REPAIR OF REINFORCED MASONRY WALLS WITH PREVIOUS SHEAR FAILURE

ANGEL SAN BARTOLOMÉ
Professor, Pontifical Catholic University of Peru, Lima, Peru

ARTURO CASTRO
Civil Engineer, Pontifical Catholic University of Peru, Lima, Peru

BRUNO VARGAS
Civil Engineer, Pontifical Catholic University of Peru, Lima, Peru

DANIEL QUIUN
Professor, Pontifical Catholic University of Peru, Lima, Peru

SUMMARY

A series of cyclic lateral load tests were performed to simulate earthquake behaviour on full scale masonry walls. One wall was made of clay bricks and confined by reinforced concrete elements, while the other one was made of fully grouted hollow concrete blocks with interior reinforcement. After the shear failure, they were repaired using welded mesh jacketing, covered with mortar.

The repaired walls were then subjected to similar cyclic lateral loads. The tests showed good results in both cases. Both repaired walls had an increase on lateral load capacity, and they changed to flexural failure mode with reduced cracking.

INTRODUCTION

Masonry bearing walls in buildings located in seismic areas have generally exhibited a shear failure when a strong earthquake happens (San Bartolomé 2007). This type of failure was produced experimentally on two different walls, wall W1 was made of clay bricks confined by reinforced concrete elements, and wall W2 was a fully grouted hollow concrete blocks with interior reinforcement. This paper deals with a series of experimental cyclic load tests to evaluate the effectiveness of a repair technique applied on both walls. The repair technique consisted in jacketing with welded mesh anchored to the wall, and covered with mortar. The repaired walls were then subjected to cyclic loads similar to the original ones, showing a good behavior in terms of resistance and ductility.

MATERIAL PROPERTIES

The walls were built to full scale. Wall W1 and W2 geometry may be seen in figure 1. The thickness for wall W1 was 130 mm and for W2 140 mm. The properties of the materials (units, mortar, grout, concrete and steel) used for the walls construction were as follows.

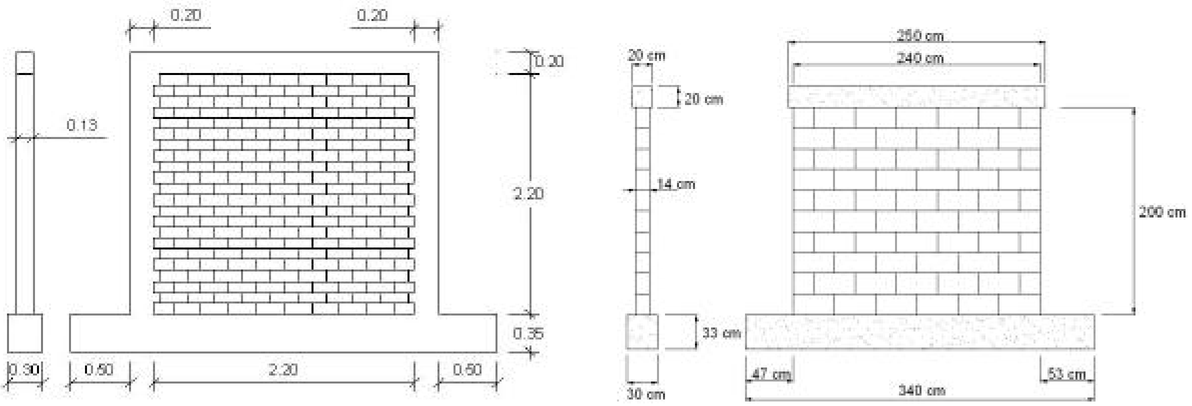

Figure 1. Geometry of Confined Wall W1 (left) and Reinforced Wall W2 (right)

Masonry Units

For wall W1, industrial clay bricks were used. The nominal dimensions of a typical brick are 230x130x90 mm. In the bearing surface, the bricks had small holes totalizing 45% of the gross area, which classified as hollow brick. Although the Peruvian Masonry Code establish that bricks for bearing walls may have holes up to only 30% (SENCICO 2006) of the bearing surface, hollow industrial clay bricks are very popular in Peru and widely used for building constructions (mostly informal). The compressive strength of this unit, measured over the gross area, reached 15.5 MPa.

