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Experimental Study of Brick Walls with Opening Strengthened During Construction by Using Steel Wire Mesh Embedded Into Bed Joint Mortar between Bricks

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Abstract : *Failure of brick walls structures can be caused by structural weakness or overloading, dynamic vibrations, settlement, and in-plane and out-of-plane deformations. In addition, the appearance of openings in brick walls has an effect on the load capacity and cracking regime after construction under working load. For these reasons, there is a need for strengthening brick walls with openings during construction. In the present study, a total of five brick wall specimens having a wall dimensions (85*65) cm and thickness (10) cm with square opening (25*25) cm were tested. The brick wall specimens were divided into two groups as follows, Group one consisted of one wall with R.C lintel 35 cm length as a control wall .Group two consisted of four strengthened specimens by number of horizontal plies of steel wire mesh (one, two three and four plies) embedded into bed joint mortar. All specimens were tested under static loads in regular increments from zero up to the crack load then failure load. In addition, wall deformations have been measured by LVDT. The obtained test results show that using one ply of horizontal steel wire mesh embedded into bed joint mortar gives an increase in the load carrying capacity up to 117 % from the control ultimate capacity. Using two plies of horizontal steel wire mesh embedded into bed joint mortar gives an increase in the load carrying capacity up to 136 % from the control ultimate capacity. However, using three plies of horizontal steel wire mesh embedded into bed joint mortar gives an increase in the load carrying capacity up to 156 % from the control ultimate capacity. In addition, using four plies of horizontal steel wire mesh embedded into bed joint mortar gives an increase in the load carrying capacity up to 190 % from the control ultimate capacity. The results suggest that increasing number of horizontal plies of steel wire mesh into bed joint mortar increases significantly the load carrying capacity of wall. In addition, ductility has been significantly increased. Thus, it was found that strengthening with this technique is durable, economic and easy to apply.*
Keywords: *Brick walls, Opening, Strengthened, during construction, Steel wire mesh, bed joint mortar*

