BEHAVIOR OF STRENGTHENED RC COLUMNS BY MEANS OF FERRO CEMENT JACKET

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ABSTRACT

This paper presents an experimental investigation to clarify the behavior of reinforced concrete square and rectangular columns strengthened using Ferro cement jacket. Strengthening using Ferro cement jacket is relatively a new technique, which has a high strength/weight ratio, good resistance to cracking and impact loading, acceptable resistance to fire, and more resistance to corrosion than traditional materials. Twelve reinforced concrete short columns with nominal cross-sectional dimensions of 250 x 200 , 200 x 200 and 150 x 200 mm with a total length of 1200 mm were cast and tested under axial loading until failure. The main parameters in this study were the number of layers of wire mesh, type of wire mesh, and the cement mortar strength. The results showed the effectiveness of the Ferro cement jacket in improving the column capacity and reducing the vertical and lateral deformation. The results from the experiment were compared with the theoretical results obtained from the modified ECP 203 and modified ACI 318 equation codes.

Keywords: Ferro cement jacket, Square column, and Strengthening of Columns.

1. Introduction

Reinforced concrete (RC) columns are often classified because they are the most vital component of the building superstructure since load from slabs and beams are both transferred to columns. The total collapse of RC building may occur because of a change in service load and lack of column strength caused by deterioration. [1,2]. In the last few decades, the incidence of failure in reinforced concrete (RC) structures has been seen widely because of increasing service loads and/or durability problems. The economic losses due to such failures are millions of dollars. Many civil structures are not any longer thought safe because of overloading, below the style of existing structures or lack of internal control. To take care of efficient serviceability, older structures must be repaired or strengthened so that they meet an equivalent requirement demanded of the structures built today and in the future. [2]

Strengthening and repairing to increase the load-carrying capacity of the column can be performed by distilling degraded concrete, patch by non-shrink mortar, and then strengthened by steel jacketing or encased by additional RC. Ferro cement jacketing is one of the alternative methodologies of repair and strengthening of the column that is low value and straightforward to use to the existing column, as homemade. As described above, behaviours of columns strengthened by additional steel reinforcement and encased by Ferro cement under static loading are studied during this work. [3,4,17]. The main types of mesh used in Ferro cement applications are welded square wire mesh, hexagonal wire mesh, woven wire mesh, and expanded metal wire mesh, shown in **Fig 1.** In general, it can be stated that properties of the Ferro cement are greatly affected by the type, and the orientation of the reinforcement used. [2,5,6]

Ferro cement could be a slim and slender material, however, at the constant time sturdy. It provides a possible resolution to various issues in construction various kinds of structures shapes, conjointly once light-weight of the structure is predicted especially just in case of earthquake-prone areas as well as presents working solutions for repairs and strengthening works.

The strengthening of RC beams with Ferro cement laminates was studied by Paramasivam et al. **(1990)** the test can be observed on the effects of the level of damage to original beams prior to repair, and repeated loading on the performance of the strengthened beams. The study found that Ferro cement is a practical method for strengthening and rehabilitation of reinforced concrete structures.[17].

Sayan Sirimontree et al. **(2015)** studied the strengthening of reinforced concrete columns via Ferro cement jacketing by testing six reinforced concrete columns (one being referenced specimen and five being tested columns wrapped by square welded wire mesh. The average compressive strength of mortar from the test is 21.7MPa. The main parameters were the number of wire mesh (7, 9, 11, 13, and 15). Results showed the optimum number of wrapping rounds of wire mesh is 13. Increasing of ductility is caused by the efficient confinement of wire mesh and mortar cement composite. [18]

Abeer M. Erfan et al **(2019)** Performed a laboratory and theoretical tests to study the structural performance of eccentric Ferro cement reinforced concrete columns and concluded that the expanded wire mesh exhibited higher ultimate load than conventionally reinforced control columns by about 36.7% for specimen which used three layers of expanded wire meshes. Also, the experimental results revealed that increased Ferro cement wire meshes as reinforcement contributed to slightly higher ultimate load, ductility, and higher energy absorption. [2]

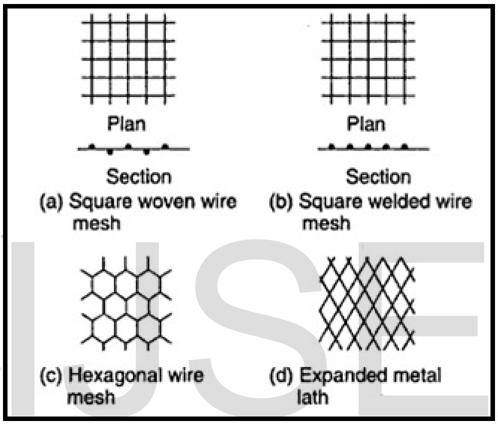

Fig. 1. Types of wire mesh used in Ferro cement applications.

2. Experimental work

The experimental program was carried out to test 12 reinforced concrete columns to investigate the effect of the number of layers of wire mesh, type of wire mesh, and the mortar strength on the behaviour and strength of square columns regarding load capacity and lateral and axial deformations. Four columns were 250 × 200 mm , Four columns were 200 × 200 mm and Four columns were 150 × 200 mm with a total length of 1200 mm , and reinforced longitudinally with 4Φ12 mm steel bars and 6Φ8 mm/m steel stirrups. One of them was a control column (A0, B4 and C8) without Ferro cement jacket. Six columns strengthening with expanded wire mesh with a two, or three layers (A1,

A2, B5, B6, C9 and C10).The last three columns strengthening with square wire mesh with a two layers (A3, B7, and C11). All columns were strengthening using expanded and square wire mesh with mortar strength of 30 MPa. All columns were tested under axial loading until failure. The details of the tested column are shown in **Fig 2** and
Table 1.

