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REHABILITATION OF MASONRY WALLS UNDER LATERAL LOADS USING FERROCEMENT

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ملخص البحث :
يهدف هذا البحث الي دراسة تاثير أستخدام طبقات المونة الأسمنتية المسلحة (الفيروسمنت) في تدعيم حوائط المبانى لمقاومة الأحمال الجانبية. تم أستخدم أحد برامج التحليل الأنشائي (ANSYS 15). حيث تم عمل 77 نموذج وذلك لدراسة عدد من المتغيرات مثل سمك طبقة الفيروسمنت, المقاومة المميزة للمونة, نسبة شبك التسليح المستخدم واخيرا دراسة تأثير طبقات الفيروسمنت في أتجاة واحد. وقد أظهرت النتائج أن أستحدام الفيروسمنت أدى الي زيادة حمل الأنهيار والممطولية للعناصر المدعمة بمقدا 180 % , 310 % على الترتيب.

Abstract
In this study, non-linear 3D numerical analyses were performed to investigate the efficiency of using ferrocement laminates on rehabilitating the concrete bricks masonry walls. Verification models have been carried out by simulating available experimental data. A total of 77 models was analyzed and examined numerically by the 3-D nonlinear finite element package (ANSYS 15). All the wall were built using concrete bricks and were tested under uniform axial vertical load and lateral load using square wire mesh. The dimensions of proposed wall models were 1000*1000*250 mm. Different parameters were taken into consideration during this study; Thickness of ferrocement layer (15, 20, 25, and 30 mm), Steel Mesh-Fabric (0, 1, 2, 3, and 4 layers per face), compressive strength of mortar (20, 40, 60, and 90 MPa), ferrocement layer location, Ultimate load capacity, the load-deflection response, energy absorption, stiffness, and ductility were calculated. The numerical results indicated that ferrocement laminates can be successfully used for increasing the ultimate carrying capacity, strength, energy absorption, and stiffness of masonry wall. It was observed that the ultimate lateral load and uncracked stiffness of strengthened models were increased respectively by about 180%, 310%, of the un-retrofitted wall.

Key Words: Ferrocement, Rehabilitation, Concrete brick, Masonry Wall, Lateral Load, and ANSYS

1. Introduction
Masonry is one of the oldest construction materials which have been in existence since the earliest days of mankind and had helped built several historically important structures. These structures have become iconic in the sense that they add to the heritage, emotion and pride to the city and even the entire nation. As a result, masonry now-a-days has been mostly used as a non-structural element, an infill of reinforced concrete and steel frames. Although reinforced concrete and steel buildings hold the center of interest in modern times, unreinforced masonry (URM) buildings still represent a significant portion of the building stock in our country. The primary disadvantage of these URM buildings located in active seismic regions is the fact that they are usually old buildings, constructed from inhomogeneous material and mainly designed to support vertical loads only. Moreover, URM is not able to carry tensile

forces due to its low tensile strength. These buildings are particularly vulnerable to seismic actions and therefore susceptible to extreme damage. Their vulnerability is caused by the failure of unreinforced masonry walls due to the in-plane and/or out of plane seismic loading. Alternative methods are used to repair structural and nonstructural elements, one of the strengthening techniques id ferrocement. Ferrocement is a layer of the little thickness of mortar hardened with one or more of thin steel wire meshes [1-2].El-Sakka, [3] studied the structure behavior of masonry units with opening strengthened with ferrocement layers under axial loading. The failure load was increased more than double compared with those without ferrocement layers. It is significant to find that the failure load of taffy wall panels with opening the failure load was increased to about 150 % compared with those without ferrocement layers. Khan Amanat et al. [4] studied the experimental investigation of the use of ferrocement laminates for repairing masonry in filled RC frames. It can be concluded that ferrocement overlay is a highly effective method of strengthening or repairing distressed reinforced concrete frame with masonry infill. From the experiment results it was also observed that the width of cracks developed in the repaired frame were smaller than those of the original frame. Sujatha, [5] studied the ferrocement coating technique on masonry walls. It was observed that the use of resistant coatings of reinforced mortar in structural walls can increase their strength, stiffness, ductility. The application of ferrocement coating gives the masonry wall better appearance, good flexural strength, impact resistance. Boen et al. [6] described the retrofitting method based on the principle of sandwich structures, having a masonry wall as core and covered on both sides with ferrocement layers. Numerical analysis result and shaking table test is both models survived when shaken by 60% JMA Kobe and also 85% JMA Kobe. There were no significant cracks or damage. Abboud et al. [7], and Haach, et al. [8] carried out full-scale out of-plane bending tests on masonry walls with externally applied steel reinforcement. The behavior of strengthened walls was studied in terms of peak load and increase in ductility, for reinforcement placed in lateral and longitudinal directions. The study concluded that longitudinal reinforcement in URM increases strength and ductility, significantly. Ashraf et al. [9] studied experimentally the strengthening of unreinforced and confined brick masonry walls using ferrocement overlays. Prawel et al. [10] Chake et al [11] studied the performance of upgraded brick piers using ferrocement subjected to in-plane or out of plane motion. Their tests included both cyclic loading and shaking table tests. They concluded that ferrocement is an appropriate material in improving the dynamic resistance of unreinforced masonry. Prawel and Reinhorn [12] had reported a study in retrofitting structural masonry using ferrocement overlay, they tested, diagonally, panels of clay brick units, unreinforced wall panel and a similar panel with ferrocement overlays increased efficiency of diagonal tensile strength and provided significant improvements in stiffness and deformational capacity.

