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Experimental Investigation of using Wooden Lintel and sill with Different Lengths for Strengthening Brick Walls with Openings

Elsamny, M.K., Abd-Elhamed, M.K., Ezz-Eldeen, H.A., Elmokrany, A.A.

Abstract: ***The presence of openings can have an effect on the load capacity and cracking regime for brick walls. Often the type and magnitude of cracking indicate the cause of cracks. However, cracks in brick walls appear after construction under working load due to different reasons. The presence of openings in brick wall with conventional length of lintel gives small bearing area. Thus, as a result of concentrated load on part of the wall, corner cracks occur above the openings. In addition, openings divide the wall to two parts, the first part next to the opening act as pillars and are stressed much more than the second part below the opening. Thus, as a result of differential stress, vertical shear cracks occur under opening in the wall. For these reasons, there is a need for redistribution the load by using sill under opening and increasing the bearing area by increasing length of lintel and sill. In the present study, a total of seven 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 three groups as follow :***

i. Group one consisted of wall with R.C lintel length of 35 cm as a control wall.

ii. Group two consisted of three strengthened brick wall specimens by wooden lintel of lengths (L= 35, 50,65cm).

iii. Group three consisted of three strengthened brick wall specimens by wooden lintel and sill of lengths (L= 35, 50,65cm).

All wall 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. A finite element analysis was performed using SAP2000 to define the stress distribution path as well as the expected positions of cracks that might occur in walls with openings using different techniques of strengthening. The obtained test results show that using wooden lintel with length (65cm) gives an increase in the load carrying capacity up to (130 %) from the control ultimate capacity. In addition, using wooden lintel and sill with length (65cm) gives an increase in the load carrying capacity up to (171%) 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 during construction. The results suggest that adding sill under openings is very effective to overcome and prevent cracks under the working load in the wall and increasing the length of lintel and sill during construction shows the best performance in increasing the load carrying capacity and ductility.

Index Terms*: *Experimental, brick walls, openings, wooden lintel, wooden sill.

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I. INTRODUCTION

Cracks appear in brick walls with openings under working loads at different positions as shown in figures (1) and (2). Many researchers investigated the behavior of solid brick walls. Only a few studies involved walls with openings. So, the purpose of the present study is strengthening brick walls with openings during construction to increase the load carrying capacity and ductility by increasing the length of lintel and adding sill with different lengths. Moussa, A., 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. Farooqa, S.H. , et.al. (2006) tested eight walls panels for compressive and shear strength evaluation. The results demonstrate that a significant increase in compressive and shear strength can be achieved by anchoring steel strips to the surface of masonry walls. Elsamny, M.K., et.al. (2011) presented an investigation for strengthening of solid brick walls by horizontal galvanized steel mesh 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 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 of 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 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 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 .

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The results demonstrate that the use of horizontal as well as vertical and combination of horizontal. and vertical steel mesh in strengthening brick walls gives a significant increase in brick walls carrying capacity. 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 through insuring aesthetic as well as safety provision at lowest possible cost. 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 .The experimental results showed that FRP gave higher strengthening level and better failure mode than using 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 showed 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 embedded into bed joint mortar above 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 embedded into bed joint mortar above lintel and sill with the whole length of wall increases the load carrying capacity of wall as well as increasing ductility and prevent cracks around 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 angles for rehabilitated of brick walls with openings . The obtained test results showed 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 angles 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 angles 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 plates inside opening corners welded with U & L-shaped steel plates at both sides. Another wall was loaded up to 80% of failure load till cracks occurred and then rehabilitated using diagonal steel plates around opening at both sides. The obtained test results showed that the walls rehabilitated by using different dimensions of L&U-shaped steel plates gives an increase in the load carrying capacity up to 63.64% of the control ultimate capacity. However, 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. Elsamny, M.K., et al. (2017) presented an investigation for strengthening brick walls with opening during construction by using number of horizontal plies of steel wire mesh (one, two three and four plies) embedded into bed joint mortar above lintel and under sill level. The results suggested that increasing number of horizontal plies of steel wire mesh embedded into bed joint mortar increases significantly the load carrying capacity of wall. In addition, ductility has been significantly increased. Elsamny, M.K., et.al. (2017) used fixed strip of vertical steel wire mesh covered with cement mortar around opening on both sides of wall with strip wide (5,10,15,20 cm) for strengthening brick walls with opening during construction.

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The results suggested that increasing the wide of wire mesh strip increases significantly the load carrying capacity of wall. However, ductility has been significantly increased.

In the present study, investigation of using wooden lintel and sill with different lengths during construction to eliminate cracks that may be occurred under working loads during life time of building after construction. However, an experimental program has been performed herein to investigate the effect of using wooden lintel and sill with different lengths on eliminates cracks around openings.

