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EXPERIMENTAL STUDY ON IN-PLANE AND OUT-OF-PLANE BEHAVIOR OF PP-BAND RETROFITTED MASONRY WALLETTE MADE OF SHAPELESS STONES

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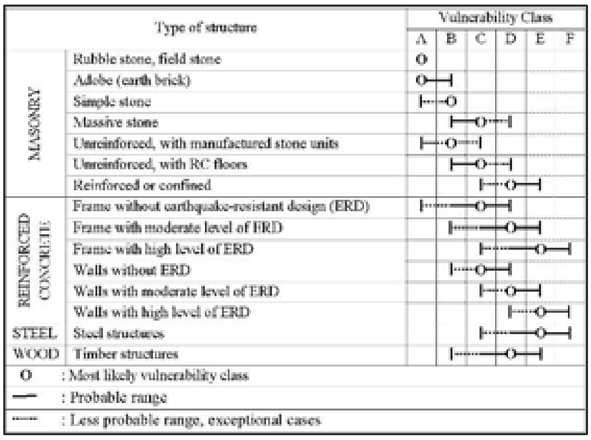
Abstract: Unreinforced masonry structure is one of the most popularly used constructions in the world, especially in developing countries. It is also unfortunately, the most vulnerable to the earthquake and its damage has caused many human casualties. Therefore, from global viewpoint, retrofitting of low earthquake-resistant masonry structures is essential to reduce the casualties by earthquake disaster. In developing countries, retrofitting method should be technically feasible and economically affordable, the retrofitting material, accessible, and the workmanship, locally available. Considering these points, PP-band (polypropylene bands, worldwide available and cheap material, commonly used for packing) retrofitting technique has been developed by Meguro Laboratory, The University of Tokyo. In this research, we conducted a series of experiments to verify the suitability of PP-band retrofitting for masonry structures made of shapeless stones. Material tests were conducted to understand the basic parameters of stone masonry, i.e. shear, tension and compression strength. After the material tests, diagonal compression test and out-of-plane test were carried out using masonry wallette made of shapeless stones with and without retrofitting. From both test results, it was clear that PP-band retrofitting improved drastically the overall stability and ductility of stone masonry structures made of shapeless stones.

1. INTRODUCTION

Masonry structure, constructed by piling burned bricks or unburned, just sun-dried, bricks called adobes, stones or concrete blocks, is one of the most popularly used constructions in the world, but also the most vulnerable to earthquakes. Because distribution of the masonry structures overlap with high seismicity area in the world, it has caused many human casualties during earthquake. Therefore in global viewpoint, retrofitting of low earthquake-resistant masonry structures is very important to save people from earthquake disaster. Considering these points, a new retrofitting technique for masonry has been developed based on the use of polypropylene band (PP-band) meshes by Meguro laboratory, The University of Tokyo[1). This PP-band retrofitting technique prevents masonry structures from collapsing by giving the stabilization.

Up to now PP-band retrofitting study mainly focus on houses build by regularly shaped bricks and adobes. But the masonry has many different kinds of construction and the effect of PP-band is not confirmed for all kinds of masonry. Especially in the mountainous region in developing countries, stone masonry is constructed using shapeless or shaped stones as constructing material[3). But stone masonry house, particularly shapeless stone masonry house is the most vulnerable during earthquake as shown in Table 1. Therefore further test of stone masonry wallettes should be carried out.

Table 1 Vulnerability Table[2)



2. MATERIAL TEST

2.1 Test Setup

Figure 1 shows the specimens used for shear, tension and compression tests to obtain the mechanical properties of the stone masonry. Shapeless stones whose size range from 60mm to 80mm were used for preparation of specimens. A mortar with the mixture ratio of cement : lime : sand = 1 : 5 : 14 and cement/water ratio = 0.20 in weight was used. To make the specimens close to real stone masonry structures made of shapeless stones in developing countries, gravel were put between the shapeless stones. The number of shapeless stones used for specimen was 3, 2 and 5 for shear, tension and compression test specimens, respectively as shown in Figure 1. Five identical specimens were constructed for each test. Specimens were tested 28 days after construction under displacement control condition and the loading rate was 0.1mm/min.

