International Journal of Scientific & Engineering Research, Volume 8, Issue 4, April-2017
ISSN 2229-5518


# Structural Behavior of Brick Walls with Openings Rehabilitated With Steel Plates Box-Section and Steel Angles

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**Abstract—** In the present study, six unreinforced brick walls with opening 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. 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.

However, increasing thicknesses of steel plate box-section or increasing the cross-sections of steel angle used in rehabilitation increases the load carrying capacity of walls and no significant increases in ductility.

**Index Terms**— rehabilitation, brick walls, openings, steel plate, box-section, steel angle



## INTRODUCTION

Load bearing wall is a composite material made of units of bricks and mortar. Common wall often need to be opened in order to meet the requirements for using function and vertical layout in building structures. On the one hand, strength and stiffness of the wall will be reduced due to the decrease of concrete area and discontinuity around the opening, moreover stress concentration can be easy to appear at the corners of opening, which will cause cracks at an earlier stage of loading process and affect using functions. The area around the openings in the form of doors and windows in axially loaded structural panels are the location of high stress concentration. Thus, tensile stresses were developed in the area around the opening, particularly at the corners. The presence of the opening in axially loaded brick walls will determine the load path. The load will transfer to the lintel supports above the opening which is causing stress concentration at the corner of the opening. The presence of the opening in axially loaded panel encourages cracks to occur as shown in figures (1) and (2). This is due to two main reasons: firstly; cracks start more readily at changes in section where the presence of the opening in a masonry wall introduces local stress concentrations which can result in initial localized failure and secondly; the opening may reduce the ability of a wall panel to span between supports. Thus, rehabilitation and strengthening of brick walls with openings are essential. The followings are some of the literature reviews for repair and strengthening of unreinforced masonry walls.

Figure (1) The cracks in brick wall with openings at filed

Figure (2) Diagonal cracks in brick wall.

ISSN 2229-5518

## LITERATURE REVIEW

Moussa A. et al. [1] used Fiberglass Reinforced Plastic laminates (FRP) for strengthening and repair of masonry shear walls with and without openings. The objective of the research was to investigate the behavior of repaired and strengthened walls under diagonal splitting tension. Tests were performed to determine compressive strength, joint shear strength and diagonal tensile strength. The behavior of masonry walls with and without openings was studied. The test results demonstrate the efficiency of using FRP laminates as a repair and strengthening technique for unreinforced load-bearing masonry walls to increase the tension and shear capacities and the deformability for resisting lateral loading. 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. Test results included the evaluation of the deformation capacity, energy dissipation characteristics and stiffness and strength degradation, cracking shear and maximum shear strength. The results showed that masonry unit type and size of the openings control the behavior and that confined masonry walls, even with large openings, have a significant deformation capacity. The result 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 the strengthening of brick walls using 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 in bearing capacity 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 included 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. However, the use of two and four steel mesh layers to strengthen the wall from one side only gave an increase of 26% to 46% of wall carrying capacity. Combination of horizontal and vertical steel mesh used in strengthening brick walls gave an increase of 85% to 96% of brick walls carrying capacity. Parisi F. et al. [7] presented a Full scale lateral loading tests on unreinforced masonry walls with an opening. The main scope of the experimental program was to investigate the role of spandrels and their interaction with piers. Elsamny, M. K. et al. [8] 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 3Ø6) 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. However, increasing the number of steel wire mesh layers or increasing the number of external steel bars used in rehabilitation increases the load carrying capacity of walls and increases ductility.

ISSN 2229-5518

## 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 two rehabilitation techniques of walls with openings to increases wall caring capacity.

i. Rehabilitation of brick walls using steel plate box-section inside opening welded with box-shaped steel plate at both sides.
ii. Rehabilitation the both sides of brick walls using steel angle around opening welded with steel angle inside opening corners.

In the present study, six unreinforced brick walls were constructed and tested 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 and tested under uniform loading. Three 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 and tested under uniform loading. Before rehabilitation process the cracks were filled with epoxy filler and epoxy injection.

All specimens having a wall 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 3Φ8 mm as bottom reinforcement and 2Φ8 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 steel plate box-section for rehabilitation technique.
Figure (8) shows the used steel angle for rehabilitation technique.
Figure (9) shows details of the used rehabilitation technique using steel plate box-section (2x100 mm, 3x100 mm) inside opening welded with square-shaped steel plate at both sides.
Figure (10) shows details of the used rehabilitation technique using steel angle 3x30 mm around opening at both sides welded with steel angle inside opening corners.
Figure (11) shows details of the used rehabilitation technique using steel angle 3x40 mm around opening at both sides welded with steel angle inside opening corners.
Figure (12) shows details of the used rehabilitation technique using steel angle 3x50 mm around opening at both sides welded with steel angle inside opening corners.