2.1 Materials

Local natural sand, well-graded clean gravel with nominal sizes ranged from 10 to 20 mm, Ordinary Portland cement, additives as BASF CO (Master Rhebuild 846) were used to form the components of the concrete and the cement mortar mixes. **Table 2** summarized the proportions of concrete mixer. The average concrete column strength in compression was 29.2 MPa. 12 mm steel bars were used as a compression steel and 8 mm diameter was used as stirrups. Two types of steel wire mesh were used (expanded and square) wire mesh. The mechanical properties of steel bars and wire mesh are given in **Tables 3** and **4**, respectively.

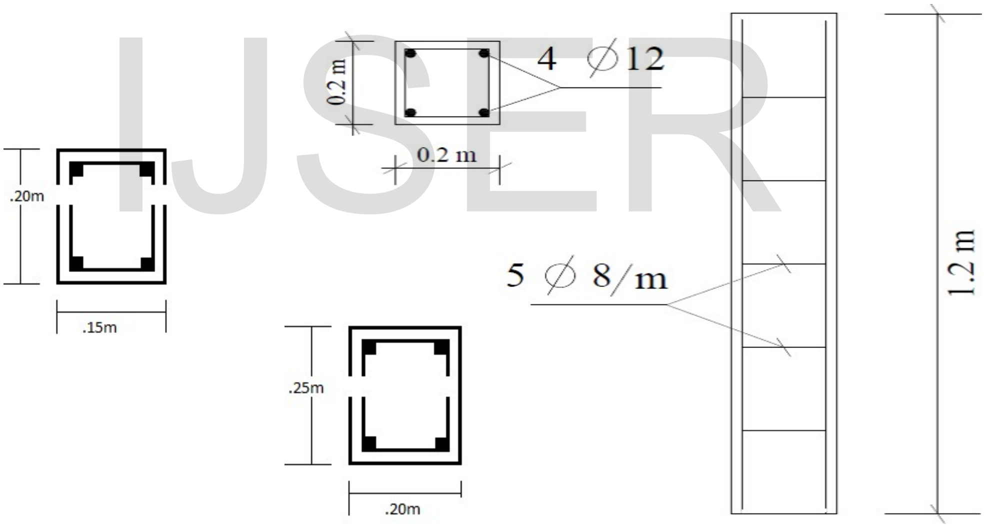

Fig. 2. Details of tested column.

Table 1. The details of the tested columns.

Group NO.	Column NO.	Layer Number	Mortar Strength (MPa) (Target values)	Layer Type
A	A0	-	-	-
	A1	2	30	Expanded
	A2	3		
	A3	2		Square
B	B4	-	-	-
	B5	2	30	Expanded
	B6	3		
	B7	2		Square
C	C8	-	-	-
	C9	2	30	Expanded
	C10	3		
	C11	2		Square

Table 2. The concrete mix proportions (f_{cu} = 30Mpa)

Material	Weight Kg/m^3
Cement	400
Sand	728
Gravel	1100
Total Aggregate	1820
Water L/m3	205
Basf (846) G	7300
Additive2	-

Table 3. Mechanical properties of steel bars.

Type of reinforcement	Diameter (mm)	Yield or Proof strength (MPa)	Ultimate Tensile strength (MPa)
steel bar	8	329	478
	12	488	681

Table 4. Mechanical properties of wire mesh (adopted from the supplier)

Type of Mesh	Opening Size (mm)	Weight (gm/m^2)	Diameter (mm)	Yield Tensile strength (MPa)	Ultimate Tensile strength (MPa)	Modules of Elasticity (Gpa)
Expanded Mesh	19*33	17	1.5 * 2.1	225	334	136
Welded Mesh	12*12	4.2	0.75	379	598	171

2.2. Preparing Test Specimens and Test Procedure

2.2.1. Casting

Rectangular steel moulds of 250 × 200 mm, 200 × 200 mm and 150 × 200 mm cross-section and 1200 mm in height were used for casting of concrete specimens. Before casting, their inner sides were coated with oil. After that, the concrete mix was prepared according to the mix design and placed into the moulds. Ten square reinforced concrete columns were cast. All columns were cast in a vertical position using steel moulds for the formwork. The prepared reinforcement cage was held carefully in the moulds. Concrete spacers of 15 mm size were used to maintain a 15 mm concrete cover to the main reinforcement. The concrete was poured in three layers and compaction of each layer was carried out using a vibration device, **See Fig 3.**

Table 6. Actual results for cubes of Mortar

Designation	Mortar Strength (MPa) Actual results for cubes After 28 days	Average mortar strength (MPa) Actual results for cubes	Mortar Strength (MPa) (Target values)
Cube A	38.50	36.39	30
Cube B	35.79		
Cube C	34.88		

2.2.2. Curing

After 24 hours of casting, all columns and cubes were de-moulded and cured under tapestry sheets until two days before testing to prepare the specimens for the test. **Fig 3** shows the Preparing of steel cage, casting and curing of the tested columns.

