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Strengthening of RC Square Columns Via Ferro-cement Technique

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ABSTRACT : *This paper presents an experimental investigation to clarify the behavior of ferrocement square columns strengthened using ferrocement jacket. Strengthening via ferrocement jacket is comparatively a replacement technique, which features a high strength/weight ratio, good resistance to cracking and impact loading, acceptable resistance to fireside, and more resistance to corrosion than traditional materials. Ten ferrocement short columns with nominal cross-sectional dimensions of 200 × 200 mm with a complete length of 1200 mm were cast and tested under axial loading until failure. the most parameters during this study were the number of layers of wire mesh, type of wire mesh, and therefore the cement mortar strength. The results showed the effectiveness of the ferrocement jacket in improving the column capacity, and reducing the vertical and lateral displacement. 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.*

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I. 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]

Ferrocement is the composite of Ferro (Iron) and cement (cement mortar). Ferrocement can be considered as a type of thin walled reinforced concrete construction in which small-diameter wire meshes are used uniformly throughout the cross section instead of discretely placed reinforcing bars and in which Portland cement mortar is used instead of concrete. In ferrocement, wire-meshes are filled in with cement mortar. It is a composite, formed with closely knit wire mesh; tightly wound round skeletal steel and impregnated with rich cement mortar. [3]

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. [4]

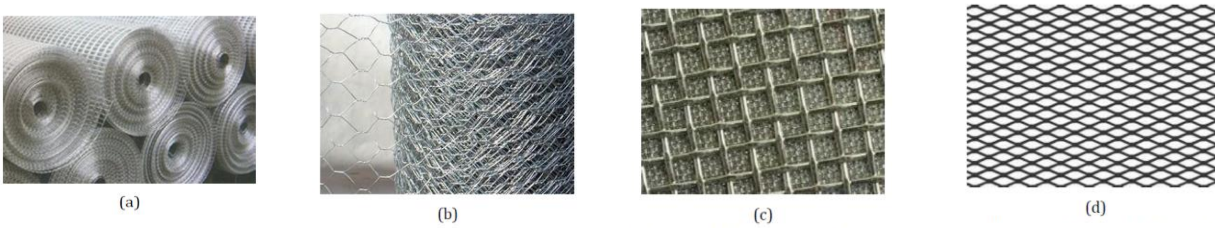

Fig. 1. Types of wire mesh used in Ferro cement applications [4]
(a) Welded square wire mesh; (b) Hexagonal wire mesh;
(c) Woven wire mesh; (d) Expanded metal wire mesh.

The strengthening of RC beams with Ferro cement laminates was studied by (Paramasivam et al. 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. [5]

Takiguchi and Abdullah studied the behavior and strength of reinforced concrete columns strengthened using Ferrocement jackets. Six identical reference columns were prepared and tested after being strengthened with circular or square Ferrocement jackets. The parameters studied included the jacketing schemes and the number of layers of wire mesh. The results showed that the peak strength and ductility were enhanced tremendously. [6]

Mohamad N. and Majeed carried out experimental work on flat and folded Ferrocement panels for studying their flexural behavior. The panels tested for flexure were of size 380mm x 600mm with 20mm thickness for both flat as well as folded slab panels. The wire mesh used was mild steel galvanized welded wire mesh of 0.65 mm diameter and 12.5 mm square grid size. From their experimental work, the authors concluded that the cracking load was not significantly affected by the number of the wire mesh, particularly for the folded panels. They also concluded that the flexural strength of the folded panel increased by 37 and 90 percent for panels having 2 and 3 wire mesh layers compared with that of a single layer; while for the flat panel, the percentage increase in the flexural strength using 2 and 3 layers was 65% and 68% compared with that of plain mortar panel. [7]

Kondraivendhan et al. studied the effect of Ferrocement confinement on the behavior of concrete. The effect of different grades of concrete confined with Ferrocement was studied by keeping all other parameters constant. In their investigation, concrete mixes a characteristic compressive strength of 25N/mm^2, 30 N/mm^{2,} 35 N/mm^2, 40 N/mm^2, 45 N/mm^2, 50 N/mm^2 and 55 N/mm^2, respectively. A total of 42 cylindrical specimens (21 each for controlled and confined specimens), Three replicates for each grade of concrete, were cast. Column specimens of size 150mm x 900mm with different grades of plain cement concrete were cast and then confined with Ferrocement. It was found that the increase in compressive strength of the concrete significantly decrease in the confinement occurred lower grades of concrete such as M25 showed a 78% increase in compression strength as compared to a higher grade of concrete M55 which increased by 45.3%.[8]

