Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering
Compte Rendu de la 9ième Conférence Nationale Américaine et
10ième Conférence Canadienne de Génie Parasismique
July 25-29, 2010, Toronto, Ontario, Canada • Paper No 1540

EXPERIMENTAL STUDY ON THE PERFORMANCE OF BRICK MASONRY PIERS BEFORE AND AFTER RETROFITTING WITH REINFORCED PLASTER

Mohammad Ashraf[1], Qaisar Ali[2], Akhtar Naeem Khan[2], Bashir Alam[1], Amjad Naseer[1]

ABSTRACT

This paper presents the in-plane behavior of brick masonry piers before and after retrofitting, tested under quasi-static loading. The research is part of study to develop a cost-effective and efficient retrofitting technique for masonry buildings damaged in October 8, 2005 Kashmir Earthquake. The material properties of bricks and mortar were chosen to be representative of a typical brick masonry building in Northern Pakistan. Reinforced plaster is one of the techniques used for the retrofitting of brick and stone masonry buildings in the earthquake affected area. To study the performance of indigenous brick masonry after being retrofitted with reinforced plaster, four brick masonry piers of size 4 ft x 4 ft were tested before and after retrofitting in the Earthquake Engineering Center, University of Engineering & Technology Peshawar. Two of the damaged piers were repaired only with grout injection to study separately its effect on the behavior of pier. The other two piers were retrofitted with reinforced plaster (ferro-cement overlay) after being injected with grout. The results indicated that the technique was useful in the performance of unreinforced brick masonry piers.

Introduction

Retrofitting and rehabilitation of structures are of great benefit to the world, as each element of structure requires extra resources to build, more resources to move, supplementary processing to recycle or additional space to dispose. Various retrofitting and rehabilitation techniques are available for unreinforced brick masonry buildings, each technique having some advantages and disadvantages. Clearly, motivation exists for further development of efficient and cost-effective retrofitting technique. A review of various conventional and innovative retrofitting and rehabilitation techniques is given in [ElGawady-2004] and [Ashraf-2009]. The factors which are considered during the design of a retrofitting scheme include typology and existing condition of building, performance objective, cost of retrofitting, available time, resources and materials, preservation of historical value (if any), etc.

Application of reinforced plaster on the surface of unreinforced masonry wall is a technique which may be effectively used for the retrofitting of unreinforced masonry buildings. The technique consists of fixing steel welded wire mesh on the surface of wall subsequently plastered with a rich

[1] Assistant Professor, Department of Civil Engineering, NWFP UET Peshawar, Pakistan
[2] Professors, Department of Civil Engineering, NWFP UET Peshawar, Pakistan

mortar. The efficacy of the technique depends upon the connection between wall and reinforced plaster which transfers shear from wall to the plaster. The connection is established partly with the bond between mortar and the wall surface and partly with the connecting screws/bolts used to fix steel mesh with wall.

Kashmir earthquake of October 2005 resulted in collapse and damage of many unreinforced masonry buildings. The reinforced plaster in combination with cement based grout injection may be effectively used for the retrofitting of damaged buildings. The technique may also be useful for the retrofitting of reinforced concrete frame with infill masonry. Many private and public buildings have been retrofitted with the above-mentioned technique. This technique has been proven to be cost-effective and efficient as it does not require any special skill or material for its application and construction.

Some research work has been reported so far on the application of reinforced plaster for the retrofitting and rehabilitation of URM buildings. D. P. Abrams et al. [Abrams-2007] worked on rehabilitation of rocking critical masonry piers with reinforced plaster tested under quasi-static load. Slight increase in the initial elastic strength was observed. Once the mesh got fractured the strength was reduced and the pier continued to rock like a non-rehabilitated specimen. The technique was thus found to be not effective in the case of rocking critical piers. Lizudia et al. [Lizudia-1997] found that the double side coating is more effective than single side coating because of the confinement effect. The technique was found to be effective in enhancing the deformation capacity of masonry wall. Alcocer et al. [Alcocer-1996] applied the technique on confined masonry. He tested one full scale double storey building and three full scale walls under quasi-static loading. The technique not only improved the lateral strength but also the deformation capacity of confined masonry.

This paper presents the in-plane behavior of shear critical masonry piers retrofitted with reinforced plaster in combination with cement based grout injection under quasi-static loading. The research is part of study to develop a cost-effective and efficient retrofitting technique for masonry buildings damaged in October 8, 2005 Kashmir Earthquake.