2.2.3. Jacket of columns with Ferro cement mesh

Nine Ferro cement jackets were cast. The skeleton of reinforcing mesh is a box section, which had 2 or 3 layers enclosed with a 20 mm mortar cover. The column specimens were jacketed with Ferro cement mesh after 28 days of curing. Jacketed specimens were again cured for 28 days. Full height jacketing was provided for all the specimens with an end gap of 20 mm at both ends to avoid direct loading on Ferro cement mesh. The final dimensions of the column were 270 × 220 mm, 220 × 220 mm and 170 × 220 mm. A steel float was used to make the surface of the Ferro cement flat, and All samples were painted before testing. **See Fig 4.**

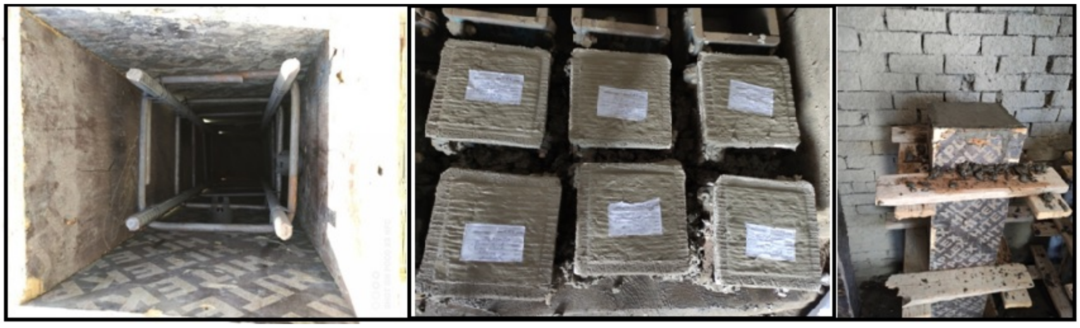

Fig. 3. Preparing of steel cage, casting, and curing of the tested columns.

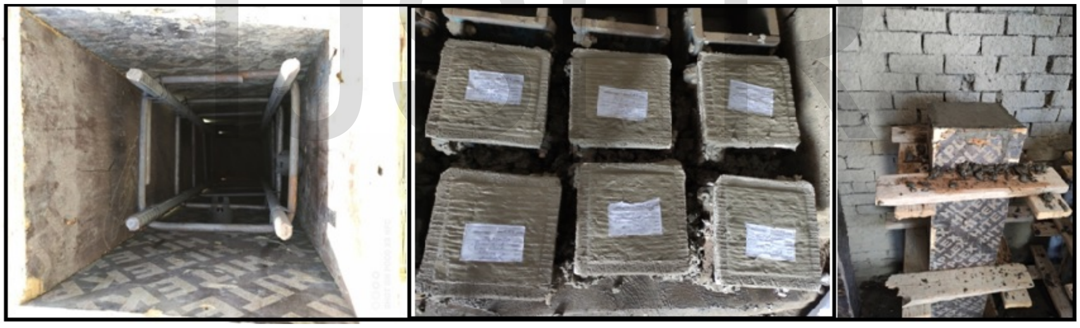

Fig. 4. Prepared of surface of columns, Jacket of columns with Ferro cement mesh and finally casting with mortar

Fig. 5. Testing Machine, Data logger device and the positions of axial and lateral LVDTs on tested column

2.2.4. Instrumentation Device

Control and jacketed columns were tested under axial compressive loading in a 250 T hydraulic column testing machine. The test set-up is shown. Vertically of the column was ensured during the test to obtain a central loading on the column. A thin layer of cement paste was applied at the top and bottom of the column. Plates of the column-testing machine were ensured to be horizontal to eliminate the column to frame relative displacement. The axial and lateral displacements were recorded using linear variable differential transformers (LVDT). Ultimate load, axial and lateral deformation were recorded using data logger and failure modes of specimens were observed, **See Fig 5.**

3. Experimental results and discussion

Test results of the experimental program were discussed through crack pattern and mode of failure, ultimate load, vertical displacement, Horizontal displacement, and strains.

3.1. Crack pattern and mode of failure

Fig. 6, shows a total of twelve columns specimens after failure. The typical collapse mechanism of the specimens was usually identified by sudden failure. The failure mode of each specimen is described in the following subsection.

3.1.1. Group (A):

The first column in this group was (C0) in dimension (250 x 200)mm

The control specimen without any jacketing showed a sudden failure with explosive sound by bursting of concrete, suffered from excessive lateral expansion, and failed by splitting of concrete. The first crack was observed at a load of 55kn and the second was observed on the same side at load 65 kn. Cracks began to appear on the other three sides when the load reached 60 kn. The columns began to fail when it was loaded by 700kn When the load reached the ultimate value of 850kn, the column failed in compression at the corners of the column. This is mainly interpreted by unstable propagation of the interna1 micro-cracks, followed by the strain softening, and eventually, the concrete strength loses its stiffness.

It was observed that after confinement with two layer of expanded wire mesh The load carrying capacity of the confined **Column (C1)** increased to almost double as compared to the unconfined control columns and the load shortening curves appeared at bvarious positions. The first crack was observed at a load of 410kn and the second was observed on the other side at load 480kn. Cracks were vertical on all sides faces with spalling of the mortar layer from the wire mesh layer and near the bottom was observed on two sides of the column.

The wire mesh continued to confine the column until the failure of the concrete occurred at a load of 1066.5kn. After the peak load, the load reduced and The smash of the outer mortar layer can also be seen clearly in Figs.

It was observed that after confinement with three-layer of Expanded wire mesh the load- carrying capacity of the confined column (**C2**) increased to almost double as compared to the unconfined control columns and the load-shortening curves appeared at various positions.

The first crack was observed at a load of 460kn and the second was observed on the other side at load 530kn. Cracks were vertical on all sides faces with spalling of the mortar layer from the wire mesh layer and near the bottom was observed on two sides of the column.

The wire mesh continued to confine the column until the failure of the concrete occurred at a load of 1135.5kn. After the peak load, the load reduced and The smash of the outer mortar layer can also be seen clearly in Figs.