II. EXPERIMENTAL WORK

The experimental program was carried out to test ten reinforced concrete columns to study the effect of the number of layers of wire mesh, type of wire mesh, and the mortar strength on the behavior and strength of square columns regarding load capacity and lateral and axial displacement. All columns were 200 × 200 mm with a total length of 1200 mm and reinforced longitudinally with 4Φ12 mm steel bars and 5Φ8 mm/m steel stirrups. One of them was a control column (C0) without Ferro-cement jacket. Three columns strengthening with expanded wire mesh with a two, three, and four layers (C1, C2, and C3). Another three columns strengthening with square wire mesh with a two, three, and four layers (C4, C5, and C6). The last three columns (C7, C8, and C9) were strengthening using expanded wire mesh with three-mortar strength of 25, 30, and 40 MPa. All columns were tested under axial loading until failure. The details of the tested column are shown in Fig 2 and Table 1.

Material

Normal-weight natural river sand, well-graded clean gravel with nominal sizes ranged from 10 to 20 mm, Ordinary Portland cement, additives as silica fume, and Sikament R2008 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. [9][10]

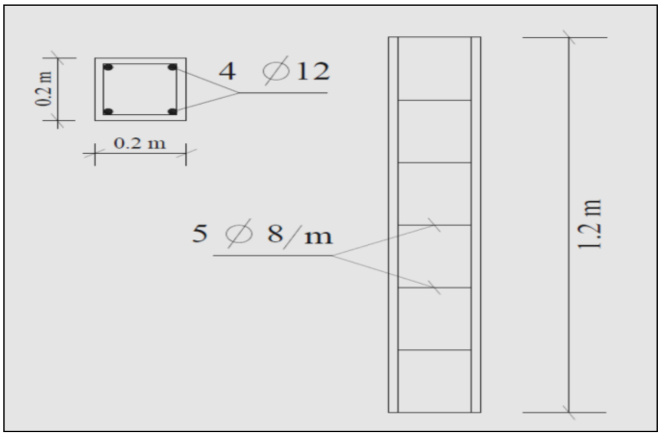

Fig. 2. Details of tested column.

Table 1. The details of the tested columns

Group NO.	Column NO.	Layer Number	Mortar Strength (MPa) (Target values)	Layer Type
A	C0	-	-	-
B	C1	2	25	Expanded
	C2	3		
	C3	4		
C	C4	2	25	Square
	C5	3		
	C6	4		
D	C7	2	25	Expanded
	C8		30	
	C9		40	

Table 2. The concrete mix proportions ($f_c^{'}$ =25Mpa)

Target fc' at 28 days (MPa)	Mix (25)'
Ordinary Portland cement (kg/m3)	350
Fine aggregate (Sand)(kg/m3)	625
Coarse aggregate (Sand)(kg/m3) (Gravel)	1295
Silica Fume (kg/m3)	25
Water	167
w/c	0.38
Sikament (L/m3)	5

Mortar

The try and error method was used in the design of mortar mixtures for the Ferro-cement tested columns. Well-graded sand, water, and possibly some admixtures such as silica fume and superplasticizer. Similar to concrete, the mortar should have adequate workability, low permeability, and high compressive strength. The water-cement ratio, sand-cement ratio, quality of water, type of cement, and curing conditions in addition to the casting and compaction can influence the mechanical properties of the mortar. [11],[12],[13]

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 (N/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

Three mixes of different water to cement ratio (0.45, 0.4, and 0.35) and (10, 15, and 25 %) of silica fumes were used for (25, 30, and 40) MPa cement mortar strength. To maintain uniform workability, the superplasticizer dosage was adjusted in the mix. Six cubes (size: 70.7 mm x 70.7 mm x70.7 mm) were used for compression test. The average cube strength at the time of testing was 25.2, 33.2 and 40.8 MPa respectively. Table 5 Shows the mortar mix proportions and the Actual results for cubes of Mortar are given in tables 6.

Table 5. The mortar mix proportions

Material	Weight Kg/m^3		
	w/c = 0.45	*w/c* = 0.4	*w/c* = 0.35
Cement	400	450	500
Sand	1425	1370	1325
Water	180	180	175
Silika fume	10%	15%	25%
Sikament R2008	3.5 %	5 %	7%
Cement/Sand	1:3	1:3	1:3

Casting of Reinforced Concrete Column Specimens:

Ten square reinforced concrete columns were cast. All square columns were cast in a vertical position using steel molds for the formwork, as shown in Fig (3). The steel molds were properly oiled on the inner sides for easy removal of the specimens at the time of demolding. The prepared reinforcement cage was held carefully in the molds.

