PROPOSAL OF A NEW ECONOMIC RETROFITTING METHOD FOR MASONRY STRUCTURES

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Masonry structures are widely used due to its low cost and construction easiness. In spite of the efforts to provide guidelines for the construction of sound earthquake resistant houses, every year casualties due to collapsing masonry houses due to earthquakes are reported. In order to promote the retrofit of masonry houses among the common population, it is important to consider both the economy of materials and construction easiness. In this paper, the use of polypropylene bands embedded in a cement mortar overlay is presented as a novel retrofitting method for masonry structures. The results of a series of shear tests on unreinforced and reinforced walls are presented and discussed.

Key words: *masonry retrofit, earthquake damage, polypropylene band, shear wall, experiment, mesh, mortar overlay*

1. INTRODUCTION

Masonry is a construction material widely used around the world due to its low cost and construction easiness. More than 30% of the world's population lives in a house of unbaked earth, which is one type of unreinforced masonry[1)]. During the last century, human casualties during earthquakes were mainly caused by structural damage, being the failure of unreinforced masonry structures responsible of more than 60% of them[2)]. The vulnerability of masonry structures under seismic loads has being recognized long ago and efforts to provide guidelines for the construction of sound earthquake resistant houses have being remarkable. In spite of this, every year casualties due to collapsing masonry houses during earthquakes are reported.

Several types of retrofitting have been developed for unreinforced masonry structures. A comprehensive review of them can be found in Lizundia et al[3)]. The existing retrofitting techniques can be categorized in: 1) grout and epoxy injections, 2) surface coatings, 3) reinforced or post-tensioned cores, and 4) addition of structural elements. There is no doubt that these methods are useful for strengthening masonry structures. Depending on the purpose of the retrofitting works, one method is more appealing than the other.

For strengthening unreinforced masonry houses in developing countries, a suitable retrofitting technique should guarantee not only its efficiency in terms of improvement of the seismic resistant characteristics of the structure (strength, ductility and energy dissipation). It should also be considered that: 1) the used material is economical and locally available and 2) the required labor skill is minimum. In this context, a new retrofitting method for unreinforced masonry structures is proposed.

2. RETROFITTING METHOD PROPOSAL

Considering the above-mentioned conditions, a novel retrofitting method consisting of polypropylene bands (PP-bands) arranged in a mesh fashion and embedded in a cement mortar overlay is proposed. These bands are worldwide used for

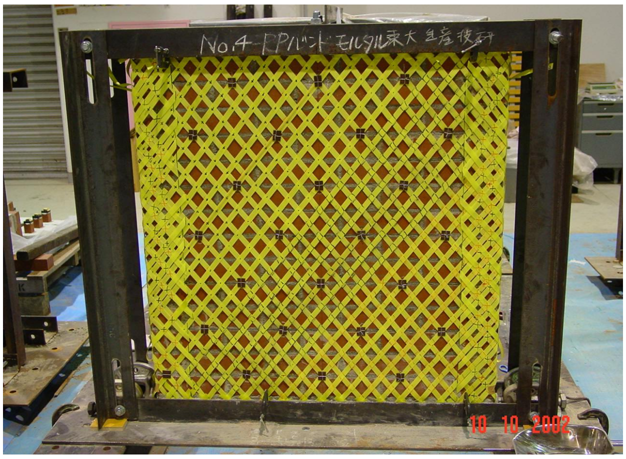

Photo 1. Retrofitted wall before mortar overlay setting

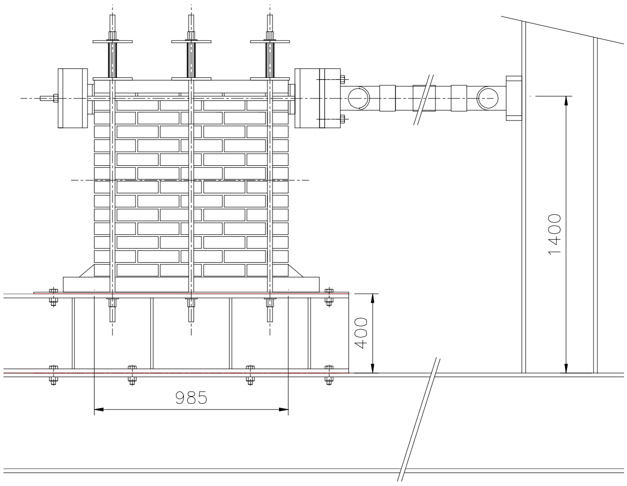

Figure 1. Test setup and dimensions in mm

packing. They are cheap, resistant, and easy to handle. The details of the retrofitting technique are discussed elsewhere[4)]. Only a brief explanation of the installation procedure is presented below.

