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Rehabilitation of Brick Walls with Openings Using Steel Wire Mesh

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Abstract— The brick walls with openings may be subjected to several problems after construction. When those problems occur, the walls cannot reach their ultimate load carrying capacity. However, in the present study, due to increasing the cracks in walls with openings, improvement by steel wire mesh technique is essential. Thus, rehabilitation of walls with additional external steel bars to steel wire mesh is essential to overcome the increasing forces in tension sides around openings. In addition, fixation the steel wire mesh and steel bars by cement mortar and fisher bolts should be done.

In the present study, ten 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. 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.

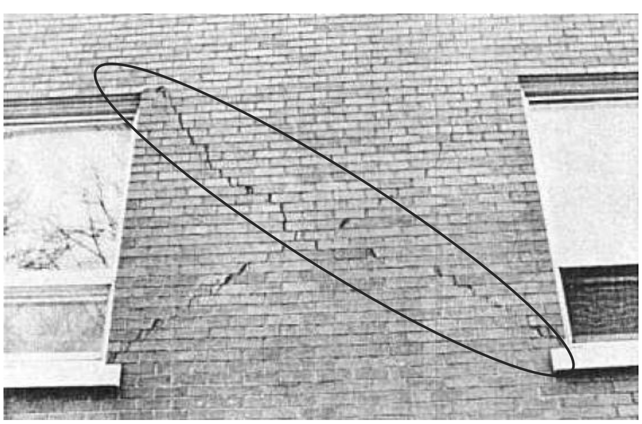
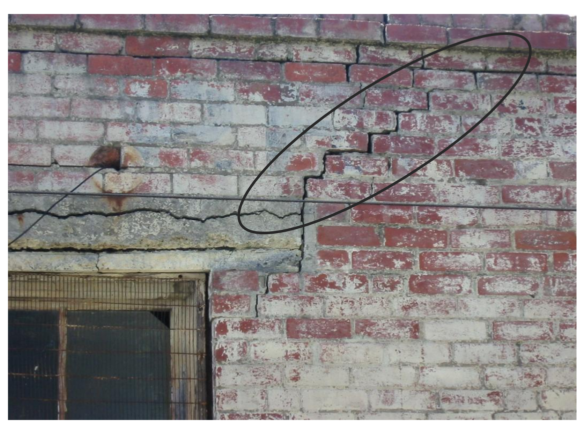
The obtained test results showed that the walls rehabilitated by a different numbers of steel wire mesh layers without external steel bars gives an increase in the load carrying capacity up to (78.79%) of the control ultimate capacity. However, added external steel bars inside steel wire mesh gives an 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.

Index Terms— rehabilitation, brick walls, openings, steel wire mesh

INTRODUCTION

Although the use of structural masonry has been dramatically reduced since the widespread introduction of concrete and steel structures, there is still a large number of existing buildings in use that are structurally composed of load-bearing brick masonry walls. Assessing the strength of these buildings is a part of the maintenance work required to enhance their useful life. Among the possible failure modes, buckling failure must be addressed to verify the safety of the walls from sudden collapse. As a result of the vertical and lateral loading, diagonal cracks are formed due of principal tension caused. 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 repair and strengthening of unreinforced masonry walls.

Figures (1) and (2) The cracking through the masonry developed primarily along the mortar joints in a diagonal stepping pattern

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LITERATURE REVIEW

Manzouri et.al. [1] evaluated the efficiency of repairing URM walls by grout injection in combination with horizontal and vertical steel reinforcement. URM walls were built in three whites with clay bricks for an overall dimension of 8.5 by 5-ft. The walls were tested under in-plane loading. First, the behavior of the walls in their original condition was investigated. Then, the walls were retrofitted to be tested once again. All the retrofitted walls were injected with grout. The severely damaged areas were repaired by replacement with similar materials. Crack widths larger than 0.06 in were injected with a coarse aggregate; whereas, crack widths ranging between 0.008 to 0.06-in. were injected with a fine grout. Steel ties for use as dry- fix remedial anchor were placed as vertical reinforcement used for the pinning of the wythes in the toe area, and horizontal reinforcement. The test results demonstrated that the injection of grout accompanied by repair of localized damaged areas can restore the original strength and stiffness of retrofitted walls. The introduction of horizontal reinforcement increases the strength and ductility of the wall system. It was also observed that the vertical reinforcement increases the lateral resistance and ductility. Moussa A. and Aly A. M. [2] 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. For the small assemblages, 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 clearly 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. [3] 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 test parameters were the masonry unit type (concrete and clay) and the size of openings. Test results include the evaluation of the deformation capacity, energy dissipation characteristics and stiffness and strength degradation, cracking shear, maximum shear strength and the interstory drift associated to different limit states. Comparisons with the behavior of previously tested confined masonry walls without openings are also made. The results show 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. Mohammed B. S. et al. [4] 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, test was 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. [5] 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 has 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. [6] presented a new technique for strengthening brick walls using galvanized steel mesh fixed at the wall faces. The experimental program includes testing of 8 walls 100 x 72 x 11 cm. The wall sides have been strengthened with different numbers of steel wire mesh layers. The steel mesh has been placed on one side as well as both sides of the walls. The vertical steel mesh has been fixed to the wall sides by nails and nuts after which plastering with cement mortar has 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. However, ductility has been increased in all cases. Mahmoud B. N. A. [7] introduced an extensive experimental program for strengthening brick walls by galvanized steel wire mesh. The experimental program includes testing of 30 walls 100 x 72 x 11 cm strengthened by different types of steel wire mesh. Strengthening by combination of horizontal steel mesh and vertical steel mesh has been examined. The use of only two vertical layers of steel mesh on the wall both sides gives an 60 % increase in wall carrying capacity while the use of four vertical layers gives an increase of 78 % in wall carrying capacity. However, the use of two and four steel mesh layers to strengthen the wall from one side only gives an increase of 26 % to 46 % of wall carrying capacity respectively. Combination of horizontal and vertical steel mesh used in strengthening brick walls gives an increase of about 85 % to 96 % of brick walls carrying capacity with increasing ductility. Kabir M. Z. and Kalali A. [8] presented a finite element modeling approach, developed with commercial software, for the analysis of the behavior of unreinforced and FRP strengthened perforated brick shear walls when they are subjected to a combination of vertical compression preload and in-plane cyclic shear loading. The numerical simulations are compared with experimental data. Finally, effects of different strengthening configurations with FRP on the in-plane cyclic performance

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of brick walls with openings (e.g. door, window) having different aspect ratios and positions are examined. Mohan A. and Jacob B. [9] developed a nonlinear finite element model for Unreinforced Masonry (URM) wall with two openings, retrofitted using Carbon Fiber Reinforced Polymers (CFRPs) by ANSYS software. The experimental results of URM wall obtained from the study of Kabir M. Z. and Kalali A. were compared with those obtained from analytical solutions. The proposed finite element model has the ability to track the behaviour of URM wall. It can be seen that the increase in performance parameters is depending on the quantity and layout arrangement of the implemented CFRP fabrics. CFRP coating which had been used as four vertical plus three diametric CFRP strips, had the most optimized behaviour, which significantly, increased lateral resistance and ductility. The load-bearing capacity of the CFRP retrofitted masonry walls is between 1.77 and 5.9 times that of the reference unreinforced masonry walls.