2. Objective of the research

Due to the existing a large number of masonry buildings does not satisfy the latest code provisions and to improve their seismic resistance, application of strengthening is necessary, this study presents numerical investigation of ferrocement overlay as a strengthening technique for masonry walls subjected to lateral loads. A finite element software program (ANSYS 15) [13] will be conducted. The influence of mortar strength, ferrocement thickness, and volume fraction of ferrocement reinforcement were considered.

3. Material properties

3.1 Brick Concrete and mortar

In this study, SOLID65 element is an eight-node solid element used to model the brick concrete with or without reinforcing bars, as shown in **Figure (1)**. The solid element has eight nodes with three degrees of freedom at each node translations in the nodal x, y, and z directions, that is used to model the brick or mortar and the rebar reinforcement feature of this element was used to model the mesh reinforcement behavior. Reinforcement is specified by its material, volume ratio and orientation angles. The volume ratio is defined as the rebar volume divided by the total element volume. The orientation is defined by two angles in degrees (θ and φ) from the element coordinate system the three-dimensional **Figure (2)** shows the uniaxial compressive stress-strain relationship for the concrete model. **Table (2)** shows martial properties for concrete, steel reinforcement, mortar, and wire mesh.

Table (3): Material Properties and Input Data of Element Types

Material	Element type	Material properties	
Brick concrete	Solid 65	Elastic modulus (Ex)	11516 MPa
		Uniaxial crushing stress (fcu)	70 MPa
		Uniaxial cracking stress (fctr)	1.5703MPa
		Poisson's ratio (υ)	0.20
		Shear coefficient for open shear (ßt)	0.3
		Shear coefficient for closed shear (ßc)	0.85
Mortar	Solid 65	Elastic modulus (Ex)	$4400\sqrt{fcu}$ MPa
		Uniaxial crushing stress (fcu)	20,40,60 and 90 MPa
		Uniaxial cracking stress (fctr)	2.7,3.8,4.65, and 5.7MPa
		Poisson's ratio (υ)	0.20
		Shear coefficient for open shear (ßt)	0.02
		Shear coefficient for closed shear (ßc)	0.4
Wire Mesh	Solid 65	longitudinal Elastic modulus	138000 MPa
		transverse Elastic modulus	138000 MPa
		Poisson's ratio (υ)	0.30
		Thickness	1.9 mm

3.2 Analytical model

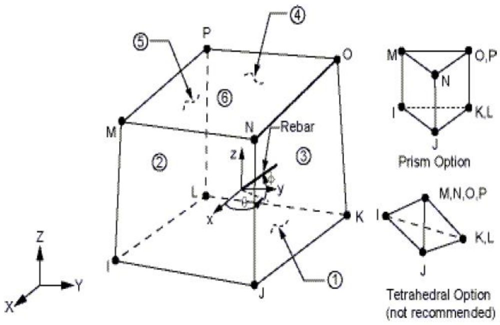
Finite element models using ANSYS 15 were proposed to investigate the rehabilitating of masonry wall using ferrocement. All the walls were built using concrete bricks and were analyzed under both vertical and lateral loads. The dimensions of wall models were 1000*1000*250 mm.

4. Verification of the numerical analysis

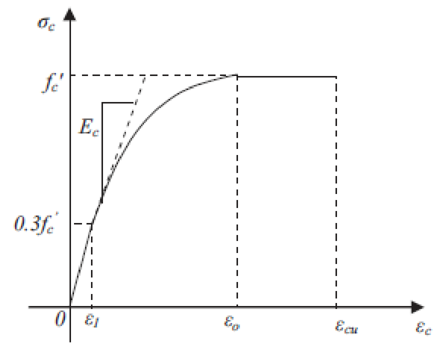
The verification study was included verifying six tested wall assemblies by Sabrah [14]. The selected verification case studies were selected to make sure of all finite element parameters used to model and assign confined masonry walls. The numerical results are compared with the experimental one. To clarify these issues, the correlation between experimental and numerical results is based on comparisons of failure modes. All the wall were built using concrete bricks with 120 mm thickness and were tested under uniform axial vertical load. The dimensions of test wall were 1000*1000*120 mm as shown in **Figures (3)** and **(4)**. The descriptions of the test specimens and comparison between experimental and numerical results are shown in **Table (2)**. It can be seen that the numerical maximum loads were in good agreement with those observed from experimental work.