For wall W2, industrial hollow concrete blocks were used. The overall dimensions of a typical block are 390x140x190 mm. Two cells in the bearing surface of the blocks totalized 32.5% of the gross area. The compressive strength of this unit, measured over the gross area reached 6.8 MPa. This block satisfied the Peruvian Masonry Code requirements for its use in bearing walls (SENCICO 2006).

Mortar, Concrete and Grout

For wall W1, a mortar of cement and coarse sand in 1:4 volume proportions was used. The mortar cubic specimens (50mm side) tested at 28 day-age had an average strength of 25.5 MPa. The confinement elements, columns and beams, were of concrete with f'c=28 MPa.

For wall W2, the mortar was composed of cement, lime and coarse sand in 1: ½: 4 proportions. The mortar cubic specimens tested at 28 day-age had an average strength of 15.6 MPa. Concrete for the collar beams had f'c=17.5 MPa. The grout mixture was 1: 2.5: 1.5 cement, coarse sand and small stones, it was prepared in a mixing machine and the slump was 250mm; the compressive strength for this grout reached 24 MPa.

Steel Reinforcement in Original Walls

All reinforcement bars were of steel with yield stress of fy=420 MPa. In the confined wall W1, the columns had 4 longitudinal bars 12-mm diameter, and the collar beam had 4 longitudinal bars 9.5-mm diameter. Stirrups in both columns and collar beam were 6-mm

diameter with 20mm spacing, with 5 stirrups at 10-mm spacing at both ends. In the reinforced wall W2, 6 vertical bars 16-mm diameter, each spaced at 400 mm and horizontal 9.5-mm diameter bars spaced at 400 mm were used.

Welded mesh used in Repaired Walls

For the repair process after the first series of tests, two different welded meshes were used. For the confined wall W1, the mesh had deformed bars 4.5-mm diameter with 150-mm spacing; the ultimate strength in tension was obtained as 611 MPa. For the reinforced wall W2, the mesh had deformed bars 5-mm diameter with 100-mm spacing; the ultimate strength in tension was 567 MPa.

MASONRY PROPERTIES

In order to get the plain masonry resistant properties, small prisms and walls were built in each case. Prisms were tested under axial compression to obtain the compressive strength f'_m, and the small square walls were tested under diagonal compression to obtain shear strength v'_m. The overall dimensions and values of strength are shown in Table 1. In figure 2 some of the small specimen's tests may be seen. The brick unit prisms had a fragile failure, due to the amount of holes in the bearing surface.

Table 1. Small masonry specimen's tests

Masonry unit	Prism height and thickness	Compressive strength f'_m	Small wall side and thickness	Shear strength v'_m
Clay brick	600mm, 130mm	8.6 MPa	600mm, 130mm	1.70 MPa
Concrete block	600mm, 140mm	9.4 MPa	800mm, 140mm	1.28 MPa

Figure 2. Small Masonry Specimens: Brick Prism (left) and Block Prism (center) Subjected to Axial Compression; and Small Wall of Blocks (right) Subjected to Diagonal Compression

CYCLIC LATERAL LOAD TESTS ON ORIGINAL WALLS

The original walls W1 and W2 were subjected to a series of cyclic lateral load tests controlling the top displacement, as shown in Table 2, where each step consisted of 1, 2 or 3 cycles until the hysteretic loop stabilizes. In figures 3 and 4, the instrumentation and test

setting for both walls are shown. Figure 5 displays the walls at the end of the test. In both walls the shear failure was produced.

