

Unreinforced Brick Walls with Openings Rehabilitated Using U & L-Shaped Steel Plates

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Abstract — In the present study, five unreinforced brick walls of dimensions 66 cm height, 86 cm width and 10 cm thickness with 25cm x 25cm opening dimensions were constructed and tested under uniform loading. One wall was tested as control wall and was loaded until failure. Three walls were loaded up to 80% of failure load till cracks occurred and then rehabilitated using (2x40mm, 2x60mm, 2x80mm) of L&U-shaped steel plate inside opening corners welded with U & L-shaped steel plate at both sides. Another wall was loaded up to 80% of failure load till cracks occurred and then rehabilitated using diagonal steel plate around opening at both sides. The obtained test results show that the walls rehabilitated by using different dimensions of L&U-shaped steel plate gives an increase in the load carrying capacity up to 63.64% of the control ultimate capacity but no significant increases in ductility. As well as for wall rehabilitated by using diagonal steel plate around opening at both sides gives an increase in the load carrying capacity up to 29.70% of the control ultimate capacity but no significant increases in ductility. However, increasing dimensions of L&U-shaped steel plate used in rehabilitation increases the load carrying capacity of walls and no significant increases in ductility.

Keywords — Brick walls, opening, rehabilitation, steel plate.

I. INTRODUCTION

There are various methods of strengthening and rehabilitation unreinforced masonry structures in different categories. Application of different methods of rehabilitation to unreinforced masonry structures is expected to increase strength and ductility of the structure. However, sometimes the cost of strengthening and rehabilitation is not reasonable. The most suitable methods for strengthening and rehabilitation of unreinforced masonry brick walls are introduced below. The cracking through the masonry developed primarily along the mortar joints in a diagonal stepping pattern as shown in figures (1) and (2). The followings are some of the literature reviews for rehabilitation and strengthening of unreinforced masonry walls.



Figure (1): The cracking through the masonry developed primarily along the mortar joints in a diagonal stepping pattern at filed.

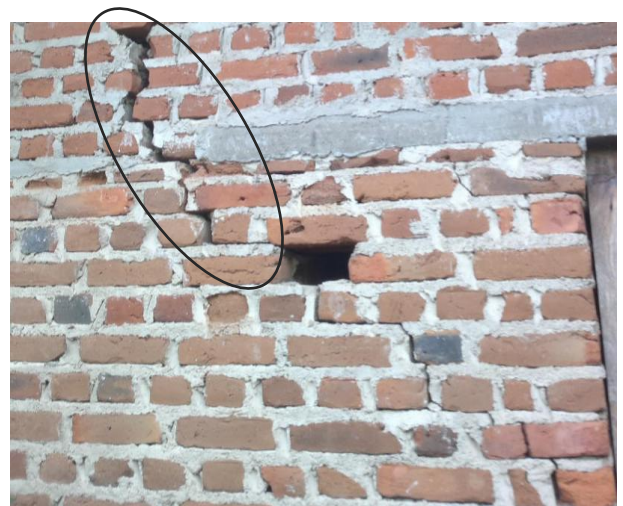


Figure (2): Diagonal cracks in brick wall.

II. Literature Review

Elhashimy et al [1] studied the shear behavior, the deformational shapes and the load carrying capacity of ten grouted partially reinforced masonry shear walls. These walls were repaired using GRP. The walls considered were of different cross sectional shape T section, L section and rectangular walls. The repaired walls were initially loaded to failure prior to