5. Studied parameters

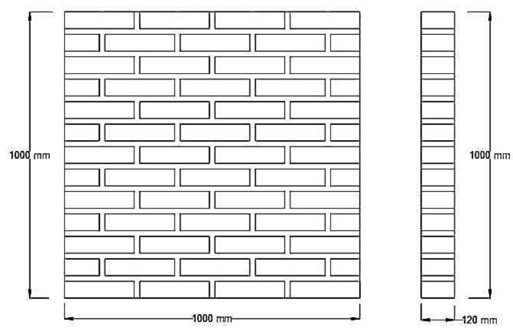
A total of 77 models were analyzed using ANSYS 15 to evaluate the performance of masonry wall strengthened by ferrocement laminates. Three variables were considered such as; four different mortar strength (20, 40, 60, and 90) MPa, four ferrocement thickness (15, 20, 25, and 30) mm, four number of steel wire meshes (0, 1, 2, 3, and 4) per face, strengthening schemes, and applying ferrocement in two sides of wall or in one side only .



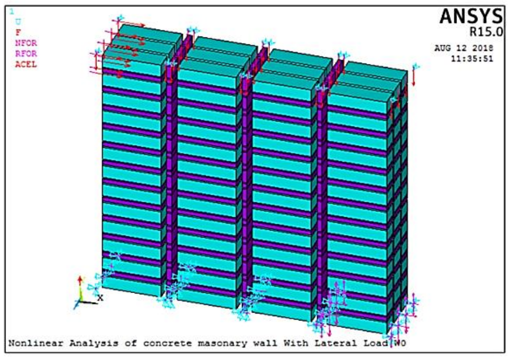
Figures (1): Solid65 3-D reinforced concrete solid



Figures (2): Uniaxial compressive stress–strain curve for concrete



Figures (3): Dimension and description of the wall



Figures (4): Numerical model of the control wall

Table (4): Comparison between experimental and numerical results

Wall ID	Characteristic Strength of Mortar (MPa)	No. Of Steel Mesh Fabric	Steel Anchors Spacing (mm)	Failure Load (kN)		EXP./Num. %
				Exp.	Num.	
W1	No mortar	0	No Rods	760	720	105
W2	20	0	No Rods	860	900	96
W3	40	0	No Rods	1120	1180	95
W4	20	2	400	1085	1100	99
W5	40	2	200	1150	1210	95
W6	40	4	200	1320	1380	96

Table (5): Description of Numerical Model

Group No	Model	Mortar Thickness (Tf) (mm)	Number of Wire Mesh Layers per side	Characteristic Strength of Mortar (MPa)	Location of Ferrocement
Control	W0	-	-	-	------
Group 1	W1,W2,W3,W4	15,20,25,30	0	20	2 - sides
Group 2	W5,W6,W7,W8	15	1,2,3,4	20	2 - sides
Group 3	W9,W10,W11,W12	15	1,2,3,4	40	2 - sides
Group 4	W13,W14,W15,W16	15	1,2,3,4	60	2 - sides
Group 5	W17,W18,W19,W20	15	1,2,3,4	90	2 - sides
Group 6	W21,W22,W23,W24	20	1,2,3,4	20	2 - sides
Group 7	W225,W26,W27,W28	20	1,2,3,4	40	2 - sides
Group 8	W29,W30,W31,W32	20	1,2,3,4	60	2 - sides
Group 9	W33,W34,W35,W36	20	1,2,3,4	90	2 - sides
Group 10	W37,W38,W39,W40	25	1,2,3,4	20	2 - sides
Group 11	W41,W42,W43,W44	25	1,2,3,4	40	2 - sides
Group 12	W45,W46,W47,W48	25	1,2,3,4	60	2 - sides
Group 13	W49,W50,W51,W52	25	1,2,3,4	90	2 - sides
Group 14	W53,W54,W55,W56	30	1,2,3,4	20	2 - sides
Group 15	W57,W58,W59,W60	30	1,2,3,4	40	2 - sides
Group 16	W61,W62,W63,W64	30	1,2,3,4	60	2 - sides
Group 17	W65,W66,W67,W68	30	1,2,3,4	90	2 - sides
Group 18	W69,W70,W71,W72	20	2,4,2,4	40,40,90,90	1 - sides
Group 19	W73,W74,W75,W76	25	2,4,2,4	40,40,90,90	1 - sides

6. Parametric analysis results

6.1 Load – Displacement response

Based on the numerical analysis, ultimate load, lateral displacement, energy absorption, stiffness, and ductility were calculated and listed in **Table (4)**. The failure load and its corresponding displacement, and stiffness were calculated and listed in **Table (4)**.