The Fourth column in this group was (**C3**) which was strengthened with Two-layers of Square wire mesh. It is noticed that the increase of wires mesh area led to increased the ultimate carrying capacities.

As the load approached 800kn, the first crack was observed in the mortar layer with a cracking sound. At a load of 820kn, two cracks were observed simultaneously, one near the upper corner extending vertically towards the mid-first height of the column and another was in the lower corner extending in a vertical pattern equally in height towards top and bottom.

The mortar layer of Ferrocement was separated from the wire mesh with compression failure of the column near one-fourth height from the base. The failure of the column occurred at a load of 1000kn.

3.1.2. Group (B):

The first column in this group was (**B4**) in dimension (200 x 200)mm,
The control specimen without any jacketing showed a sudden failure with explosive sound by bursting of concrete, suffered from excessive lateral expansion, and failed by splitting of concrete. The first crack was observed at a load of 55kn and the second was observed on the same side at load 65 kn. Cracks began to appear on the other three sides when the load reached 60kn. The columns began to fail when it was loaded by 720kn , the column failed in compression at the middle of the column. This is mainly interpreted by unstable propagation of the interna1 micro-cracks, followed by the strain softening, and eventually, the concrete strength loses its stiffness.

The first crack grew and more cracks were observed at a load of 120kn right side of the column in a vertical direction, which continued to become wide as the load increased when two layers of expanded wire mesh were used in column (**B5**).

the first crack appeared at a load of 410kn and the second crack was observed on the same side at load 420kn in the vertical direction.

The Spalling of Ferrocement jacket from the mortar surface was observed at an average load of 600kn at the top and near the bottom. The failure of columns was observed at an ultimate load of 930kn. The spalling of concrete was observed entirely from the rupture zone, which also resulted in the buckling of the longitudinal reinforcement.

The outer Ferrocement jacket played a confinement role, which provides a significant increase in the load capacity. As the ductility of the welded mesh is high, it produces a smoother descent stage in the load-shortening curve. The Strengthening with three layers of Expanded wire mesh (B6) increased the value of the load.

At a load of 470kn, firstly, two cracks were observed simultaneously, one near the upper corner extending vertically towards mid-height of the column and another was in the lower corner extending in a vertical pattern equally in height towards top and bottom.

Suddenly, at load 1082.80kn, the column began to a clear completely fail and smash of the mortar layer.

The Fourth column in this group was (**B7**) which was strengthened with Two-layers of Square wire mesh. It is noticed that the increase of wires mesh area led to increased the ultimate carrying capacities.

The first crack of this group was vertical and it was observed on the top surface near at the fixed end when the load reached at 430kn and some low-level cracking sounds were heard which may be due to micro cracking of mortar.

As the load increased, new cracks were created along the column and began to appear more profusely when the load reached 550kn. When the load reached the ultimate value of 840kn, the load dropped and the cracks continued to expand. Under the fixed-ends concrete fragments started to drop from the specimens.

3.1.3. Group (C):

The first column in this group was (C8) in dimension (150 x 200)mm

The control specimen without any jacketing showed a sudden failure with explosive sound by bursting of concrete, suffered from excessive lateral expansion, and failed by splitting of concrete. The first crack was observed at a load of 55kn and the second was observed on the same side at load 65 kn. Cracks began to appear on the other three sides when the load reached 60kn. The columns began to fail when it was loaded by 630kn. the column failed in compression at the corner of the column. This is mainly interpreted by unstable propagation of the interna1 micro-cracks, followed by the strain softening, and eventually, the concrete strength loses its stiffness.

It was observed that after confinement with two-layer of Expanded wire mesh the load- carrying capacity of the confined column (**C9**) increased to almost double as compared to the unconfined control columns and the load-shortening curves appeared at various positions.

The first crack was observed at a load of 440kn and the second was observed on the other side at load 500kn. Cracks were vertical on all sides faces with spalling of the mortar layer from the wire mesh layer and near the bottom was observed on two sides of the column.

The wire mesh continued to confine the column until the failure of the concrete occurred at a load of 830kn. After the peak load, the load reduced and The smash of the outer mortar layer can also be seen clearly in Figs.

It was observed that after confinement with Three-layer of Expanded wire mesh the load- carrying capacity of the confined column (**C10**) increased to almost double as compared to the unconfined control columns and the load-shortening curves appeared at various positions.

The first crack was observed at a load of 380kn and the second was observed on the other side at load 450kn. Cracks were vertical on all sides faces with spalling of the mortar layer from the wire mesh layer and near the bottom was observed on two sides of the column.

The wire mesh continued to confine the column until the failure of the concrete occurred at a load of 910kn. After the peak load, the load reduced and The smash of the outer mortar layer can also be seen clearly in Figs.

The Fourth column in this group was (**C11**) which was strengthened with Two- layers of Square wire mesh. It is noticed that the increase of wires mesh area led to increased the ultimate carrying capacities.

As the load approached 580kn, the first crack was observed in the mortar layer with a cracking sound. At a load of 600kn, two cracks were observed simultaneously, one near the upper corner extending vertically towards the mid-first height of the column and another was in the lower corner extending in a vertical pattern of unequally height towards the top and bottom.

The mortar layer of Ferrocement was separated from the wire mesh with compression failure of the column near one-fourth height from the base. The failure of the column occurred at a load of 790kn.

3.2 Ultimate Loads:

From **Figs. 7–9** and **Table 6** it is seen that the axial load, carrying capacity of all Ferro cement jacketed columns specimens is higher than those obtained from the non-jacketed specimens.