I. INTRODUCTION

Most buildings crack at some time during their service life. The appearance of cracks can affect the value of the building, its insurability, the salability and can be the subject of litigation. Cracks in brick walls appear after construction under working load as shown in fig. 1, 2. So, the purpose of the present study is strengthening brick walls with opening during construction to increase the load carrying capacity and ductility by using plies of horizontal steel wire mesh embedded into bed joint mortar. Moussa, A. and Aly, A.M. (2001) used Fiberglass Reinforced Plastic laminates (FRP) for strengthening and repair of masonry shear walls with and without openings. The test results clearly demonstrate the efficiency of using FRP laminates as a repair and strengthening technique for unreinforced load-bearing masonry walls. Behrokh H. Hashemi, et.al. (2002) collated information by various earthquake engineering professionals around the world. This is a typical confined brick masonry housing construction common in rural areas of Iran. This building type is often used as a single-family house. Brick masonry shear walls confined with concrete tie columns and beams were investigated to provide earthquake resistance in both directions. Andrew Smith and Thomas Redman (2009) collated information and categories the various types of retrofitting methods for unreinforced masonry (URM) buildings under research or early implementation, and critically compare them to help further understand which methods are most suitable. Elsamny, M.K., et.al. (2011) presented an investigation for strengthening solid brick walls by horizontal galvanized steel mesh embedded into bed mortar between bricks during construction and investigated the effect of the number of horizontal steel mesh layers and the type of mortar used on walls carrying capacity. The experimental results showed that the use of this technique in strengthening solid brick walls has a great effect on walls carrying capacity depending on number of horizontal steel mesh layers and the type of mortar used. Elsamny, M.K., et.al. (2011) carried out an experimental study to investigate the strengthening solid brick walls using vertical galvanized steel mesh fixed at one side as well as both sides of the walls with different number of layers and investigated the effect of the number of vertical steel mesh layers and the type of mortar used on walls carrying capacity. The test results clearly demonstrate the efficiency of using this technique in strengthening solid brick walls and showed that increasing number of vertical steel mesh layers gives an increase in brick walls carrying capacity. Mahmoud .B.N.A (2011) tested thirty solid brick walls strengthened by different types of steel mesh, horizontal galvanized steel mesh embedded into bed mortar between bricks . Vertical galvanized steel mesh fixed at one side as well as both sides of the walls with different number of layers and combination of horizontal and vertical steel mesh were used . The results demonstrate that the use of horizontal, vertical and combination of horizontal and vertical steel mesh in strengthening brick walls gives an increase in brick walls carrying capacity as well as increasing ductility. Almherigh Mohamed Abdalla (2014) summarized the wide varieties of cracks in walls and their causes and how they can be avoided contributing to good masonry design .El-Salakawy, Tarik S., et.al. (2014) presented experimental investigation of strengthening masonry walls and vaults using FRP composites, as well as other traditional methods. Elsamny, M.K., et.al. (2016) tested ten unreinforced brick walls under uniform load up to 80% of failure load till cracks occurred. 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 results showed that the walls rehabilitated by a different numbers of steel wire mesh layers only 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. Elsamny, M.K., Abd-Elhamed, M.K. , and Elmokrany, A.A. (2017) introduced an experimental program for strengthening brick walls with opening during construction. The experimental program included testing of seven brick wall specimens divided into three groups according to the different methods of strengthening .Group one consisted of wall with R.C lintel 35 cm length as a control wall , group two consisted of three strengthened brick wall specimens by 3Ø8 steel bars embedded into bed joint mortar above lintel only with lengths (L = 50, 65, 85cm) and group three consisted of three strengthened brick wall specimens by 3Ø8 steel bars embedded into bed joint mortar above lintel and sill with lengths (L = 50, 65, 85cm) . The obtained test results show that using 3Ø8 steel bars embedded into bed joint mortar above lintel only with length (85cm) gives an increase in the load carrying capacity up to (179%) from the control ultimate capacity. However using 3Ø8 steel bars into bed joint mortar on lintel and sill with length (85cm) gives an increase in the load carrying capacity up to (223%) from the control ultimate capacity. However, ductility has been significantly increased. In addition, it was found that strengthening with this technique is durable, economic and easy to apply. The results suggest that using 3Ø8 steel bars into bed joint mortar on lintel and sill with the whole length of wall increases the load carrying capacity of wall as well as increasing ductility and prevent cracks a round opening. Elsamny, M.K., Abd-Elhamed, M.K., and Elmokrany, A.A. (2017) presented an investigation for strengthening brick walls with opening during construction by using R.C. lintel and sill and investigated the effect of R.C. lintel and sill lengths on carrying capacity of brick walls with openings. The experimental program included testing of eight brick wall specimens divided into three groups according to the different methods of strengthening .Group one consisted of wall with R.C lintel length of 35 cm as a control wall , group two consisted of three strengthened brick wall specimens by R.C. lintel only of lengths (L=50,65,85cm) and group three consisted of four strengthened brick wall specimens by R.C. lintel and sill of lengths (L= 35,50,65,85cm).The obtained test results show that using R.C lintel only with length (85cm) gives an increase in the load carrying capacity up to (189%) from the control ultimate capacity. However, using R.C. lintel and sill with length (85cm) gives an increase in the load carrying capacity up to (235%) from the control ultimate capacity. However, ductility has been significantly increased. In addition, it was found that strengthening with this technique is durable, economic and easy to apply. The results suggest that adding sill under openings is very effective to overcome and prevent cracks under the working load in the wall. However, using R.C lintel and sill with length (85cm) shows the best performance in increasing the load carrying capacity and ductility. Elsamny, M.K., Ezz-Eldeen, H.A.and Mahmoud, M.H. (2017) used steel plate box-section and steel angle for rehabilitated of brick walls with openings. 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. Elsamny, M.K., et.al. (2017) tested five unreinforced brick walls with opening 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 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. 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. However, increasing dimensions of L&U-shaped steel plate used in rehabilitation increases the load carrying capacity of walls.

Figure 1. *Cracks around window opening By Ingval Maxwell Published by Technical Conservation Group*

Figure 2. *Cracks around window opening*
Mahmud, M. A (2016) "Rehabilitation of brick walls with opening" Ph.D. Thesis under study Al-Azhar University

II. PROPOSED TECHNIQUE OF STRENGTHENING AND EXPERIMENTAL PROGRAM

In the present study, two different approaches well considered for strengthening brick walls with opening during construction to prevent cracks after construction and increase the load carrying capacity of wall as well as increasing ductility:

Using plies of horizontal steel wire mesh embedded into bed joint mortar between bricks.