6.1.1 Effect of Steel Mesh-Fabric (Number of wire mesh layers)

Figures (5) show the lateral load-displacement curves for the group1. It can be noted that the addition of one overlay of plain mortar on each face as wall (W1) has increased the failure load by 4.76% as compared to the control model (W0). The ultimate lateral force of models (W2, W3, and W4) has increased by (11.9%, 28.6%, and 31.9%) respectively more than that of the control model. The influence of number of steel mesh-fabric on rehabilitation of masonry wall with ferrocement is illustrated. **Figures (6) and (7)** show the load-displacement curves form group 2 to group17. It was found that the increasing of number of wire mesh layers from 1 to 4 for strengthened models of group 2 resulted in an increase in the percentage of average gain in load capacity from 9.52 % to 23.81 %.

6.1.2 Effect of Ferrocement thickness

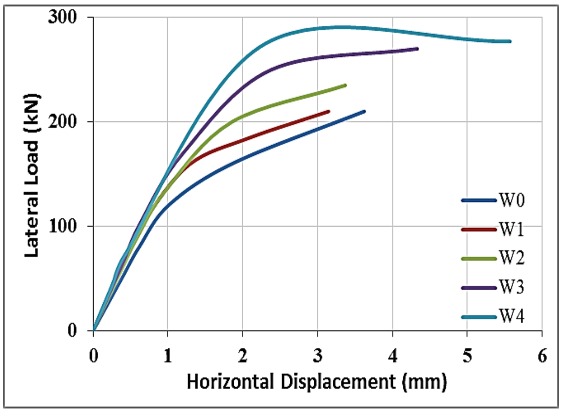
The effect of ferrocement thickness was studied. The influence of the ferrocement thickness and the characteristic strength of mortar are essentially important to enhance the lateral load capacity, and develop the improved wall characteristics. Thickness of ferrocement layer were (15, 20, 25, and 30) mm. **Figures (8)** shows the load-displacement curves due to changing the ferrocement thickness. From this figure it can be observed that the increase of ferrocement thicknesses improved the cracking behavior, failure load of the masonry wall. Increasing Ferrocement thicknesses (Tf) from 15 mm to 30 mm tend to increase the failure load by (9.52% to 42.86%).

6.1.3 Effect of ferrocement locations

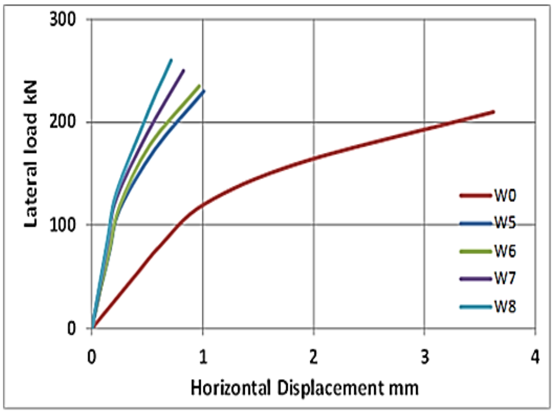
Ferrocement layer on one side of masonry wall was applied on the rehabilitation of masonry wall. **Figures (9)** show the load-displacement curves for comparing between ferrocement layer on one face and on each face of masonry wall. It was noticed that the different in the location of ferrocement layer changed the failure load as wall (W26) had increased the failure load by 24% as compared to (W69), (W28) had increased the failure load by 42.59% as compared to (W70), (W34) had increased the failure load by 39.62% as compared to (W71), (W36) had increased the failure load by 65.45% as compared to (W72), (W42) had increased the failure load by 30.77% as compared to (W73), (W44) had increased the failure load by 49% as compared to (W74), (W50) had increased the failure load by 51.92% as compared to (W75), and (W52) had increased the failure load by 76.67% as compared to (W76).