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.
Three approaches were considered using steel wire mesh-mortar technique:

i. Rehabilitation the both sides of cracked brick walls using steel wire mesh-mortar only around opening.
ii. Rehabilitation the both sides of cracked brick walls using steel wire mesh-mortar only as diagonal shape.
iii. Rehabilitation the both sides of cracked brick walls by adding external steel bars to the steel wire mesh-mortar.

In the present study, ten unreinforced brick walls were constructed and tested 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 under uniform loading until failure. 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) was used contained 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).

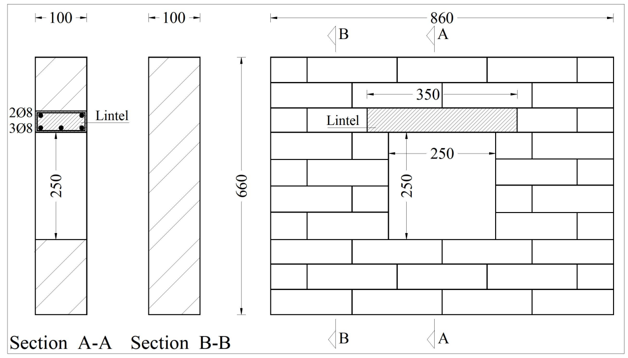

Figure (3) Wall specimen dimensions

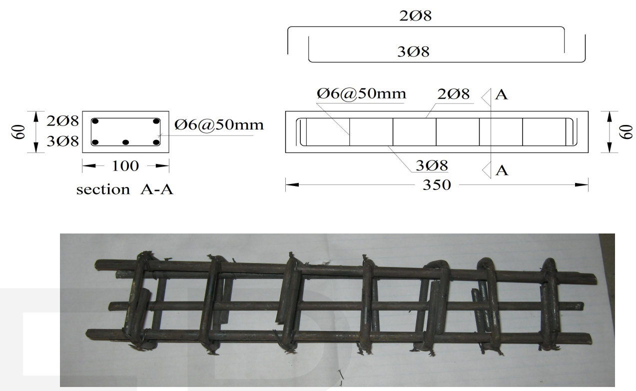

Figure (4) lintel reinforcement

Figure (5) shows the crack pattern for tested wall specimen before rehabilitation. However, figure (6) shows the used steel wire mesh.
Figure (7) shows details of the used rehabilitation technique using (2, 3, 4) layers of steel wire mesh fixed with fisher bolts.
Figure (8) shows details of the used rehabilitation technique using (2, 3, 4) layers of steel wire mesh as diagonal shape fixed with fisher bolts.
Figure (9) shows details of the used rehabilitation technique using two layers of steel wire mesh with 1Ø6mm additional external steel bar in between.
Figure (10) shows details of the used rehabilitation technique using two layers of steel wire mesh with 2Ø6mm additional external steel bars in between.
Figure (11) shows details of the used rehabilitation technique using two layers of steel wire mesh with 3Ø6mm additional external steel bars in between.

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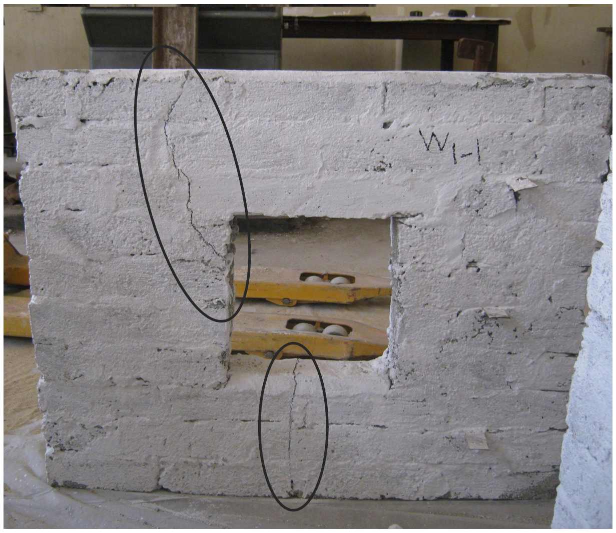

Figure (5) The crack pattern for tested wall specimen before rehabilitation

Figure (6) The used steel wire mesh

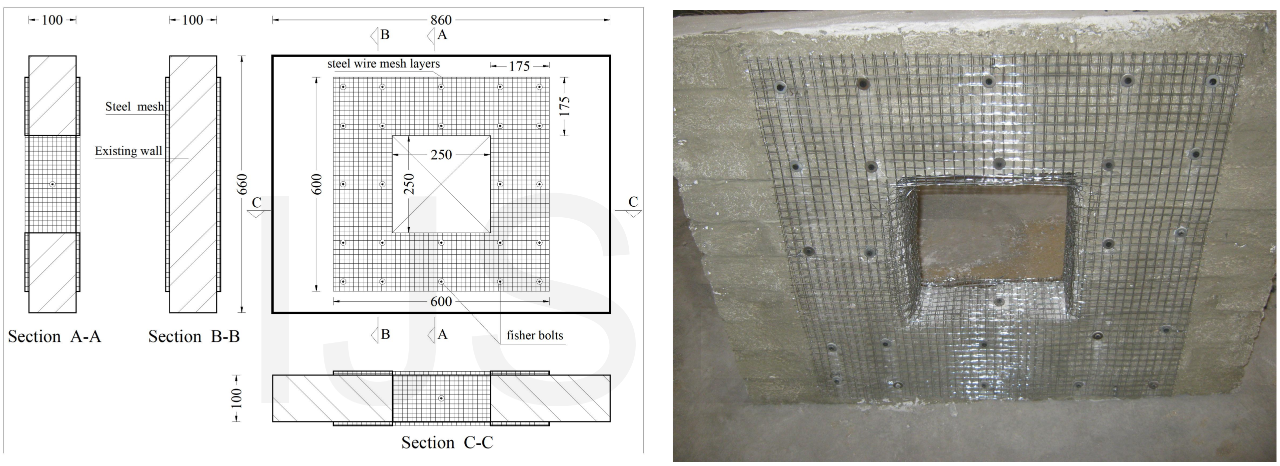

Figure (7) Details of the used rehabilitation technique using (2, 3, 4) layers of steel wire mesh fixed with fisher bolts.