At first, the meshes are prepared with the PP-bands. The pitch and inclination may vary according to the required earthquake resistance. Then, the masonry wall surfaces are cleaned and holes are drilled through the wall at a spacing of approximately 4 times the mesh pitch. After this, the PP-band meshes are set on both wall sides and fixed at the borders. Galvanized steel wires are passed through the wall holes and used to fix the meshes. **Photo 1** shows the wall at this stage of the process. Finally, a mortar overlay is placed on the wall surface.

3. EXPERIMENTAL PROGRAM

In order to assess the retrofitting by PP-band mesh, eight masonry walls were constructed: four with and four without reinforcement. The wall dimensions were 985×1072×100mm^3 and consisted of 15 brick rows of 4.5 bricks each. Clay bricks were used. The mortar mix proportion in volume was cement:sand=1:4.5 and the joint thickness was 10mm. The bottom and top brick layers were embedded in steel channels. The walls were cured with water spray for 14 days. At the end of the curing process, the upper channel was installed. **Figure 1** shows the test setup and specimen dimensions.

Two meshes were prepared per retrofitted wall. The mesh pitch, equal to 45mm, was chosen so that each brick would be crossed by at least three bands. Because the bricks were very strong, the connectors, 27 in total, were placed only at the mortar interface. This constrain defined the band inclination, which was 50°. A cement mortar mix (cement:sand=1:3) was used for the protection overlay of 8mm thickness.

At first, a vertical pre-compression load was applied by closing the bolts at the bottom end of six vertical rods. The force increment at the bars was closely monitored. Then, the actuator was positioned and the forces at the vertical rods were readjusted in case of unbalance. Finally, the horizontal loading, which consisted of 5 steps was applied with a hydraulic pump operated manually. In the first step, the wall was loaded until diagonal cracking. The second step consisted on additionally pushing the wall 10mm in the same direction. In the third step, the actuator displacement direction was reversed and the specimen was loaded until the diagonal crack in the opposite direction occurred. In the fourth step, the wall was loaded 10mm more in the same direction. Finally, the wall was unloaded. **Table 1** shows the experiment program summary.

Due to the brick high strength, the resulting masonry was stronger than the material typically available in developing countries. In order to intentionally reduce the wall strength and highlight the retrofitting effect, holes were drilled through some of the walls. Two hole distributions were considered, uniform and diagonal. Further details of the experimental program may be found in Mayorca[5)].

Table 1 Summary of experiment conditions

Case name	VL (kN)	PP-band	Mortar	Holes
Bare wall	9			None
Bare wall w/ holes	9			Uniform
Bare wall w/mortar	9		O	None
Reinforced wall	9	O	O	None
Reinforced wall w/ holes	9	O	O	Uniform
Bare wall w/mortar	30		O	None
Reinforced wall	30	O	O	None
Reinforced wall w/ diagonal holes	30	O	O	Diagonal

