and install. Therefore, it was selected as the optimum type for retrofitting.

(4) For vertical deformations smaller than 10mm, 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 2 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.

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