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Influence of Strengthening with Perforated Steel Plates on the Behavior of Infill Walls and RC Frame

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***Abstract*—**The contribution of the infill walls to the overall earthquake response of a structure is limited and this contribution is generally ignored in the analyses. Strengthening of the infill walls through different techniques has been and is being studied extensively in the literature to increase this limited contribution and the ductilities and energy absorption capacities of the infill walls to create non-structural components where the earthquake-induced energy can be absorbed without damaging the bearing components of the structural frame. The present paper summarizes an extensive research project dedicated to investigate the effects of strengthening the brick infill walls of a reinforced concrete (RC) frame on its lateral earthquake response. Perforated steel plates were used in strengthening due to several reasons, including the ductility and high deformation capacity of these plates, the fire resistant, recyclable and non-cancerogenic nature of mild steel, and the ease of installation and removal of the plates to the wall with the help of anchor bolts only. Furthermore, epoxy, which increases the cost and amount of labor of the strengthening process, is not needed in this technique. The individual behavior of the strengthened walls under monotonic diagonal and lateral reversed cyclic loading was investigated within the scope of the study. Upon achieving brilliant results, RC frames with strengthened infill walls were tested and are being tested to examine the influence of this strengthening technique on the overall behavior of the RC frames. Tests on the wall and frame specimens indicated that the perforated steel plates contribute to the lateral strength, rigidity, ductility and energy absorption capacity of the wall and the infilled frame to a major extent.

***Keywords*—**Infill wall, Strengthening, External plate, Earthquake Behavior.

I. INTRODUCTION

DUE to the design of structures before the development and implementation of modern building codes and the errors in the design and construction stages, there a significant number of buildings, which are liable to crucial damage in the case of moderate to severe earthquakes, in several parts of the world. The structures with inadequate earthquake resistance need to be strengthened through strengthening techniques which are not costly and time consuming and do not impair the use of the structures by their inhabitants. Adding new members (reinforced concrete infills) to the load bearing system of a structure or strengthening the existing ones are among the system improvement applications, aiming at increasing the lateral strength and rigidity of a structure. Nevertheless, these costly and time-consuming applications, which require skilled labor, are not feasible for the multibay multistory reinforced concrete frames. Strengthening the non-bearing infill walls of a structure is another retrofit practice which gained wide popularity among the researchers in the last decades since it gives the infill walls the ability to absorb significant proportions of the earthquake-induced energy and to contribute to the lateral strength and stiffness of the overall structure. Consequently, the bearing components of the structure are subject to less damage and the overall behavior of the structure during an earthquake is improved.

Different strengthening schemes have been applied and tested in the literature. Several researchers [1]-[4] investigated the use of CFRP sheets and GFRP laminates in strengthening and repair of infill walls due to the ease of their application. Although these sheets proved to be effective in contributing to the lateral rigidity and energy absorption capacity of the infill wall [3], the success of this method was found to depend primarily on the number and characteristics of the anchors between the strengthening layer and the wall. The high costs and skilled labor required for these materials, the low fire resistances of FRP and epoxy and the difficulties related to connecting the laminates or sheets to the wall with the help of bolts (tearing of the sheet) are among the disadvantages of this method.

The low fire resistance of the FRP sheets and the epoxy motivated several researchers [5]-[8] to use FRP textiles inside mortar (TRM), particularly in historical structures and found out that TRM contributed to the in- and out-of-plane capacities of the stone and masonry walls to a considerable extent. The application of shotcrete reinforced with steel mesh [9], [10] improved the behavior of brick wall when applied on both faces of the wall. The use of mortar of 2% steel fiber content increased the lateral load capacity of an infilled frame about 100% while also greatly contributing to its modulus of toughness [11]. Strengthening the infill walls with the help of precast concrete panels provided significant improvement in their behavior in the case of adequate anchorage of the panels to the infill wall and surrounding frame [12], [13]. The ferrocement layers increased the lateral load capacities of the walls and the number of diagonal cracks in the wall at failure while decreasing the crack widths [14], [15]. Although these studies yielded to promising results, the application of mortar, shotcrete or concrete reinforced with steel or FRP reinforcement to several walls in a structure is not feasible considering the amount of work and labor needed. The

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difficulty in the implementation of these strengthening techniques to real structures and the related costs stimulated the researchers to use mild steel strips, plates or profiles in strengthening or repair of infill walls [16]-[18]. As well as being less costly and easily applicable, the use of mild steel in different forms was found to greatly contribute to the lateral load-deflection behavior. In the case of mild steel strips, the flag plates connecting the strips to the corners of the wall increased the contribution of this strengthening technique to the lateral strength of the wall [18].