Curing

After 24 hours of casting, all columns and cubes were de-molded 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.

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 or 4 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 220 × 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.

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 1	25.1	25.2	25
Cube 2	25.31		
Cube 3	25.2		
Cube 4	33.2	33.2	30
Cube 5	33.1		
Cube 6	33.3		
Cube 7	40.4	40.8	40
Cube 8	40.8		
Cube 9	41.2		

Instrumentation Device

Control and jacketed columns were tested under axial compressive loading in a 250T 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 displacement s were recorded using linear variable differential transformers (LVDT). Ultimate load, axial and lateral Displacement were recorded using data logger and failure modes of specimens were observed, See Fig 5.

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

Fig. 6: Tested columns after failure for all groups.

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.

➢ ***Crack pattern and mode of failure***

Fig. 6, shows a total of ten 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.

Group (A):

The control specimen without any jacketing showed a sudden failure with explosive sound by the bursting of concrete, suffered from excessive lateral expansion, and failed by splitting of concrete. The first crack was observed at a load of 3.5t. As the load reached the ultimate value of 70t, the column failed in compression. 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.

Group (B):

The first column in this group was (C1) which strengthening with two-layers of expanded wire mesh. As the load started, some low-level cracking sounds were heard which may be due to micro cracking of mortar. As the loading continued the specimen started to show vertical and horizontal displacement. As the load reached 30t some cracking and spalling of the surface of the mortar at the top, and near the bottom was observed. As the load reached the ultimate value of 84.75 t, the column failed in compression and complete crushing of concrete cover occurred in about one-fourth and last fourth of the column height.

It was observed that after confinement with three-layer wire mesh the load-carrying capacity of the confined column (C2) increased to almost double as compared to the unconfined control columns. The first crack was observed at a load of 43 T. Cracks were vertical on all sides faces with spalling of the mortar layer from the wire mesh layer. The wire mesh continued to confine the column until the failure of the concrete occurred at a load of 108.75 T. The smash of the outer mortar layer can also be seen clearly in the figs.

The third column in this group was (C3) which strengthening with four-layers of expanded wire mesh. At a load of 47 t, firstly, two cracks were observed simultaneously, one near upper left corner extending vertically towards mid-height and another was on right to half-width extending in a vertical pattern equally in height towards top and bottom. Suddenly, at load 81.8 t, the column began to a clear completely failure and smash of the mortar layer.

Group (C):

The confining of column (C4) with two-layers of square wire mesh increased the value of load and a decrease in the lateral displacement. The first crack was observed at a load of 30 t. Cracks were vertical on two adjacent faces with spalling of the mortar layer from the wire mesh layer. The wire mesh continued to confine the column until the failure of the core concrete occurred at a load of 81t.

When three layers of square wire mesh were used in column (C5) the first crack was observed at a load of 12t right side of the column in a vertical direction, which continued to become wide as the load increased. The failure occurred at an ultimate load of 80 t. The specimen failed in compression at one-fourth height from the top.

The Strengthening with four layers of square wire mesh (C6) increased the value of the load. The first crack was observed at a load of 56 t left the side of the column in the vertical direction, which continued to become wide as the load increased. The column failed in compression when the load reached 82 t, which is the ultimate value.

Group (D):

(C7) was the first column in this group which strengthening with two-layers of expanded wire meshes and its strength of mortar was 25 MPA. The column was tested under axial load and the first crack appeared at a load of 41t. When the load reached the ultimate value of 83t, the column failed in compression and crushing of concrete cover was noticed.

The column specimen, which is confined by Ferro-cement jacket with two-layers of expanded wire mesh and with the strength of mortar 30 MPa in column (C8), spalling of Ferro-cement jacket from the concrete surface was observed at an average load of 36t and the failure of columns was observed at an ultimate load of 93t. The spalling of concrete was observed entirely from the rupture zone, which also resulted in the bending of the longitudinal reinforcement as shown in Fig 6.

When the strength of mortar reached 40 MPa in column (C9) the column did not show any sign of cracking up to a load of 79 t. As the load approached 80t first crack was observed in the mortar layer with a cracking sound. The mortar layer of Ferro-cement 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 106t.

- ***Ultimate Loads***

From Figs. 7–9 and Table 7 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. Group A for the control specimen (C0), the failure load was 70t as shown in Table 7.