3.2.1. Group (A), Group (B) and Group (C):

In these groups, the increase in expanded or square wire mesh layer from two layers to three layers led to an increase in ultimate load capacity until failure. While, when the layer increased to three layers, the applied load increased rapidly until 60% of the ultimate load, and then this applied load decreased gradually. The control specimen failed at a load of 850kn, 720kn and 630kn, while the specimens strengthened with two layers of expanded wire mesh (A1, B5) and(C9) collapsed at a load of 1060kn, 930kn and 830kn with about 40%, 26% and 16% increase in column strength respectively. The enhancement in the load-carrying capacity were 60%, 55 and 36 % when three layers of expanded wire mesh were used, (A2, B6) and (C10). When two layers of expanded and square wire mesh were used in specimens (A3, B7) and (C11), the ultimate load were 1000kn, 840kn and 790kn with about 20%, 16% and 14 % enhancement.

According to the results in **Table 6** and **Figs 7, 8, 9, 10** the effect of using ordinary types of expanded wire mesh was more effective than the welded wire mesh. This enhancement was due to increased confinement due to small spaces between the wires of expanded mesh, which increased the failure load and enhanced the behaviour of the crack, which enhanced the whole behaviour of columns.

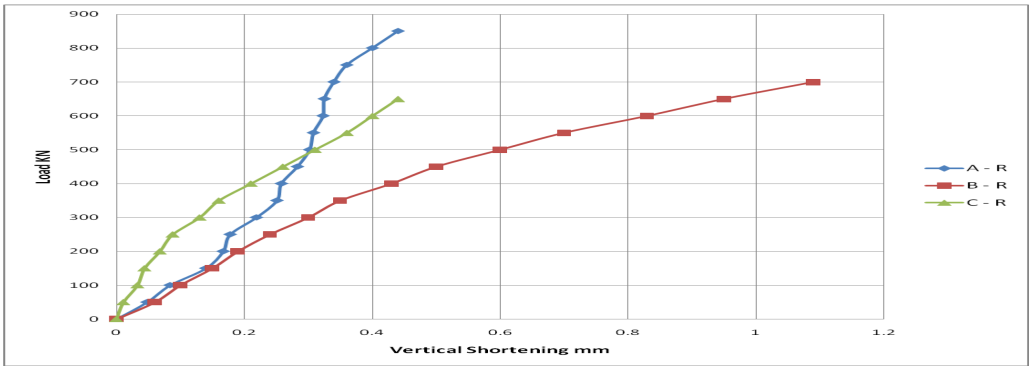

Fig. 7. Variation of load with respect to vertical shortening in columns **(A0, B4, C8)**

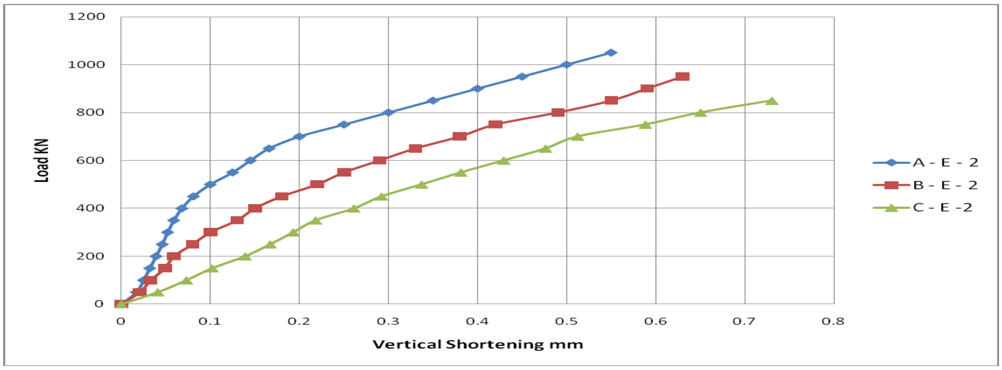

Fig. 8. Variation of load with respect to vertical shortening in columns **(A1, B5, C9)**

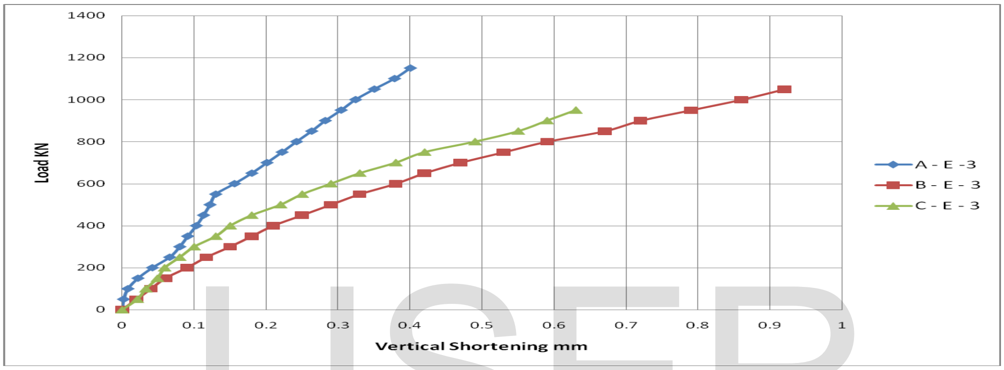

Fig. 9. Variation of load with respect to vertical shortening in columns **(A2, B6, C10)**