Based on the advantages of the mild steel plates and the promising results obtained by the previous researchers [16]-[18], a new strengthening technique was adopted in the present research program. Perforated steel plates bonded on both faces of the wall and connected to the wall and to each other with the help of bolts were used for strengthening brick walls. The advantages of this technique are as follows:

1. Mild steel is a ductile material. The high ductility of this material contributes to the ductility and deformation capacity of a brick wall strengthened with this material.
2. Mild steel plates are among the least costly strengthening materials. The low cost of these plates contributes to the overall economy of the procedure.
3. In contrast to FRP, mild steel is a recyclable, fire resistant and non-cancerogenic material.
4. The perforations in the plates, which are initially circular, elongate and increase the deformation capacity of the strengthening plate when loaded. The high deformation capacities of the perforated steel plates before rupture increase the ductilities and energy absorption capacities of the strengthened walls.
5. The holes in the wall, needed for the anchor bolts, can easily be drilled thanks to the perforations. In the case of solid plates (no perforations), drilling holes in the plate corresponding to the holes drilled in the wall is cumbersome, if not impossible.
6. Plates are anchored to the wall only with the help of bolts. Epoxy, which is a costly material, is not needed in this procedure, which reduces the overall cost. Furthermore, the plates can easily be installed, removed and reinstalled with the help of these bolts when needed.
7. If the locations of the sanitary and electrical fixtures inside the wall are marked on the wall before the process, these fixtures are not damaged when drilling the holes.
8. The plates can be hidden under the plaster for aesthetical purposes. Moreover, the plaster oozing through the plate perforations and reaching the wall provides a better connection between the plate and the wall and contributes to the composite behavior of the wall.

Regarding all the above-mentioned advantages, an extensive research program composed of three stages was and is being conducted to investigate the influence of these plates on the individual behavior of the brick infill walls and overall behavior of the infilled RC frame. In the first stage of the program, infill wall specimens strengthened with perforated steel plates were tested under diagonal monotonic loading [19]. This technique proved to be quite effective in improving the diagonal capacities and load-deflection behavior of the brick walls. In the second stage, the strengthened wall specimens were tested under reversed cyclic lateral loading and quite impressive results were reached [20]. The effects of different additional corner strengthening techniques were also tested in the second stage. In the final stage, which is still progressing, RC frame specimens with strengthened infill walls were and will be tested to examine the influence of this technique on the overall frame behavior. The present paper briefly summarizes the conclusions reached in the first and second stages and discusses the experiments carried out in the third stage.

II. FIRST STAGE OF THE PROGRAM

A total of thirteen 1000x1000mm (39.4x39.4 in.) brick infill walls (Table I) with a thickness of 125mm (4.9 in.) were tested under monotonic diagonal loading [19]. The specimens were strengthened with perforated steel plates on both faces with four different thickness values, which are 0.5, 1.0, 1.5, and 2.0mm (0.02, 0.04, 0.06 and 0.08 in). The specimens had three different bolt spacing values, which are 100, 150 and 200mm (3.93, 5.90 and 7.97 in., respectively). M6 anchor bolts were used in the specimens and these bolts were post-tensioned with a torque of 3 N.m (26 in-lbf).The bricks had measured compressive strengths of 12.0 MPa (1700 psi), 2.8 MPa (290 psi) and 3.2 MPa (430 psi) parallel to the horizontal channels, perpendicular to the channels in the lateral direction and perpendicular to the channels in the transverse direction, respectively. The mortar and plaster used in the specimens had a measured compressive strength of 42 MPa (6000 psi).

The walls were tested with the help of the setup, illustrated in Figs. 1 and 2. The wall specimens were placed in a steel test frame with hinged connections at all corners. These hinged connections provided the steel frame with negligible diagonal load capacity and stiffness, so that the frame did not affect the test results to a considerable extent. Furthermore, the test frame allowed the contact surface between the wall and the frame to change during the test in accordance with the damage level of the specimen identical to the conditions in a real structure.