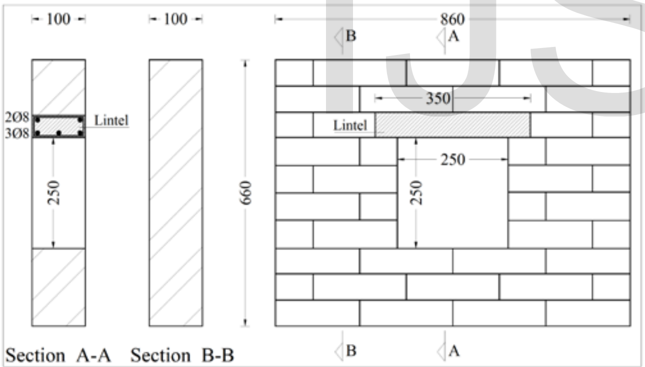

Figure (3) Wall specimen dimensions


Figure (4) Lintel reinforcement

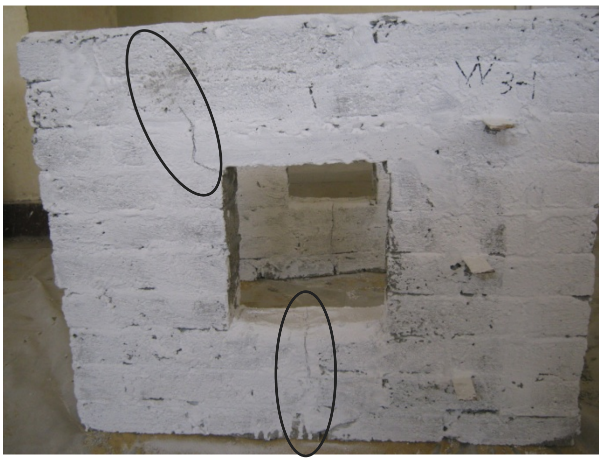
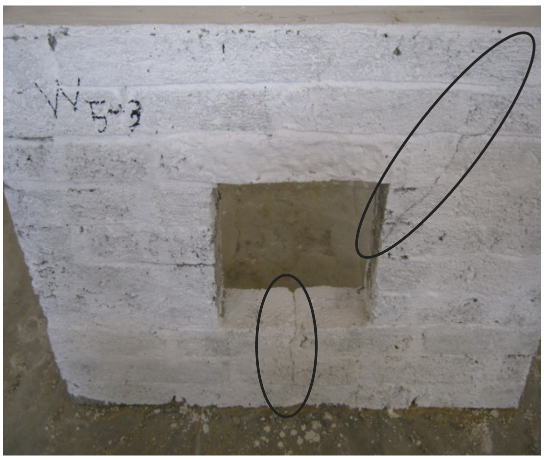
Figures (5) and (6) The crack pattern for tested wall specimen before rehabilitation

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Figure (7) The used steel plate box-section.

Figure (8) The used steel angle.



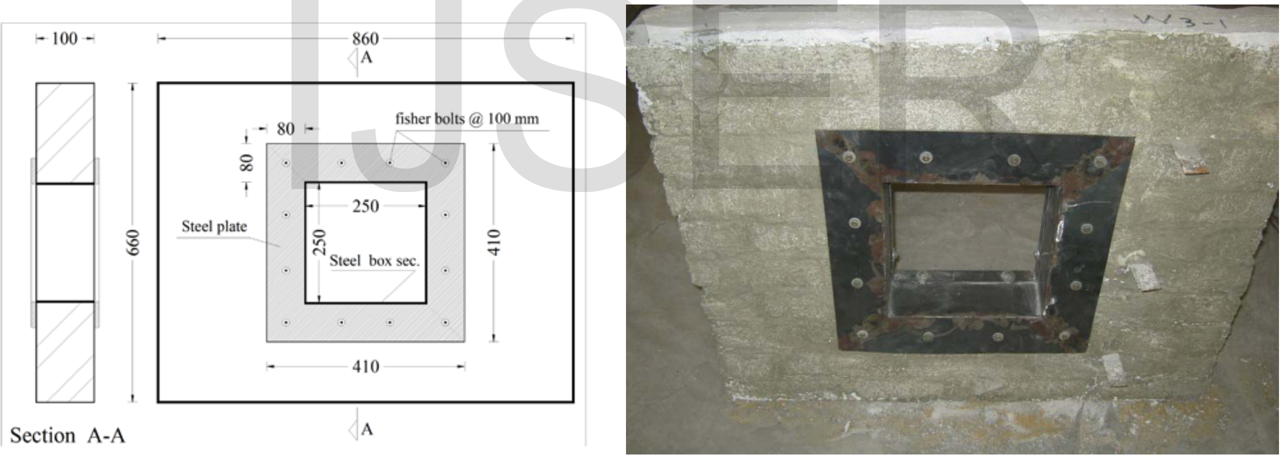


Figure (9) Details of the used rehabilitation technique using steel plate box-section (2x100 mm, 3x100 mm) inside opening welded with square-shaped steel plate at both sides.