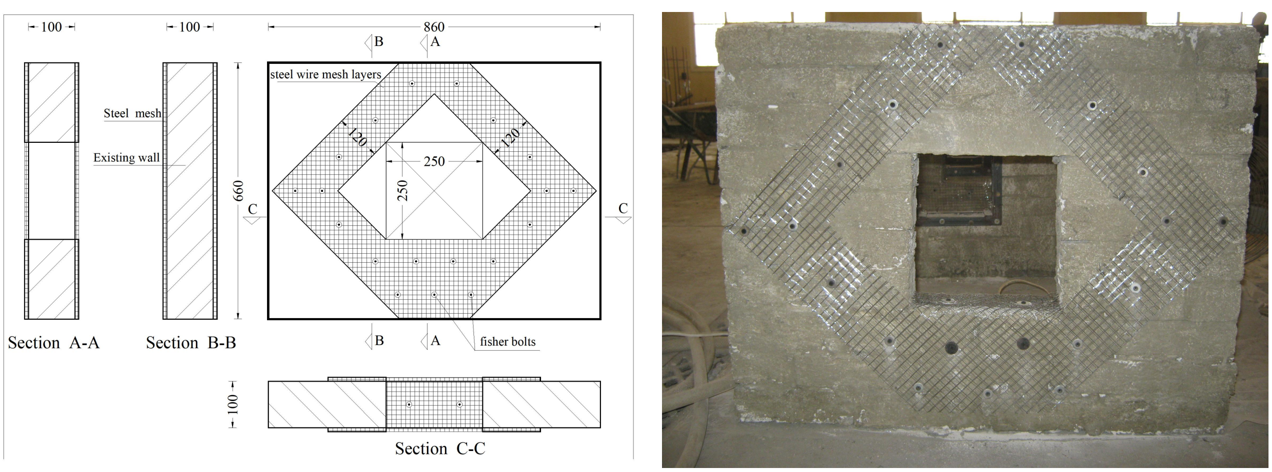

Figure (8) Details of the used rehabilitation technique using (2, 3, 4) layers of steel wire mesh as diagonal shape fixed with fisher bolts.

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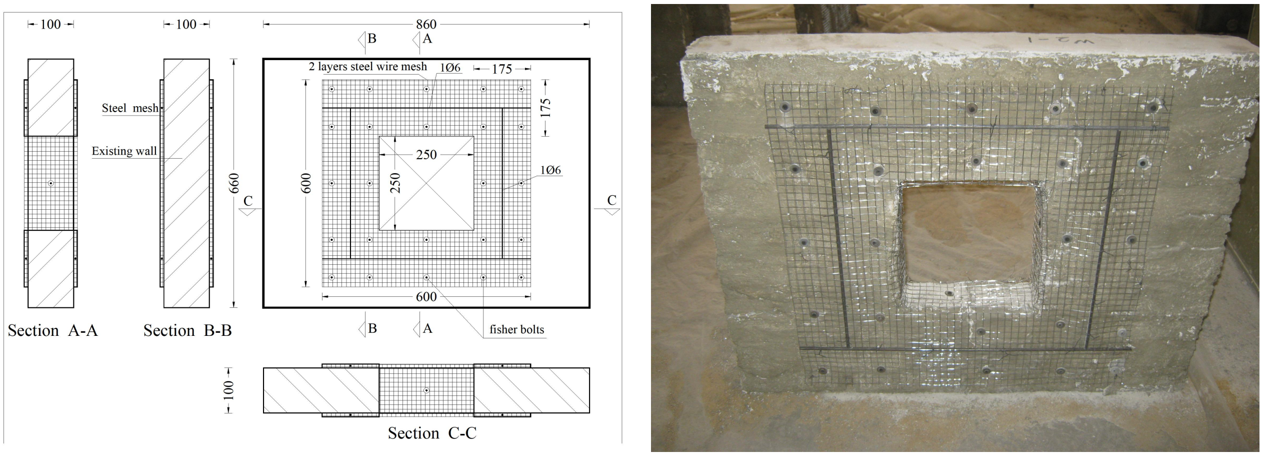

Figure (9) Details of the used rehabilitation technique using two layers of steel wire mesh with 1Ø6 additional external steel bar in between.

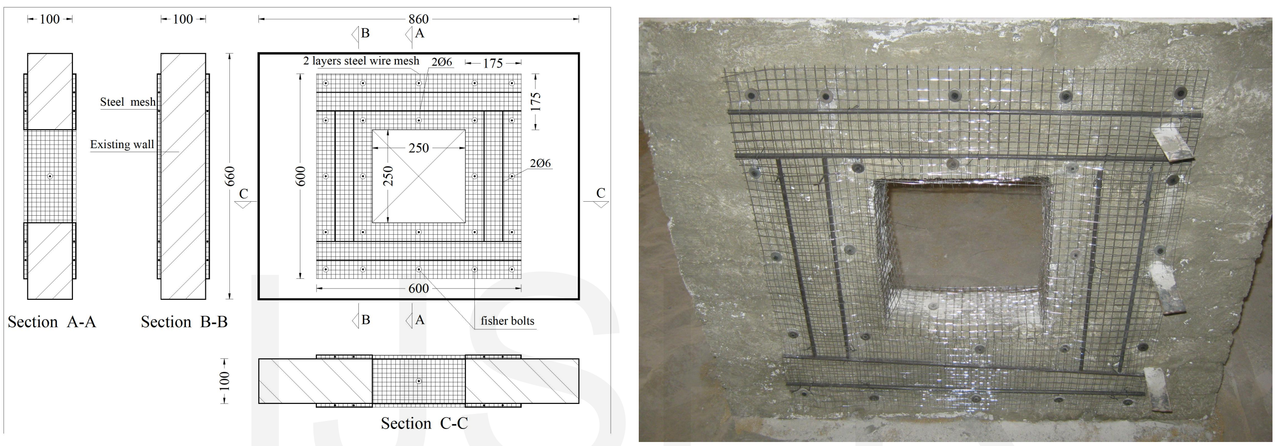

Figure (10) Details of the used rehabilitation technique using two layers of steel wire mesh with 2Ø6 additional external steel bars in between.