Experimental Work

Four unreinforced brick masonry piers were subjected to increasing intensities of reverse cyclic loading in Earthquake Engineering Center of department of Civil Engineering, NWFP University of Engineering & Technology Peshawar, Pakistan. The material properties of bricks and mortar were chosen to be representative of a typical brick masonry building in Northern Pakistan. Besides cyclic test on masonry piers, direct compression test and diagonal compression test on masonry specimens were also performed to determine the compressive and diagonal tension strength of masonry. Before retrofitting, the specimens were tested up to their maximum resistance. The specimens were then repaired and/or retrofitted and retested under the same test setup till their final failure.

Materials

All the materials used for the construction of masonry pier specimens were selected according to the current practice in the Northern areas of Pakistan. The specimens were constructed in a 9″ thick English bond. Cement-sand-khaka (stone dust) mortar prepared in 1:4:4 ratio with a water cement ratio of 1.6 was used for the construction of all specimens. Average compressive strength of mortars was found to be 950 psi for specimens P5 and P6 and 1720 psi for specimens P9 and P16. The high variation in mortar strength is attributed to the variation in type of sand and khaka. First class solid burnt clay bricks with a nominal size of 9″x3″x4.5″ and average compressive strength equal to 3170 psi (Table-2) were used in the construction of test specimens. Compressive strength and modulus of elasticity of masonry prisms of size 16″ x 18″ x 9″ were found to be 720 psi and 204 ksi respectively. The average tensile strength calculated from the diagonal compression test was 35.2 psi.

Cement based grout (10 parts of Portland cement, one part of lime, Ultra expansion agent at a rate of 250 grams per 50 kilograms of cement with a water cement ratio of 0.9) was used as injection material. The water cement ratio of grout mix was decided based on the flow test proposed by Department of Building and Safety, Loss Angles [P/BC-2000]. Diagonal tensile strength of the specimen of size 18″x18″x4.5″ made from bricks and grout material was found to be 159 psi. 1/2″ x 1/2″ galvanized steel welded wire mesh made of 0.04″ diameter wires of 30.0 ksi tensile strength was used as reinforcement and connected to the pier surface by 1.5″ long No.10 screws and plastic Rawal plug. The screws were spaced at rate of 2 screws per square feet. The welded wire mesh was not connected to the bottom beam. Cement-sand mortar, prepared in 1:4 ratios, with an average compressive strength of 2550 psi was used as plaster and repair mortar for damaged specimens. An average thickness of plaster was 3/4″. The specimens were moist cured by covering the exposed surfaces with gunny bags which were kept moist by spraying water frequently for 28 days.