VL=Vertical pre-compression load

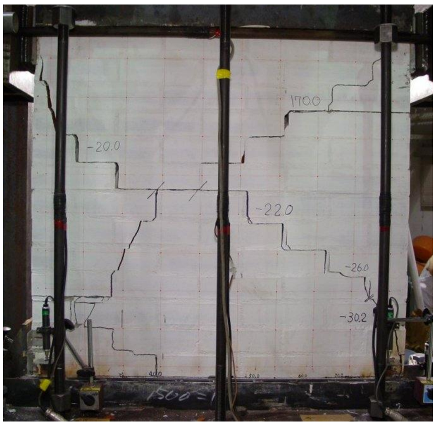

Photo 2. Unreinforced wall crack pattern

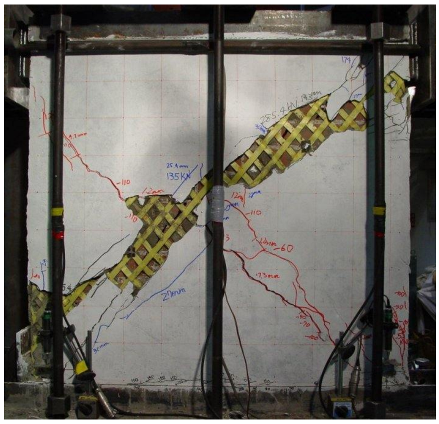

Photo 3. Reinforced wall crack pattern

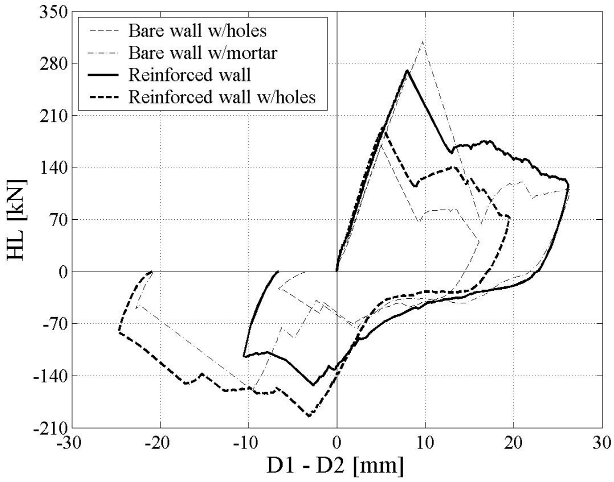

Figure 2. Force-deformation curve (VL=9kN)

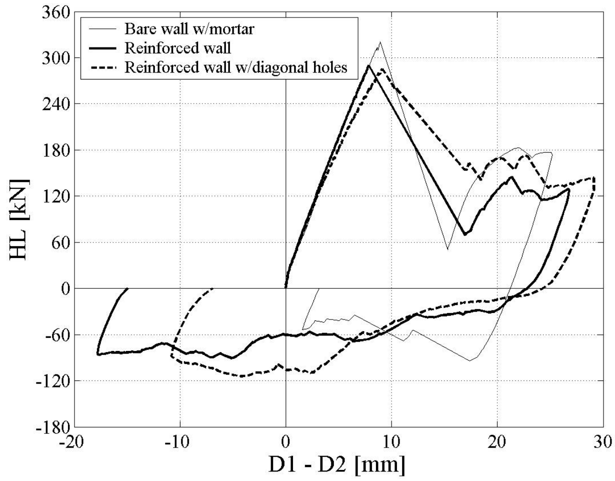

Figure 3. Force-deformation curve (VL=30kN)

4. RESULTS DISCUSSION

Photos 2 and **3** show typical crack patterns. **Figures 2** and **3** show the force-deformation curves obtained in the experiments grouped according to the pre-compression load. The experimental observations are briefly discussed below.

(1) Crack pattern

As observed in **Photos 2** and **3**, the crack pattern did not change considerably due to the reinforcement presence. In both cases, the flexural stresses caused a crack at the lower most mortar layer at an early load stage. This crack became gradually longer and wider as the horizontal load increased. In the case of the reinforced walls, the crack propagated slowly and as a result, a wall strength drop was not observed in the force-deformation curve. This effect was identified in the walls with VL=9kN.

The flexural crack caused the horizontal force, which was originally transferred to the support by a shear-flexural mechanism, to be resisted through a compression strut along the wall diagonal. As the bottom crack stopped propagating, the specimen stresses continued to build up and were eventually released through a diagonal crack.

After the first diagonal crack, the wall strength was notoriously reduced and the subsequent imposed deformation was related to the movement of the upper half of the failed wall. Because of this, when the load was reversed it did not produce any additional flexural cracking. It was mainly the upper wall displacement. After the initial shear crack closed, the stresses started to build up again and the second diagonal crack, along the other diagonal, appeared. The main difference between the unreinforced and reinforced walls was the crack propagation speed rather than the location.