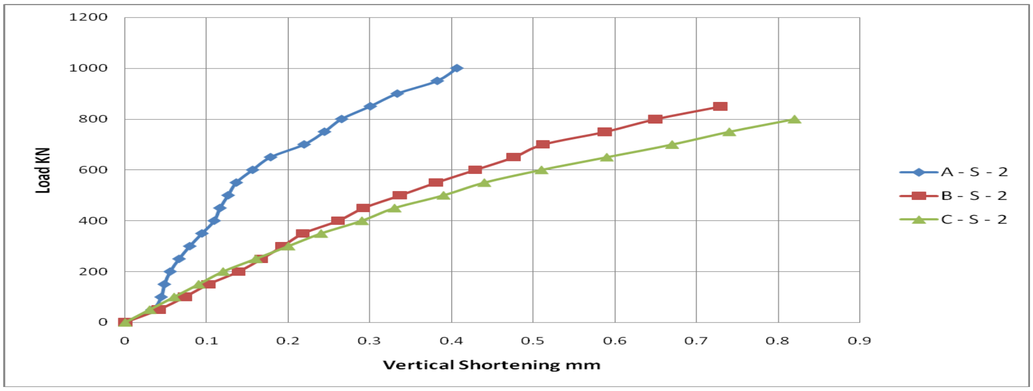

Fig. 10. Variation of load with respect to vertical shortening in columns **(A3, B7, C11)**

3.3. Vertical Deformation

The load – vertical displacement curves for the square jacketed reinforced columns are shown in **Figs. 7 to 10**, respectively. It can be observed that the columns with three-layer wire mesh performed better. Also using two layers of expanded wire mesh with 30 MPa mortar strength gives a good performance in load – vertical displacement behaviour. This may be due to the column was previously loaded up to its failure. It is observed that the use of expanded wire mesh is better than using square wire mesh to strengthen the square reinforced concrete columns.

Table 6: The results of strengthened column specimens compared with reference specimens

Group NO.	Column NO.	Ultimate load		Axial displacement	Lateral Displacement
		kn	+%	Mm	Mm
A	A0	850	-	0.44	0.778
	A1	1060	510	0.55	0.6
	A2	1130	600	0.4	1.41
	A3	1000	570	0.203	0.889
B	B4	720	-	1.09	0.9
	B5	930	360	0.63	0.801
	B6	1080	540	0.92	0.66
	B7	840	200	0.73	0.86
C	C8	630	-	0.44	0.954
	C9	830	190	0.73	0.78
	C10	910	330	0.63	0.80
	C11	1060	140	0.82	0.74

3.4. Lateral displacement

For columns that were examined under axial loads, the lateral displacement was mostly affected by the increase in layers or increasing in cement mortar strength. From **Figs. 11–13** all jacketed columns with Ferro cement showed lower lateral displacement than the non-jacketed column at the ultimate load. The ratio between lateral deformations (Δ) at 0.8 of the ultimate loads in the descending part to the lateral deformation at the ultimate load was used to calculate the ductility index (ψ)., as discussed below. In columns (A0, B4) and (C8), the displacement increased from 0.77 to 0.95 and then decreased to 0.9. In columns (A1, B5) and (C9), the displacement increased from 0.6 to 0.8 and then decreased to 0.78. In columns (A2, B6) and (C10), the displacement increased from 0.66 to 0.80.

. In columns (A3, B7) and (C11) increased from 0.74 to 0.88 and then dropped to 0.85. This decreased or dropped in the ductility due to using four layers of mesh. A comparison between lateral displacement for column with two or three layers of expanded and square wire mesh were shown in **Figs 11 and 13.**

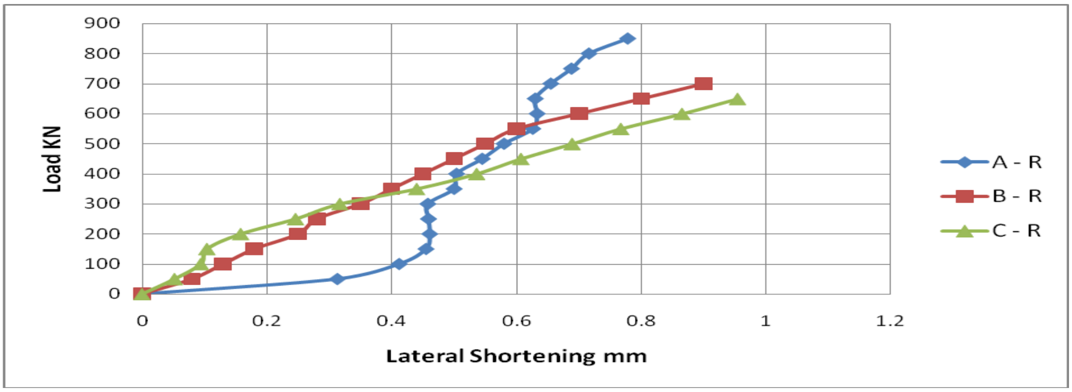

Fig. 11. Variation of load with respect to lateral displacement in columns (A0,B4,C8)

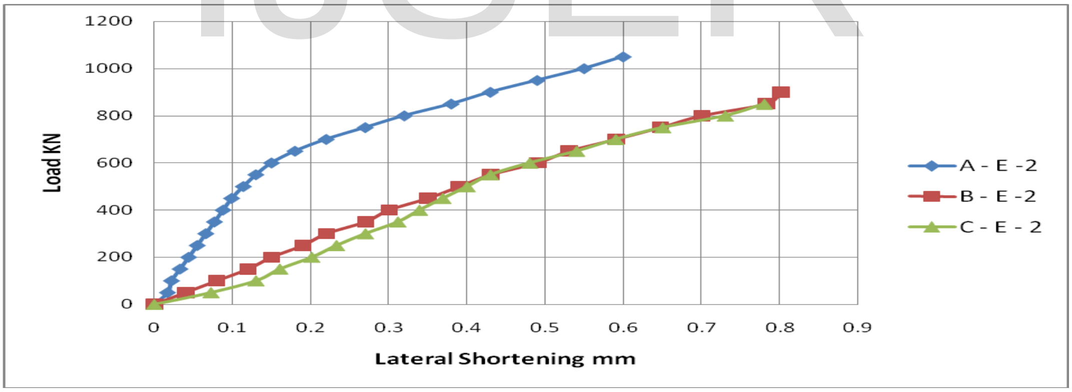

Fig. 12. Variation of load with respect to lateral displacement in columns (A1,B5,C9)