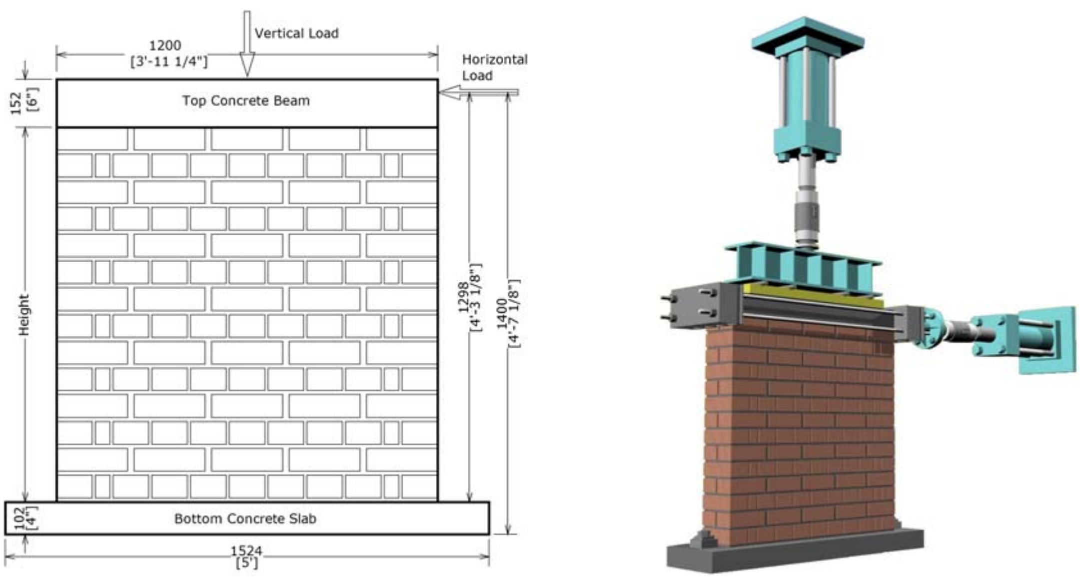

Figure 1. Experimental test Specimens before Retrofitting

Test specimens

A total of four unreinforced masonry specimens (P5, P8, P9 and P16) , of size 4ft x 4ft x 9″ thick, were tested under quasi-static loading before retrofitting, Figure 1. The damaged specimens were repaired/retrofitted and re-tested under the same loading conditions. Two of the damaged specimens i.e. P9 and P16 were repaired with plain plaster and grout injection. Other two damaged specimens P5 and P8 were retrofitted with reinforced plaster (ferro-cement overlay) and grout injection. The specimens, re-tested after repair/retrofitting, were named by adding letter “R” with the name of virgin specimens tested before retrofitting, e.g. P5 was named as P5R after retrofitting. The vertical stress was 140 psi in the case of P6, P6R, P8, P8R, P9 and P9R and 155 psi for specimens P16 and P16R. The variation in the vertical stress due rocking of the specimens was adjusted during the test. The high value of the vertical stress was applied to simulate the shear behavior in the piers.

Test setup

The experimental test setup is shown in Figure 2. The bottom concrete beam was fixed with test floor while the top was allowed to freely rotate and translate. Horizontal and vertical loads were applied through hydraulic jacks. The loads were measured with load cells of 112 kips capacity. Eight displacement transducers were used to record displacements. The load cells and displacement transducers were attached to a data acquisition system shown in Figure 2. In-plane displacements were measured through gauges 1 and 2 installed on front and back face of the specimen at the level of horizontal load. Average of the two values was used to plot the hysteresis loops and envelope curves.

The test was conducted in a displacement control environment. Displacement recorded by guage-1 was used as control displacement. Each displacement cycle was repeated three times.

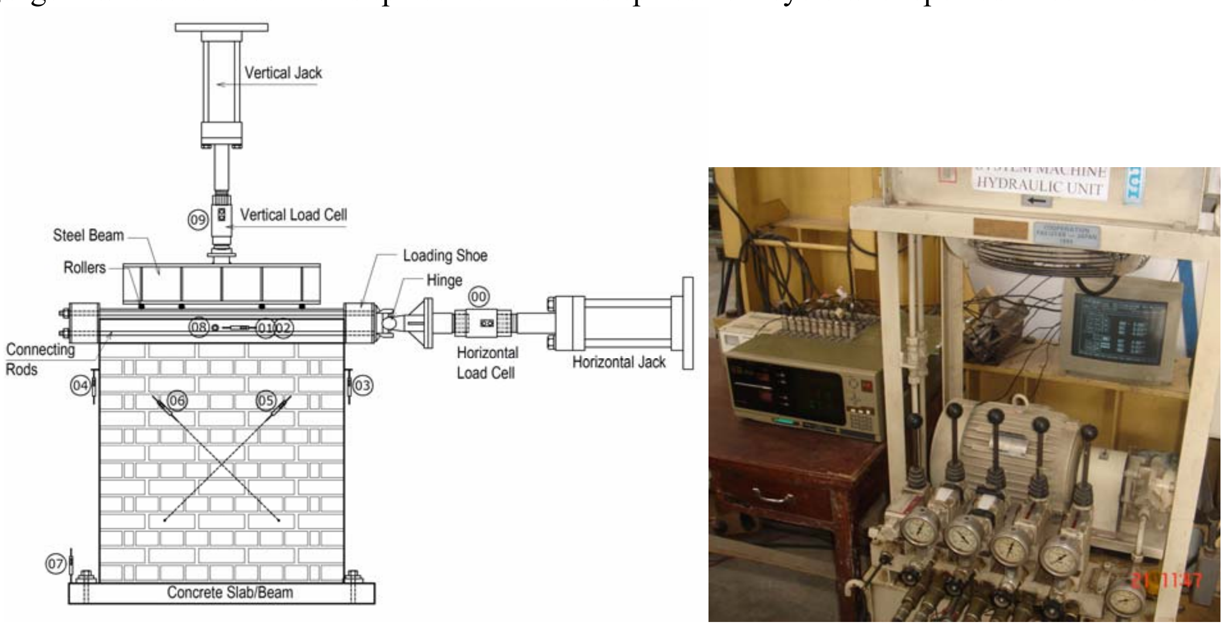

Figure 2. Experimental test setup (left), hydraulic system and data acquisition system (right)