Increasing number of horizontal steel wire mesh plies embedded into bed joint mortar increases the load carrying capacity of wall.

A total of five specimens of brick walls having a wall dimensions (85*65) cm and thickness (10) cm with square opening (25*25) cm were built. Fig. 3 shows brick wall specimens during construction.

The brick walls specimens were divided into two groups as follows: Group one consisted of one brick wall with R.C lintel 35 cm length as a control wall as shown in fig.4.

Group two consisted of four strengthened brick walls specimens by number of horizontal plies of steel wire mesh (one, two three and four plies) embedded into bed joint mortar. as shown in fig. 5,6,7 ,8a and 8b.

All specimens were tested under static loads in regular increments from zero up to the cracking load then failure load.

Figure 3. *Brick wall specimen during construction*

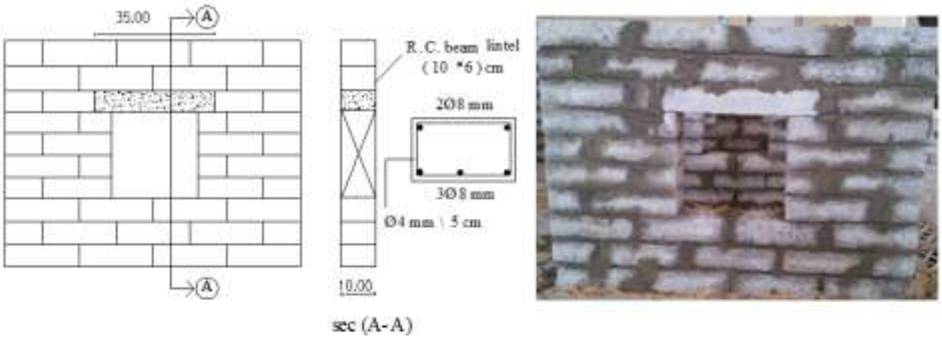


Figure 4. *Brick wall with R.C. lintel 35 cm (control wall)*

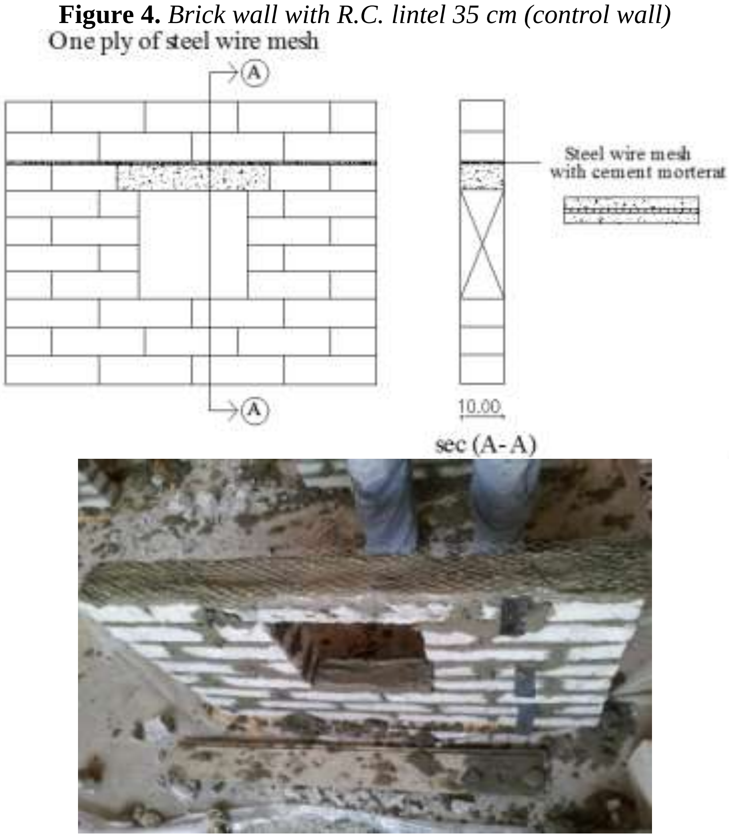


Figure 5. *Strengthening brick walls with opening using one horizontal ply of steel wire mesh embedded into bed joint mortar above lintel.*

