Strengthening of masonry structures using polypropylene bands

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1. Introduction

Masonry is a construction material widely used around the world due to its low cost and construction easiness. As a result, this material accounts for more than 60% of the current worldwide housing stock [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 these casualties [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. This situation needs to be reverted by strengthening the existing masonry structures.

Masonry strengthening is not a new research topic. In fact, several retrofitting techniques have been developed such as grout injection [3], ferrocement [4], steel strips [5], etc. Most of these methods have being proposed for the restoration of monumental or historical structures or the reparation of masonry infill panels. These applications and the strengthening of masonry low earthquake resistant houses are quite different. In the latter case, the availability economic retrofitting materials in remote areas as well as the easiness of the strengthening procedure so as to be executed by the local workmanship are vital. With this in mind, the authors considered using polypropylene bands such as the ones used for packing as retrofitting material. This material is characterized by its low cost and its availability in wide regions in the world. In order to verify the suitability of the bands, a series of material and shear wall tests were undertaken and part of these results are reported hereinafter.

2. Retrofitting material and installation process

15.5mm width polypropylene (PP) bands were used for the present testing program. In order to preliminary assess the suitability of the material direct tensile tests were carried out on five 20cm long strips. The test results, presented in **Fig. 1**, show the large elongation capacity of the band, over 10%, as well as its strength, approximately 130kgf. These characteristics were considered good for its application on masonry strengthening and therefore the shear wall tests proceeded.

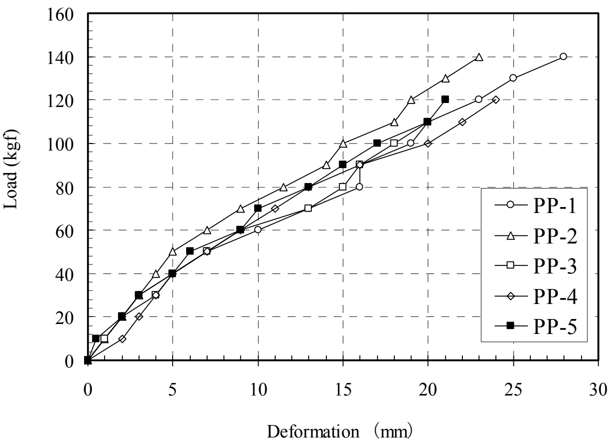

Fig. 1 Mechanical properties of the PP-band

Eight 985mmx1072mm masonry walls, 15-rows height and 4.5-bricks long, were constructed. The units consisted of burned clay bricks and the mortar cement to sand proportion was 1:4.5 in volume. Material testing for evaluating the compression and splitting tensile strength of brick and mortar were carried out. Because the masonry assembly strength depends not only on the materials themselves but also on their conditions during laying, workmanship, etc., material testing of masonry pillars was also undertaken.

Four of the eight walls were retrofitted with PP-band meshes as shown in **Photo 1**. These meshes were specially prepared for this experimental program, as they are not currently available in the market. The mesh pitch was 45mm and it was chosen to make every wall brick crossed by at least three bands. Although special tools are available to connect the ends of two bands, those are not useful to make cross connections as the ones required for preparing the mesh. Therefore, at this stage, the bands were pasted together using epoxy. It is expected that as the applicability of these bands for retrofitting purposes is demonstrated, tools to prepare meshes in an easier and faster way will be developed.

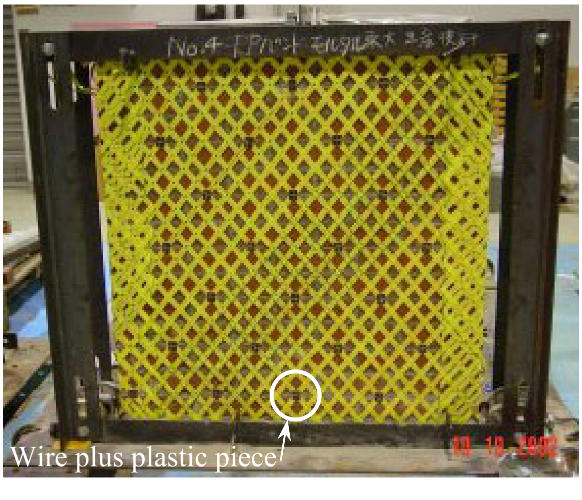

Photo 1 Retrofitted wall

Holes with 6mm diameter were drilled through the walls and a PP-band mesh was attached to both sides through wires. To prevent the wires from damaging the PP-band, pieces of plastic were placed between the wires and the bands. Each mesh was folded around the wall borders and spliced 10cm with the mesh on the opposite side. Both meshes were pasted together with the same epoxy used to fabricate the PP-band mesh. Finally, a 8mm thick mortar-finishing layer was placed over the retrofitted wall to protect the mesh from the environment agents.