Test Results and Discussion

The aim of the research work was to evaluate the in-plane capacity of shear critical unreinforced masonry piers retrofitted with reinforced plaster (ferro-cement overlay) in combination with grout injection. The vertical stress was kept more than the stresses produced in single and double storey buildings in order to simulate the shear failure mode.

Table 1. Summary of experimental results

Pier	Retrofitting	Vertical Stress, psi	Initial Cracking Load, kips	Initial Stiffness, kips/inch	Peak Load, kips	Ultimate drift (%)
P5	None	140	7.63	193.8	29.7	1.45*
P8	None	140	7.14	181.4	31.7	1.66*
P9	None	140	7.61	386.8	27.1	0.85
P16	None	155	-	525.2	35.6	1.04
P5R	Reinforced Plaster	140	-	461.0	36.3	1.69
P8R	Reinforced Plaster	140	-	578.7	38.0	1.62
P9R	Grout Injection	140	-	499.1	30.6	1.45
P16R	Grout Injection	155	-	664.5	32.0	1.20

* Ultimate drift is calculated from the yield drift of specimen times the ductility of control specimens tested up to complete failure

The vertical stress, initial cracking loads, initial stiffness, ultimate load and ultimate drift for all specimens tested before and after retrofitting are given in Table 1. Variation in the results of specimens tested before retrofitting may be attributed to the variation in mortar strength and mainly to the workmanship. In pier P16 the strength of brick was higher than the other specimens. The first two piers (P5 and P8) were tested up to the ultimate load and rests were tested till their ultimate failure. The ultimate drift of the first two specimens P5 and P8 was calculated as the product of their yield drift and the ductility ratio ($\mu = 5.4$) of the control specimen. The test results demonstrate that the reinforced plaster in combination with grout injection is capable of restoring strength of piers, Figure 3. Significant increase in the initial stiffness of the retrofitted specimens was observed in all specimens which was expected due to increase in pier thickness due to plaster and improvement in the mechanical properties due to grout injection. The increase in stiffness of specimens retrofitted with reinforced plaster (P5R and P8R) was very high when compared with the stiffness of specimens retrofitted with plain plaster (P9R and P16R). The reason may be the establishment of a proper bond between wall and plaster in specimens retrofitted with reinforced plaster. Comparison of each test pier before and after retrofitting is discussed in the following paragraphs.

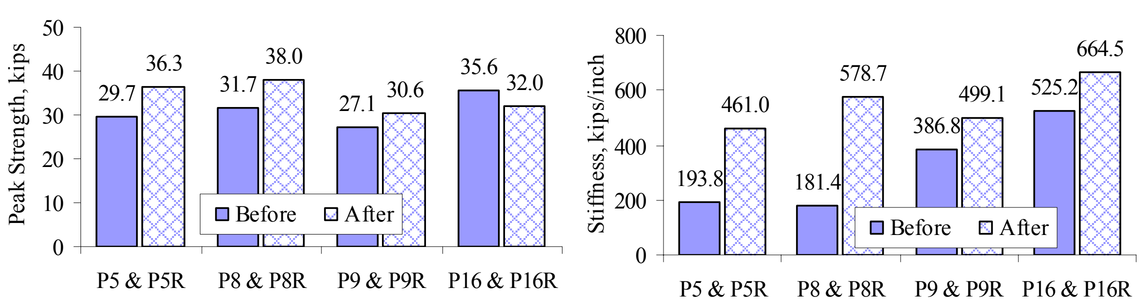

Figure 3. Comparison of force-deformation characteristics before and after retrofitting

Test Results for Specimens P5 and P5R

The force-deformation hysteresis loops of specimen P5 and P5R are given in Figure 4. The pattern of hysteresis loops of P5 are representative of a typical shear behavior while that of P5R represents a mixed rocking-shear mode. The application of reinforced plaster in combination with grout injection, thus, changed the behavior mode from shear to rocking-shear mode. Figure 5 shows the final damaged photograph of both specimens. The damages in specimen P5 were distributed in the whole specimen. First vertical compression cracks appeared and finally a diagonal crack was noticed at the peak strength. On the other hand in P5R the damages were mostly confined to the bed joint at the bottom. Initial cracking in the specimen P5 and P5R has been observed during 1.5 mm cycle. Increase in the shear strength of the pier was the reason to activate the rocking mode. The deformation capacity was limited by the out-of-plane sliding at the base of bear.