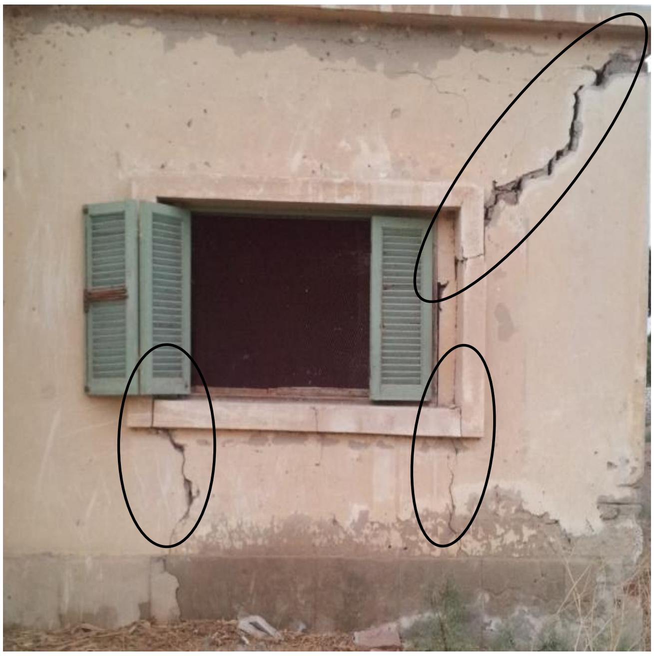


Fig.1. Diagonal cracks over lintel and vertical cracks below window opening (Old building in elhagar city, El.fayoum)

Fig. 2. Cracks around window opening Elmokrany A.A.SH, (2016) "Strengthening 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, three different approaches were considered for strengthening brick walls with openings during construction to prevent cracks under working loads after construction and increase the load carrying capacity of wall as well as ductility :-

i. Increasing the length of wooden lintel.
ii. Adding wooden sill under opening.
iii. Using wooden lintel with sill together.

A total of seven specimens of brick walls having a dimensions (85*65) cm and thickness (10) cm with square opening (25*25) cm were tested. The specimens were divided into three groups according to the different methods of strengthening:

i. Group one consisted of brick wall with R.C lintel 35 cm as shown in figure (3).
ii. Group two consisted of three strengthened brick wall specimens by wooden lintel with lengths (L= 35, 50, 65cm) as shown in figure (4)
iii. Group three consisted of three strengthened brick wall specimens by wooden lintel and sill with lengths (L= 35, 50, 65cm) as shown in figure (5).

All specimens were tested under static loads in regular increments from zero up to the crack load then failure load. All groups are shown in Table (1) and figure (6).

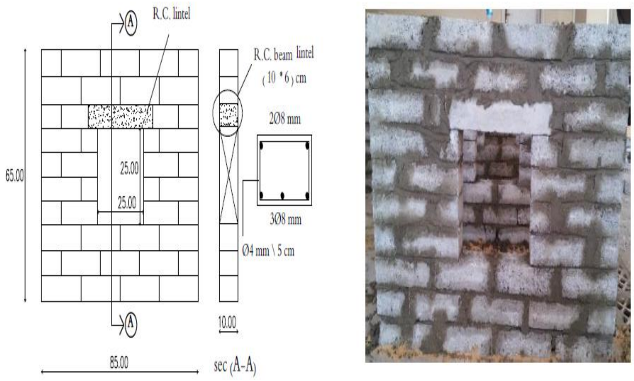
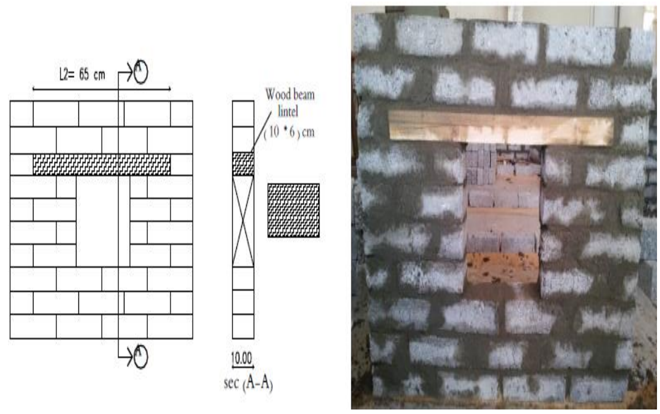


Fig. 3. Brick wall with R.C .lintel 35 cm (control wall)