Group (B) and (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 four layers, the applied load increased rapidly until 85% of the ultimate load, and then this applied load decreased gradually. The control specimen failed at a load of 70t, while the specimens strengthened with two layers of expanded and square wire mesh (C1) and (C4) collapsed at a load of 84t and 81t with about 20% and 16% increase in column strength respectively. The enhancement in the load-carrying capacity was 54% and 36 % when three layers of expanded and square wire mesh were used, (C2) and (C5). When four layers of expanded and square wire mesh were used in specimens (C3) and (C6), the ultimate load were 81t and 79t with about 16% and 14 % enhancement.

According to the results in Table 6 and Figs 7, 8, 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 behavior of the crack, which enhanced the whole behavior of columns.

Group (D):

In this group, the increase in mortar strength from 25 MPa to 40 MPa led to an increase in the ultimate load capacity from 83t to be 106t. Compared with the reference column, the ratio of this increase was 20% and 33% and 51% for columns (C7), (C8), and (C9) respectively. See Fig.

- **Vertical Displacement:**

The load – vertical displacement curves for the square jacketed reinforced columns are shown in Figs. 7 to 9 respectively. It can be observed that the columns with three-layer wire mesh performed better. Also using two layers of expanded wire mesh with 40 MPa mortar strength gives a good performance in load – vertical displacement behavior. This may be due to the column was previously loaded up to its failure and can no longer show much ductile nature. It is observed that the use of expanded wire mesh is better than using square wire mesh to strengthening the square reinforced concrete columns.

- **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. 10–12 it is clear that all jacketed columns with Ferro-cement showed lower lateral displacement than the non-jacketed column at the ultimate load. The ratio between lateral Displacement s (Δ) at 0.8 of the ultimate loads in the descending part to the lateral displacement at the ultimate load was used to calculate the ductility index (ψ). The ductility obtained from the experimental test is shown in Table 8, as discussed below.

The ductility index obtained for the control specimen (C0) was 1.06 but a progressive increase in ductility was obtained for different groups of specimens. In group (B), the ductility increased from 1.25 to 1.72 and then decreased to 1.26. For group (C), the ductility increased from 1.23 to 1.63 and then dropped to 1.26. This decreased or dropped in the ductility due to using four layers of mesh. Group (D), the ductility varied from 1.25 to 1.83.

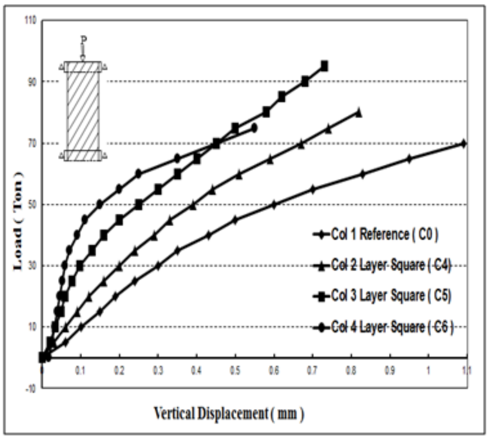

Fig. 8. Variation of load with respect to vertical displacement For columns in a group (C) compared with reference column (A0).

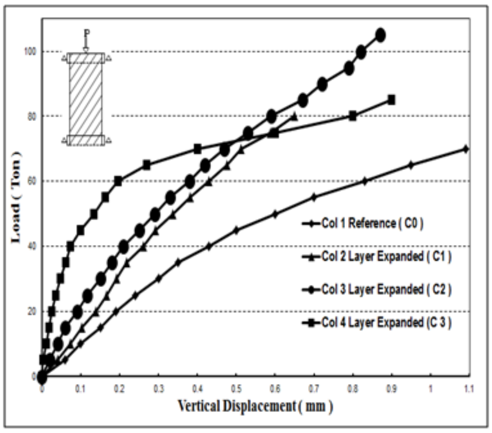

Fig. 7. Variation of load with respect to vertical displacement For columns in a group (B) compared with the reference column (A0).