(2) Stiffness

The force-deformation curves presented in **Figure 2** may suggest that the reinforced walls have a slightly higher stiffness than the unreinforced ones. However, it must be noted that the deformations showed in the figures correspond to two effects, the wall deformation itself and the wall rotation. The later is larger. **Figure 4** shows the deformation along the wall diagonals, which is a direct measurement of the wall shear deformation. Note that the deformation of both reinforced and unreinforced

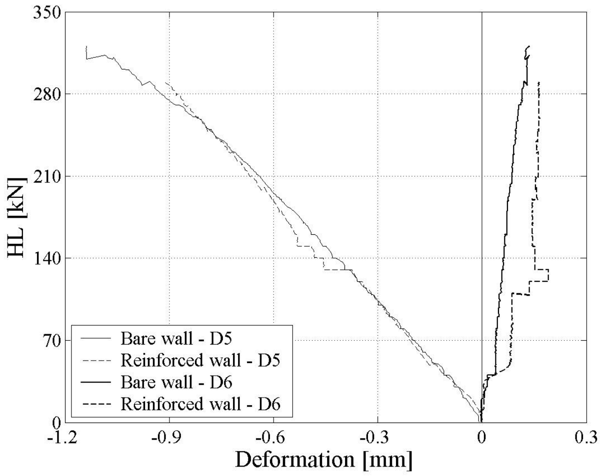

Figure 4. Diagonal deformation (VL=30kN)

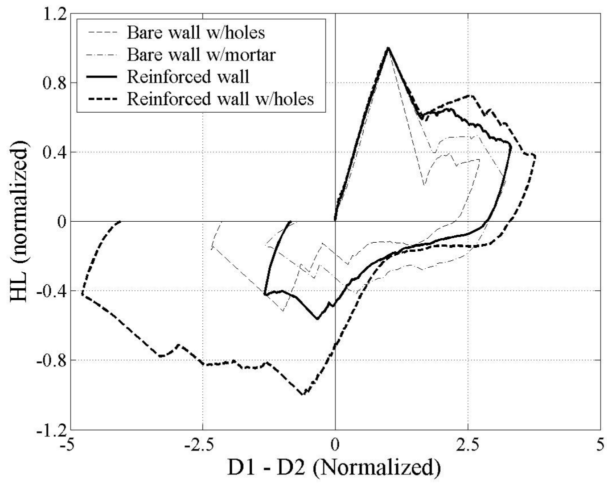

Figure 5. Normalized force-deformation relation (VL=9kN)

walls is small and almost the same. This shows the high stiffness of the masonry wall and suggests that the stiffness difference observed in the force deformation curves is mainly due to the reinforcement restrain to the wall rotation.

(3) Peak strength

The PP-bands have a relatively low stiffness compared to the masonry walls[5)]. Because of this, they did not contribute to increase the wall peak strength. Although some differences are observed, these are due to: 1) mortar overlay presence, 2) bonding between mortar overlay and masonry wall, and 3) variability of masonry properties due to the workmanship effect. The PP-band mesh contribution was only observed after the wall cracked.

(4) Post-peak strength

Figure 5 shows the force-deformation relation normalized to the peak strength and corresponding deformation for the group of walls with VL=9kN. It is observed that immediately after the peak, the normalized strength dropped to 10 to 40% for the unreinforced walls. On the other hand, the reinforced walls exhibited a 60% residual strength after the peak, which was sustained even for large deformations. In the reverse direction, the reinforced walls also exhibited a larger normalized strength.

(5) Effect of connectors and mortar overlay

The reinforced wall with VL=30kN deserves special attention because the wall strength after the diagonal crack dropped to almost 25% of the peak strength. This was the only reinforced wall that exhibited such a sharp drop. After the test, the specimen was examined and broken wire connectors were found. Furthermore, a severe cracking of the mortar overlay due to drying shrinkage was observed before the experiment. This may have caused a reduction of the mortar support to the bands resulting in a larger demand to the wire connections, which ultimately caused their failure. It is worth noting that this was the first retrofitted wall constructed and eventually the steel wires may have been damaged during the installation process.

5. CONCLUSIONS

A new technique for strengthening masonry structures using PP-bands is proposed. The results of shear wall tests showed the reinforcement effect on the masonry wall behavior. Although the reinforcement did not increase the structure peak strength, it contributed to improve its performance after the crack occurrence. The reinforced walls exhibited a larger post-peak strength and were capable of better sustaining their strength even for large deformations. The importance of the connectors and the mortar overlay for the retrofitted wall performance was recognized.

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