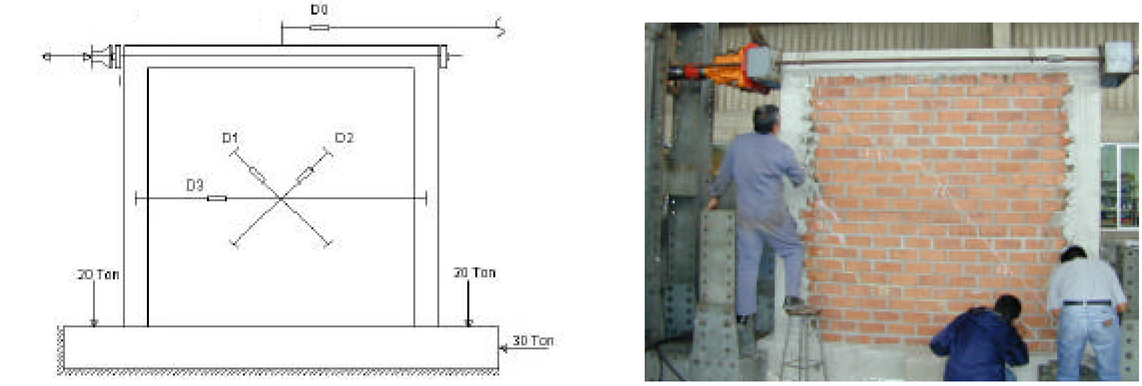

Figure 3. Lateral Load Test for Original Wall W1: Instrumentation and Overall View

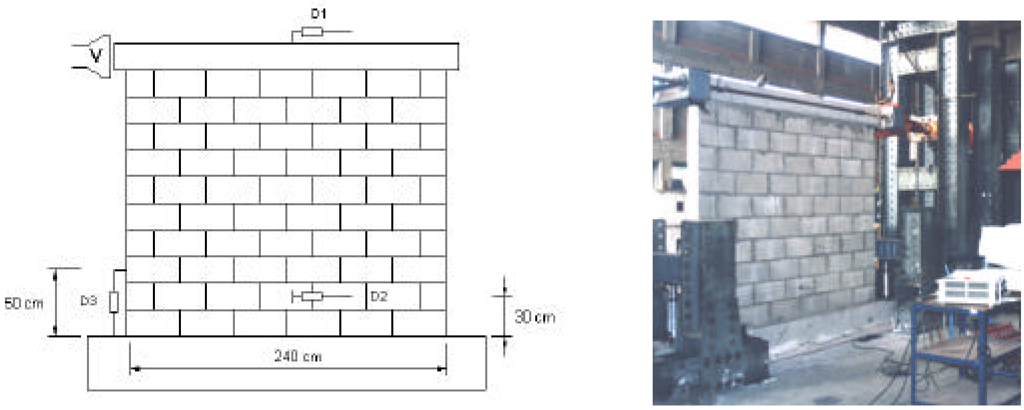

Figure 4. Lateral Load Test for Original Wall W2: Instrumentation and Overall View