repairing them, and then the walls were retested in the same way after repairing with GRP. Different parameters were investigated as wall aspect ratio, axial stress, wall flange width and effect of repairing walls with GRP on wall reinforcement. The conclusions reached were: (i) GRP laminate is considered an efficient repair technique for damaged reinforced masonry walls because it prevented the occurrence of the original shear and splitting failures. (ii) The load carrying capacity of the repaired walls exceeded that of the plain walls. (iii) The GRP laminates decreased the internal deformations of the repaired walls. (iv) The GRP laminates changed the failure mode of the repaired walls from shear mode of failure to rocking mode of failure with vertical steel reinforcement yielding. (v) GRP is considered an efficient repairing method for increasing the load bearing capacity and ductility of reinforced masonry walls. Fernando Y. et al. [2] studied the behavior of lightly reinforced confined masonry shear walls with openings, sixteen full-scale specimens were tested. Eight specimens were of concrete masonry units and eight of hollow clay brick masonry units. The results showed that masonry unit type and size of the openings control the behavior and that confined masonry walls. The results also showed that it is conservative to consider the shear capacity proportional to the net transverse area of the walls. Mohammed B. S. et al. [3] said that the area around openings in the form of doors, windows and opening for mechanical and electrical services in axially loaded structural masonry panels are locations of strain concentration. In order to capture the true distribution of strains in discontinuous regions such as opening, tests were made to measure the surface strain variation around the opening in masonry panels subject to compressive load using uniaxial foil strain gauges. Experimental results were compared with results of finite element analysis. Measured strains near the opening boundary showed high localized strain concentration near the opening boundary, which reduce as the distance from the opening boundary increase.. Elsamny, M. K. et al. [4] investigated strengthening brick walls by galvanized steel mesh embedded in bed mortars. The experimental program includes testing of 10 walls 100 x 72 x 11 cm. Horizontal galvanized steel mesh 10 cm wide was used as embedded material into bed mortar between bricks during construction. The effect of the number of horizontal steel mesh layers have been investigated. However, the use of this technique in strengthening has a great effect on wall bearing capacity of walls. An increase of 8.64% to 24.88%

has been obtained depending on the type of mortar used and on the number of the steel mesh layers. Elsamny, M. K. et al. [5] presented a new technique for strengthening brick walls using galvanized steel mesh fixed at the wall faces. The experimental program include testing of 8 walls 100 x 72 x 11 cm. The wall sides have been strengthened with different numbers of layers. The steel mesh layers have been placed on one side as well as both sides of the walls. The vertical steel mesh layers have been fixed to the wall sides by nails and nuts after which plastering with cement mortar have been placed. The use of two vertical steel mesh layers fixed on both sides on the wall gave an increase in wall carrying capacity of 60.98 % while four vertical steel mesh layers fixed on both sides on the wall gave an increase in wall carrying capacity of 78.05 % and that for 300 kg/m³ mortar. However, two vertical steel mesh layers fixed on one side on the wall gave an increase in wall carrying capacity of 26.83 % while four vertical steel mesh layers fixed on one side on the wall gave an increase in wall carrying capacity of 46.34 % and that for 300 kg/m³ mortar. In addition, for 150 kg/m³ mortar increase of 69.75 % in wall carrying capacity have been obtained using two layers of steel mesh placed on both sides and an increase of 116.05 % for 4 layers of steel mesh placed on both sides. Mahmoud B. N. A. [6] introduced an extensive experimental program for strengthening brick walls by galvanized steel wire mesh. The experimental program included testing of 30 walls 100 x 72 x 11 cm strengthened by different types of steel mesh. Horizontal galvanized steel mesh 10 cm wide was used as embedded material into bed mortar between bricks. The effect of the number of horizontal steel mesh layers have been investigated. In addition, the wall sides have been strengthened by galvanized steel mesh with different number of layers. The steel mesh has been placed on one side as well as both sides of the walls. Also, strengthening by combination of horizontal steel mesh and vertical steel mesh has been examined. The vertical steel mesh has been fixed to the wall sides by nails and nuts after which plastering with cement mortar has been applied. An increase of all bearing capacity have been obtained using one or two and/or three layers of horizontal steel mesh. Elsamny, M. K. et al. [7] tested ten unreinforced brick walls of dimensions 66 cm height, 86 cm width and 10 cm thickness with 25cm x 25cm opening dimensions under uniform loading. One wall was tested as control wall and was loaded until failure. Nine walls were loaded up to 80% of failure load till cracks occurred and then rehabilitated with

