研　究　速　報

Experimental Study of PP-Band Retrofitted Masonry Structure made of Shapeless Stone

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1. Introduction

Masonry is the oldest building material. In spite of this, the technological development of masonry in earthquake engineering has lagged behind compared to other structural material like concrete and steel. Therefore, 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. When we propose the retrofitting in developing countries, retrofitting method should respond to the structural demand on strength and/or deformability as well as to availability of material with low cost including manufacturing and delivery, practicability of construction method and durability in each region. Considering these issues of developing appropriate seismic retrofitting techniques for masonry buildings to reduce the possible number of casualties due to future earthquakes in developing countries, a technically feasible and economically affordable PP-band (polypropylene bands; PP-band is commonly used for packing.) retrofitting technique has been developed and many different aspects have been studied by Meguro Laboratory, Institute of Industrial Science, The University of Tokyo.

Masonry walls made of regular shape brick unit have been widely studied both from experimental and numerical point of view, but scarce experimental information is available for shapeless stone masonry walls that constitute the material still used in the construction of non-engineering structures. Therefore, the present work aims at increasing the insight about the behavior of typical shapeless masonry structure under static and dynamic loading.

Basic experimental study of PP-band retrofitted masonry wallette made of shapeless stone has been done and some aspects have been studied by Meguro lab (Sakurai 2009). In order to verify the suitability of the PP-band retrofitting technique on shapeless stone masonry, further 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 ¼ scale models was used to investigate the static behavior of masonry walls.

Diagonal shear tests were carried out on masonry wallettes with and without retrofitting for shapeless stone masonry to evaluate the beneficial effects of the proposed PP-band mesh retrofitting method. 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 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 $15.5\times0.6\,mm^2$ was used. As the matter of fact, the band has a corrugated surface and therefore its thickness is not uniform. The stress-strain curve is fairly bilinear with an initial and resid-

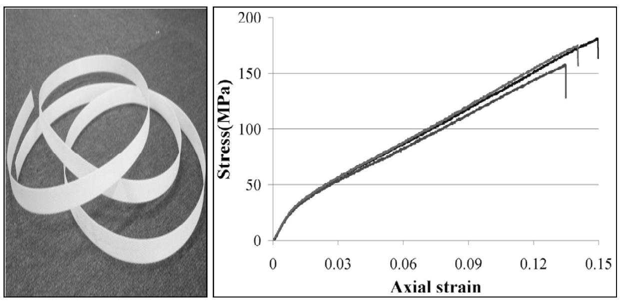

Fig. 1 (a) Polypropylene band used for retrofitting (left)
(b) Behavior of PP-band under tension (right)

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ual 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 PP-band mesh retrofitted method, diagonal shear tests were carried out using masonry wallettes with and without retrofitting for shapeless stone.

The wallette dimensions were 300×300×150mm^3 and consisted of 5 stone rows of 3 stones each, and 2 stones in the direction of depth (Fig. 2). A Cement/Water ratio equal to 0.30 was used. Four wire connectors were used to link the meshes attached from both surfaces of the wallette. For retrofitted specimens, four cases varying PP-band mesh pitches of 33 mm, 40 mm, 50 mm, 66 mm were used for retrofitting keeping other parameters same. 3 identical wallettes were constructed for each test. Specimens were tested 28 days after construction, under displacement control loading condition. The loading rate was 0.5 mm/min up to first 10 mm of diagonal deformation, and then it was increased to 2 mm/min for remaining deformation.

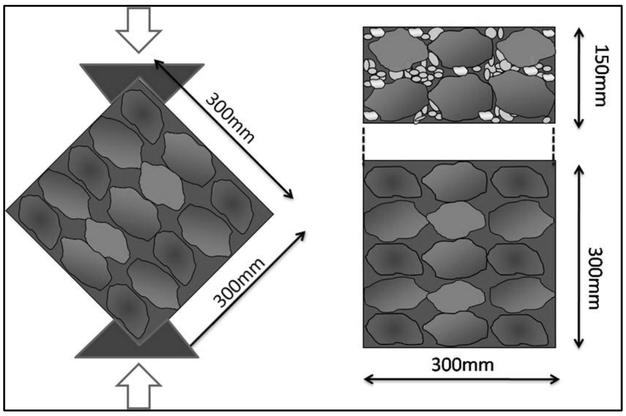


Fig. 2 Diagonal shear test specimen dimensions

The specimens were named according to the following convention: **A-T-X. A** indicated the brick type, **S** in case shapeless stone are used. **T** shows with or without retrofitting by PP-band meshes: **NR**: Non-retrofitted, **RE**: Retrofitted by PP-band meshes. **X** shows the PP-band mesh pitch in mm.