Figure (10) Details of the used rehabilitation technique using steel angle 3x30 mm around opening at both sides welded with steel angle inside opening corners.

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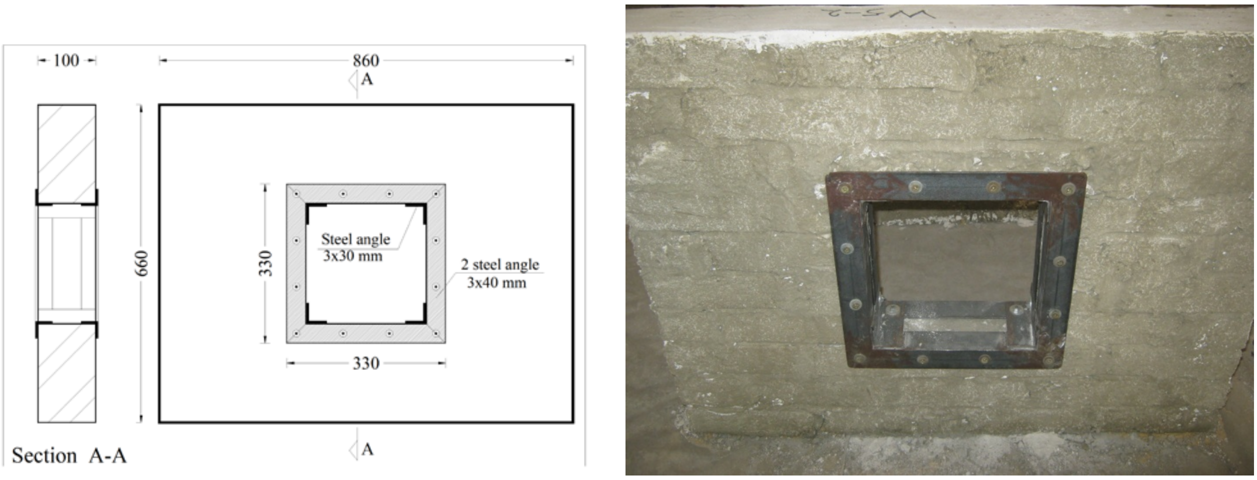


Figure (11) Details of the used rehabilitation technique using steel angle 3x40 mm around opening at both sides welded with steel angle inside opening corners.

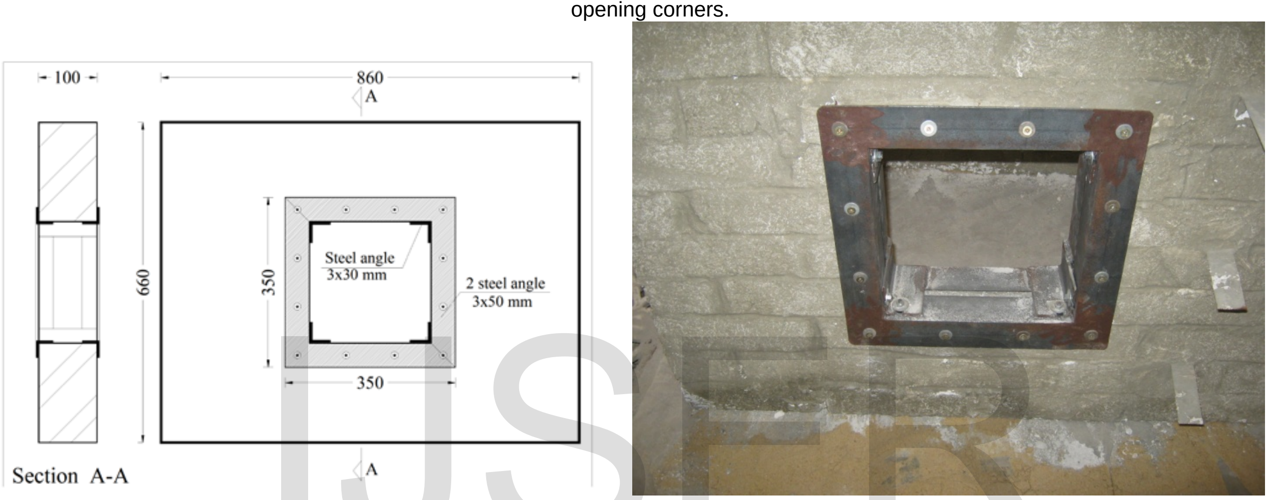


Figure (12) Details of the used rehabilitation technique using steel angle 3x50 mm around opening at both sides welded with steel angle inside opening corners.