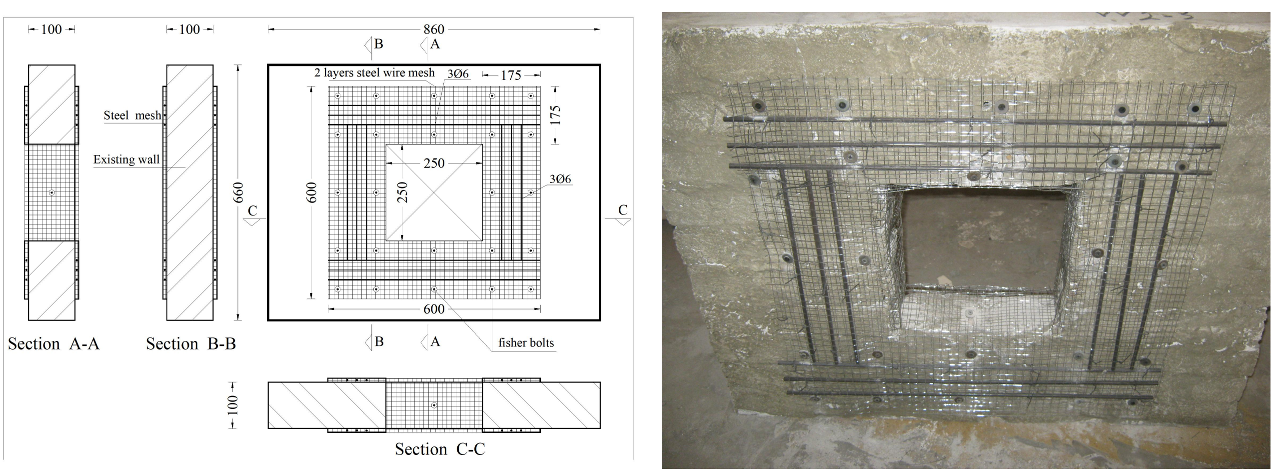

Figure (11) Details of the used rehabilitation technique using two layers of steel wire mesh with 3Ø6 additional external steel bars in between.

EXPERIMENTAL PROGRAM:-

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

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

II. Rehabilitated group: The Rehabilitated group contains nine walls 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 and then loaded until failure.

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

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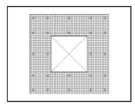
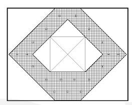
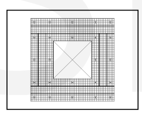
TABLE 1

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 (a)	W_{1-1}	two layers steel wire mesh		262	165	58.79%	8.0	0.00095
Group 1 (a)	W_{1-2}	three layers steel wire mesh		280	165	69.70%	9.2	0.00106
Group 1 (a)	W_{1-3}	four layers steel wire mesh		295	165	78.79%	10.2	0.00120
Group 1 (b)	W_{1-4}	two diagonal layers steel wire mesh		188	165	13.94%	6.8	0.00080
Group 1 (b)	W_{1-5}	three diagonal layers steel wire mesh		198	165	20.00%	7.1	0.00083
Group 1 (b)	W_{1-6}	four diagonal layers steel wire mesh		211	165	27.88%	7.5	0.00091
Group 2	W_{2-1}	two layers steel wire mesh with 1Φ6 additional steel bar		270	165	63.64%	7.8	0.00091
Group 2	W_{2-2}	two layers steel wire mesh with 2Φ6 additional steel bars		289	165	75.15%	9.1	0.00112
Group 2	W_{2-3}	two layers steel wire mesh with 3Φ6 additional steel bars		313	165	89.70%	10.2	0.00126

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 all wall specimens were designed according to the Egyptian code of practice as shown in table (2).

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 %

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Normal mild steel bars St24/37-smooth rebar's of diameter 6.0 mm were used in Rehabilitation. Galvanized steel wire mesh was used in Rehabilitation as external reinforcement.

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 strain and one dial gauges was used for measuring deflection at mid span of lintel.

The test setup is shown in figures (12) to (15) as follows:
Figure (12) shows the test setup.
Figure (13) shows the used dial gauge for measuring lintel deflection.
Figure (14) shows the used LVDT for measuring vertical deformation.
Figure (15) 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 (12) The test setup

Figure (13) The used dial gauge for measuring lintel deflection.

Figure (14) The used LVDT for measuring vertical deformation.

Figure (15) A steel beam as C-channel for transfer the uniform load to wall.

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EXPERIMENTAL TEST RESULTS:-

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

Figure (16) shows the crack pattern for a tested wall specimen after rehabilitation. It was found that cracks occurred at the edge of steel wire mesh.

Figures (17), (18) and (19) show the stress-strain relationship for walls rehabilitated using (2, 3, and 4) steel wire mesh layers without and with (1, 2, and 3Ø6) additional external steel bars.

Figures (20), (21) and (22) show the relationship between load and deflection at mid span of lintel for walls rehabilitated using (2, 3, and 4) steel wire mesh layers without and with (1, 2, and 3Ø6) additional external steel bars.

Figures (23), (24) and (25) show the percentage of increase in ultimate capacity for walls rehabilitated using (2, 3, and 4) steel wire mesh layers without and with (1, 2, and 3Ø6) additional external steel bars.