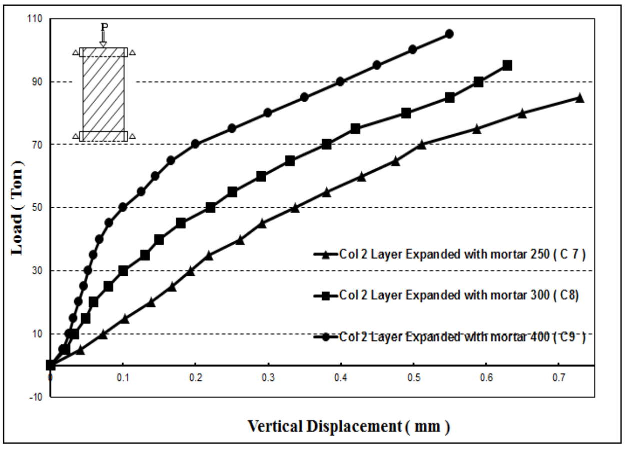

Fig. 9. Variation of load with respect to vertical Displacement for columns in a group (D).

Table 7: The results of strengthened column specimens compared with reference specimens

Group NO.	Column NO.	Ultimate load		Axial displacement	Lateral displacement
		ton	+%	mm	mm
A	C0	70	-	1.09	0.09
B	C1	84	20	0.73	0.86
	C2	108	54	0.79	0.78
	C3	81	16	0.9	0.95
C	C4	81	16	0.89	0.89
	C5	95	36	0.73	0.78
	C6	79	14	0.85	0.9
D	C7	83	19	0.72	0.85
	C8	93	33	0.63	0.80
	C9	106	51	0.55	0.60

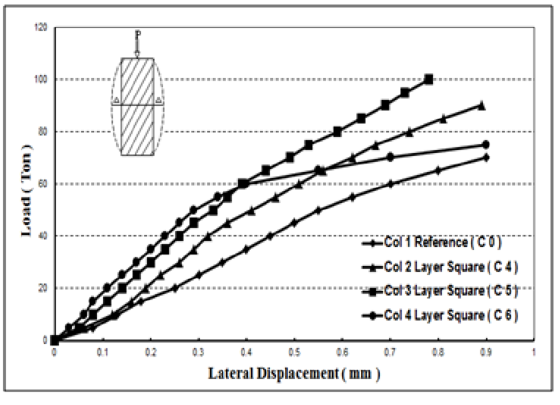

Fig. 11. Variation of load with respect to lateral displacement for columns in a group (C) compared with the reference column (A0).

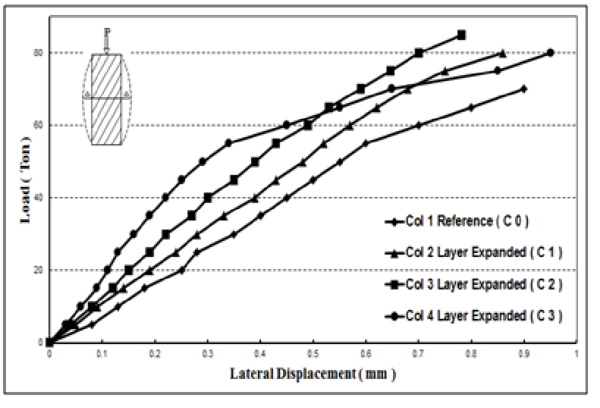

Fig. 10. Variation of load with respect to lateral displacement for columns in a group (B) compared with the reference column (A0).

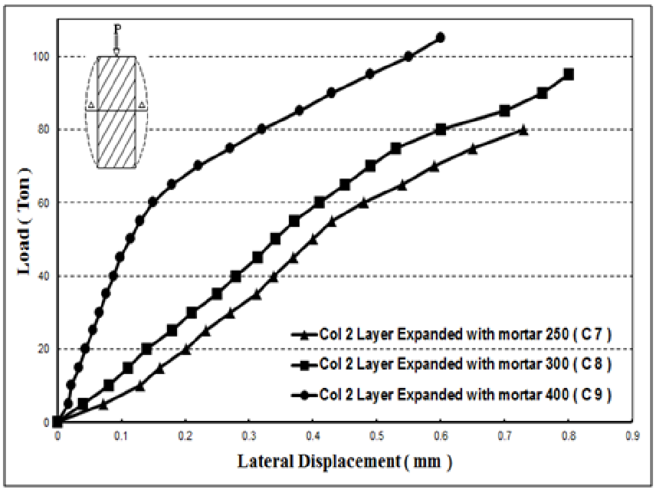

Fig. 12. Variation of load with respect to lateral displacement for columns in a group (D) compared with reference column (A0).

III. THEORETICAL WORK

The Egyptian and American codes have been used for estimated study as the basic equations for the ultimate load capacity for columns. Also, to study and know the significant improvement of the static strength of all strengthened specimens. It can be said that Ferrocement is equivalent to RC but its advantage is higher ductility due to the confinement of wire mesh composite with mortar cement.