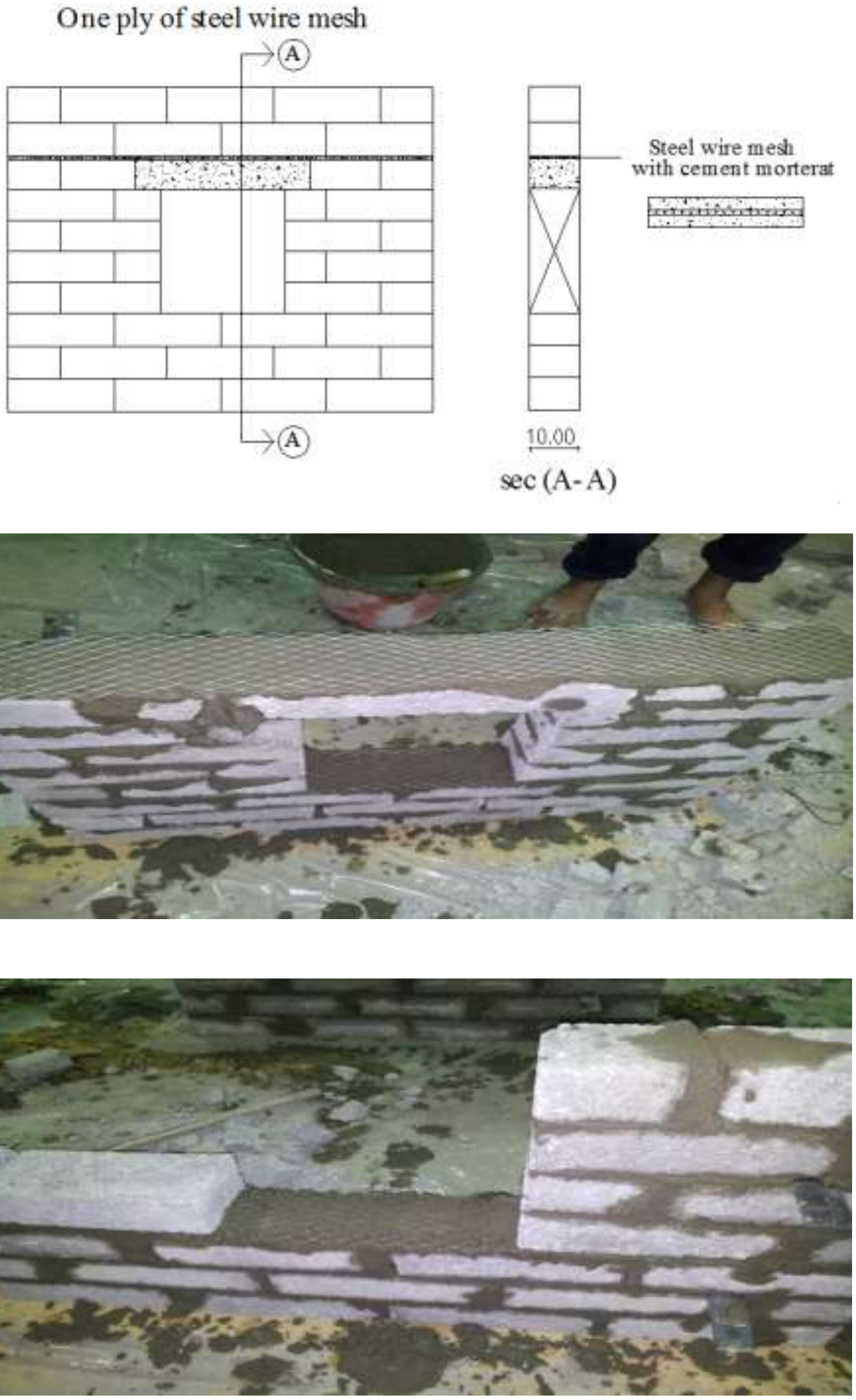
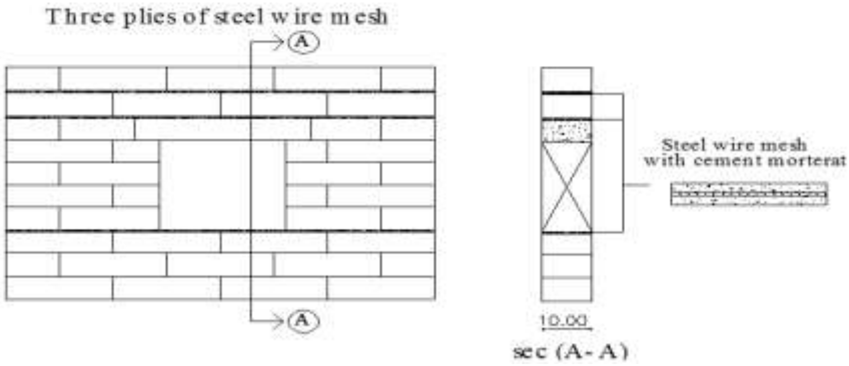