different number of steel wire mesh layers only as well as with (1, 2 and 3 Φ 6) additional external steel bars then tested until failure. The obtained test results showed that the walls rehabilitated by a different numbers of steel wire mesh layers without external steel bars gives an increase in the load carrying capacity up to (78.79%) of the control ultimate capacity. However, added external steel bars inside steel wire mesh gives an increase in the load carrying capacity up to (89.70%) of the control ultimate capacity. Elsamny, M. K. et al. [8] tested six unreinforced brick walls with opening of dimensions 66 cm height, 86 cm width and 10 cm thickness with 25cm x 25cm opening dimensions under uniform loading. One wall was tested as control wall and was loaded until failure. Two walls were loaded up to 80% of failure load till cracks occurred and then rehabilitated using (2 and 3 mm thickness) steel plate box-section inside opening welded with box-shaped steel plate. Three other walls were loaded up to 80% of failure load till cracks occurred and then rehabilitated using (30, 40 and 50mm) steel angle around opening welded with steel angle inside opening corners. The obtained test results show that the walls rehabilitated by using different thicknesses of steel plate box-section gives an increase in the load carrying capacity up to 46.67% of the control ultimate capacity but no significant increases in ductility. However, for walls rehabilitated by using different cross-sections of steel angle an increase in the load carrying capacity is obtained up to 66.06% of the control ultimate capacity but no significant increases in ductility.

III. PROPOSED TECHNIQUES USED FOR REHABILITATION OF BRICK WALLS WITH OPENINGS

The main purpose of the present study is to rehabilitate cracked brick walls with openings using different techniques.

Two approaches were considered using rehabilitation techniques of walls with openings to increase wall carrying capacity.

- i. Rehabilitation of brick walls using L&U-shaped steel plate inside opening corners welded with U & L-shaped steel plate at both sides.
- ii. Rehabilitation the both sides of brick walls using diagonal steel plate around opening.

In the present study, five unreinforced brick walls were constructed and tested under uniform loading. One wall was tested as control wall and was loaded until failure. Three walls were loaded up to 80% of failure load till cracks occurred and then rehabilitated using (2x40mm, 2x60mm, 2x80mm) L&U-shaped steel plate inside opening corners welded with U &

L-shaped steel plate and tested under uniform loading. One wall was loaded up to 80% of failure load till cracks occurred and then rehabilitated using 3x50 mm diagonal steel plate around opening and tested under uniform loading. Before rehabilitation process the cracks were filled with epoxy filler and epoxy injection.

All wall specimens having dimensions of 66 cm height, 86 cm width and 10 cm thickness with 25cm x 25cm opening dimensions as shown in figure (3). R.C. lintel of (35 cm) has been used having a longitudinal reinforcement 3 Φ 8 mm as bottom reinforcement and 2 Φ 8 mm top reinforcement and two branches Φ 6 mm stirrups @ 50 mm spacing as shown in figure (4).

Figures (5) and (6) show the crack pattern for tested wall specimen before rehabilitation.

Figure (7) shows the used L&U-shaped steel plate for rehabilitation technique.

Figure (8) shows the used diagonal steel plate for rehabilitation technique.

Figure (9) shows details of the used rehabilitation technique using (2x40mm) L&U-shaped steel plate inside opening corners welded with U & L-shaped steel plate.

Figure (10) shows details of the used rehabilitation technique using (2x60mm) L&U-shaped steel plate inside opening corners welded with U & L-shaped steel plate.

Figure (11) shows details of the used rehabilitation technique using (2x80mm) L&U-shaped steel plate inside opening corners welded with U & L-shaped steel plate.

Figure (12) shows details of the used rehabilitation technique using (3x50 mm) diagonal steel plate around opening at both sides.