## EXPERIMENTAL PROGRAM:-

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

I. Control wall: One wall was tested as control wall and loaded until failure.

II. Rehabilitated group (1): The Rehabilitated group (1) contains two walls 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 and then loaded until failure.

III. Rehabilitated group (2): The Rehabilitated group (2) contains Three walls 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 and then loaded until failure.

However, table (1) shows the different techniques of rehabilitation.

## 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 strength test result for brick 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 all 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. Hot-rolled sections equal angle with thickness 3 mm were used in Rehabilitation.

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TABLE (1)

MAXIMUM PERCENTAGE OF INCREASE IN CAPACITY, MAXIMUM DEFLECTION AT MID SPAN OF LINTEL AND AVERAGE VERTICAL STRAIN FOR WALL SPECIMENS

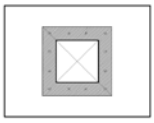
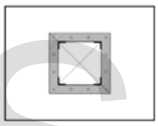
| groups | Wall No. | Rehabilitation reinforcement | Key | failure load (KN) | Control Failure load (KN) | % increase in ultimate capacity | Max. deflection at mid span of lintel (mm) | Average vertical strain |
|---|---|---|---|---|---|---|---|---|
| Control wall | $W_{0-1}$ | Non-Rehabilitated | | 165 | 165 | 0.00% | 9.2 | 0.00109 |
| Group 1 | $W_{3-1}$ | steel plate box-section 2x100 mm |  | 218 | 165 | 32.12% | 4.7 | 0.00064 |
| | $W_{3-2}$ | steel plate box-section 3x100 mm | | 242 | 165 | 46.67% | 5.0 | 0.00070 |
| Group 2 | $W_{5-1}$ | steel angle 3x30 mm |  | 220 | 165 | 33.33% | 6.2 | 0.00083 |
| | $W_{5-2}$ | steel angle 3x40 mm | | 258 | 165 | 56.36% | 6.9 | 0.00097 |
| | $W_{5-3}$ | steel angle 3x50 mm | | 274 | 165 | 66.06% | 7.1 | 0.00103 |



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 % |

## 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 strain.
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 (13) The test setup

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

Figure (15) The used LVDT for measuring vertical strain.

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

## 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 (2 and 3 mm thickness) steel plate box-section and walls rehabilitated using (30, 40 and 50mm) steel angle around opening.

Figure (20) and (21) show the relationship between load and deflection at mid span of lintel for walls rehabilitated using (2 and 3 mm thickness) steel plate box-section and walls rehabilitated using (30, 40 and 50mm) steel angle around opening.

Figure (22) and (23) show the percentage of increase in capacity for walls rehabilitated using (2 and 3 mm thickness) steel plate box-section and walls rehabilitated using (30, 40 and 50mm) steel angle around opening.