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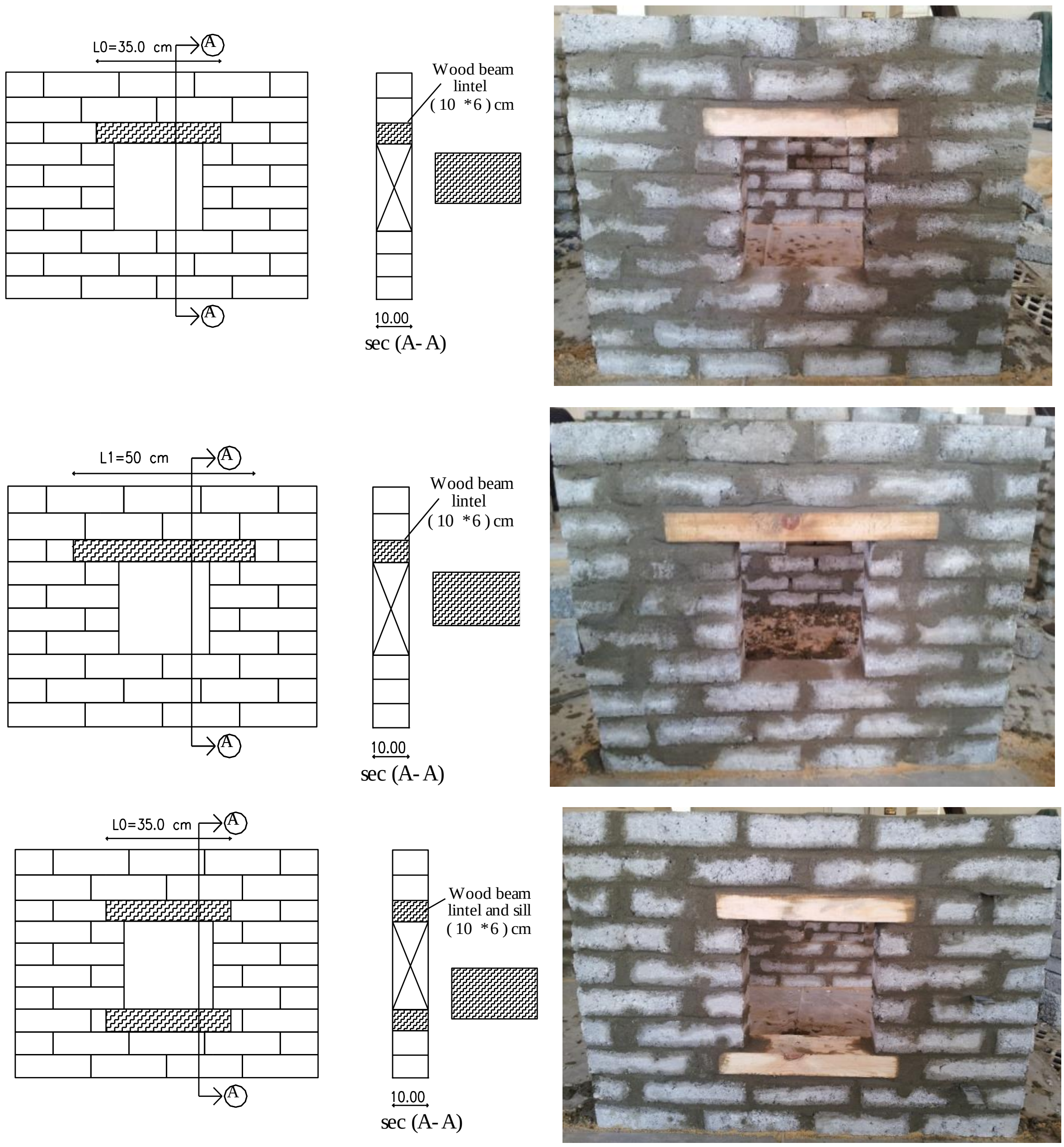
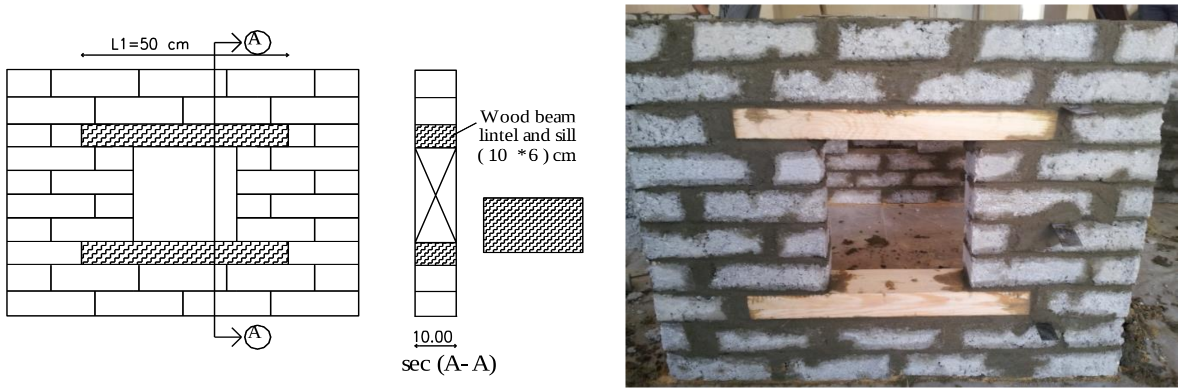


Fig.4. Details of strengthening brick walls with opening using wooden beam at lintel with (L0, L1, L2) (all dimensions with cm)



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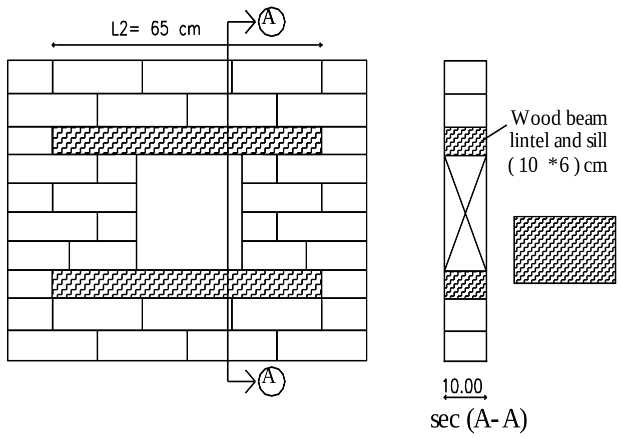