6.2 Stiffness, Energy Absorption and Ductility

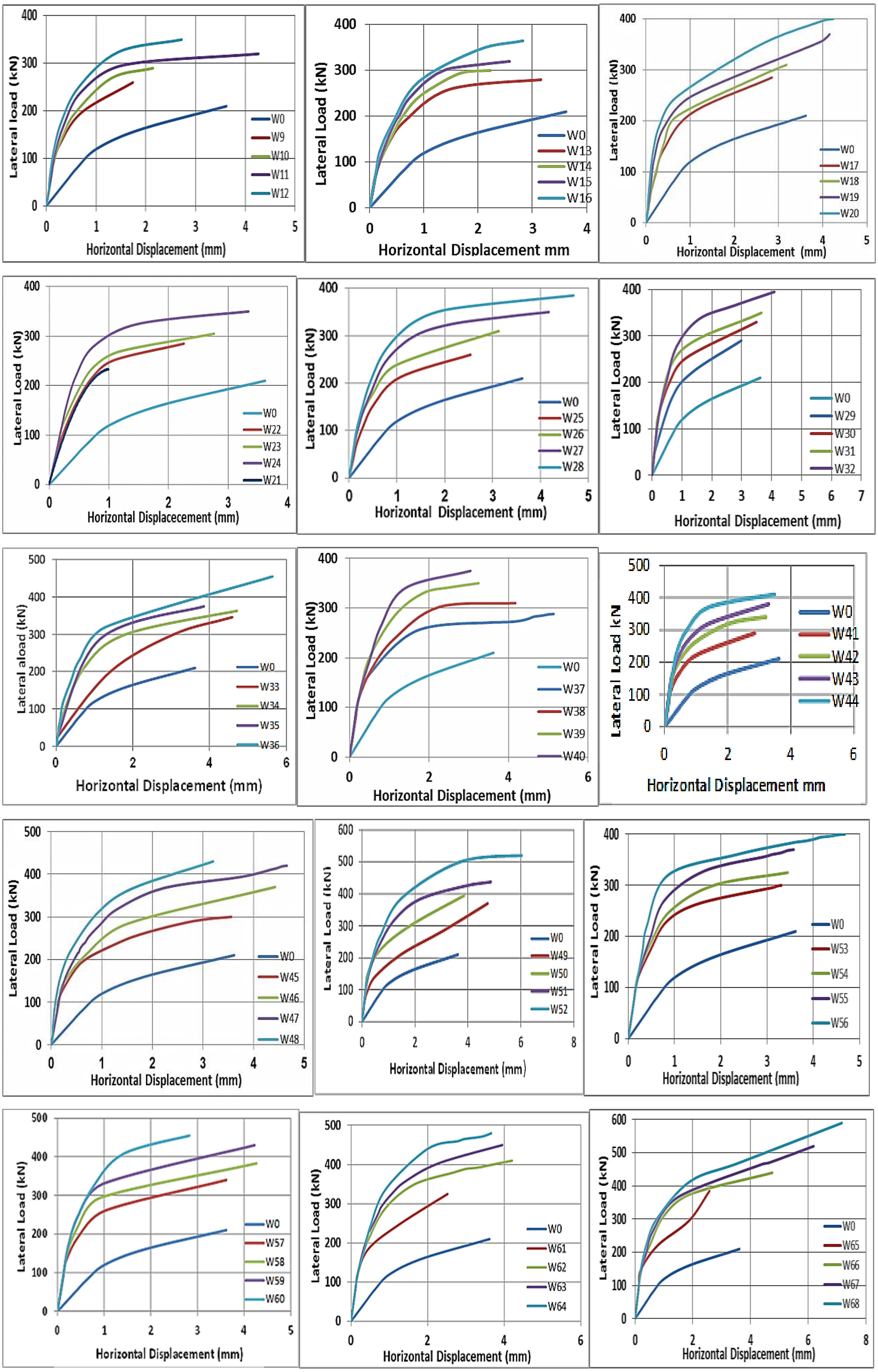
From load displacement curve, values of the stiffness, energy absorption and ductility were calculated and tabled in **Table (4)**. It can be realized that the increasing ferrocement thickness significantly increased the initial stiffness and led to gain in energy absorption was found to increase with increasing the thickness of ferrocement layer. It was observed that the average of ductility ratio, initial stiffness, and strain energy were measured as 12%, 220%, and 77% of the control mode respectively.



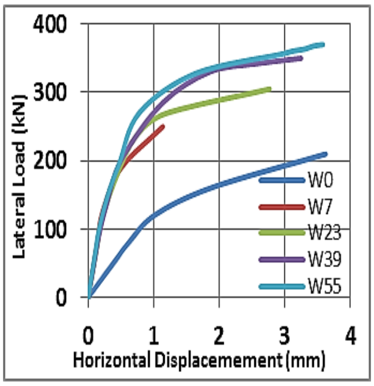
Figures (5): Load-Horizontal Displacement for walls of Group 1



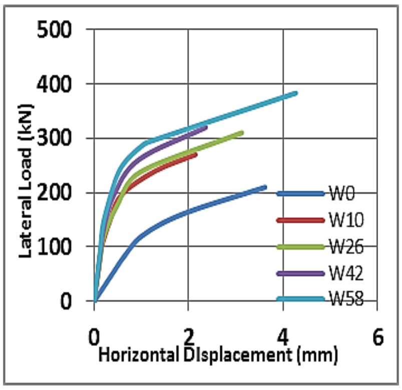
Figures (6): Load-Horizontal Displacement for walls of Group 2



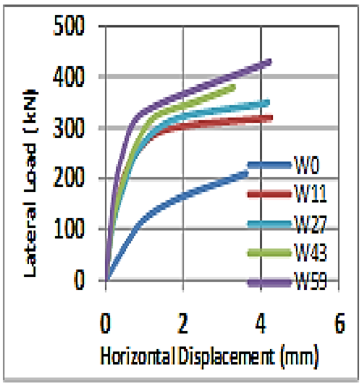
Figures (7): Load-Horizontal Displacement for walls from Group 3 to Group 17