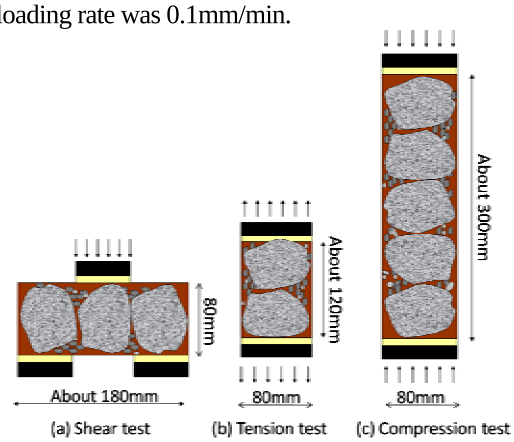


Figure 1 The Structure of The Specimens for Material Test

2.2 Results of Material Tests

Based on the difference of failure mechanism, major failure patterns of masonry can be divided into 3 types[4].

a) Failure occurred within the mortar.
b) Failure occurred along the interface between mortar and stone surface.
c) Failure occurred within the brick or stone.

Type c) failure can be observed only in case of special combination of very strong mortar and very weak brick or stone.

From the shear test's results, it is found that the failure pattern of masonry made of shapeless stones is type b) that is the separation along interface between stone surface and mortar because interface strength is less than that of mortar. Figure 2 shows the average strength of each test, i.e. shear, tension and compression tests. Figure 3 shows the failure pattern of stone masonry made of shapeless stones.

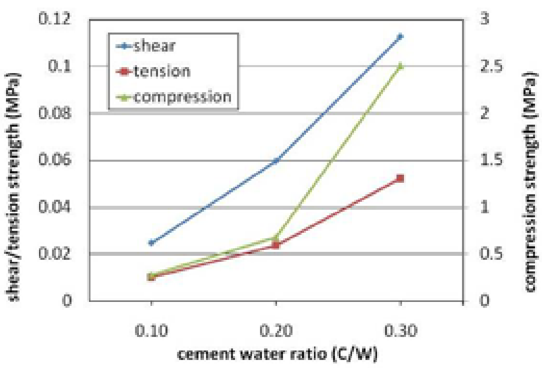


Figure 2 Mechanical Properties Obtained from Material Tests

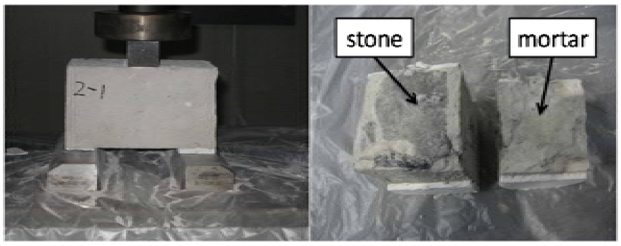


Figure 3 Separation along Stone-Mortar Interface

3. DAIAGONAL SHEAR TEST

3.1 Outline of The Diagonal Compression Test

To verify the suitability of PP-band retrofitting technique for stone masonry, diagonal shear test using 1/4 scaled model was conducted. The wallette dimension was 300×300×150mm^3 and it was composed of 5 × 3 stones, and 2 stones in the direction of depth as seen in Figure 4. Because the size and shape of stones were variable, there is approximately 10mm variation in the height of the specimens. Considering the results of material tests, we used a mortar with the mixture ratio of cement : lime : sand = 1 : 7.3 : 18.7 and cement/water ratio = 0.15 in weight for diagonal shear test to make the specimens close to real masonry structures made of shapeless stones in developing countries.

In this experimental program, masonry wallettes made of shapeless stones with and without retrofitting were prepared. In addition, specimens with 10mm surface finishing were prepared. Three identical wallettes were constructed for each test. Specimens were tested 28 days after construction under displacement control loading condition. The loading rate was 0.5mm/min up to the first 10mm of diagonal deformation, and then it was increased to 2mm/min up to 50mm and 5mm/min up to 100mm of diagonal deformation.

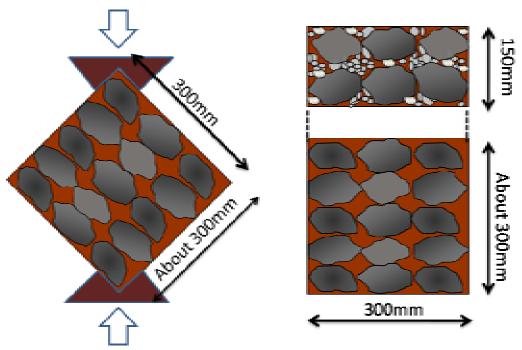


Figure 4 Specimen for Diagonal Shear Test

3.2 The Result of Experiment

Figure 5 shows the diagonal shear stress variation with strain for the non-retrofitted and retrofitted specimens. In the non-retrofitted case, there was no residual strength after the first crack occurred and the specimens split into two pieces at strain equal to 1.1%. If we consider average behavior of retrofitted specimens, although the initial crack was followed by a sharp drop, at least 64% of the peak stress remained. As the matter of fact, 3 specimens were used for each non-retrofitted and retrofitted case. Subsequent drops were associated with new cracks such as the ones observed in the retrofitted specimen that shown in figure 5, at the strain of 2.5%. After this, the stress was regained by readjusting and packing by PP-band mesh. The stress equal to 72% and 81% of the initial peak stress was remained at the strain equal to 10% and 20%, respectively. The residual peak stress of the specimen was 99% of initial peak stress. If we consider the overall behavior of retrofitted specimens, specimen didn't break at the strain equal to 24%, which indicates that retrofitted specimen was at least 21 times more ductile than non-retrofitted one.