Fig. 5. Details of strengthening brick walls with opening using wooden beam at lintel and sill with (L0, L1, L2) (all dimensions with cm)

Fig. 6. Brick wall specimens before testing

Table 1 Test results of strengthened walls

Group	Wall no.	Lintel or sill material	Lintel Length (cm)	Sill Length (cm)	Failure Loads (kN)	Deformation (mm)	Failure stress kg\cm2	% Wall Carrying capacity from control wall	Strain
1	W1	R.C	35	-	135	1.51	15.88	100 %	0.0023
2	W2	Wood	35	-	125	1.41	14.71	93 %	0.0022
	W3		50	-	150	1.81	17.65	111 %	0.0028
	W4		65	-	175	2.71	20.59	130 %	0.0042

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3	W5	Wood	35	35	154	2.15	18.12	114 %	0.0033
	W6		50	50	205	2.71	24.12	152 %	0.0042
	W7		65	65	231	4.11	27.18	171 %	0.0063

III. USED MATERIALS

i. 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.

ii. 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).

iii. R.C lintel for control wall was reinforced with steel bars 5Ø8 mm and stirrups Ø4 \ 5 cm , cross section is (10x6) cm with length 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.

iv. Wooden lintel and sill have been used with cross section (10x6) cm with different lengths (L0 = 35cm , L1 = 50cm, L2 = 65cm).

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 figure (7). Carrying the used wall specimen with wood panels as shown in figure (8). Loads have been measured by the testing machine and wall deformation have been measured with LVDT under the applied loads as shown in figure (9) .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 figure (10).

Fig.7.Two U-steel beams for distribution the load on walls

Fig.8. Carrying wall on testing machine by wood panels

Fig.9. Wall deformation have been measured with LVDT

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Fig.10. Test set up

V. EXPERIMENTAL TEST RESULTS

Table (1) shows the failure loads, deformation, failure stress and strain as well as increasing in ultimate capacity for control and strengthened walls with different types of strengthening.

Using wood lintel with lengths (L= 35,50,65cm) made the failure almost started by appearance vertical cracks under opening followed by appearance corner cracks above opening at the end of lintel even the load reaches its peak value. However, using wooden lintel and sill made the failure almost started by appearance corner cracks above opening at the end of lintel even the load reaches its peak value.

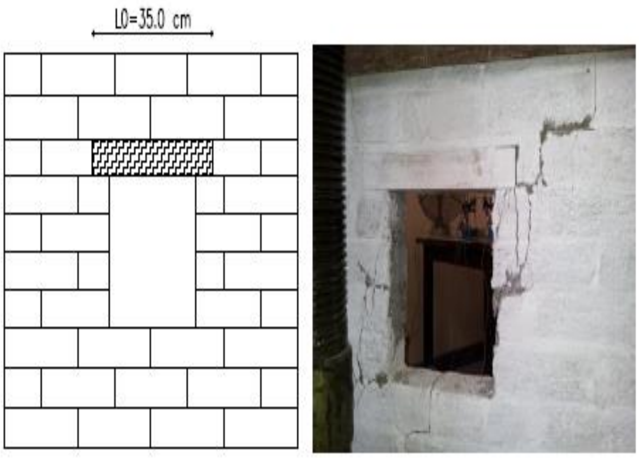
Failure pattern shows that:

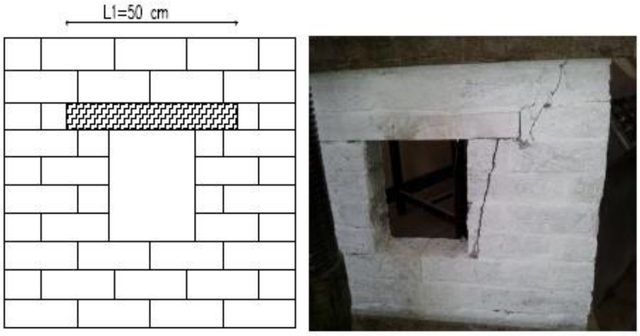
i. Increasing the length of wooden lintel during construction distribute the load to a larger resisting area of wall and reducing the stress field, thus overcome the corner cracks above opening.

ii. Adding wooden sill under opening during construction is very effective to overcome the vertical shear cracks occur in the wall.

Figure (11) shows the failure patterns for strengthened brick wall specimens by wooden lintel of lengths (L= 35, 50,65cm).

Figure (12) shows the failure patterns for strengthened brick wall specimens by wooden lintel and sill with lengths (L= 35, 50,65cm).