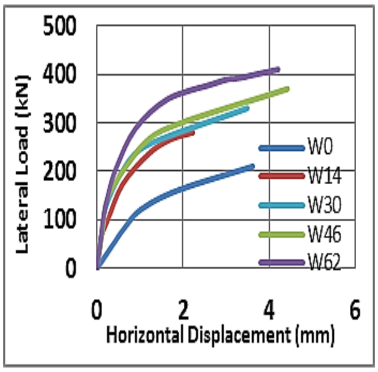
3 layer mesh FC: 20MPa



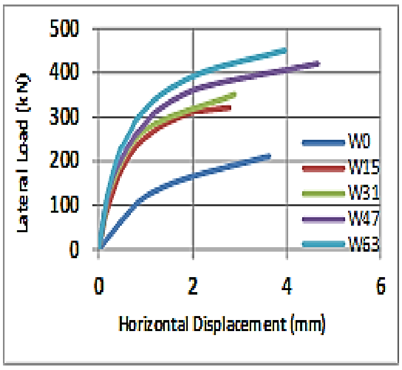
2 layer mesh FC: 40MPa



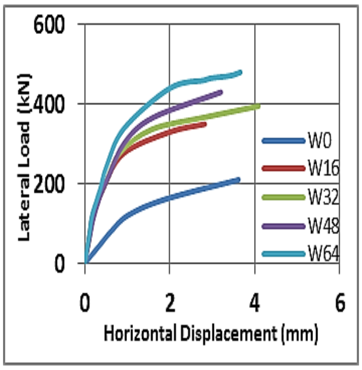
3 layer mesh FC: 40MPa



2 layer mesh FC: 60MPa

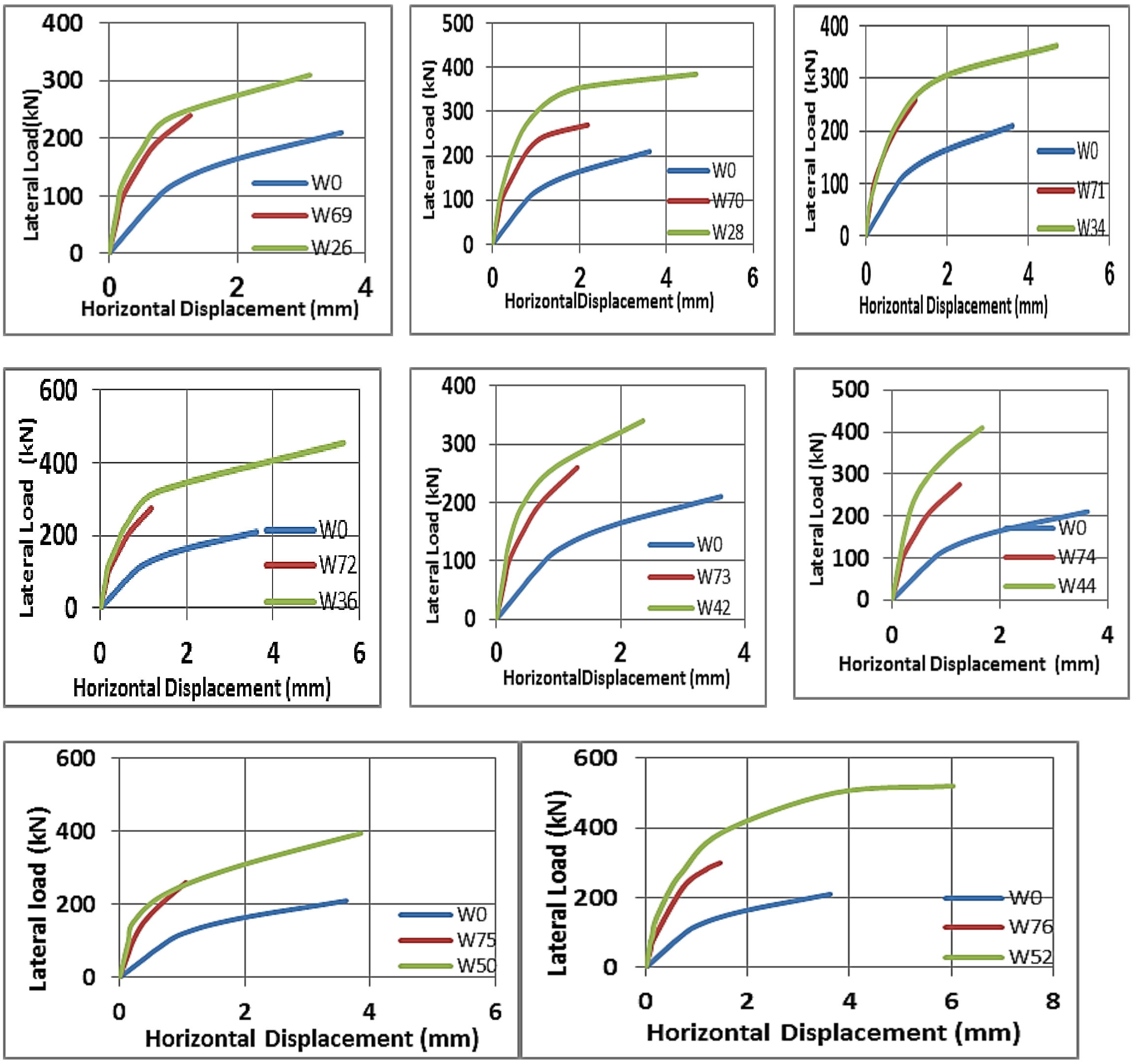


3 layer mesh FC: 60MPa



4 layer mesh FC: 60MPa

Figures (8): Load-Horizontal Displacement for walls due to changing the ferrocement thickness