Key Words: Masonry, strengthening, PP-band, shear wall, earthquake damage, polypropylene
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3. Test setup

The test setup is shown in **Fig. 3**. Six vertical 26mm diameter steel bars were used to apply vertical pre-compression to the specimen. Two horizontal bars were used to push and pull the specimen with only one actuator. Five walls were tested with a vertical load equal to 900kgf and the rest with 3000kgf pre-compression. The walls were first pushed under force control until the diagonal shear crack occurred. Then, the specimen was pushed another 10mm in the same direction to evaluate the post-peak wall strength. After this, the wall was pull back to evaluate the strength of the damaged wall in the opposite direction. After the second shear crack appeared the wall was pulled until the structure strength degradation was evident.

The loads were measured at the actuator with a loading cell and at the steel bars with full bridge strain gages. Wall deformations and relative displacements between the specimen and the loading frame were recorded with LVDT's and laser displacement meters.

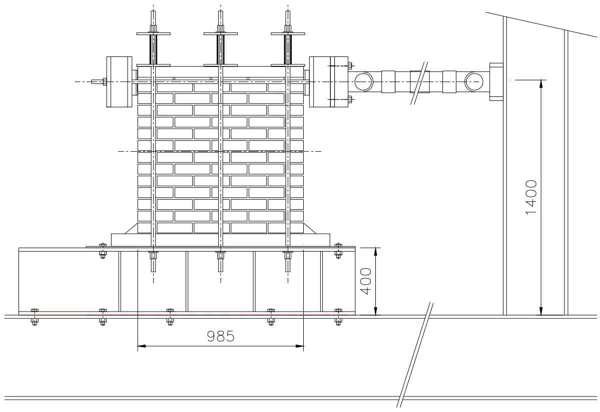

Fig. 3 Test setup (dimensions in mm)

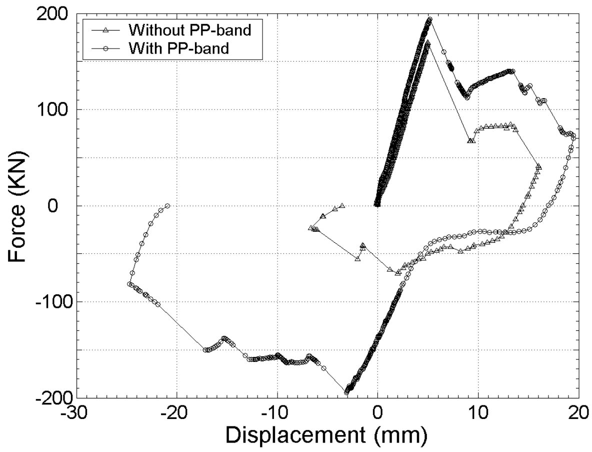

Fig. 4 Force-displacement curves of bare and strengthened walls

4. Results and discussion

Figure 4 shows the force-displacement relations of one unreinforced and one reinforced wall tested under a pre-compression load of 900kgf. Due to the very low Young's modulus of the band, the initial stiffness of both specimens is basically identical. Because of the relatively high strength of the masonry assembly, the effect of the PP band mesh on the wall strength is small. The effect of the band, however, is observed after the first diagonal crack. In the case of the reinforced wall, the post-peak strength is more than 70% of the maximum load. Due to the bands presence, the specimen is very stable and can sustain larger deformations without losing its resistance. The wall behavior during reverse loading with and without bands is also remarkably different. The wall strength of the specimen with bands is more than three times the strength of the wall without bands. The deformation capacity of the reinforced wall is also higher. It could be argued that the unreinforced wall does not have mortar overlay and a comparison between the two reported cases is not possible. However, after the first diagonal crack appears and the effect of the PP band mesh is clearly observed, the mortar is cracked and therefore does not contribute to the wall strength.

Photos 2 and **3** show the wall cracking patterns. In both cases there are two clear diagonal cracks. The unreinforced wall failure was brittle compared to the failure of the reinforced wall. In the former case, small pieces of broken brick and mortar fell apart. In the latter, all the broken pieces were kept within the mesh. At the end of the testing, the mesh condition was examined. The mesh presented basically no damage. The connections performed efficiently. In general, the presence of the PP-band mesh kept the wall integrity, thus enhancing its performance.

The current testing program has preliminarily assess the efficiency of a new type of economic and worldwide available retrofitting material to solve the problem of low strength houses in earthquake prone regions which will certainly cause great number of casualties in the earthquakes to come. To this end, the test results have shown the great potential of this material. Additional dynamic tests on shaking table are needed to further verify the goodness of the PP-band.

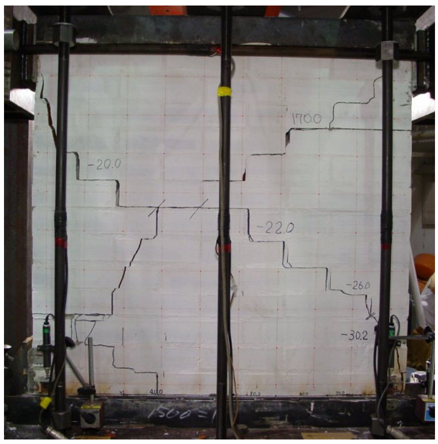

Photo 2 Unreinforced wall cracks

Photo 3 Reinforced wall cracks

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