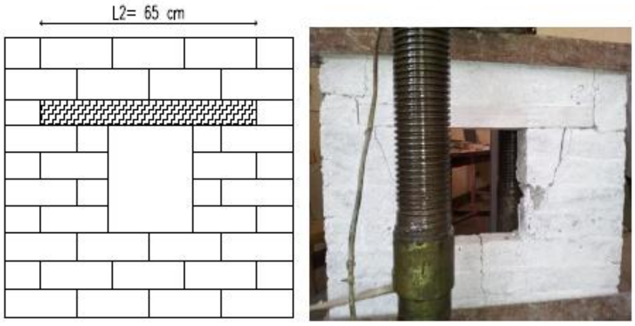
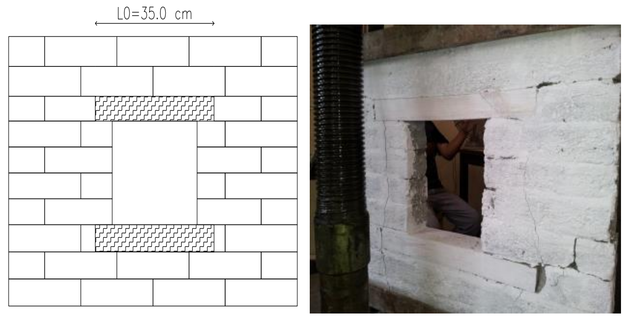
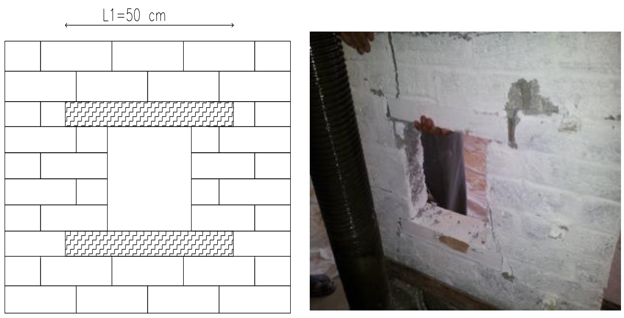


Fig.11. Failure patterns for strengthened brick walls by wooden lintel of lengths (L= 35, 50, 65cm)





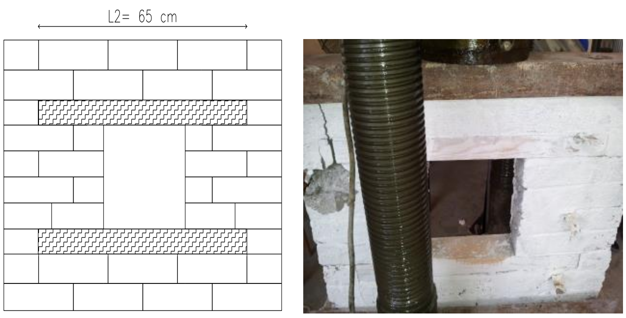


Fig.12. Failure patterns for strengthened brick walls by wooden lintel and sill with lengths (L= 35, 50, 65cm)

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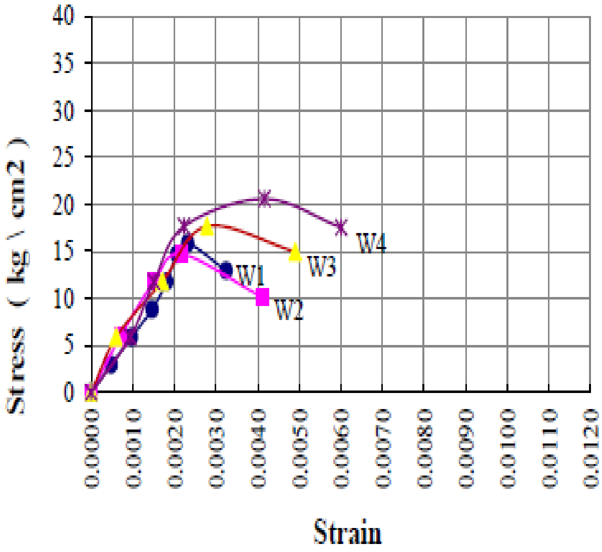

Fig.13.The relationship between stress and strain for control and strengthened brick walls by wooden lintel only with lengths (35, 50, 65cm).

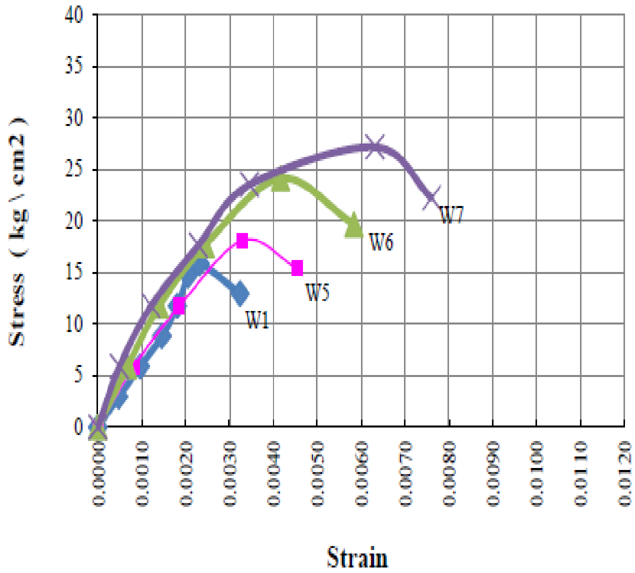

Fig.14. The relationship between stress and strain for control and strengthened brick walls by wooden lintel and sill with lengths (35, 50, 65cm).