The following conclusions were drawn from the first stage of the research program:

1. The perforated steel plates increased the diagonal load capacity, ductility index and energy absorption capacity values of the walls by 30-160%, 3-6 times and 4-14 times, respectively, with respect to unstrengthened wall. The initial stiffness values were not increased by strengthening considerably. All strengthened walls remained intact and had a ductile load-deflection behavior up to failure, generally caused by the corner crushing of the wall and out-of-plane buckling of the strengthening plates.

TABLE I
SPECIMENS OF THE FIRST STAGE

Specimen	Plate Thickness (mm)	Bolt Spacing (mm)
S0.5-100	0.5	100
S0.5-150	0.5	150
S0.5-200	0.5	200
S1.0-100	1.0	100
S1.0-150	1.0	150
S1.0-200	1.0	200
S0.5-100	1.5	100
S0.5-150	1.5	150
S0.5-200	1.5	200
S1.0-100	2.0	100
S1.0-150	2.0	150
S1.0-200	2.0	200

Conversion Factors: 1mm=0.039 in.

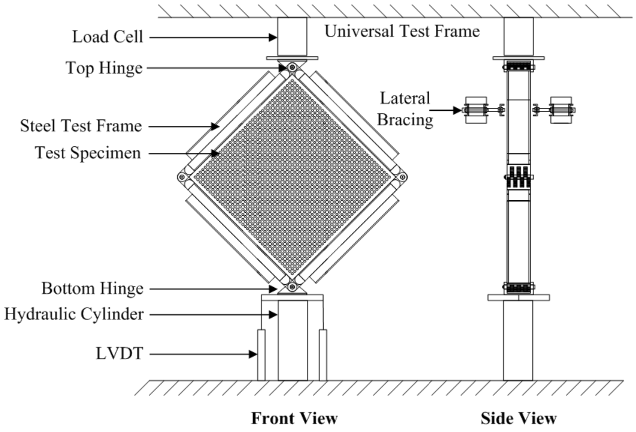

Fig. 1 Test setup of the first stage [19]

Fig. 2 Tests of the first stage

2. Spacing of the bolts proved to be quite influential on the wall behavior. In the case of inadequate number of bolts, the deformation capacities of the plates do not develop and the behavior of the strengthened wall does not improve significantly. Closely-spaced bolts prevent fluctuations in the load with increasing deformations, providing a smooth load-deflection curve. An increase in the plate thickness contributes to the diagonal strength and ductility of the wall only if the plates are connected to the wall with closely-spaced bolts, a spacing of 100mm (3.94 in.).
3. The ultimate diagonal strength of a strengthened wall is only provided by the strengthening plates since the contribution of the wall vanishes as soon as diagonal cracking takes place in the wall and the diagonal crack extends rapidly from the middle portion of the wall to the loaded corners.

III. SECOND STAGE OF THE PROGRAM

A total of thirteen 1500x1250mm (59x49 in) brick wall specimens (Fig. 3) were subjected to reversed cyclic lateral loading with the help of the test setup illustrated in Fig. 4 [20]. Both faces of the wall were covered with a plaster layer of 25 mm (0.98 in) thickness. Bricks from the same batch as the first stage of the program were used. The mortar and the plaster had measured compressive strengths of 14.2 and 12.3 MPa (2030 and 1740 psi), respectively. The perforated steel plates had a yield strength of 280 MPa (40.6 ksi).