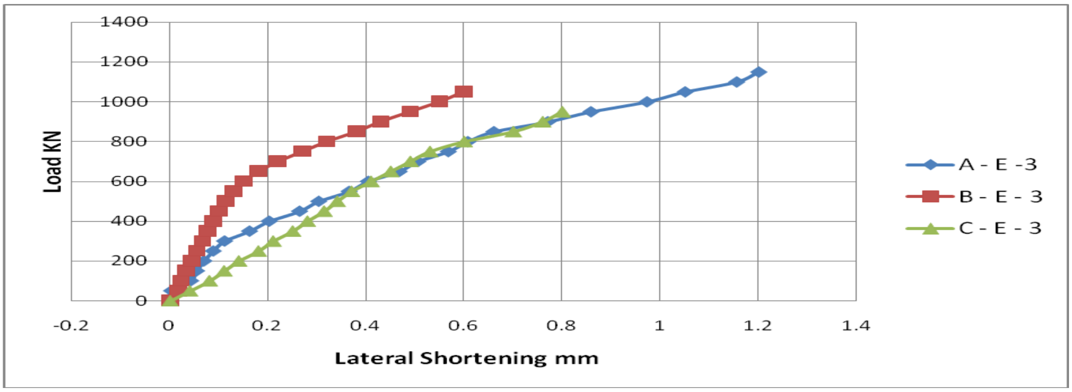

Fig. 13. Variation of load with respect to lateral displacement in columns (A2,B6,C10)

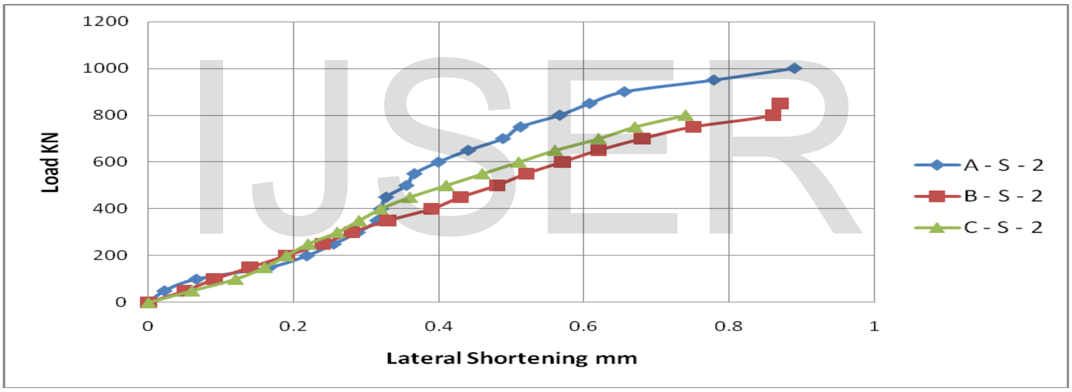

Fig. 14. Variation of load with respect to lateral displacement in columns (A3,B7,C11)

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4. Comparison between experimental and theoretical results

It can be said that Ferro cement is equivalent to RC, but its advantage is higher ductility due to the confinement of wire mesh composite with mortar cement. The Egyptian and American codes have been used for theoretical study as the basic equations for the ultimate load capacity:

Egyptian Code (ECP) Equation [8]

$$P_u = 0.35\ A_c\ f_{cu} + 0.67\ A_s\ f_y \quad (1)$$

ACI 318 Code Equation [6]

$$P_u = 0.85\ A_c\ f_{cu} + A_s\ f_y \quad (2)$$

To study and know the significant improvement of static strength of all strengthened specimens, these equations were modified according to [2], [16],[18] to be as follows:

The modified Egyptian Code (ECP) Equations

$$P_u = 0.35\ A_c\ f_{cu} + 0.67\ A_s\ f_y + 0.95\ A_{cf}\ f_{cf} + A_{sf}\ N\ f_{sf} \quad (3)$$

The modified ACI 318 Code Equations

$$P_u = 0.85\ A_c\ f_{cu} + A_s\ f_y + 0.85\ A_{cf}\ f_{cf} + A_{sf}\ N\ f_{sf} \quad (4)$$

Where:

P_u = Ultimate load capacity of column
f_{cu} = Concrete compressive strength
f_{cf}'= Compressive strength of cement mortar
f_y = Yield strength of steel bars
A_c = Gross area of concrete
A_{cf} = Area of cement mortar
A_{sf} = Area of additional steel
N = Number of wire mesh layers
f_{sf} = tensile strength of wire mesh

Table 8. Comparison between experimental and theoretical results.