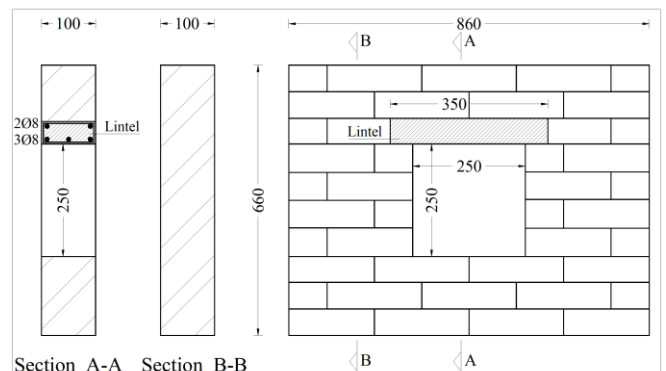


Figure (3): Wall specimen dimensions

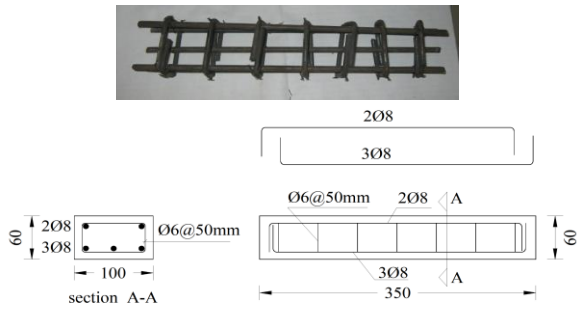


Figure (4): Lintel reinforcement



Figure (5): The crack pattern for tested wall specimen before rehabilitation



Figure (6): The crack pattern for tested wall specimen before rehabilitation



Figure (7): The used L&U-shaped steel plate.



Figure (8): The used diagonal steel plate.

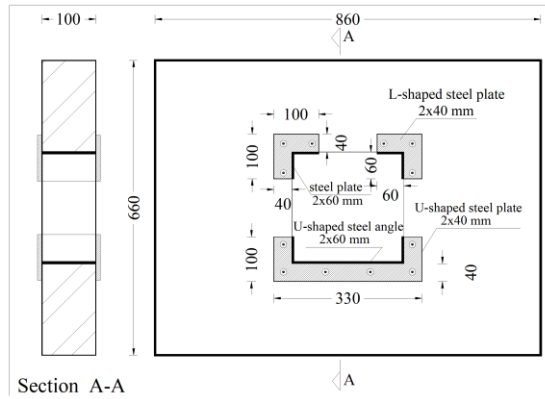


Figure (9): Details of the used rehabilitation technique using (2x40mm) L&U-shaped steel plate inside opening corners welded with U & L-shaped steel plate.

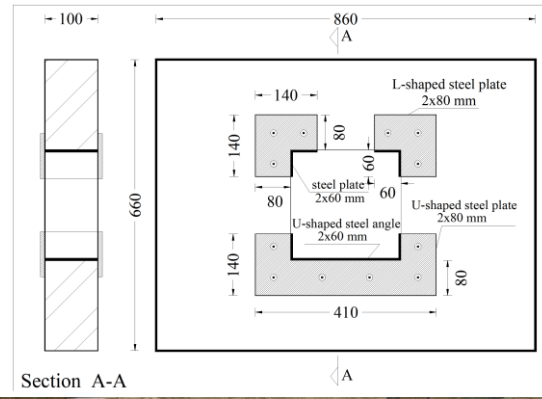


Figure (11): Details of the used rehabilitation technique using (2x80mm) L&U-shaped steel plate inside opening corners welded with U & L-shaped steel plate.

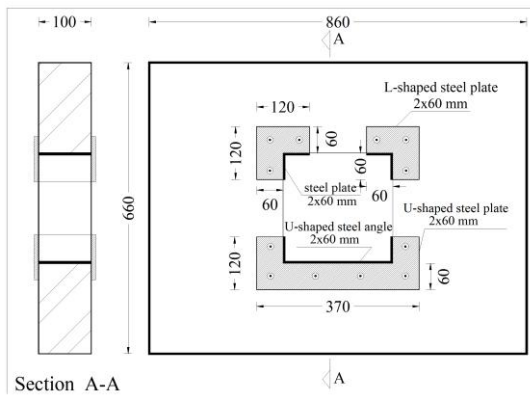


Figure (10): Details of the used rehabilitation technique using (2x60mm) L&U-shaped steel plate inside opening corners welded with U & L-shaped steel plate.