Figures (9): Comparison between ferrocement layer on one face and on each face of masonry wall of Load-Horizontal Displacement

Table (6): Summary of Tested Walls

Model	Failure Load (P) (kN)	Max Displacement (mm)	% Increment in ultimate lateral load	Ductility	Initial Stiffness (kN/mm)	Energy absorption (kN.mm)
W0	210	3.62	0.0	3.56	184.60	509
W1	220	3.15	1.05	2.45	190.00	463
W2	235	3.37	11.90	1.82	217.06	546
W3	270	4.33	28.57	1.82	231.25	865
W4	277	5.57	31.90	2.42	244.36	1244
W5	230	1.01	9.52	4.00	506.99	150
W6	235	0.97	11.90	3.88	511.73	148
W7	250	0.83	19.05	3.73	574.86	130
W8	260	0.71	23.81	3.26	609.66	112
W9	260	1.74	23.81	2.45	634.41	328
W10	290	2.15	38.10	1.65	635.57	475
W11	320	4.27	52.38	2.75	636.97	1171
W12	350	2.72	66.67	1.88	638.54	764
W13	280	3.16	33.33	2.13	658.22	718

W14	300	2.23	42.86	1.31	660.64	513
W15	320	2.58	52.38	1.22	616.47	660
W16	365	2.83	73.81	1.41	662.45	792
W17	285	2.85	35.71	2.72	532.09	601
W18	310	3.18	47.62	4.58	535.98	736
W19	370	4.16	76.19	3.97	690.79	1138
W20	400	4.24	90.48	6.11	691.59	1306
W21	247	0.99	17.62	1.15	545.18	158
W22	285	2.26	35.71	2.07	547.21	494
W23	305	2.77	45.24	2.33	550.34	676
W24	350	3.34	66.67	2.23	552.75	978
W25	270	2.54	28.57	2.38	454.11	496
W26	310	3.13	47.62	3.19	586.79	745
W27	350	4.17	66.67	3.11	588.64	1188
W28	385	4.69	83.33	3.50	647.51	1520
W29	290	2.99	38.10	2.20	556.48	616
W30	330	3.49	57.14	3.04	616.48	887
W31	350	2.89	66.67	3.76	589.70	996
W32	395	4.09	88.10	2.61	619.91	1293
W33	346	4.59	64.76	1.50	604.89	1061
W34	363	4.71	72.86	2.60	652.50	509
W35	375	3.85	78.57	3.36	654.23	1071
W36	455	5.64	116.67	4.33	654.30	1956
W37	288	5.14	37.14	3.04	534.28	1231
W38	310	4.17	47.62	1.85	506.45	1072
W39	350	3.26	66.67	1.75	545.40	907
W40	375	3.04	78.57	2.17	551.12	895
W41	290	2.85	38.10	2.81	619.42	627
W42	340	2.36	61.90	2.49	658.80	594
W43	380	1.69	80.95	2.08	715.52	448
W44	410	1.66	95.24	2.38	689.17	480
W45	300	3.56	42.86	2.02	657.09	852
W46	370	4.43	76.19	2.93	612.70	1255
W47	420	4.66	100.00	3.57	661.31	1549
W48	430	3.21	104.76	3.46	559.15	1065
W49	370	3.31	76.19	3.14	663.71	1162
W50	395	3.45	88.10	5.40	704.12	1111
W51	450	3.63	114.29	4.22	691.61	1792
W52	530	4.68	152.38	4.02	693.79	2546
W53	300	3.31	42.86	2.14	595.76	799
W54	325	3.45	54.76	3.83	600.69	907
W55	385	3.63	83.33	4.64	604.61	1061
W56	400	4.46	90.48	5.45	604.24	1567
W57	340	3.62	61.90	3.54	717.36	967
W58	383	4.27	82.38	4.67	737.90	1316
W59	430	4.23	104.76	4.36	762.59	1455
W60	455	2.83	116.67	2.02	767.17	1004
W61	325	2.52	54.76	5.33	683.73	589
W62	410	4.21	95.24	4.70	701.60	1388
W63	450	3.96	114.29	4.96	704.56	1395
W64	480	3.66	128.57	3.98	707.75	1378
W65	385	2.58	83.33	3.28	752.92	645
W66	440	4.76	109.52	4.79	754.43	1676
W67	520	6.19	147.62	4.20	755.73	2468
W68	590	7.17	180.95	3.73	757.53	3199
W69	250	1.27	19.05	1.73	473.56	205