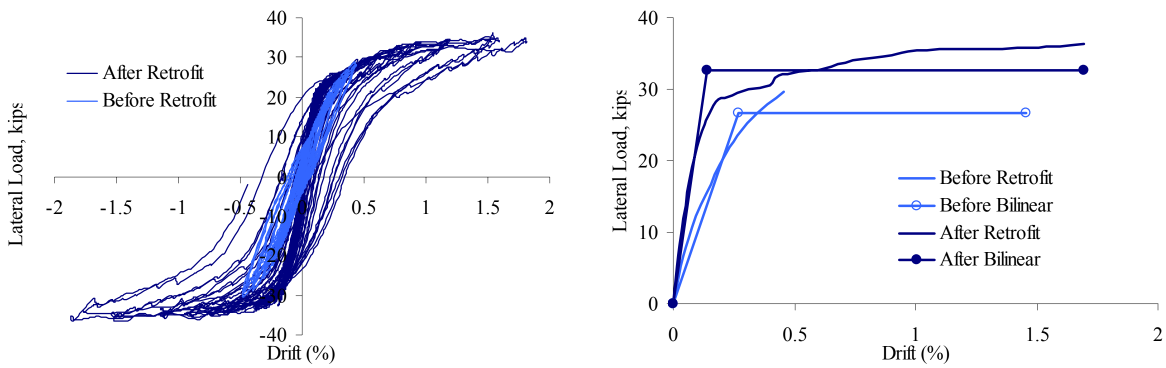

Figure 4. Force-deformation hysteresis loops (left) and average envelope curves (right) of Piers P5 and P5R

Figure 5. Final damage photograph of specimens P5 (left) and P5R (right)

Significant increase in the initial stiffness of the specimen was observed (Figure 3). The specimen continued to gain strength at almost constant post yield stiffness and no decrease in the strength of specimen P5R was observed even at drift of more than 1.5%. A 22% increase in the strength of specimen P5R was noticed in comparison to P5, Figure 3.

Test Results for Specimen P8 and P8R

The behavior of P8 and P8R was similar to that of P5 and P5R respectively. The retrofitting changed the behavior of specimen from shear to flexure (rocking) mode as obvious from the shape of force-deformation hysteresis loops of Figure 6. Similar to P5, first vertical cracks in P8 were appeared in mortar joints and then converted to diagonal cracks passing through the bricks near the peak strength (Figure 7). The pier P8R continued to rock with bed joint crack opening and closing. In the last cycles (1.5% drift) some out-of-plane sliding and twisting have also been observed which limited the deformation capacity of the retrofitted pier.

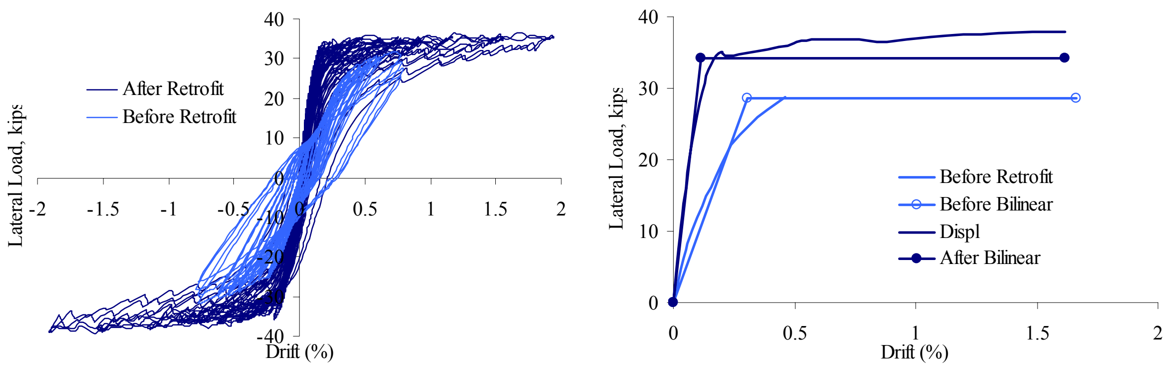

Figure 6. Force-deformation hysteresis loops (left) and average envelope curves (right) of Piers P8 a P8R

Initially the behavior of pier in positive and negative load directions was different. The pier was stiffer in negative load direction than in positive direction. But at the ultimate load both the curves coincided with each other. A little increase in the lateral strength but significant increase in initial stiffness has been noticed in the retrofitted specimen (Figure 3).