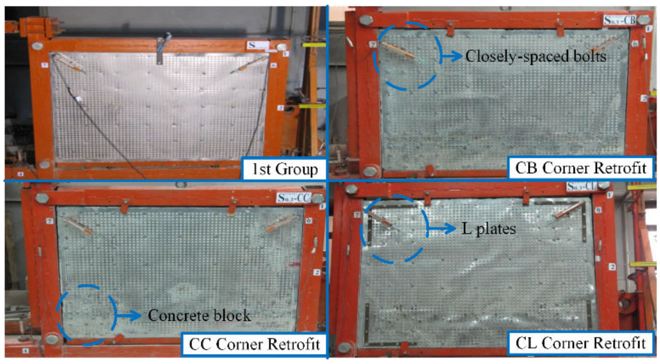

Fig. 3 Tests of the second stage

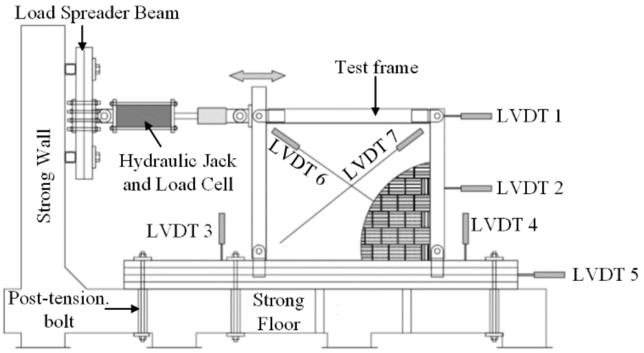

Fig. 4 Test setup of the second stage

The specimens tested in this stage are presented in Table II and Fig. 3. The twelve strengthened specimens are classified into two groups. The specimens in the first group were only strengthened with perforated steel plates on both faces of the wall. The specimens in this group are denoted with the capital letter "S", a number representing the thickness of the plate in mm (0.3, 0.5, 1.0) and a number representing the spacing of the bolts in mm (100, 150, 200).In addition to the perforated steel plates bonded to both faces of the wall, additional measures were taken in the second group of specimens to strengthen the corners, which are more susceptible to damage when loaded. All specimens in the second group had identical bolt spacing, 200mm (7.8 in). These specimens were denoted with the capital letter “S”, a number representing the plate thickness (0.3, 0.5) and a group of letters representing the method used for strengthening the corners (“CB” for reduced bolt spacing, “CL” for the use of L-shaped steel plates and “CC” for the use concrete blocks at the corners of the wall). In the specimens with a plate thickness of 0.3 mm (0.012 in.), the perforated plates were lapped along the length of the wall to investigate the influence of the lapped splices on the wall behavior. The strengthened walls exhibited a much more ductile behavior compared to the reference one (Fig. 5).

TABLE II
SPECIMENS OF THE SECOND STAGE

Group	Specimen	Plate Thickness (mm)	Bolt Spacing (mm)	Corner Strengthening Method	Lapped Splice
1	S0.5-100	0.5	100	-	-
	S0.5-150	0.5	150	-	-
	S0.5-200	0.5	200	-	-
	S1.0-100	1.0	100	-	-
	S1.0-150	1.0	150	-	-
	S1.0-200	1.0	200	-	-
2	S0.3-CB	0.3	200	Reduced Bolt Spacing	Yes
	S0.5-CB	0.5	200	Reduced Bolt Spacing	-
	S0.3-CC	0.3	200	R/C Block	Yes
	S0.5-CC	0.5	200	R/C Block	-
	S0.3-CL	0.3	200	Steel Plate	Yes
	S0.5-CL	0.5	200	Steel Plate	-

Conversion Factors: 1 mm=0.039 in.

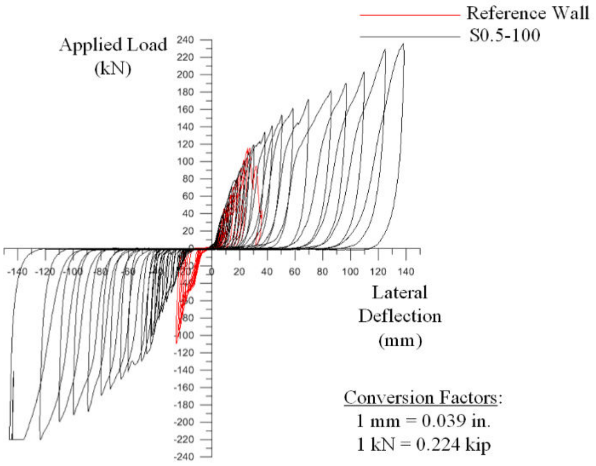

Fig. 5 Ductile behavior of the strengthened specimens compared to the reference one

This stage of the program yielded to the following conclusions:

1. The perforated steel plates have a great contribution to the lateral load-deflection behavior of the brick walls. The lateral load capacity, deformation ductility index, modulus of toughness and initial stiffness values of the strengthened walls exceeded the respective values of the reference wall by 15-130%, 40-450%, 5-10 times and 50-100%, respectively.
2. The corner retrofit applications prevented corner crushing of the walls, one of the most significant failure modes of the infill walls. Nonetheless, these applications resulting in over-rigid corners, causing the middle portions of the walls to undergo excessive damage and a wide horizontal crack to form around the mid-height of the specimen. Accordingly, the formation of the over-rigid corners should be avoided in corner retrofit techniques.
3. The lapped splices did not influence the behavior of the strengthened wall if the lapped plates are bonded to each other and to the wall with closely-spaced bolts.
4. A decrease in the spacing of the bolts has a greater impact on the behavior of the strengthened wall compared to an increase in the plate thickness.