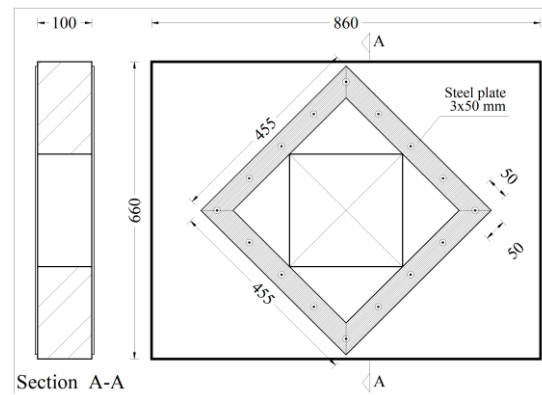


Figure (12): Details of the used rehabilitation technique using (3x50 mm) diagonal steel plate around opening at both sides.

IV. EXPERIMENTAL PROGRAM:-

A total of five brick walls were tested under uniform loading as divided in the followings:

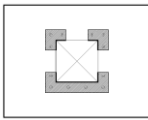
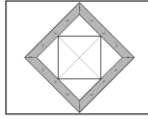
- 1) Control wall: One wall was tested as control wall and loaded until failure.
- 2) Rehabilitated group (1): The Rehabilitated group (1) contains two walls loaded up to 80% of failure load till cracks occurred and then rehabilitated using (2x40mm, 2x60mm, 2x80mm) L&U-shaped

steel plate inside opening corners welded with U & L-shaped steel plate and then loaded until failure.

- 3) Rehabilitated group (2): The Rehabilitated group (2) contains one wall loaded up to 80% of failure load till cracks occurred and then rehabilitated using (3x50 mm) diagonal steel plate around opening and then loaded until failure.

Table (1) shows the different used techniques of rehabilitation.

**TABLE (1)
MAXIMUM PERCENTAGE OF INCREASE IN CAPACITY, MAXIMUM DEFLECTION AT MID SPAN OF LINTEL AND AVERAGE VERTICAL STRAIN FOR WALL SPECIMENS**

groups	Wall No.	Rehabilitation reinforcement	Key	failure load (KN)	Control Failure load (KN)	% increase in ultimate capacity	Max. deflection at mid span of lintel (mm)	Average vertical strain
Control wall	W ₀₋₁	Non-Rehabilitated		165	165	0.00%	9.2	0.00109
Group 1	W ₄₋₁	L&U-shaped steel plate 2x40mm		180	165	9.09%	8.5	0.00106
	W ₄₋₂	L&U-shaped steel plate 2x60mm		223	165	35.15%	9.4	0.00123
	W ₄₋₃	L&U-shaped steel plate 2x80mm		270	165	63.64%	11.1	0.00141
Group 2	W ₆₋₁	diagonal steel plate 3x50 mm		214	165	29.70%	9.7	0.00118

V. USED MATERIALS:-

All specimens were constructed using solid cement brick units with nominal dimensions 205 mm long, 100 mm wide and 57 mm high. Six standard brick units have been tested after 7 days from the date of curing. The average compression strength test result for bricks was 20.87 N/mm². Graded sand having sizes in the range of (0.075 - 0.3 mm) was used as the fine aggregate in the mix of the mortar. Ordinary Portland cement was used in all the experimental work. Clean drinking fresh water was used for mixing and curing the specimens. The mix proportions of the mortar used for wall specimens were designed according to the Egyptian code of practice as shown in table (2). Mild steel plate grade B with thickness 2&3 mm were used in Rehabilitation.

**TABLE (2)
MORTAR MIX DESIGN**

Constituents	Mix proportions by weight for m ³
Gradate sand	1570 kg
Water	150 liter
Cement	300 kg
Water/cement%	50 %

VI. TEST SETUP AND PROCEDURE:-

All wall specimens were tested under uniform loading using the testing machine mounted on the Material laboratory of Al-Azhar University, which has an ultimate compressive load capacity of 2000 kN. The data acquisition system used in the present study consisted of a Laptop computer, a Keithley-500A Data Acquisition System. Three LVDT were used for measuring vertical deformation and one dial gauge was used for measuring deflection at mid span of lintel.

The test setup is shown in Figures (13) to (16) as follows:

Figure (13) shows the test setup.