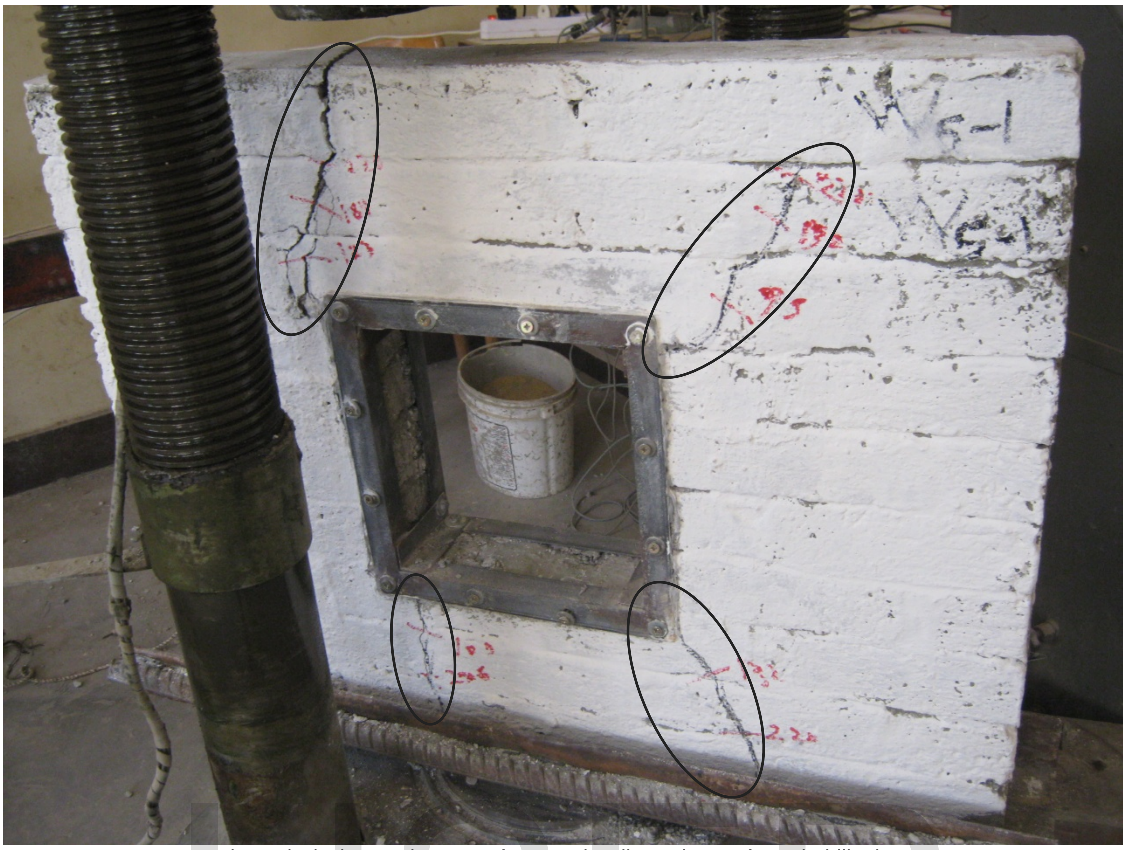


Figure (17) The crack pattern for tested wall specimen after rehabilitation



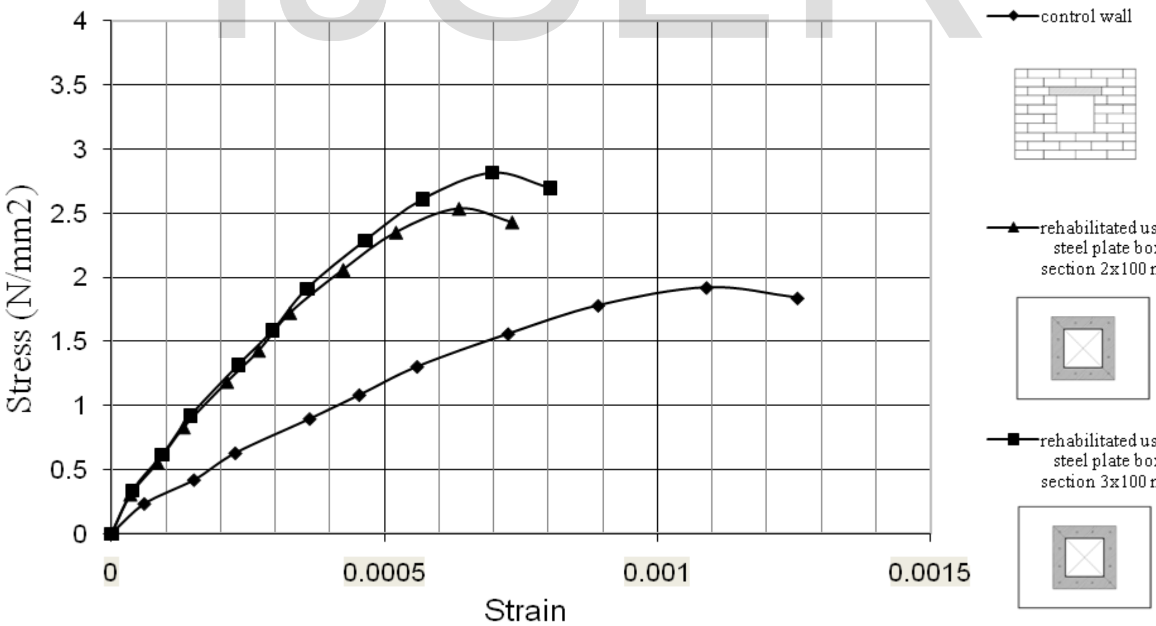



Figure (18) The stress-strain relationship for walls rehabilitated using (2 and 3 mm) thicknesses of steel plate box-section inside opening welded with square-shaped steel plate at both sides.