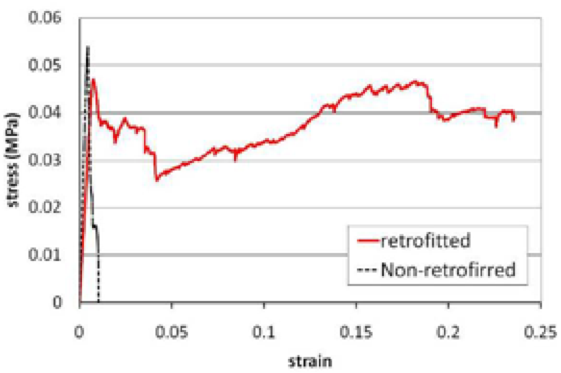


Figure 5 Stress vs. Strain for Stone Masonry Wallette with and without Retrofitting by PP-band Mesh

Figure 6 shows the non-retrofitted and retrofitted specimens at the end of test, which corresponded to the strain equal to 1.1% and 24%, respectively. As strain became larger, due to very low mortar strength, PP-band penetrated to the specimens. Therefore, increase of strength was not observed with strain. However, for specimens used for 1/4 scaled experiment, scaled PP-band whose width was approximately 6mm was used and it increased penetration-rate. But in case of full-scale structure, because 15mm PP-bands are used, penetration of PP-band meshes to the masonry houses are reduced relatively. Therefore additional increase of strength is expected, when the real masonry structures are retrofitted by PP-band meshes.

Figure 6 Failure Pattern of Stone Masonry Wallette (Left: without Retrofitting, Right: with Retrofitting)

Figure 7 shows the diagonal shear stress variation with strain for retrofitted specimens with and without surface finishing. As a surface finishing, mortar with the thickness of 10mm was pasted on specimens. In case of retrofitted specimen without surface finishing, 64% of the peak stress remained after the first crack. On the other hand, if we consider average behavior of retrofitted specimens with surface finishing, 77% of the peak stress was remained after the first crack. By overlaying mortar onto PP-band mesh, surface finishing fill the gap between PP-band mesh and masonry wallette and the residual strength became higher than that of the specimens without surface finishing. It was found that surface finishing makes beneficial effect in residual strength for masonry made of shapeless stones as well as for adobe and brick.

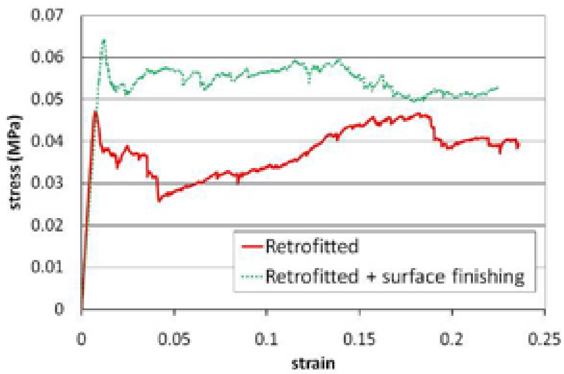


Figure 7 Stress vs. Strain for Retrofitted Stone Masonry Wallette with and without Surface Finishing

4. OUT-OF-PLANE TEST

4.1 Outline of The Out-of-plane Test

Out-of-plane test was carried out to investigate the effectiveness of PP-band mesh in walls exhibiting arching action. Wallette used was 1/4 scaled model and its dimension was 480×240×150mm^3 and it was composed of 4×5 stones, and 2 stones in the direction of depth as seen in Figure 8. Because the size and shape of stones were variable, there is the approximately 10mm variation in the height of the specimens. Considering the result of material tests, we used a mortar with mixture ratio of cement : lime : sand =1 : 4 : 11.2 in weight for out-of-plane test to make the specimens close to real masonry structures made of shapeless stones in developing countries. And also, not to give damage to the specimen before test, the cement/water ratio used was 0.25.

Masonry wallettes made of shapeless stones with and without retrofitting were prepared and three identical wallettes were constructed for each test. Specimens were tested 28 days after construction under displacement control loading condition. The wallettes were simply supported with a 440mm span and steel rods were used to support the wallette 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 0.5mm/min for the first 6mm of vertical deformation, and then it was increased to 2mm/min up to 65mm vertical deformation.