Figure (14) shows the used dial gauge for measuring lintel deflection.

Figure (15) shows the used LVDT for measuring vertical deformation.

Figure (16) shows a steel beam as C-channel for transfer the uniform load to wall. However, there is another steel beam as C-channel at the bottom of the wall.



Figure (14): The used dial gauge for measuring lintel deflection.



Figure (15): The used LVDT for measuring vertical deformation.



Figure (13): The test setup



Figure (16): A steel beam as C-channel for transfer the load to wall.

VII. EXPERIMENTAL TEST RESULTS:-

Table (1) shows the maximum percentage of increase in capacity, maximum deflection at mid span of lintel and average vertical deformation for wall specimens.

Figure (17) shows the crack pattern for a tested wall specimen after rehabilitation.

Figure (18) and (19) show the stress-strain relationship for walls rehabilitated using (2x40mm, 2x60mm, 2x80mm) L&U-shaped steel plate and wall rehabilitated using (3x50 mm) diagonal steel plate around opening.

Figure (20) and (21) show the relationship between load and deflection at mid span of lintel for walls rehabilitated using (2x40mm, 2x60mm, 2x80mm) L&U-shaped steel plate and wall rehabilitated using (3x50 mm) diagonal steel plate around opening.

Figure (22) and (23) show the percentage of increase in capacity for walls rehabilitated using (2x40mm, 2x60mm, 2x80mm) L&U-shaped steel plate and wall rehabilitated using (3x50 mm) diagonal steel plate around opening.

In all cases increasing the dimensions of L&U-shaped steel plate increases the ultimate capacity and no significant increases in ductility.