Figure 6 . *Strengthening brick walls with opening using two horizontal plies of steel wire mesh embedded into bed joint mortar above lintel and sill level.*



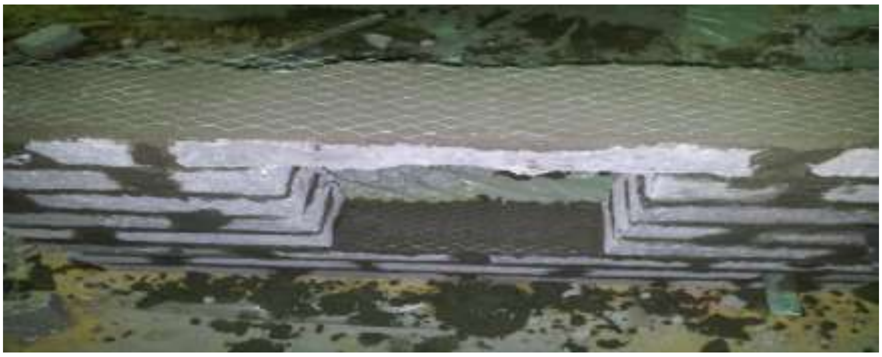


Figure 7. *Strengthening brick walls with opening using three horizontal plies of steel wire mesh embedded into bed joint mortar (two plies above lintel and one ply at sill level)*

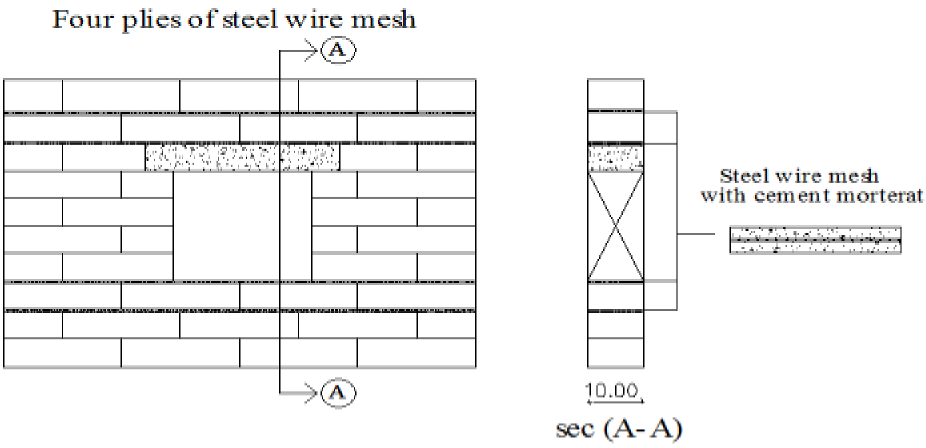


Figure 8a. *Strengthening brick walls with opening using four horizontal plies of steel wire mesh embedded into bed joint mortar (two plies above lintel and two plies at sill level)*

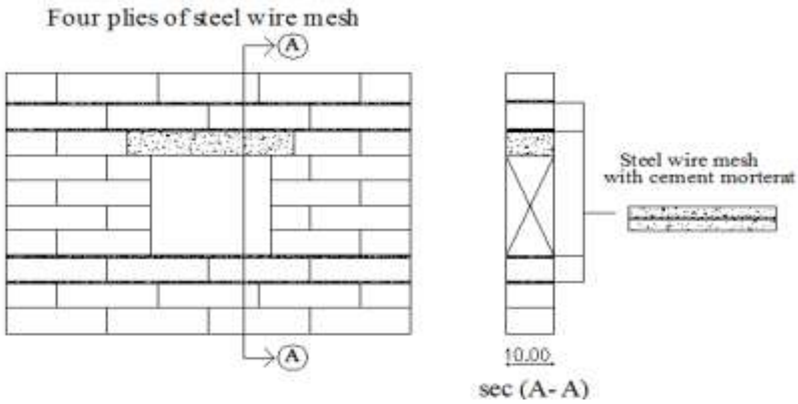


Figure 8b . *Strengthening brick walls with opening using four horizontal plies of steel wire mesh embedded into bed joint mortar (two plies above lintel and two plies at sill level)*