IV. THIRD STAGE OF THE PROGRAM

A total of 38 infilled reinforced concrete frame specimens were and will be tested in this stage of the program (Table III and Fig. 6). Based on the tests conducted in the first and second stages, plate thickness values of 1.0, 1.5 and 2.0mm (0.04, 0.06 and 0.08 in) and bolt spacing values of 150 and 200mm (5.90 and 7.97 in.) are adopted in the third stage. In a real structure, strengthening might be needed in the lower, middle and upper stories of the structure. To represent different stories of the structure, the specimens of this stage differed in the magnitude of the axial load applied to the columns. Three magnitudes of axial load, namely 0, 75 and 150 kN (0, 16.7 and 33.7 kips) were adopted to represent the columns of the upper, middle and lower stories of a multistory RC frame, respectively. 75 and 150 kN (16.7 and 33.7 kips) correspond to approximately 25% and 50% of the axial load capacity of the columns of the specimens. In contrast to several studies in the literature, in which only 10% of the axial load capacity of the columns could be applied to the specimens due to the limitations of the test setup, axial loads as high as 50% of the column capacity could be applied in the present experimental program.

The specimens were denoted with the capital letter “S”, a number (1, 1.5 and 2) representing the plate thickness in mm; a capital letter corresponding to the level of the axial load applied to the columns (“Z” for no axial load, “L” for 75 kN axial load and “H” for 150 kN axial load); a capital letter corresponding to the presence of the connections between the perforated steel plates and the surrounding columns (“Y” for connection, “N” for no connection); and a final number (150 and 200) corresponding to the spacing of the bolts in mm. In half of the specimens, the perforated steel plates are only connected to the infill walls while they are connected to both the infill walls and the columns surrounding the walls in the other half. The connections to the surrounding columns were adopted as a test parameter to investigate whether this connections are able to prevent the out-of-plane deformations and displacements of the strengthening plates or not.

The experiments were and will be conducted at the Structural Mechanics Laboratory of the Engineering Faculty, Gazi University. The specimens will be fixed to the strong floor with the help of post-tensioning bolts, as illustrated in Fig. 7. The lateral load will be applied with the help of an automated double-action hydraulic jack. This jack will be connected to the reaction wall at one end and to a load cell at the other. The load will be conveyed to the specimen through hinges (Fig. 7) so that no forces perpendicular to the applied load form.

TABLE III
SPECIMENS OF THE FINAL STAGE OF THE PROGRAM

Specimen	Plate Thickness (mm)	Bolt Spacing (mm)	Axial Load (kN)	Connection to Columns
R1	-	-	-	-
R2	-	-	-	-
S1ZY150	1.0	150	-	Yes
S1ZN150	1.0	150	-	No
S1LY150	1.0	150	75	Yes
S1LN150	1.0	150	75	No
S1HY150	1.0	150	150	Yes
S1HN150	1.0	150	150	No
S1ZY200	1.0	200	-	Yes
S1ZN200	1.0	200	-	No
S1LY200	1.0	200	75	Yes
S1LN200	1.0	200	75	No
S1HY200	1.0	200	150	Yes
S1HN200	1.0	200	150	No
S1.5ZY150	1.5	150	-	Yes
S1.5ZN150	1.5	150	-	No
S1.5LY150	1.5	150	75	Yes
S1.5LN150	1.5	150	75	No
S1.5HY150	1.5	150	150	Yes
S1.5HN150	1.5	150	150	No
S1.5ZY200	1.5	200	-	Yes
S1.5ZN200	1.5	200	-	No
S1.5LY200	1.5	200	75	Yes
S1.5LN200	1.5	200	75	No
S1.5HY200	1.5	200	150	Yes
S1.5HN200	1.5	200	150	No
S2ZY150	2.0	150	-	Yes
S2ZN150	2.0	150	-	No
S2LY150	2.0	150	75	Yes
S2LN150	2.0	150	75	No
S2HY150	2.0	150	150	Yes
S2HN150	2.0	150	150	No
S2ZY200	2.0	200	-	Yes
S2ZN200	2.0	200	-	No
S2LY200	2.0	200	75	Yes
S2LN200	2.0	200	75	No
S2HY200	2.0	200	150	Yes
S2HN200	2.0	200	150	No