Result of the experiment

Fig. 4 and Fig. 5 are show the non-retrofitted and retrofitted specimens at the end of the test, which corresponded to strain, equal to 0.8% and 16%, respectively. In the non-retrofitted case, the specimens split in two pieces just 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 small strength drop. As strain became larger, due to PP-band was penetrated to the specimens, increase of strength was not observed with strain. Although at the end of the test almost all the mortar joints were cracked, the retrofitted wallettes did not lose stability.

Fig. 6 shows the diagonal shear stress variation with strain for the non-retrofitted and retrofitted specimens. In the non-retrofitted case, the average initial strength was 0.08MPa, there was no residual strength after first crack occurred and the specimens split into two pieces at strain equal to 0.8%. In the retrofitted case, although the initial crack was followed by a sharp drop, at least 50% of the peak stress remained. The final strength of the specimen was equal to 0.046MPa and specimen didn't break even at the strain equal to 16%. Which indicate that; retrofitted specimen was at least 20 times more ductile than non-retrofitted one.

Effect of PP-band mesh pitch

For retrofitted specimen, four cases varying PP-band mesh pitches of 33 mm, 40 mm, 50 mm, 66 mm were used for retrofitting

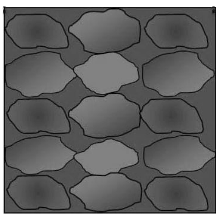
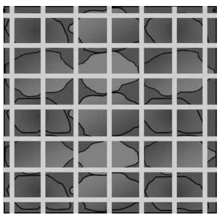
Wallette	Specimen	Unit type	Retrofitted condition	PP-band pitch (mm)	No. of Specimen
	S-NR-xx	Stone	X	40	3
	S-RE-33	Stone	√	33	3
	S-RE-40	Stone	√	40	3
	S-RE-50	Stone	√	50	3
	S-RE-66	Stone	√	66	3