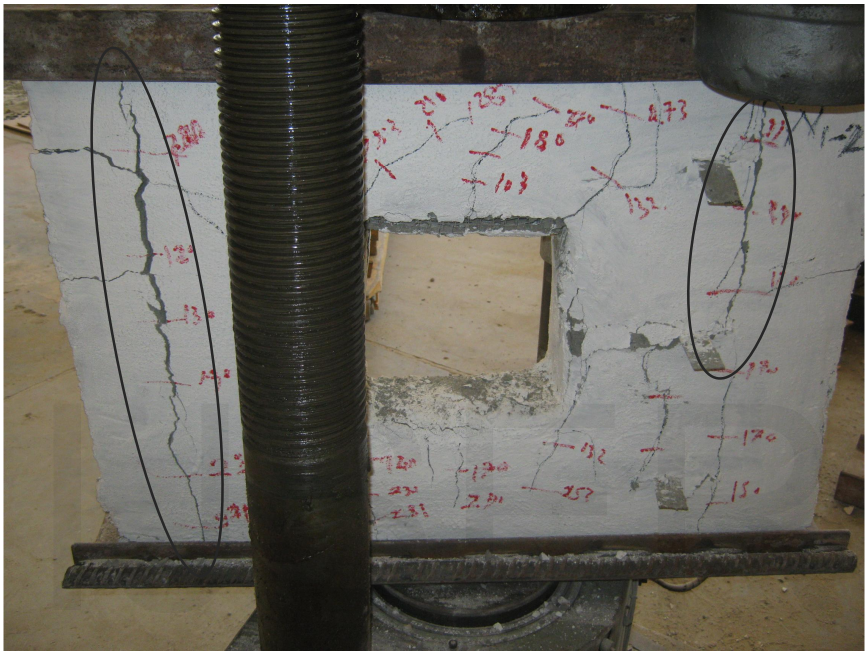

Figure (16) The crack pattern for tested wall specimen after rehabilitation

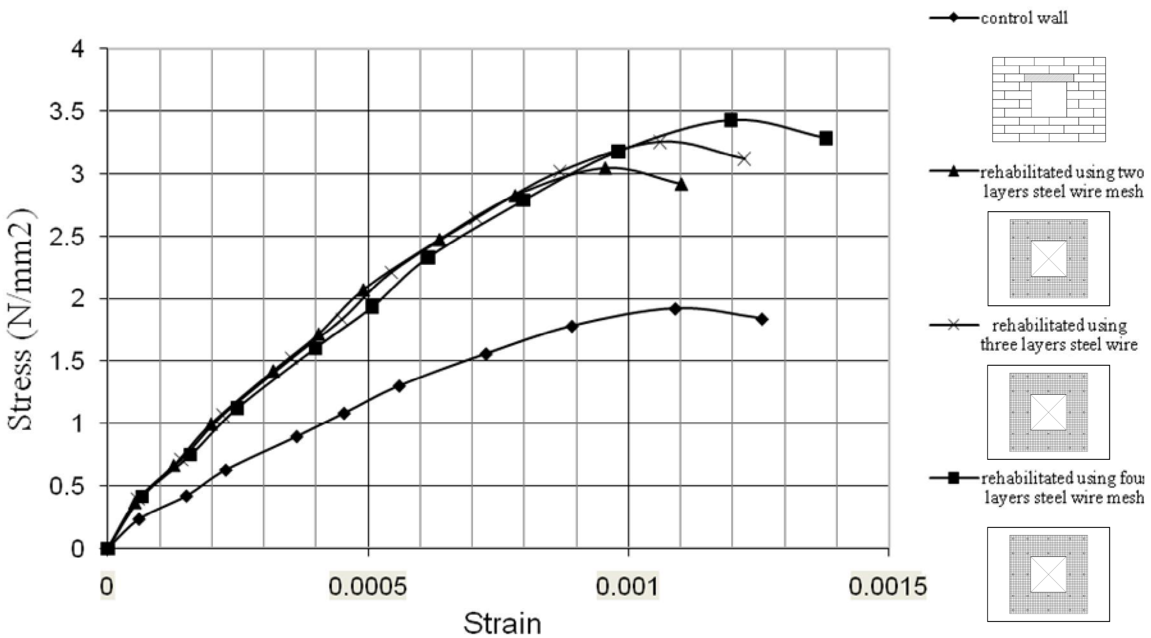

Figure (17) The stress-strain relationship for walls rehabilitated using (2, 3, and 4) steel wire mesh layers without external steel bars.

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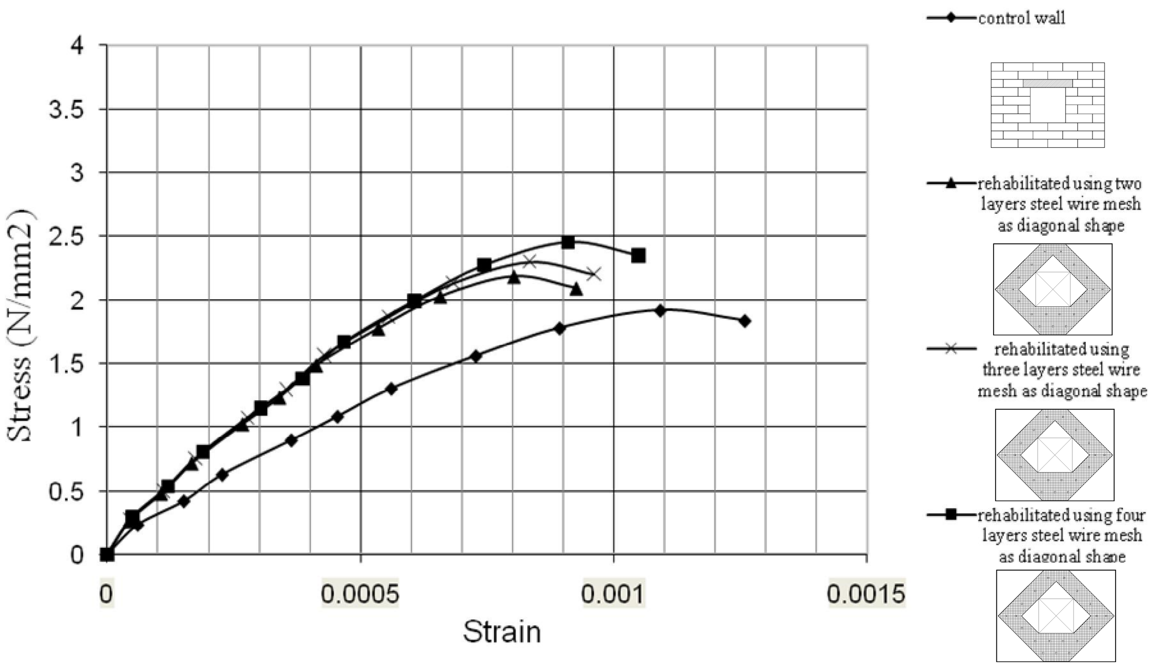

Figure (18) The stress-strain relationship for walls rehabilitated using (2, 3, and 4) steel wire mesh layers as diagonal shape without external steel bars.