Figure 7. Final damage photograph of specimens P8 (left) and P8R (right)

Test Results for P9 and P9R

Typical shear behavior has been observed for specimen P9 (Figure 8). Initial cracking was observed at 0.04 % drift. With increasing drift, first vertical cracks appeared in the mortar joint followed by the formation of diagonal cracks passing through bricks at the ultimate load. The specimen was then repaired with grout injection and re-tested as P9R. P9R showed a mix rocking and shear behavior. The cracks were mainly confined in the lower half portion. No clear diagonal crack has been noticed (Figure 9). The ultimate condition appeared in the form of toe crushing.

Slight increase in the initial stiffness of the P9R was observed (Figure 3) which may be due to the plaster which is adding to the thickness of pier. Grout injection appeared effective in restoring the overall integrity of pier and thus resulting in increase in the shear strength of masonry. The deformation capacity was increased because of change in the behavior mode from pure shear to rocking-shear mode.

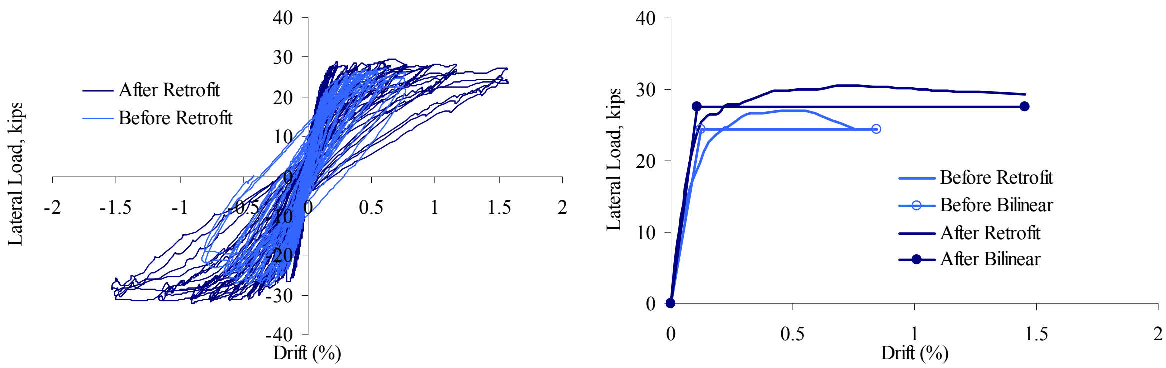

Figure 8. Force-deformation hysteresis loops (left) and average envelope curves (right) of Piers P9 and P9R

Figure 9. Final damage photograph of specimens P9 (left) and P9R (right)

Test Results for P16 and P16R

The specimen P16 was cast with stronger brick and different mason. The compressive strength of masonry prism was found to be 780 psi (about 8% more than the other specimes). In order to get the shear behavior, the compressive stress was increased from 140 psi to 155 psi.

P16 showed initially rocking behavior (Figure 10). Initial flexural cracking appeared at 0.07% drift. But in the last displacement cycle (0.9% drift) a diagonal shear crack appeared giving a sudden loss of strength. After being repaired with grout injection and plain plaster the specimen P16 was re-tested as P16R. The behavior of P16R was very similar to P16. First P16R rocked and then a diagonal crack appeared in the last few cycles. Toe crushing has also been observed (figure 10). No changes in the initial stiffness and deformation capacity have been noticed (Figure 3). About 90% of the pre-damaged strength has been restored with grout injection.