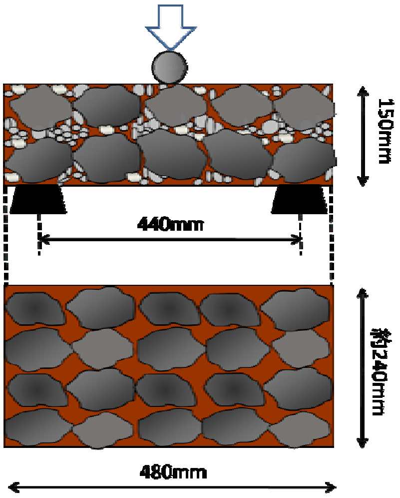


Figure 8 Specimen for Out-of-plane Test

4.2 The Result of Experiment

Figure 9 shows the out-of-plane load variation with net vertical deformation for the non-retrofitted and retrofitted specimens at the mid span. If we consider average behavior of non-retrofitted specimens, the initial strength was 1.34 KN and the specimens split into two pieces at the mid span deformation equal to 1.4mm. In the retrofitted case, although the initial crack was followed by a sharp drop, at least 33% of the peak strength remained. After this, the strength was regained progressively due to the PP-band mesh effects. In the retrofitted specimen shown in figure 9, the strength equal to 225% and 433% of the initial peak strength was observed at the mid span deformation equal to 20mm and 40mm, respectively. The residual peak strength of the specimen was 439% of initial peak strength. Specimen didn't break at the mid span deformation equal to 62mm, which indicates that; retrofitted specimen was at least 45 times more ductile than non-retrofitted one.

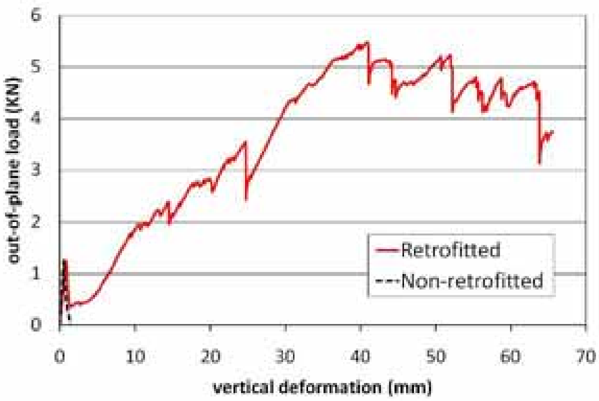


Figure 9 Out-of-plane Load Variation vs. Vertical Deformation

Figure 10 shows the non-retrofitted and retrofitted specimens at the end of test, which corresponded to deformation equal to 1.4mm and 62mm, respectively. In out-of-plane test, the improvement of final strength became much bigger than that of diagonal compression test. The cement/water ratio of the specimens used for the diagonal shear test was 0.15, but in case of out-of-plane test, the cement/water ratio equal to 0.25 was used. Because strength of mortar is high enough, PP-band didn't penetrate to the specimens and the drastic improvement of residual strength was observed.

Figure 10 Failure Pattern of Stone Masonry Wallette (Left: without Retrofitting, Right: with Retrofitting)

5. CONCLUSION

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

5.1 Summary of Diagonal Compression Test

If we consider average behavior of the specimens

1) Masonry wallette without PP-band mesh lost the entire load bearing capacity after crack appeared.
2) Masonry wallette with PP-band mesh retrofitting lost some of load bearing capacity immediately after the crack-initiation, but 64% of the peak stress was remained. With the effects of the PP-band meshes, it could regain the load bearing capacity, and its strength and deformability improved. According to the experimental result, 1.3 times higher peak stress and at least 21 times larger ductility were observed.
3) By overlaying mortar onto PP-band mesh retrofitted masonry wallette, 77% of the peak stress was remained after the first crack. It was higher than that of the specimens without surface finishing.

5.2 Summary of Out-of-plane Test

If we consider average behavior of the specimens

1) In case of out-of-plane tests, the mesh effect was not observed before the wall cracking. After cracking, the mesh presence positively influenced the wallette behavior. Also in case of retrofitted wallette, 33% of the peak strength was remained after the first crack occurred, and then strength was regained and improved.
2) The retrofitted wallettes could have 2.9 times higher strength and 45 times larger deformation than those of the non-retrofitted ones.

Considering the overall performance of the specimens, we can conclude that PP-band mesh retrofit method can effectively increase the seismic capacity of masonry wall made of shapeless stones, too. Based on the fact, we can expect that with PP-band mesh retrofit method, seismic capacity of weak stone masonry houses made of shapeless stones can also be improved very much and reduce drastically human casualties due to future earthquakes.

References:

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