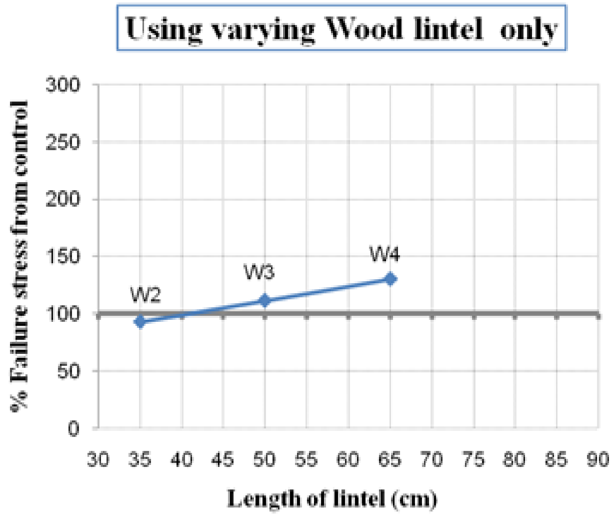

Fig.15. The relationship between % Failure stress from control and length of lintel for strengthened brick walls with wooden lintel with different lengths

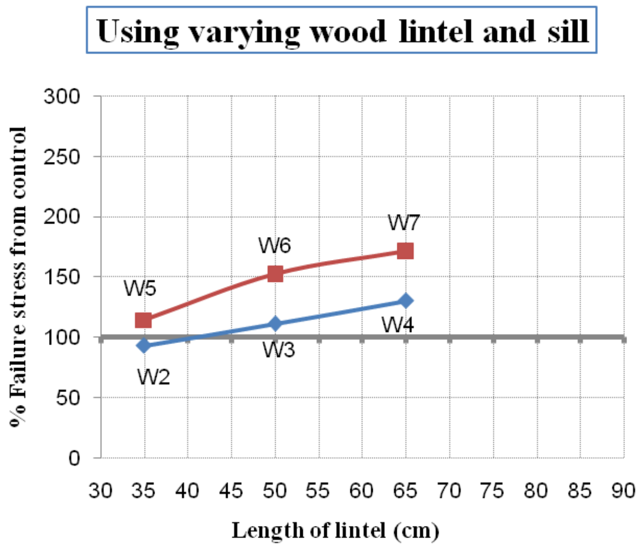

Fig.16. The relationship between % Failure stress from control and length of lintel and sill for strengthened brick walls with wooden lintel and sill with different lengths

Figure (13) shows the relationship between stress and strain for control wall with R.C. 35 cm lintel only and strengthened brick walls by wooden lintel with lengths (35, 50,65cm).

Figure(14) shows the relationship between stress and strain for control wall with R.C. 35 cm lintel only and strengthened brick walls by wooden lintel and sill with lengths (35,50,65cm).

Figure (15) shows the relationship between failure stress (%) from control wall with R.C. 35 cm lintel only and length of lintel for strengthened brick walls with wooden lintel with different lengths.

Figure (16) shows the relationship between failure stress (%) from control wall with R.C. 35 cm lintel only and length of lintel and sill for strengthened brick walls with wooden lintel and sill with different lengths.

VI. FINITE ELEMENT ANALYSIS

A finite element modelling program SAP2000 was used in the present study to analyze stress distribution of the control wall with R.C. lintel 35 cm and strengthening walls with wooden lintel only with different lengths (L1 = 50cm , L2 = 65cm) as well as strengthening walls with wooden lintel and sill with different lengths (L0 = 35 cm , L1 = 50cm , L2 = 65cm). The presence of the opening in the wall forced the load path to be transferred to the lintel supports by arching action formed above the opening. The strain profile obtained from this study can also be explained by referring to the density of the load paths around the opening as shown in figure (17). However, figure (18) shows the stress distribution in the vertical direction for the control brick wall with R.C. lintel 35 cm. In addition, the stresses for the control wall were calculated in horizontal direction (X) by SAP2000 as shown in figure (19).

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It was found that the stresses are concentrated above the opening corners as well as tension stresses at middle of the sill level for the wall opening. However, the stress distribution in the X direction shows the area at which failure took place.

The stress distribution for strengthening walls with wooden lintel only with different lengths (L1 = 50cm , L2 = 65cm) were calculated in horizontal direction (X) by SAP2000 as shown in figures (20) and (21). It was found that the stresses are distributed above the opening corners at the end of lintel as well as tension stresses at middle of the sill level for the wall opening.

The stress distribution for strengthening walls with wooden lintel and sill with different lengths (L0 = 35 cm, L1 = 50cm, L2 = 65cm) were calculated in horizontal direction (X) by SAP2000 as shown in figures (22) to figure (24). It was found that the stresses are distributed above the opening corners at the end of lintel and under the opening corners at the end of sill. However, tension stresses disappears at middle of the sill level.