Conversion Factors: 1 mm=0.039 in.; 1 kN = 0.224 kip

In order to apply axial loading to the columns similar to the loading conditions in an actual frame, a rigid truss system composed steel members and roller bearings was designed and constructed. Accordingly, a hydraulic jack is placed on top of each column and the magnitudes of the axial loads in the columns are measured with the help of pressure gauges connected to the hoses of the jacks. As the frame deflects in the lateral direction, the rigid truss moves laterally and the vertical orientation of the axial loads is maintained thanks to the lateral translation of the rigid truss.

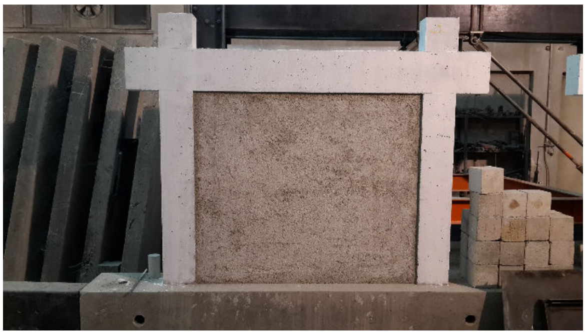

Fig. 6 Specimens of the third stage

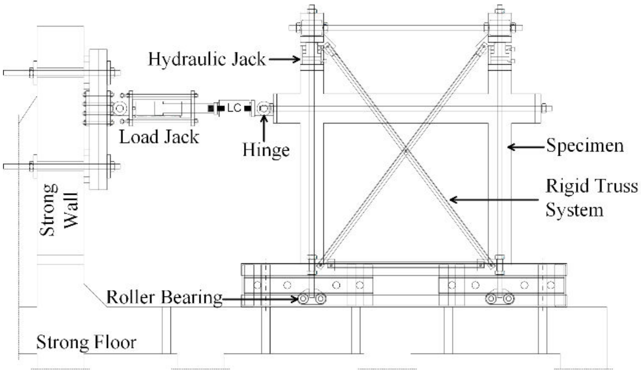

Fig. 7 Test setup of the third stage
(All dimensions are in cm and 1cm = 0.39 in.)

V. CONCLUSION

An extensive research program dedicated to investigate the influence of perforated steel plates on the earthquake behavior of RC frames with brick infill walls was conducted. The individual behavior of the brick wall specimens were tested under monotonic diagonal loading in the first stage of the experimental program, whose test parameters were the bolt spacing and the plate thickness. In the second stage of the program, the wall specimens were subjected to reversed cyclic lateral loading and the bolt spacing, plate thickness, corner retrofit applications and the presence of lapped splices in the perforated plates were adopted as the test parameters. Upon receiving promising results from the diagonal monotonic and reversed cyclic lateral loading of wall specimens, RC frames with strengthened infill walls were and are being tested under reversed cyclic lateral loading. A special experimental setup was constructed to apply reversed cyclic lateral loading to the frame while applying axial loads to the columns, which always maintain their vertical orientation while the frame deflects in lateral direction. The bolt spacing, plate thickness, axial load in the column and presence of the connections between the strengthening plates and the columns were chosen as the test parameters.

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REFERENCES

[1] T. C. Triantafillou, “Strengthening of masonry structures using epoxy-bonded FRP laminates,” *ASCE J. Compos. Construct.*, vol. 2, no.2, pp. 96-104, 1998.

[2] G. Ozcebe, U. Ersoy, T. Tankut, E. Erduran, R. S. O. Keskin, and H. C. Mertol, *Strengthening of brick infilled RC frames with CFRP*. SERU-Structural Engineering Research Unit, Report No. 2003/1, TUBITAK-METU, Ankara, Turkey, 2003.

[3] I. Erdem, U. Akyuz, U. Ersoy, and G. Ozcebe, “An experimental study on two different strengthening techniques for RC frames,” *Eng. Struct.*, vol. 28, no. 13, pp. 1843-1851, 2006.