III. USED MATERIALS

Solid concrete bricks with dimension (20 * 10 * 6) cm. The average of bricks compressive strength is (200.87 kg/cm2) .Concrete mix consisted of crushed stone which has a maximum nominal size of (10.0mm) was used as the coarse aggregate in the mix. Graded sand having sizes in the range of (0.3 mm) was used as the fine aggregate in the mix. Ordinary Portland cement and clean drinking fresh water were used for mixing and curing.

Cement mortar mix used in building the brick wall specimens was made of water-cement ratio = 0.50 and cement sand ratio of 1:3 Natural sand passing through JIS sieve designed no. 1.2 (1.19 mm). Standard mortar cubes were taken during construction with average compressive strength (90.82 kg/cm2) .

R.C lintel was reinforced with steel bars 5Ø8 mm and stirrups Ø4 \ 5 cm ,cross section is (10x6) cm with length of 35cm. The concrete mix consisted of crushed stone which has a maximum nominal size of (1.0 mm) as the coarse aggregate in the mix, graded sand having sizes in the range of (0.3 mm) used as the fine aggregate in the mix. Ordinary Portland cement and clean drinking fresh water were used for mixing and curing.

The used steel mesh is galvanized steel expanded metal 10 cm wide , as shown in fig. 9 were used embedded into bed joint mortar between bricks with length 85cm.

Figure 9. *Steel mesh used into bed joint mortar*

IV. TEST SETUP AND PROCEDURE

All wall specimens were tested under static loads using the testing machine mounted on the material laboratory of Al-Azhar University which has an ultimate compressive load capacity of 2000kN. Two u-steel beams were used for distribution the load on the wall specimens as shown in fig.10 .Carrying the wall specimen with wood panels as shown in fig. 11. Loads have been measured by the testing machine and wall deformation have been measured with LVDT under the applied loads as shown in fig. 12 .The readings of loads and wall deformation were recorded through the data acquisition system. The data acquisition system consisted of a laptop computer, a Keithley-500a data acquisition system and the lab tech notebook software package .Test setup is shown in fig.13.

Figure 11. *Carrying wall on testing machine by wood panels*

Figure 10. *Two U-steel beams for distribution load*

Figure 13. *Test set up with LVDT*

Figure 12 . *Wall deformation has been measured*

V. EXPERIMENTAL TEST RESULTS

Table (1) shows the failure loads, deformation, ultimate stress and strain for control and strengthened walls as well as increasing in ultimate capacity with different numbers of horizontal steel wire mesh plies embedded into bed joint mortar.

Fig.14 shows the relationship between stress and strain for control and strengthened brick walls by number of horizontal plies of steel wire mesh (one, two three and four plies) embedded into bed joint mortar.

Fig.15 shows the relationship between ultimate stress (%) from control wall with R.C. 35 cm lintel length and number of horizontal plies of steel wire mesh embedded into bed joint mortar for strengthened brick walls.

Table (1)

Strain	% Wall carrying Capacity from control wall	Failure Stress (kg\cm2)	Failure Loads (kn)	No. of plies of steel wire mesh	Wall no.	Group
0.0008	100 %	15.88	135	-	W1	1
0.0015	117 %	18.59	158	1	W2	2
0.0021	136 %	21.53	183	2	W3	
0.0020	156 %	24.71	210	3	W4	
0.0022	190 %	30.12	256	4	W5	