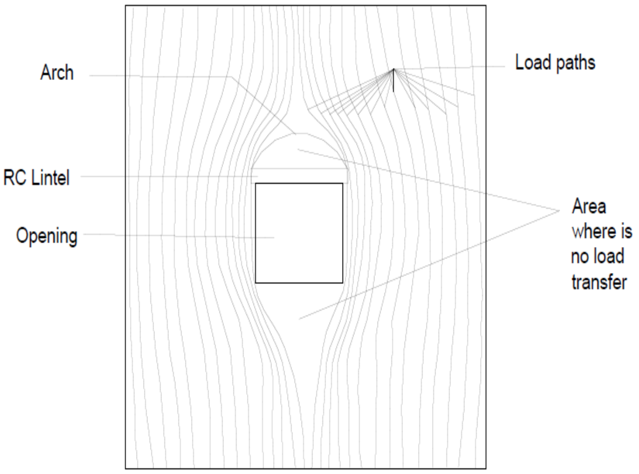

Fig.17.The development of the load paths around the opening

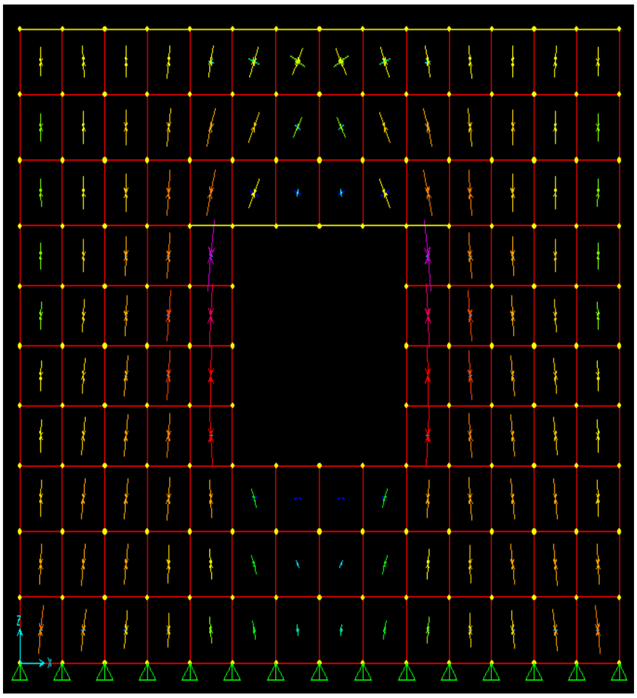

Fig.18. The Stress distribution around the opening in the vertical direction for control wall

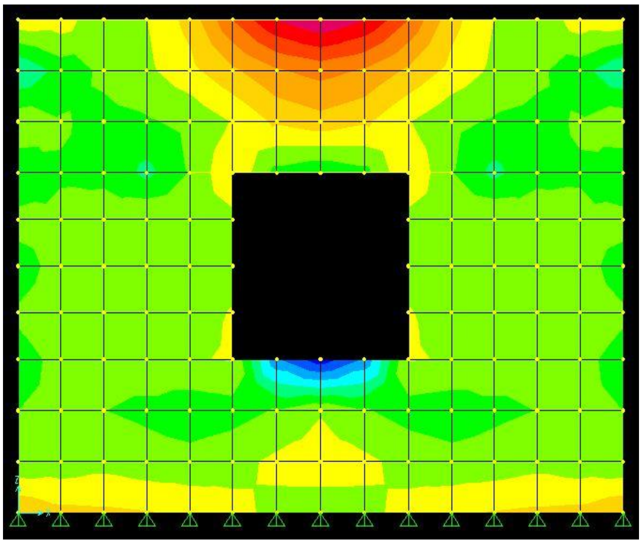

Fig.19. The Stresses distribution around the opening for the control wall in horizontal direction (X).

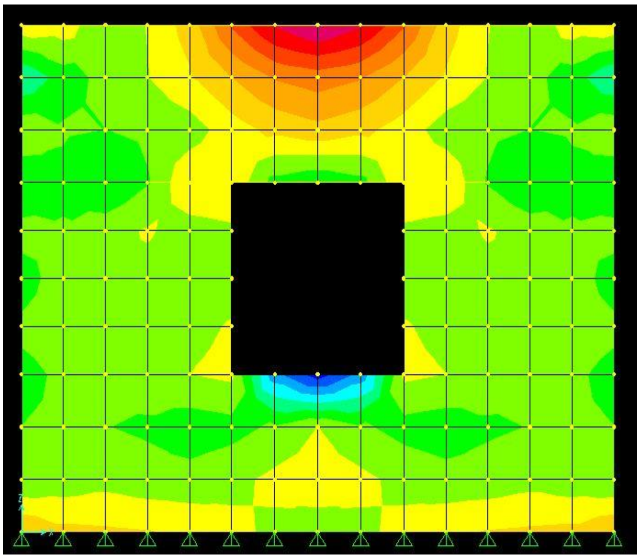

Fig.20. The Stresses distribution around the opening for strengthening wall with wooden lintel only 50cm