W70	270	2.19	28.57	2.02	478.64	452
W71	260	1.23	23.81	1.72	520.07	208
W72	275	1.18	30.95	1.72	523.34	207
W73	260	1.30	23.81	1.82	500.48	223
W74	275	1.25	30.95	1.77	506.83	223
W75	260	1.06	23.81	1.63	469.54	172
W76	300	1.46	42.86	1.14	560.43	298

CONCLUSION

The nonlinear analysis of the rehabilitating of masonry wall under lateral loads using ferrocement was simulated to predict the effect of some parameters on rehabilitating of masonry wall. The main conclusions of this study were

1. The suggested numerical model gives acceptable results compared with the available experimental ones, thus it can be utilized effectively in the investigation of masonry wall retrofitted by ferrocement overlays.
2. The numerical analysis of finite element method by using the ANSYS program is a good tool for represent the behavior of the masonry wall strengthened with ferrocement laminates.
3. The ferrocement jacketing gives a considerable enhancement in shear strength and deformation capacity strengthened models.
4. All retrofitted walls have a higher strength than the control specimen.
5. Wrapped masonry wall by ferrocement laminates lead to an improvement in the lateral load capacity of the wall. It was observed that the shear strength of retrofitted unreinforced masonry wall was increased by 180% compared to the un-retrofitted wall.
6. The marked improvements of the masonry wall mechanical characteristics ensure the effectiveness of the rehabilitation of wall using ferrocement techniques. It was observed that the average of ductility ratio, initial stiffness, and strain energy were measured as 12%, 220%, and 77% of the control model.
7. The influence of the ferrocement thickness and the characteristic strength of mortar is essentially important to enhance the lateral load capacity, and to develop the improved wall characteristics.

REFERENCES

[1] ACI Committee 549-1R-199 (1993), "Guide for Design Construction and Repair of Ferrocement", ACI 549-1R-93, Manual of Concrete Practice, Detroit.

[2] ACI Committee 549, (1997), "State of the Art Report on Ferrocement, ACI 549–R97, in Manual of Concrete Practice, ACI, Detroit.

[3] El-Sakka, Aly. M. M ,(2007), Structure behavior of masonry units with opening strengthened with ferrocements layers under compression loading, Thesis (M.S.) ,Menoufiya University, Faculty of Engineering.

[4] Amanat. K. M, Alam. M. M. M, and Alam. M. S, (2007), Experimental investigation of the use of ferrocement laminates for repairing masonry in filled RC frames, Journal of Civil Engineering (IEB) 35(2): 71-80.

[5] Sujatha. A, June (2014),Case Study of Ferrocement Coating Technique on Masonry Walls, Bharath University, Selaiyur, Chennai, Tamil Nadu, India, Indian Journal of Science and Technology 7 (S5): 9-9.

[6] Boen. T, Imai H, Ismail.H , Hanazato. T , and Lenny ,(2015), Brief Report of Shaking Table Test on Masonry Building Strengthened with Ferrocement Layers, Journal of Disaster Research 10(3).

[7] Abboud BE, Hamid AA, Harris HG ,(1996) ,Flexural behavior of reinforced concrete masonry walls under out-of plane monotonic loads, ACI Struct J 93(3): 327–335.
[8] Haach VG, Vasconcelos G, Lourenc¸o PB ,(2011), Numerical analysis of concrete block masonry beams under three point bending, Eng. Struct 33(12): 3226–3237.
[9] Ashraf M, Khan AN, Naseer A, Ali Q, Alam B ,(2012), Seismic behavior of unreinforced and confined brick masonry walls before and after ferrocement overlay retrofitting. Int J Archit Herit 6 (6): 665–688.
[10] Prawel, S.P. and lee, H.H., June (1990), The Performance of Upgraded Brick Piers Subjected to out of plane Motion, Proceeding of the 5th North American Masonry Conference, University of Illinois at Urbana- Champaign, I: 411-427.
[11] Chake, R.P., and Sharma, A.K., April (2000), Earthquake Strengthening of Story Unreinforced Block Masonry Houses in Trinidad and Tobago Using Ferrocement, Public Information Series/ Earthquake, Booklet No.1, University of
[12] Prawel, S.P. and Renihorn, A.M., June (1985), Seismic retrofit of structural Masonry using a Ferrocement overlay, Proceeding of the Third North American Masonry Conference, Arlington, Texas:59-1 to59-19.
[13] ANSYS, (2010). ANSYS User's Manual and Help Revision 15. USA.
[14] Sabrah. T. B , Dr Hodhod. O. A, Dr El-Hefnaw. A. A, (2003), Rehabilitation of Masonry Walls Using Ferrocement Overlays, Master (Msc) Thesis, Cairo University, Giza, Egypt.