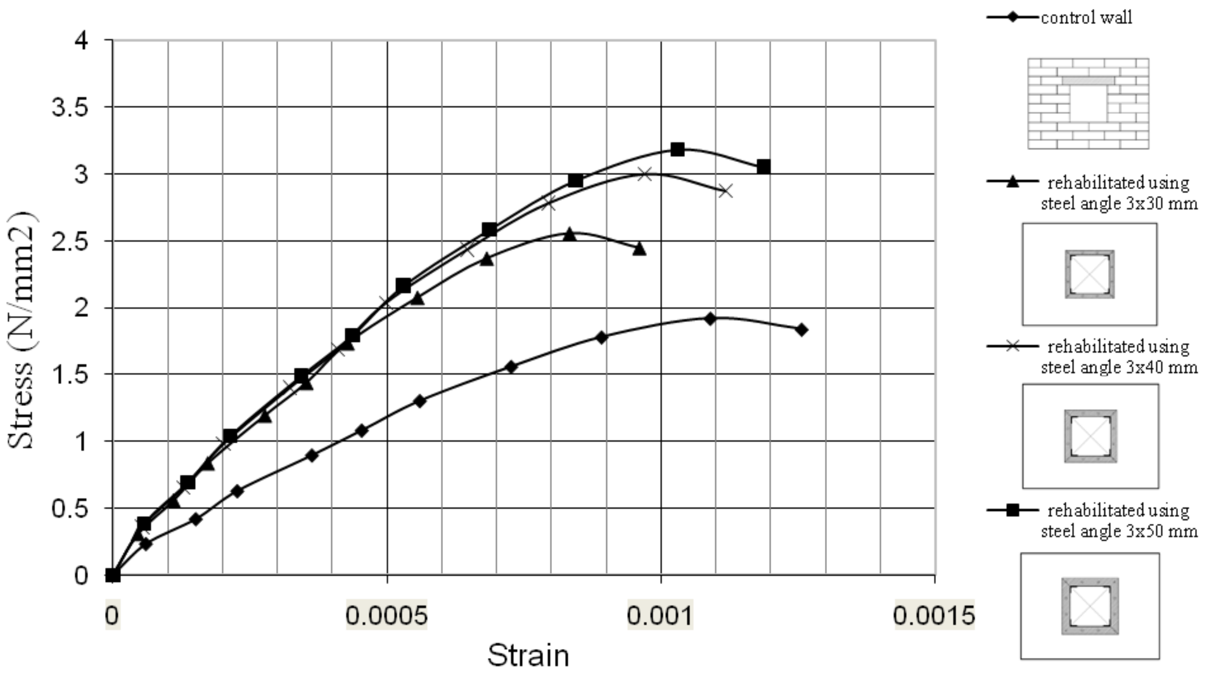



Figure (19) The stress-strain relationship for walls rehabilitated using (3x30, 3x40, 3x50mm) cross-sections of steel angle around opening at both sides welded with steel angle inside opening corners.