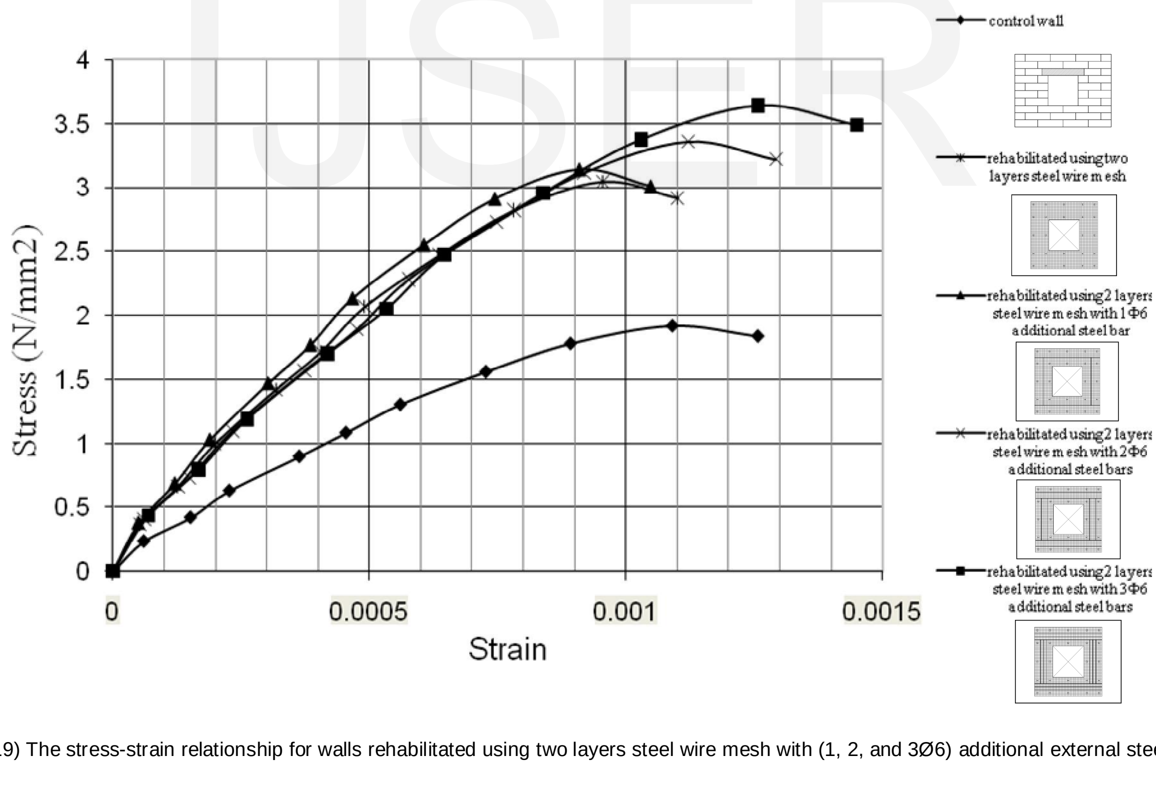

Figure (19) The stress-strain relationship for walls rehabilitated using two layers steel wire mesh with (1, 2, and 3Ø6) additional external steel bars.

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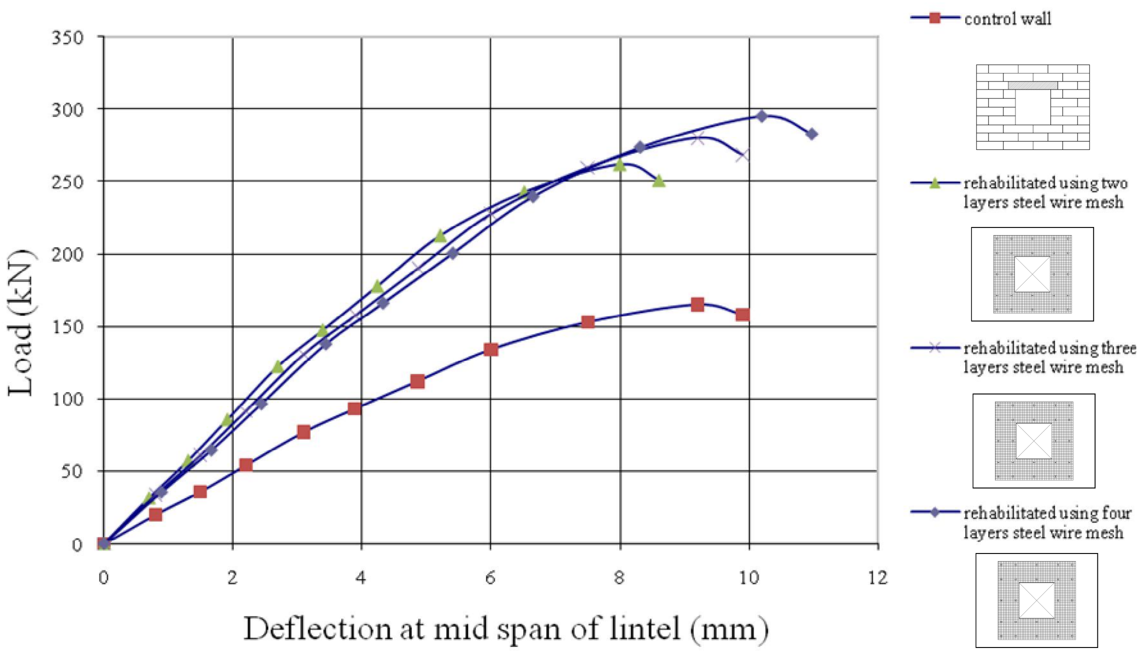

Figure (20) The relationship between load and deflection at mid span of lintel for walls rehabilitated using (2, 3, and 4) steel wire mesh layers without external steel bars.