Table 2. Top displacements for lateral load tests in original walls

Step	1	2	3	4	5	6	7	8
Top displ. (mm)	0.5	1.0	2.5	5.0	7.5	10.0	12.5	15.0

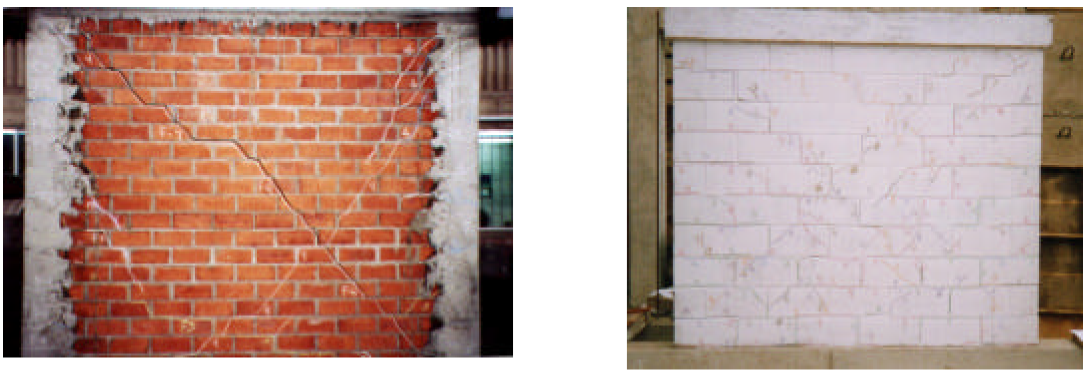

Figure 5. Original Walls after Lateral Load Tests

REPAIR OF TESTED WALLS

Jacketing Confined Wall W1

Figure 6 illustrates some of the steps taken during the repair process. The thicker cracks were cleaned, wetted and filled up with mortar 1:3. The thinner cracks were not treated. Crushed bricks were replaced with plain concrete. The concrete at the column-beam joint that cracked was replaced by other similar, using an epoxy resin to glue the concrete of different ages.

Afterwards, the wall was lightly covered with mortar 1:4. Then, holes were performed at the brick wall every 450 mm, which is three times the spacing of the welded mesh. Immediately, these holes were cleaned up with compressed air.

The welded meshes were placed, connecting wires were introduced through the holes, bend to 90°, and tied to the mesh with smaller wires. Later, the holes were filled with a liquid mortar with a proportion cement to fine sand 1:3. Finally, the whole wall was covered with mortar with a proportion cement to fine sand 1:4. The final wall thickness was 180 mm, including the meshes and coverings.

Figure 6. Repair of the Tested Brick Confined Wall W1

Jacketing Reinforced Wall W2

Figure 7 illustrates some of the steps taken during the repair process. With a cutter, 15-mm depth slots were done on the mortar and the blocks with the main cracks. The thinner cracks and the grout were not treated. Two powder admixtures were prepared with mortar to cover the slots; these admixtures increase the bond between the existing blocks and mortar.

Afterwards, holes were performed at the wall every 400 mm, at the intersection of vertical and horizontal joints, in order to not drill the original wall grout where existing reinforcing bars are. The connecting wires and the welded meshes were installed and tied together with smaller wires.

At both ends of the wall, a U-shape piece of welded mesh was added. This mesh had the objective to provide confinement to the free borders of the wall, in prevention of crushing due to flexural failure. Later, the holes were filled with a liquid mortar. Finally, the whole wall was covered with two layers of mortar with cement: sand 1:4 proportions. The wall thickness increased from 140 to 200 mm.

Figure 7. Reparation of the Tested Concrete Block Reinforced Wall W2

CYCLIC LATERAL LOAD TEST ON REPAIRED WALLS

The cyclic lateral load test on the repaired walls was similar to the original ones, with two more steps on each wall, in addition to the steps indicated in table 2. These extra steps were performed in order to study the wall behavior in extreme conditions. Therefore, the confined wall W1 had additional steps 8 and 9, with top displacements of 15 and 17.5 mm. Wall W2 had additional steps 9 and 10, with top displacements of 17.5 and 20 mm.

Behavior of Repaired Confined Wall W1

The welded mesh controlled the diagonal shear cracks, and the wall showed a pattern of flexure cracks. In step 7, a vertical crack in the column-wall lower joint; this crack occurred at a drift similar to the maximum limit established by the Peruvian Seismic Code (SENCICO 2003), which is 0.005. The covering started to fell in step 9, and a wall sliding of 10 mm was recorded. Figure 8 display the wall after the end of the test (after step 9). The crack pattern, the sliding and buckling of the vertical column bars may be observed.

Figure 8. Repaired Confined Wall W1 After the Cyclic Load Test

Behavior of Repaired Wall W2

Some small diagonal cracks appeared is step 4, located toward the upper half of the wall, which were much thinner than those in the original wall. However, the flexural failure was predominantly clear in steps 5 through 7, with some crushing of one of the free ends. At step 8, a sliding failure started at the wall base with the foundation beam. Figure 9 show the repaired wall after the test and some details of the cracks mentioned.

Figure 9. Repaired Wall W2 After the Cyclic Load Test

COMPARISON OF ORIGINAL AND REPAIRED WALLS

Confined Wall W1

The lateral stiffness of the original and repaired wall is shown in table 3, determined from test results. Nearly 85% of the original stiffness was recovered with the repair process.