Column NO.	Pu (kn) Experimental	Pu (kn) Modified ECP - Code [5]	Pu (kn) Modified ACI 318 Code [2]	P_{Uexp} / P_{Uth} Modified ECP	P_{Uexp} / P_{Uth} Modified ACI 318
C0	850	1021.8	1276.8	0.83	0.66
C1	1060	1631.1	1510.9	0.65	0.70
C2	1130	1667.9	1529.3	0.68	0.74
C3	1000	1614.1	1502.4	0.62	0.67
C4	720	817.8	1021.8	0.88	0.70
C5	930	1362.6	1301.5	0.68	0.71
C6	1080	1395.6	1334.5	0.77	0.81
C7	840	1347.3	1286.2	0.62	0.65
C8	630	613.8	766.8	1.03	0.82
C9	830	1094.1	1013.5	0.76	0.82
C10	910	1123.4	1042.7	0.81	0.87
C11	790	1080.5	999.9	0.73	0.79

Comparisons between the ultimate load-carrying capacities of all tested columns and the corresponding ultimate load predicted by Equations (3), (4)**.** Equation (3) can be applied to predict maximum applied load-carrying capacity for both RC column and RC column strengthened by Ferro cement. According to the P_{Uexp} / P_{Uth} Modified results as shown in **Table 8**, the values of the modified Egyptian code gives an overestimated value while the values obtained from the modified ACI code are underestimated.

5. CONCLUSION

This experimental study is carried out to analyse the behaviour of reinforced concrete square columns strengthened using Ferro cement jacket. Based on test results, observations, and discussions, some points can be concluded:

1. The confinement with Ferro cement techniques in reinforced concrete columns can improve the strength and ductility of strengthening.
2. Test results indicated that Ferro cement jackets made of 3 layers of non-structural expanded wire mesh and applied on square reinforced concrete columns have a promising performance on increasing its load capacity and enhancing its failure mode.
3. Confinement with three-layers of expanded wire mesh increased the strength up to 51% as compared to the specimen strengthened with two-layers of expanded wire mesh. In addition, the results showed that using expanded wire mesh was better than Using square wire mesh.
4. The ductility index for column strengthen by two layers of expanded wire mesh was better than that strengthen by two layers of square wire mesh.
5. We concluded from the experimentally and theoretical results, that the values of the modified Egyptian code are overestimated and the values of the modified ACI code are underestimated.
6. We suggest changing and adjusting the modified equations to be more agreement with the experimentally results.

References

[1] Abdullah and Takiguchi, K. (2003), "An investigation into the behaviour and strength of reinforced concrete columns strengthened with Ferro cement jackets". Cement & Concrete Composites, vol. 25: pp 233–242.

[2] Abeer M. E, Hossam H. A, Bishoy A. M, and Taha A. El-Sayed, (2019)," Structural Performance of Eccentric Ferro cement Reinforced Concrete Columns " Nanoscience and Nanotechnology journal, Volume 11, SP 1213-EP 1225.

[3] A.B.M.A. Kaish, M. Jamil, S.N. Raman, M.F.M. Zain, L. Nahar, "Ferro cement composites for strengthening of concrete columns": A review Construction and Building Materials, 160 (2018), pp. 326-340

[4] A. B. M. A. Kaish, (2016), "An approach to improve conventional square Ferro cement jacket for strengthening application of Short Square RC column. Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia.

[5] American Concrete Institute (ACI), (1988). "Guide for the Design, Construction, and Repair of Ferrocement". ACI 549, Detroit, American Concrete Institute.

[6] American Concrete Institute (ACI), (2008). "Building Code Requirements for Structural Concrete" (ACI 318-08) and Commentary (ACI 318R-05). Detroit, American Concrete Institute.

[7] Afaf H Abdallah, Abeer M. Erfan, Taha A. El-Sayed, (2019,) Experimental and analytical analysis of lightweight Ferro cement composite slabs. Engineering Research Journal (ERJ), Vol. 1, No. 41 July 2019, pp. 73-85.

[8] Egyptian Code for Design and Construction of Reinforced Concrete Structures) ECP 203- 2007) -)ECP 203- 2018(.

[9] El-Sayed, T.A. and Erfan, A.M. (2018), "Improving shear strength of beams using Ferro cement composite". Construction and Building Materials, 172, pp.608–617.

[10] Jianqi Wang, (2013), "Behavior of Ferro cement columns under static and cyclic loading" Doctor of Philosophy, in the Faculty of Manchester for Engineering and Physical Sciences.

[11] Ornela Lalaj, (2015), “Recent perspectives for ferrocement" Res. Eng. Struct. Mat. Vol. 1 Iss.1 (2015) 11-23.

[12] Kaish, A. B. M. A, Alam, M. R., Jamil, M. & Waheed, M. A., (2013). "Ferro cement Jacketing for restrengthening of Square Reinforced Concrete Column under Concentric Compressive Load". Procedia Engineering, 54 (0), 720-728.

[13] Kim, J.-K. & Lee, S.-S., (2000). "The behaviour of reinforced concrete columns subjected to axial force and biaxial bending". Engineering Structures, 22 (11), 1518-1528.

[14] Mansur, M. & Paramasivam, P., (1985). "Ferro cement under combined bending and axial loads. International Journal of Cement Composites and Lightweight Concrete, 7 (3), 151-158.

[15] Mourad, S. & Shannag, M., (2012). "Repair and strengthening of reinforced concrete square columns using Ferro cement jackets". Cement and Concrete Composites, 34 (2), 288-294.

[16] Nedwell, P., Ramesht, M. & Rafei-Taghanaki, S. (1994)" Investigation into the repair of short square columns using ferrocement, FERRO CEMENT INTERNATIONAL SYMPOSIUM, 1994. 277-285.

[17] Paramasivam, P., Lim, C. T. E., & Ong, K. C. G. (1998). "Strengthening of RC beams with Ferro cement laminates". Cement and Concrete Composites, 20(1), 53-65.

[18] Sayan Sirimontree, Boonsap Witchayangkoon and Krittiya Lertpocasombut, (2015)." Strengthening of Reinforced Concrete Column via Ferro cement Jacketing". American Transactions on Engineering & Applied Sciences. Volume 4 No.1 ISSN 2229-1652 eISSN 2229-1660, pp 39-47.