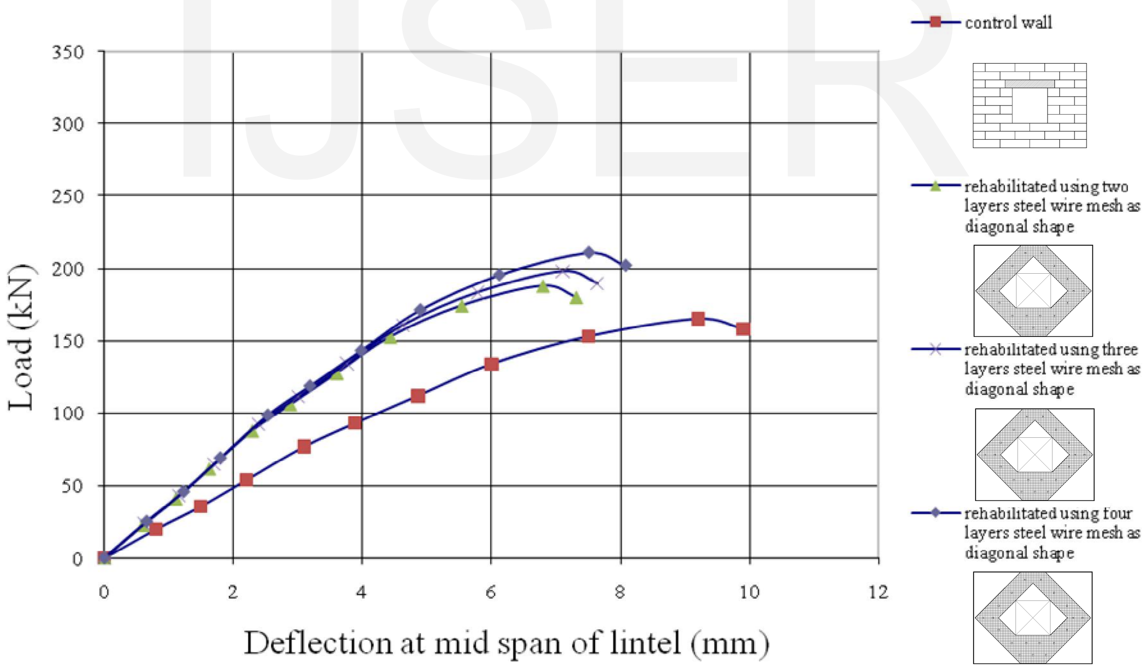

Figure (21) The relationship between load and deflection at mid span of lintel for walls rehabilitated using (2, 3, and 4) steel wire mesh layers as diagonal shape without external steel bars.

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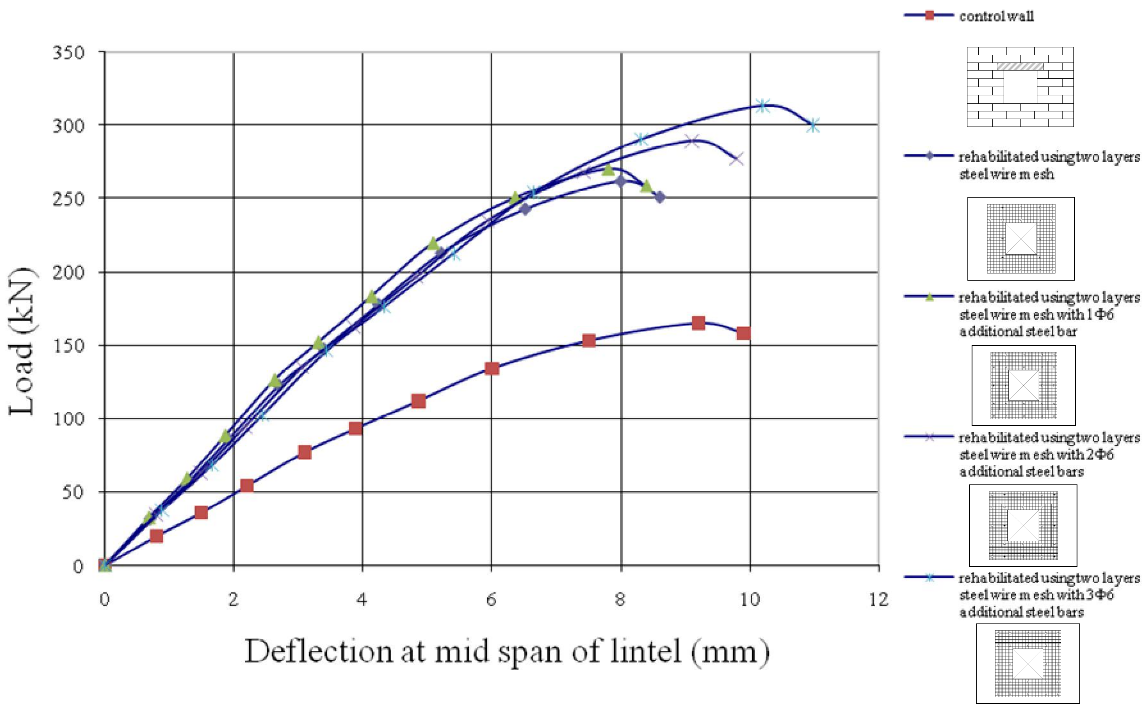

Figure (22) The relationship between load and deflection at mid span of lintel for walls rehabilitated using two layers steel wire mesh with (1, 2, and 3Ø6) additional external steel bars.

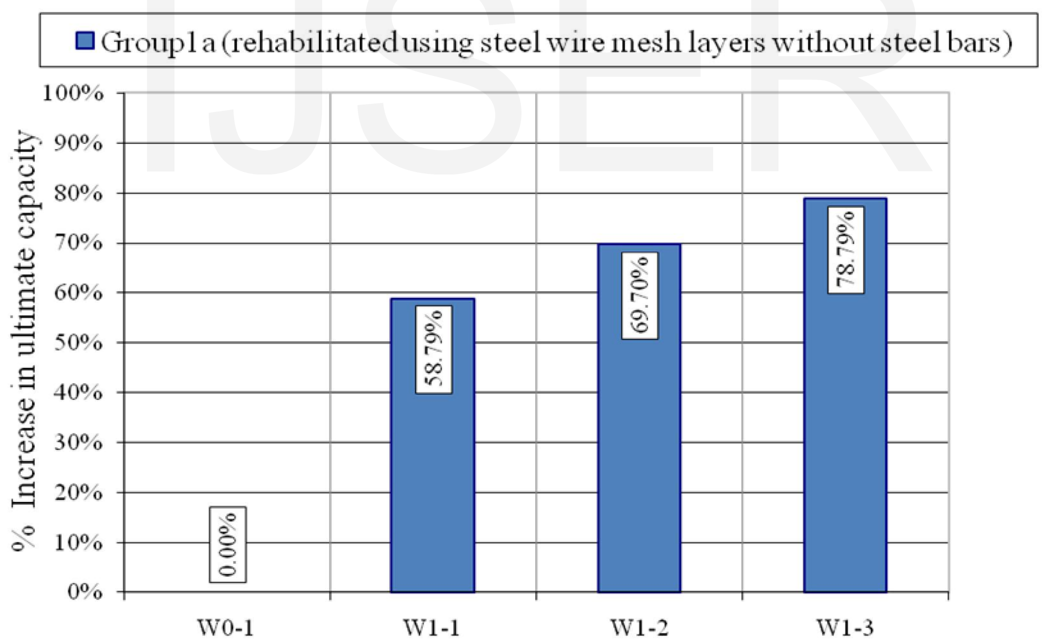

Figure (23) The percentage of increase in ultimate capacity for walls rehabilitated using (2, 3, and 4) steel wire mesh layers without external steel bars