[4] W. W. El-Dakhakhni, A. A. Hamid, Z. H. R. Hakam, and M. Elgaaly, “Hazard mitigation and strengthening of unreinforced masonry walls using composites,” *Compos. Struct.*, vol. 73, no. 4, pp. 458-477, 2006.

[5] T. C. Triantafillou and C. G. Papanicolaou, “Shear strengthening of reinforced concrete members with textile reinforced mortar (TRM) jackets,” *Mater. Struct.*, vol. 39, no. 1, pp. 93-103, 2006.

[6] T. C. Triantafillou, C. G. Papanicolaou, P. Zissimopoulos, and T. Laourdekis, “Concrete confinement with textile-reinforced mortar jackets,” *ACI Struct. J.*, vol. 103, no. 1, pp. 28-37, 2006.

[7] A. Prota, G. Marcari, G. Fabbrocino, G. Manfredi, and C. Aldea, “Experimental in-plane behavior of tuff masonry strengthened with cementitious matrix-grid composites,” *ASCE J. Compos. Constr.*, vol. 10, no. 3, pp. 223-233, 2006.

[8] C. G. Papanicolaou, T. C. Triantafillou and M. Lekka, “Externally bonded grids as strengthening and seismic retrofitting materials of masonry panels,” *Construct. Buil. Mater.*, vol. 25, no. 2, pp. 504-514, 2011.

[9] L. F. Kahn, “Shotcrete strengthening of brick masonry walls,” *ACI Struct. J.*,vol. 6, no. 7, pp. 34-40, 1984.

[10] M. A. ElGawady, P. Lestuzzi, and M. Badoux, “Retrofitting of masonry walls using shotcrete,” *Proc. New Zealand Soc. Earthq. Eng. Conf.*, March 2006, Napier, New Zealand.

[11] T. Sevil, M. Baran, T. Bilir, and E. Canbay, “Use of steel fiber reinforced mortar for seismic strengthening,” *Constr. and Build. Mat.*, vol. 25, no. 2, pp. 892-899, 2011.

[12] R. J. Frosch, W. Li, J. O. Jirsa, and M. E. Kreger, “Retrofit of non-ductile moment-resisting frames using precast infill wall panels,” *Earthq. Spectra*, vol. 12, vol. 4, pp. 741-60, 1996.

[13] M. Baran and T. Tankut, “Experimental study on seismic strengthening of RC frames by precast concrete panels,” *ACI Struct. J.*, vol. 108, no. 2, pp. 227-237, 2011.

[14] İ. B. Topcu, B. Isikdag, O. Tatar, and E. Abi, “Depremde hasar görmüş binaların ferrocement panellerle güçlendirilmesi (in Turkish),” *Earthq. Symp.*, Aug. 2005, Kocaeli, Turkey.

[15] K. M. Amanat, M. M. M. Alam, and M. S. Alam, “Experimental investigation of the use of ferrocement laminates for repairing masonry infilled RC frames,” *J. Civ. Eng. (IEB)*, vol. 35, no. 2, pp. 71-80, 2007.

[16] M. Taghdi, M. Bruneau,and M. Saatcioglu, “Seismic retrofitting of low-rise masonry and concrete walls using steel strips,”*ASCE J. Struct. Eng.,*vol. 126, no. 9, pp. 1017-1025, 2000.

[17] S. H. Farooq, M. Ilyas, and A. Ghaffar, “Technique for strengthening of masonry wall panels using steel strips,” *Asian J. Civ. Eng.*, vol. 7, no. 6, pp. 621-638, 2006.

[18] E. Ozbek and H. Can, “Dolgu tuğla duvarların çelik profillerle güçlendirilmesi (in Turkish),” *J. Fac. Eng. Archit. Gazi Uni.*, vol. 27, no. 4, pp. 921-929, 2012.

[19] S. Aykac, I. Kalkan, and M. Seydanlioglu, “Strengthening of hollow brick infill walls with perforated steel plates (Accepted for publication),” *Earthq. Struct.*,to be published.

[20] I. Kalkan, B. Aykac, M. Baran, R. Babayani, and S. Aykac, “Delikli çelik levhalarla güçlendirilmiş dolgu duvarların deprem davranışı (in Turkish),” *The Turkish Chamber of Civil Engineers 5th Symp. on Steel Struct.* , March 2013, Istanbul, Turkey.