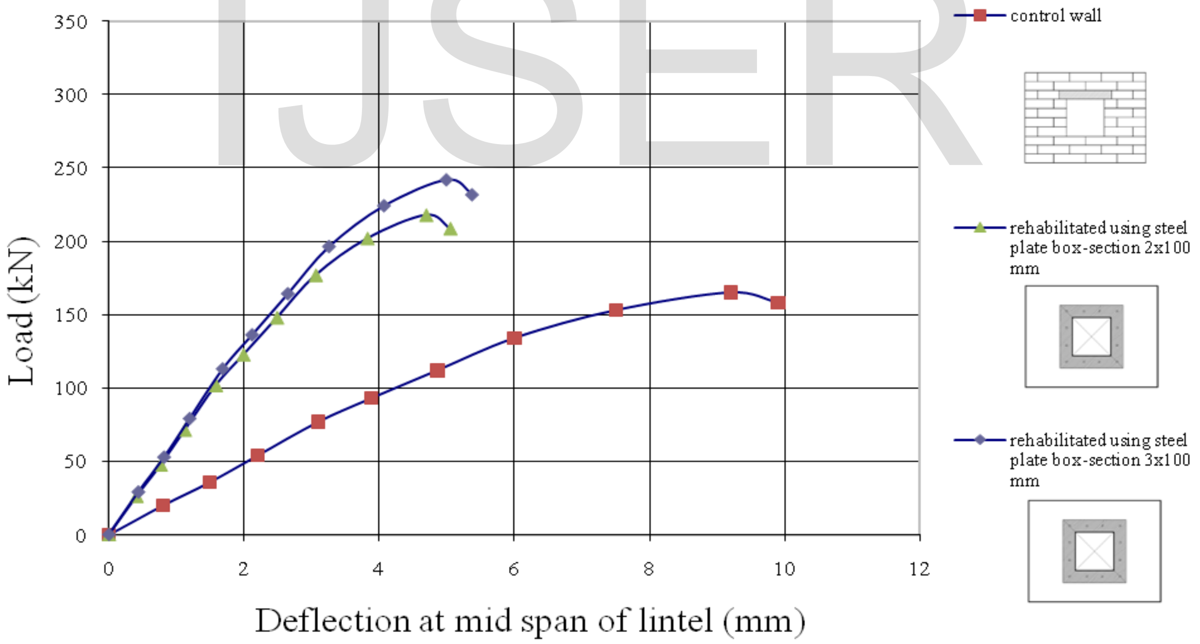



Figure (20) The relationship between load and deflection at mid span of lintel for walls rehabilitated using (2 and 3 mm) thicknesses of steel plate box-section inside opening welded with square-shaped steel plate at both sides.

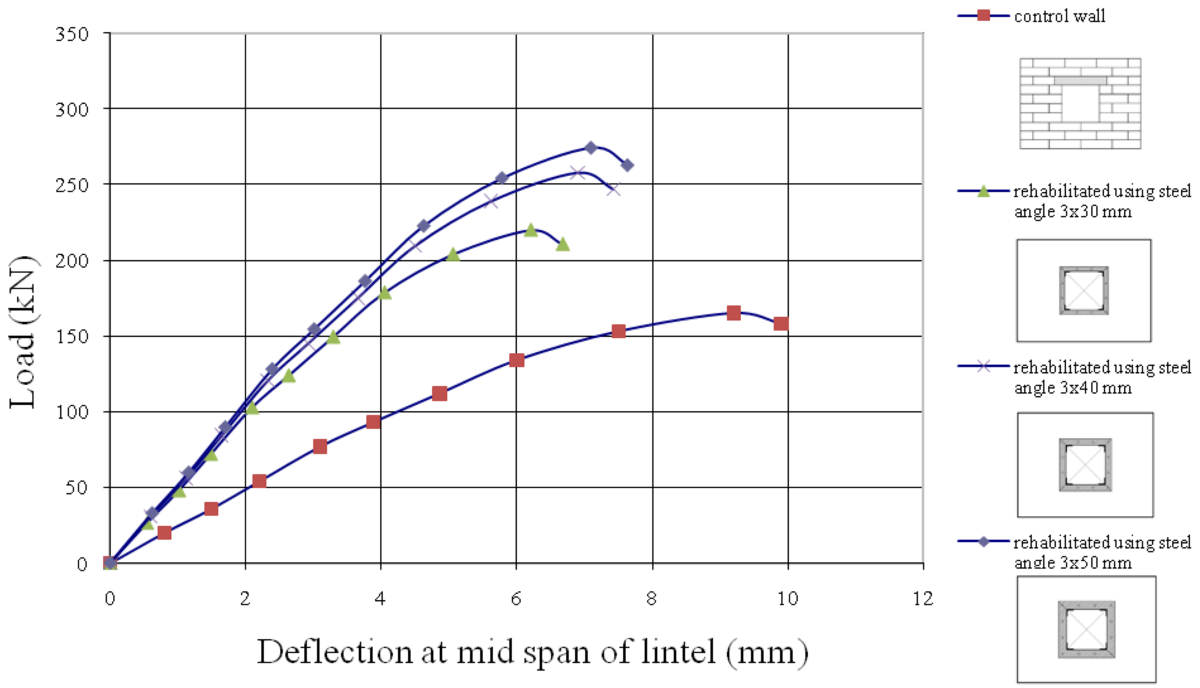



Figure (21) The relationship between load and deflection at mid span of lintel for walls rehabilitated using (3x30, 3x40, 3x50mm) cross-sections of steel angle around opening at both sides welded with steel angle inside opening corners.