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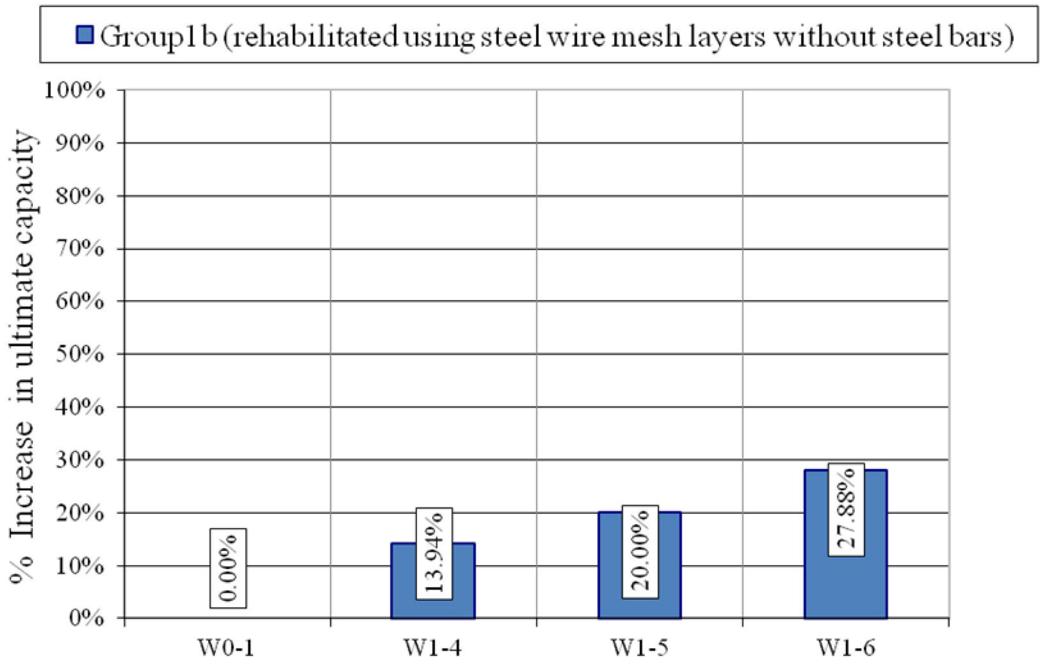

Figure (24) The percentage of increase in ultimate capacity for walls rehabilitated using (2, 3, and 4) steel wire mesh layers as diagonal shape without external steel bars.

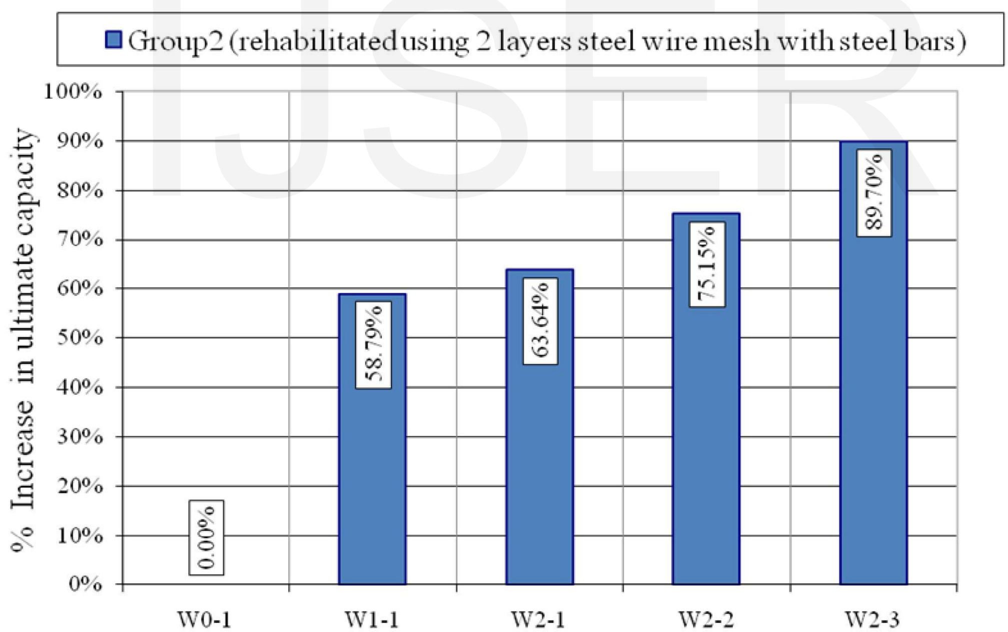

Figure (25) The percentage of increase in ultimate capacity for walls rehabilitated using two layers steel wire mesh with (1, 2, and 3Ø6) additional external steel bars

In all cases the followings have been observed:

I. Increasing number of steel wire mesh layers increases the ultimate capacity of walls as well as increasing ductility.

II. Increasing number of additional external steel bars increases the ultimate capacity of walls and increases ductility.

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CONCLUSIONS

From the present study, the followings have been concluded:

i. For walls rehabilitated by using different numbers of steel wire mesh layers at both sides of brick walls and around openings without external steel bars an increase was obtained in the ultimate capacity up to 78.79%.
ii. For walls rehabilitated by using different numbers of external steel bars with two layers steel wire mesh at both sides of brick walls and around openings an increase was obtained in the ultimate capacity up to 89.70%.
iii. Increasing the number of steel wire mesh layers used in rehabilitation walls increases the load carrying capacity of walls as well as increasing ductility.
iv. Increasing the number of external steel bars used in rehabilitation walls increases the load carrying capacity of walls and increases ductility.

Finally, the results of the present study show that considerable increases in strength as well as ductility of rehabilitated walls by using steel wire mesh with or without added steel bars techniques can be achieved at modest costs.

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