Fig. 3 Experimental program

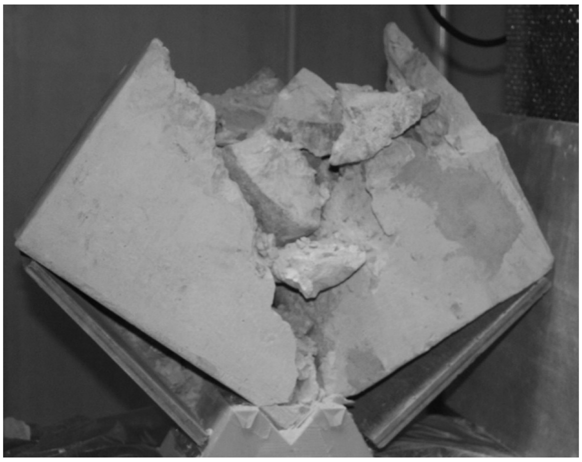


Fig. 4 Non-retrofitted specimen failure pattern

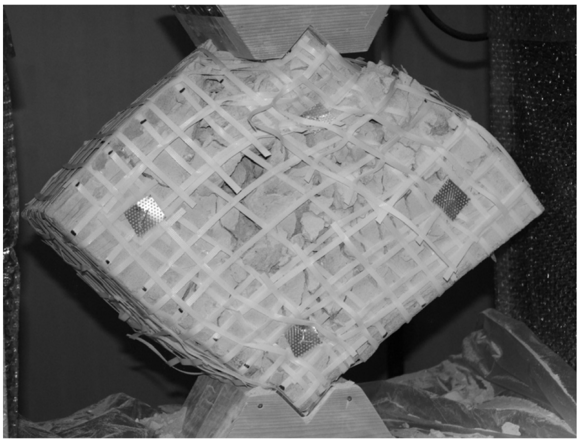


Fig. 5 Retrofitted Specimen failure pattern

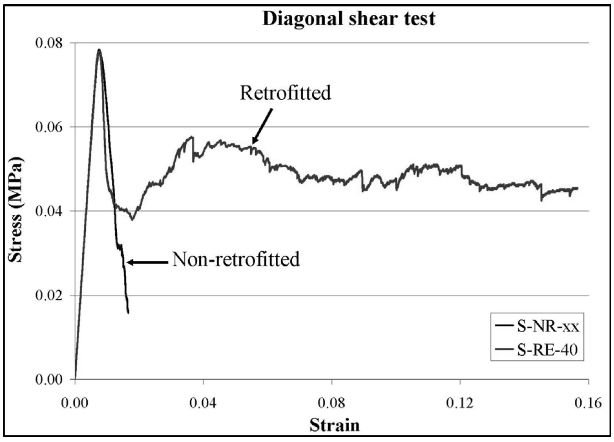


Fig. 6 Diagonal shear stress vs. Strain for shapeless stone masonry wallette

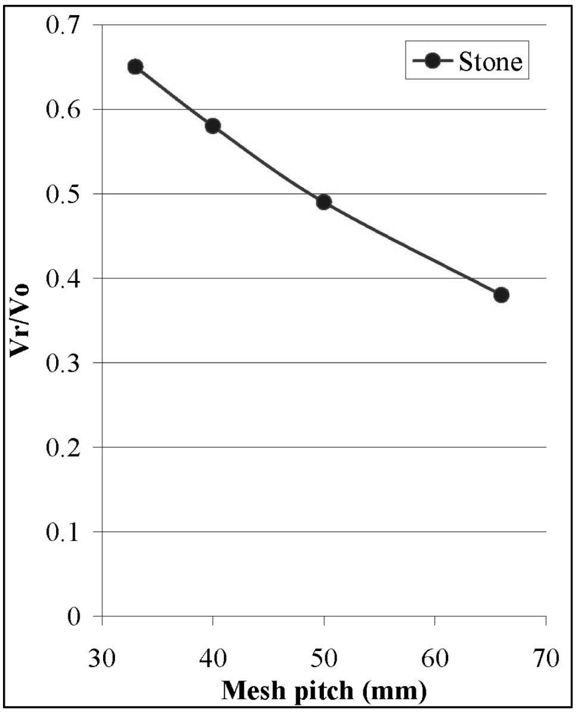


Fig. 7 Effect of PP-band density in residual strength of masonry wallette

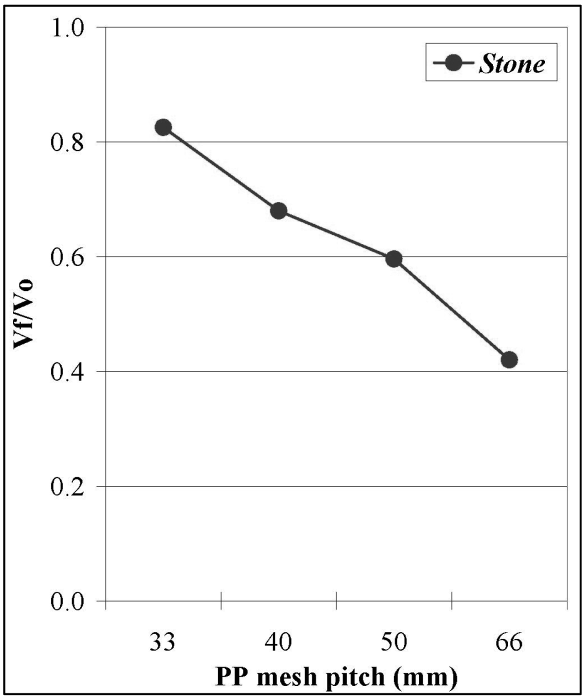


Fig. 8 Effect of PP-band density in final strength of masonry wallette

keeping other parameters same. To easy compare the behavior of retrofitted masonry wallettes; initial strength (Vo), initial Stiffness (Ko) , residual strength after initial crack (Vr) and final strength (Vf) were calculated. Initial strength (Vo) and initial stiffness (Ko) were mainly depending on the masonry properties. Residual strength after initial crack (Vr) and final strength (Vf) mainly depend on PP-band properties and PP-band density.

Fig. 7 shows the residual strength/initial strength (Vr/Vo) variation with PP-band mesh pitch width 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 of masonry wallette with PP-band mesh retrofitting is 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.

Fig. 8 shows the final strength/initial strength (Vf/Vo) variation with PP-band mesh pitch width of the masonry wallette. In general final strength of masonry wallette with PP-band mesh retrofitting is directly proportional to PP-band density up to some value.

4. Conclusion

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

1. Masonry wallette without PP-band mesh would loose the entire load bearing capacity after initial 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 of masonry wallette with PP-band mesh retrofitting is 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 is not increase with amount of the PP-band density. Similarly final strength of masonry wallette with PP-band mesh retrofitting is directly proportional to PP-band density.

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