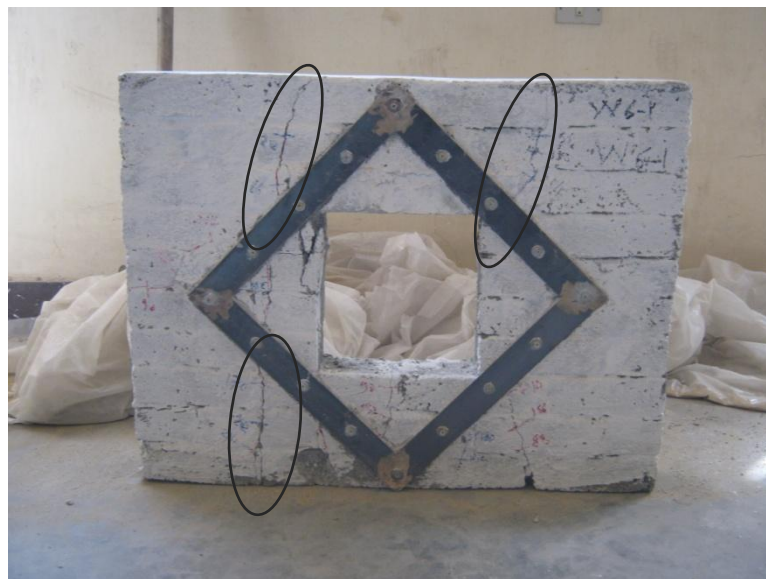


Figure (17): The crack pattern for tested wall specimen after rehabilitation

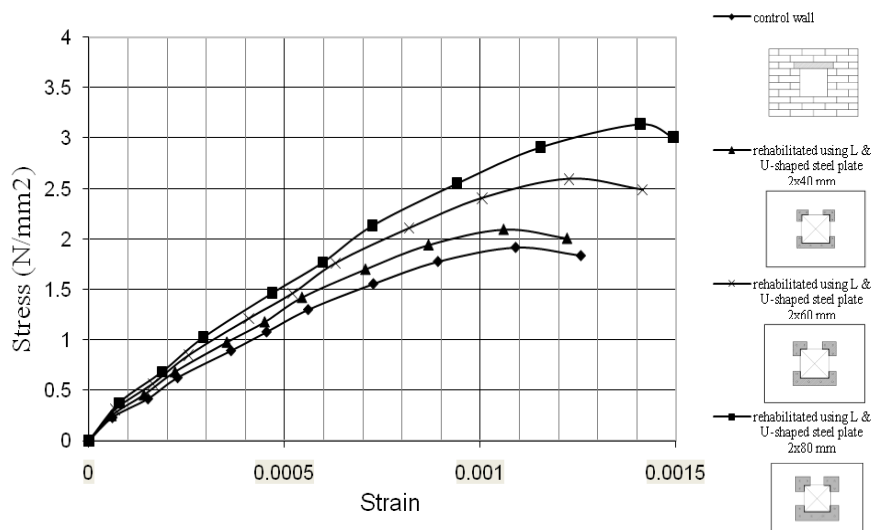


Figure (18): The stress-strain relationship for walls rehabilitated using L&U-shaped steel plate inside opening corners welded with (2x40, 2x60, 2x80mm) U & L-shaped steel plate at both sides.

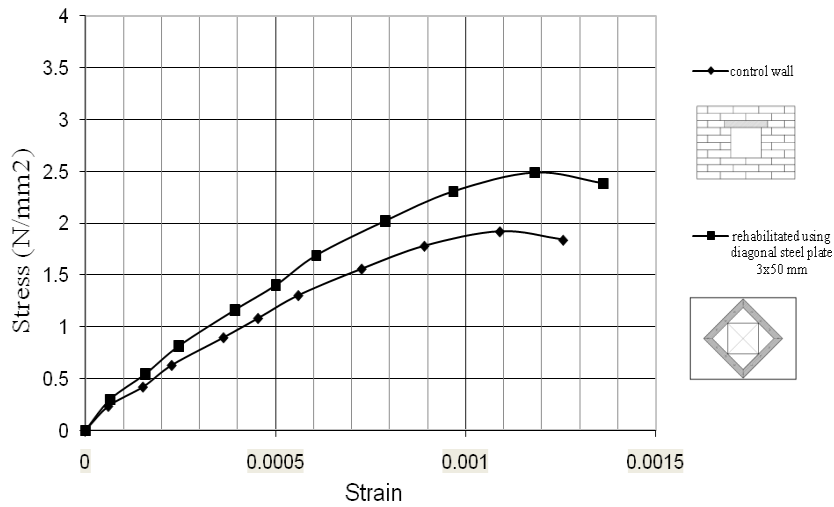


Figure (19): The stress-strain relationship for walls rehabilitated using (3x50mm) diagonal steel plate around opening.

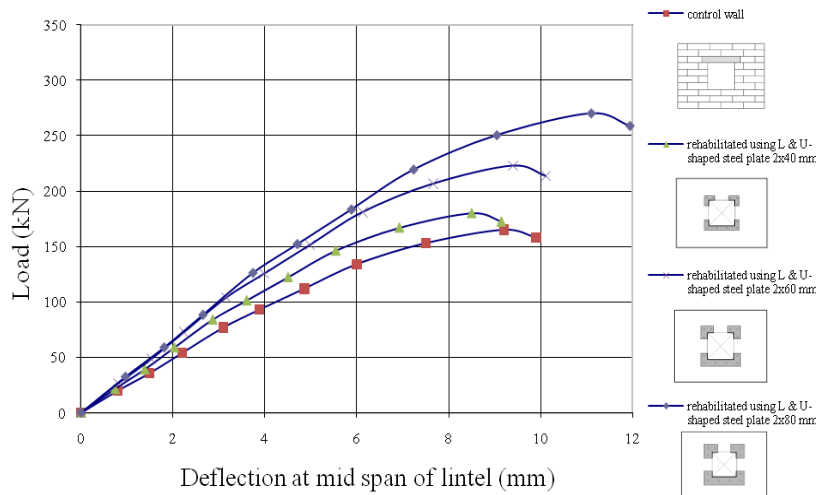


Figure (20): The relationship between load and deflection at mid span of lintel for walls rehabilitated using L&U-shaped steel plate inside opening corners welded with (2x40, 2x60, 2x80mm) U & L-shaped steel plate at both sides.