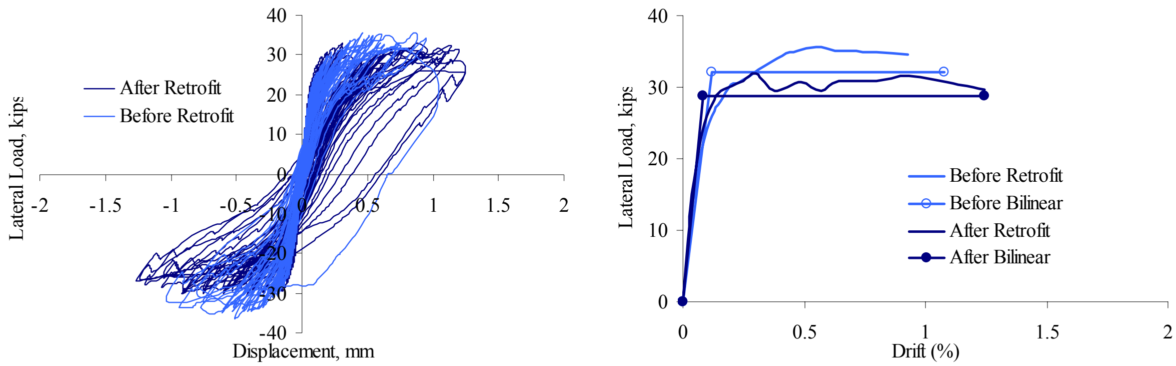

Figure 10. Force-deformation hysteresis loops (left) and average envelope curves (right) of Piers P16 and P16R

Figure 11. Final damage photograph of specimens P16 (left) and P16R (right)

Conclusions

The effectiveness of cement based grout injection and reinforced plaster (ferro-cement overlay) for the repair and retrofitting of damaged brick masonry building has been investigated under in-plane quasi-static loading. The following conclusion may be drawn from the experimental study:

- Cement based grout injection (10 parts of Portland cement, one part of lime, Ultra expansion agent at a rate of 250 grams per 50 kilograms of cement with a water cement ratio of 0.9) is an effective technique in restoring the initial stiffness, ultimate strength and deformation capacity of the masonry piers.

- No significant increase in the deformation capacities of the piers has been noticed.

- There was a substantial increase in the stiffness of piers retrofitted with reinforced plaster (more than 2.5 times of the stiffness before retrofitting) which is mainly attributed to the proper bond between plaster and wall surface established due to wire mesh.

- A 20% increase in the overall lateral capacity of piers retrofitted with reinforced plaster in combination with grout injection, was recorded. The increase in shear capacity of the piers, however, might be more than 20%, but the rocking response of the retrofitted piers limited the increase in overall lateral strength. In single and double storey brick masonry buildings with rigid diaphragm and deep spandrels, the piers may be considered as fixed at both ends and thus shear behavior is expected in piers with low aspect ratio even at low vertical stress. In such shear critical piers the techniques will be very much effective in enhancing their strength and deformation capacities.

Acknowledgements

Financial support provided by the Higher Education Commission Pakistan is gratefully acknowledged. The University of Engineering and Technology Peshawar is thanked for providing access to the testing facilities. The writers are also grateful to AHWA Chemicals Rawalpindi, Pakistan for providing Ultra expansion agent used in the cement based grout injection material.

References

M. ElGawady, P. Lestuzzi, M. Badoux, 2004. A Review of Conventional Seismic Retrofitting Techniques for URM, *13th IB²MaC*, Amsterdam.

M. Ashraf, A. Naseer, A. Naeem, K. Shahzada, 2009. Seismic Upgradation of Unreinforced Masonry Buildings as a Part of Disaster Management Policy, *Interntional Disaster Management Conference-2009*, Nathiagali, Pakistan.

D. P. Abrams, T. Smith, J. Lynch and S. Franklin, 2007. Effectiveness of Rehabilitation on Seismic Behavior of Masonry Piers, *ASCE Journal of Structural Engineering* 133 (1), 32-43.

Lizudia B., Homes W. T., Longstreth M., Kern A. and Abrams D. P., 1997. Development of procedures to enhance the performance of rehabilitated URM buildings, *Technical Report No. NIST GCR 97-724-1*, National Institute of Standards and Technology, Gaithersburg, Mary Land.

S. M. Alcocer, J. Ruiz, J. A. Pineda and J. A. Zepeda, 1996. Retrofitting of Confined Masonry Walls with Welded Wire Mesh, *11th World Conference on Earthquake Engineering,* Paper No. 1471.

Information Bulletin/ Public-Building Code, 2000. Crack Repair of Unreinforced Masonry Walls with Grout Injection, *P/BC 2002-056*, Department of Building and Safety, Loss Angles.