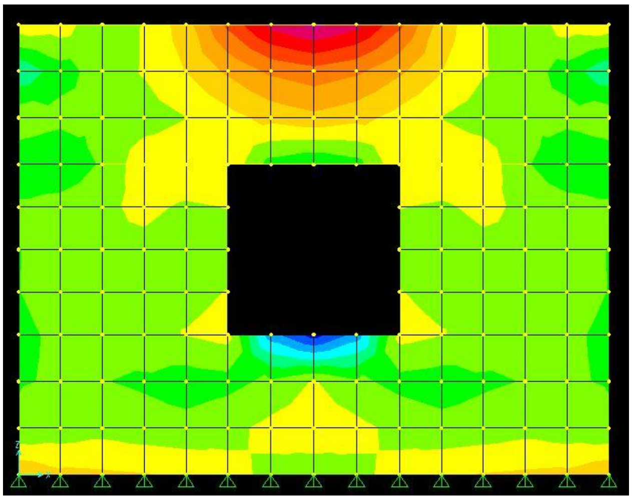

Fig.21.The Stresses distribution around the opening for strengthening wall with wooden lintel only 65cm

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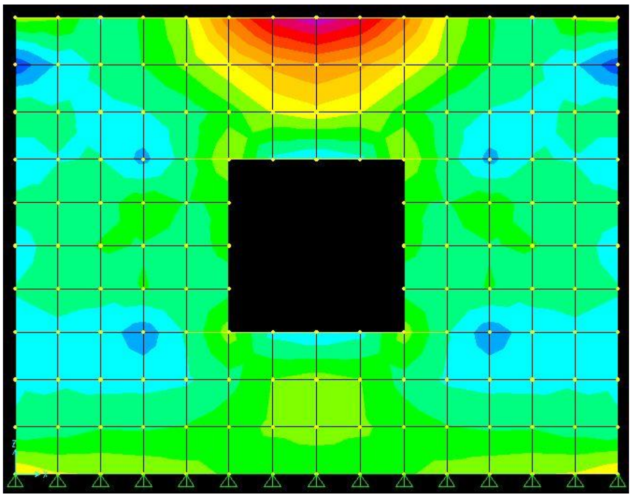

Fig.22. The Stresses distribution around the opening for strengthening wall with wooden lintel and sill 35cm

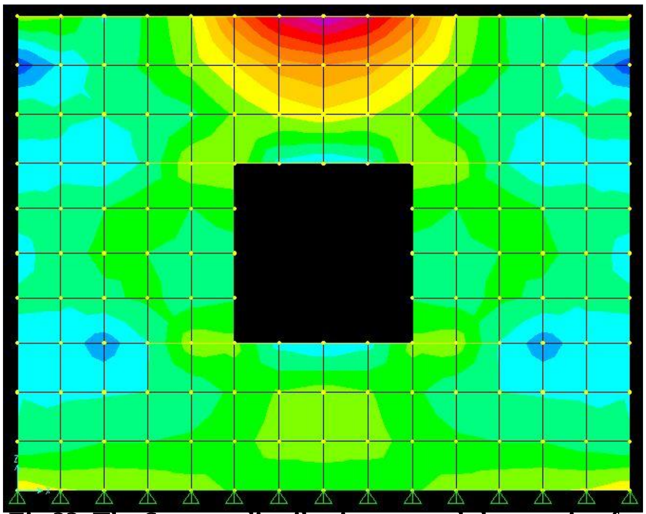

Fig.23. The Stresses distribution around the opening for strengthening wall with wooden lintel and sill 50cm

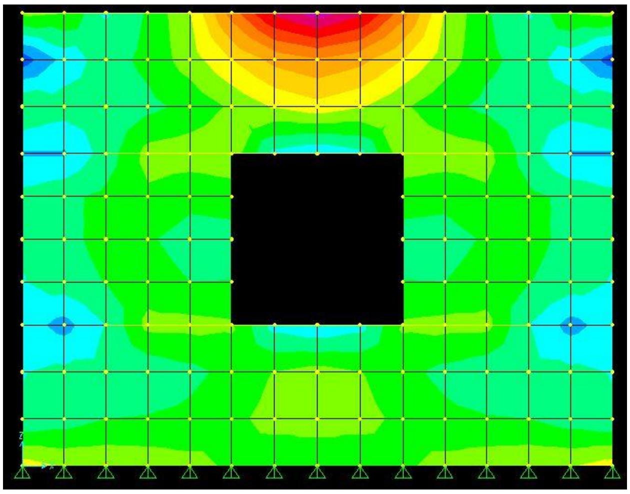

Fig.24. The Stresses distribution around the opening for strengthening wall with wooden lintel and sill 65cm

VII. CONCLUSIONS

From the present study the followings have been concluded: Increasing the length of wooden lintel during construction increases significantly the load carrying capacity of wall. However, adding wooden sill under the opening during construction has a great effect on preventing the vertical shear cracks occurred in the wall .Thus, increases significantly the load carrying capacity of wall with increasing the ductility. In additional, using wooden lintel as well as lintel and sill together with length (65cm) gives an increase in the load carrying capacity up to (130 %) to (171%) from the control ultimate capacity with increasing in the ductility. However, a finite element analysis was performed using SAP2000 to define the stress distribution paths as well as the expected positions of cracks that might occur in walls with openings using different techniques of strengthening. Finally, the results suggest that strengthening brick walls with opening during construction by using both wooden lintel and sill is the easiest and economic method for eliminating cracks as well as increasing the load carrying capacity and ductility.

For future study, the effect of opening size and location on the development of cracks should be thoroughly investigated.

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