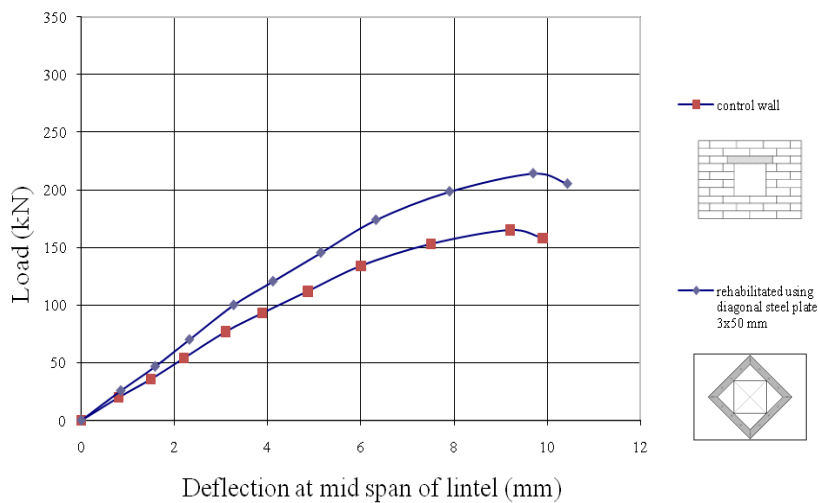


Figure (21): The relationship between load and deflection at mid span of lintel for walls rehabilitated using (3x50mm) diagonal steel plate around opening.

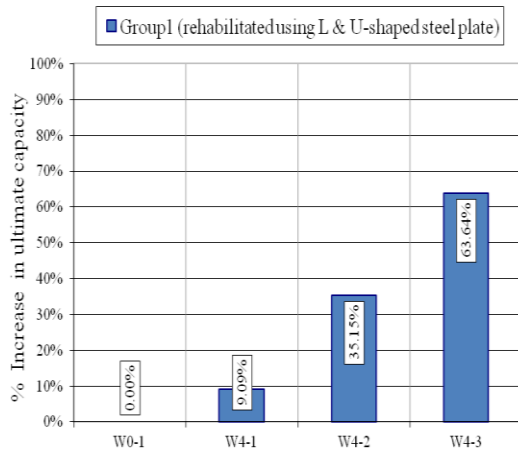


Figure (22): The percentage of increase in capacity for walls rehabilitated using L&U-shaped steel plate inside opening corners welded with (2x40, 2x60, 2x80mm) U & L-shaped steel plate.

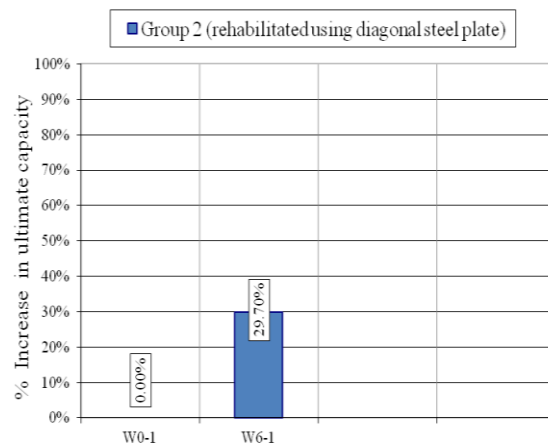


Figure (23): The percentage of increase in capacity for walls rehabilitated using (3x50mm) diagonal steel plate around opening.

VIII. CONCLUSIONS

From the present study, the followings have been concluded:

- 1) For walls rehabilitated by using different dimensions of L&U-shaped steel plate inside opening corners welded with U & L-shaped steel plate an increase was obtained in the ultimate capacity up to 63.64% with increasing ductility.
- 2) For walls rehabilitated by using diagonal steel plate around opening at both sides welded with steel angle inside opening corners an increase was obtained in the ultimate capacity up to 29.70%.
- 3) Increasing the dimensions of L&U-shaped steel plate used in rehabilitation walls increases the load carrying capacity of walls and no significant increases in ductility.

Finally, the results of the present study show that considerable increases in strength of rehabilitated walls by using steel plate techniques can be achieved at modest costs.

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