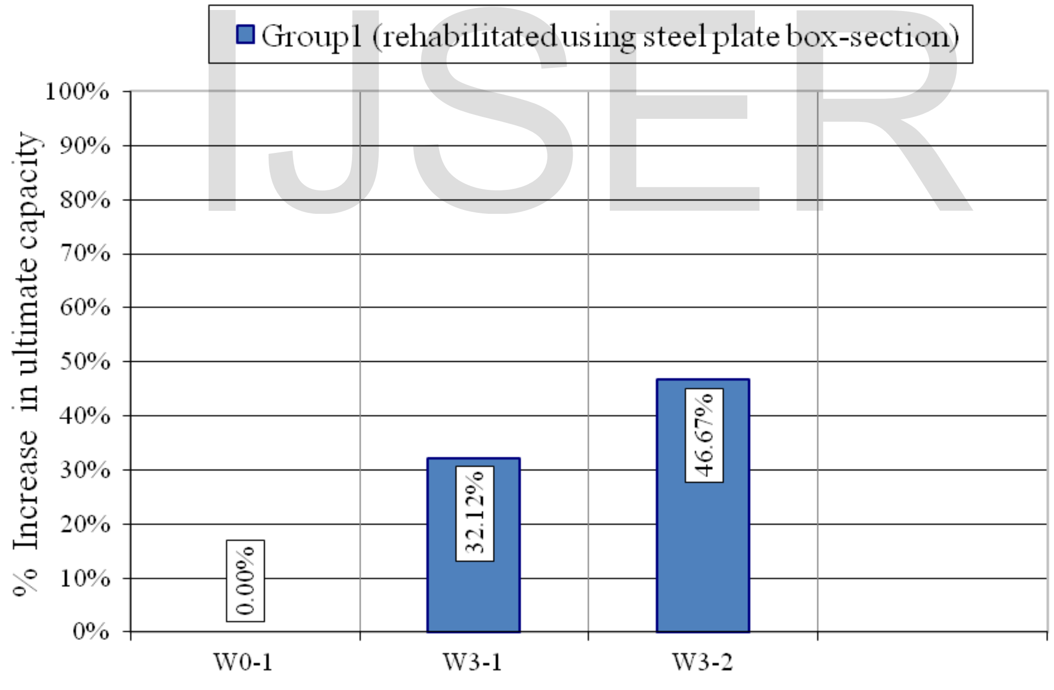



Figure (22) The percentage of increase in capacity for walls rehabilitated using (2 and 3 mm) thicknesses of steel plate box-section inside opening welded with square-shaped steel plate at both sides.

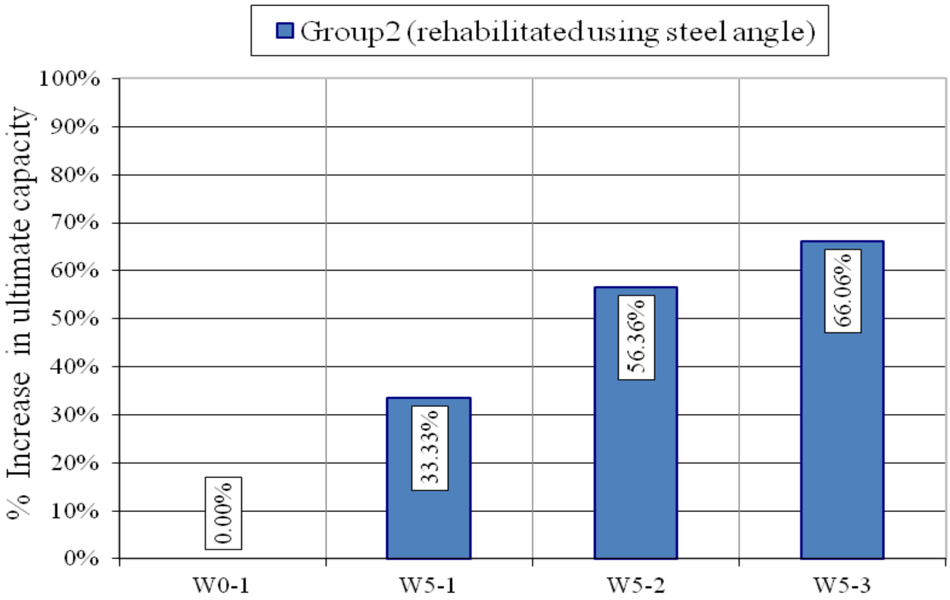



Figure (23) The percentage of increase in capacity for walls rehabilitated using (3x30, 3x40, 3x50mm) cross-sections of steel angle around opening at both sides welded with steel angle inside opening corners.

In all cases the followings have been observed:

I. Increasing the thicknesses of steel plate box-section increases the ultimate capacity and no significant decreases in ductility.
II. Increasing the cross-sections of steel angle increases the ultimate capacity and no significant increases in ductility.

## CONCLUSIONS

From the present study, the followings have been concluded:

i. For walls rehabilitated by using different thicknesses of steel plate box-section inside opening welded with square-shaped steel plate at both sides an increase was obtained in the ultimate capacity up to 46.67% with decreases in ductility.
ii. For walls rehabilitated by using different cross-sections of steel angle around opening at both sides welded with steel angle inside opening corners an increase was obtained in the ultimate capacity up to 66.06% with no significant increases in ductility.
iii. Increasing the thicknesses of steel plate box-section used in rehabilitation walls increases the load carrying capacity of walls and no significant decreases in ductility.
iv. Increasing the cross-sections of steel angle 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 and steel angle techniques can be achieved at modest costs with no significant increases in ductility.

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