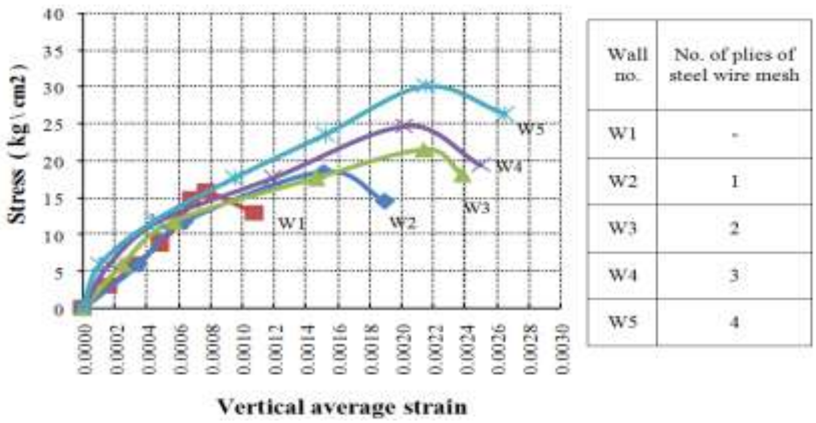


Figure 14 . *The relationship between stress and strain for control and strengthened walls by using horizontal plies of steel wire mesh embedded into bed joint mortar (one, two three and four plies)*

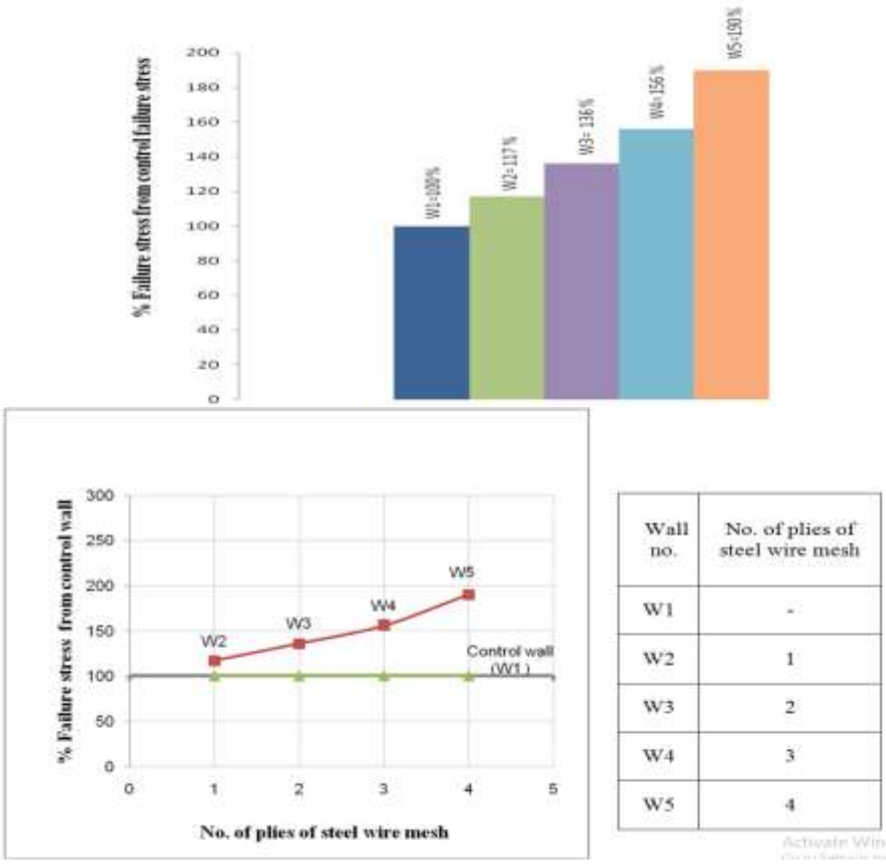


Figure15. *The relationship between stress and strain for control and strengthened walls by using horizontal plies of steel wire mesh embedded into bed joint mortar (one, two three and four plies)*

VI. CONCLUSIONS

From the present study, the followings have been concluded:

- Using horizontal plies of steel wire mesh embedded into bed joint mortar during construction increases the load carrying capacity of wall.
- Increasing number of horizontal plies of steel wire mesh embedded into bed joint mortar increases significantly the load carrying capacity of brick walls as well as increasing the ductility.
- The percentage of increasing the ultimate stress for strengthened walls with horizontal (one, two three and four plies) of steel wire mesh embedded into bed joint mortar was found to be between of 117% and 190%.

Finally, the results suggest that strengthening brick walls with opening during construction by using horizontal plies of steel wire mesh embedded into bed joint mortar during construction is very efficient and economic method for increasing the load carrying capacity and ductility as well as preventing of cracks under working load conditions.

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