Table 3. Stiffness K of Wall W1

Wall W1	K initial (kN/mm)	K final (kN/mm)
Original	138	14 (step 7)
Repaired	117	11 (step 9)

Figure 10 displays the envelopes of lateral load of the original and repaired wall. An increase of 40% in lateral load resistance was achieved. Also, the load started to decrease in the original wall with 9-mm lateral displacement, due to the crushing of the bricks, while in the repaired wall, this effect started with 14-mm lateral displacement, due to the sliding failure observed. Therefore, it can be concluded that the reparation technique showed good results.

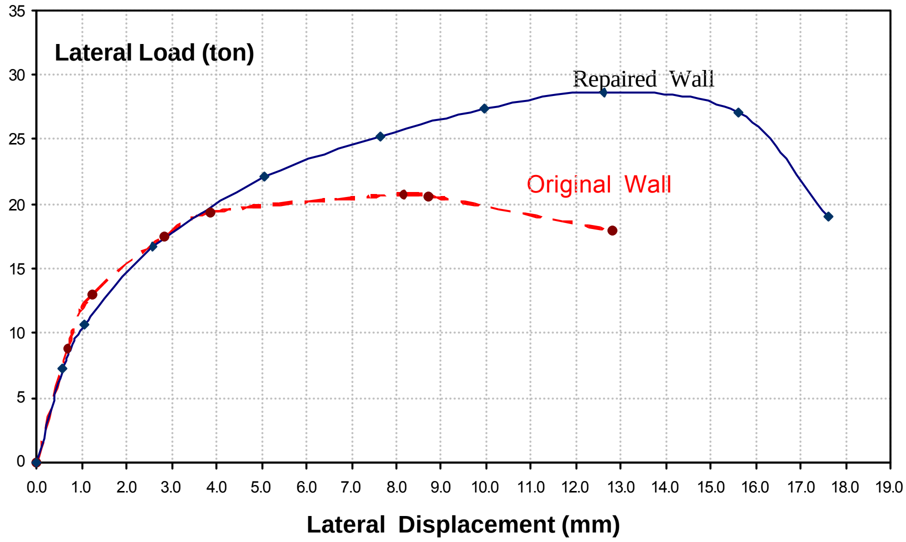

Figure 10. Envelopes of Lateral Loads in Confined Wall W1

Reinforced wall W2

The lateral stiffness of the original and repaired wall is shown in table 4, obtained from test results. Nearly 71% of the original stiffness was recovered with the repair process.

Table 4. Stiffness K of Wall W2

Wall W2	K initial (kN/mm)	K final (ton/mm)
Original	149.7	16.3 (step 8)
Repaired	105.7	20.0 (step 8), 14.9 (step 10)

Figure 11 displays the envelopes of lateral load of the original and repaired wall, corresponding to the hysteretic loops shown in figure 12. An increase of 23 % in lateral load resistance was achieved.

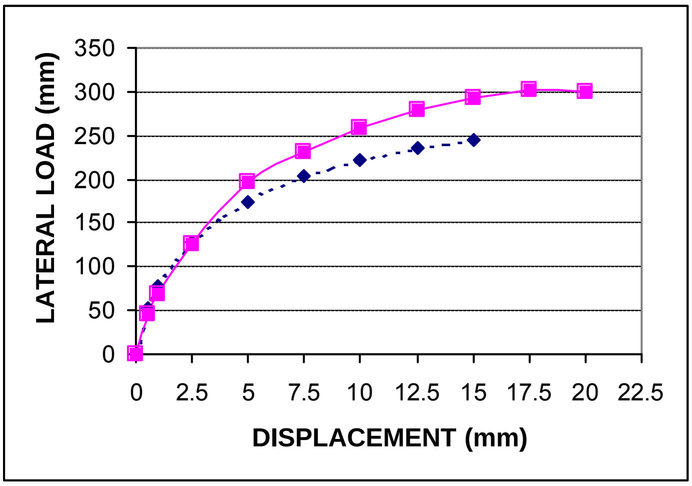

Figure 11. Envelopes of Lateral Loads in Wall W2

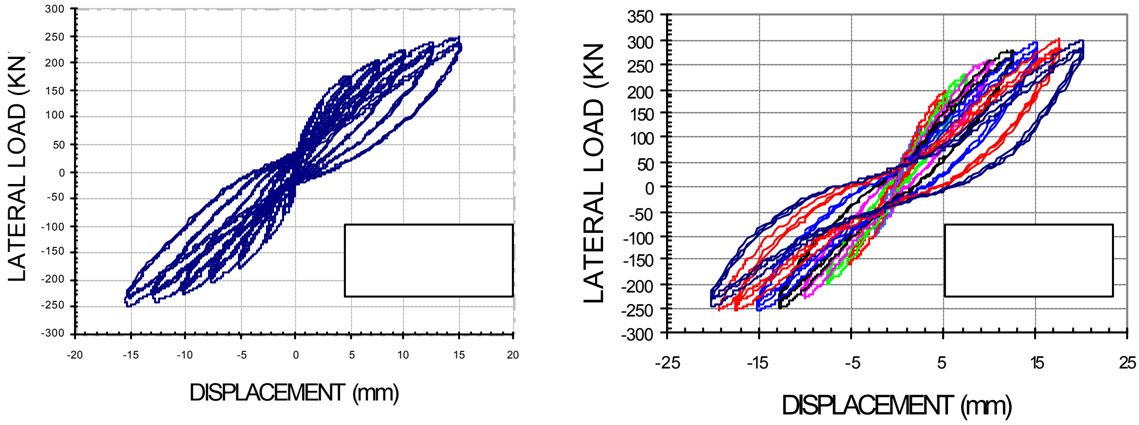

Figure 12. Hysteretic Loops for Wall W2

Failure Mode for Both Walls

The original walls W1 and W2, had a shear failure with diagonal cracking. After being repaired using jacketing technique, both walls showed a flexural failure with crushing of the wall base endings, which switched to a sliding failure; this behavior can be explained due to the increase of shear strength given by the welded mesh and mortar cover. The sliding failure is extremely dangerous, however, the sliding occurred for lateral drifts of 0.007, larger than the maximum drift allowed by the Peruvian Seismic Code for economic repair purposes, which is 0.005 (SENCICO 2003).

CONCLUSIONS

The bricks used in the confined wall W1 classified as hollow. When the original wall was subjected to moderate lateral loads, these fragile units started to crush, and the shear load capacity of the wall was reduced. If axial vertical load are applied, this poor behavior would had be even worst. Therefore, use of such hollow units should be discarded for bearing walls in seismic areas, except if a welded mesh covered with mortar is uses as a jacket.

In both walls W1 and W2, the repair technique of jacketing using welded mesh to both sides, properly anchored to the wall, was simple to apply. The lateral stiffness in the repaired walls was recovered up to 85% for wall W1, and up to 71% for the wall W2. A total recovery in stiffness is very difficult due to numerous thin cracks in the tested original walls that could not be repaired.

In terms of lateral load resistance, the repaired walls showed an important increase respect to the original ones (40% for wall W1 and 23% for wall W2). Also, the repaired walls showed a flexural failure with thinner diagonal cracks, which is preferable than the shear failure. This means that the welded meshes added to the walls could improve significantly the structural behavior of the walls when subjected to severe earthquakes.

The sliding failure that was observed in both repaired walls is not relevant, because this failure occurs for drift (0.007) larger than the maximum allowed by the Peruvian Seismic Code (0.005). In other words, in a properly Code-designed structure, such sliding should never occur.

It can be finally concluded that the overall repair process was successful. The repaired walls showed a better behavior than the original ones, except that the lateral stiffness was not completely recovered.

REFERENCES

San Bartolomé A., Website http://blog.pucp.edu.pe/albanileria, Lima, Perú, 2007 (in Spanish).

SENCICO, “Norma Técnica de Edificación E.030 Diseño Sismorresistente”, Lima, Perú, 2003 (in Spanish).

SENCICO, “Norma Técnica de Edificación E.070 Albañilería”, Lima, Perú, 2006 (in Spanish).