Egyptian Code (ECP) Equation [14]

$$P_u = 0.8*0.85\, f_{cu}\, (A_g - A_s) + f_y\, A_s \qquad (1)$$

ACI 318 Code Equation [4]

$$P_u = 0.85\, f_{cc'}\, (A_g - A_s) + f_y\, A_s \qquad (2)$$

Canadian Standard Code [15]

$$P = (\alpha_1\, F_c\;\; f_{c'}\;\; a\, b) + (F_s\, A_{s1}\, f_y) + + A_{s2}(F_s\, f_y - \alpha_1 F_c\, f_{c'}) \qquad (3)$$

Europe Code

$$P_u = 0.35\, A_c\, f_{ck} + 0.67\, A_s\, f_y \qquad (4)$$

The Egyptian code (ECP) equation for estimating the ultimate strength of reinforced concrete strengthened with Ferrocement may be **modified** as follows to include the effect of strengthening:

$$P_u = 0.8*0.85\, f_{cu}\, (A_g - A_s) + f_y\, A_s + 1.9\, A_{cf}\, f_{cf} + A_{sf}\, N\, f_{sf} \qquad (5)$$

The American code (ACI) equation for estimating the ultimate strength of reinforced concrete strengthened with Ferrocement may be **modified** as follows to include the effect of strengthening:

$$P_u = 0.85\, f_{cc'}\, (A_g - A_s) + f_y\, A_s + 0.7\, A_{cf}\, f_{cf} + 0.5\, A_{sf}\, N\, f_{sf} \quad (6)$$

The Canadian Code equation for estimating ultimate strength of reinforced concrete strengthened with ferro-cement may be **modified** as sollows to include the effect of strengthening:

$$P = (\alpha_1\, F_c\;\; f_{c'}\;\; a\, b) + (F_s\, A_{s1}\, f_y) + + A_{s2}(F_s\, f_y - \alpha_1 F_c\, f_{c'}) + 2.4\, A_{cf}\, f_{cf} + A_{sf}\, N\, f_{sf} \quad (7)$$

The Europe Code equation for estimating ultimate strength of reinforced concrete strengthened with ferro-cement may be **modified** as follows to include the effect of strengthening:

$$P_u = 0.35\, A_c\, f_{ck} + 0.67\, A_s\, f_y + 2.9\, A_{cf}\, f_{cf} + A_{sf}\, N\, f_{sf} \qquad (8)$$

Where:

P_u = Ultimate load capacity of a column
P = Forces Resultant
f_{cu} = Concrete compressive strength (ECP Code)
$f_{c'}$ = Concrete compressive strength (ACI Code)
f_{ck} = Concrete compressive strength (Euro Code) = 0.8 f_{cu}
f_{cf} = Compressive strength of cement mortar
f_y = Yield strength of steel bars
A_c = Cross 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
F_c = 0.6
F_S = 0.85
α_1 = 0.85-0.0015 $f_{c'}$

Comparison between experimental and theoretical results

Comparisons between the ultimate load-carrying capacities of all tested columns and the corresponding ultimate load predicted by Equations (5), (6),(7) and (8). It can be seen that equation (5) can be applied to predict maximum applied load-carrying capacity for both the RC column and RC column strengthened by Ferro-cement. According to the P_{Uexp} / P_{Uth} Modified results shown in table 8, it is clear that the values of the modified Egyptian code give a better value of the ultimate load-carrying capacities than the values obtained from all the modified equation codes.

Table 8. Comparison between experimental and theoretical results.

No . Of Specimens	P_u (Ton) Experimental	P_u (Ton) Egy Code	P_u (Ton) ACI Code	P_u (Ton) Can Code	P_u (Ton) Euro Code	E_{xp} / P_u Egy	E_{xp} / P_u ACI	E_{xp} / P_u Can	E_{xp} / P_u Euro	No . Of Layers
Col 1	70	35.13	85.19	28.82	28.10	1.99	0.82	2.43	2.49	Ideal Specimens
Col 2	84	88.23	106.49	92.42	87.38	0.95	0.79	0.91	0.96	2 Layer Ex
Col 3	108	104.73	114.74	108.92	100.58	1.03	0.94	0.99	1.07	3 Layer Ex
Col 4	81	127.83	126.29	132.02	119.06	0.63	0.64	0.61	0.68	4 Layer Ex
Col 5	81	85.17	104.96	89.36	84.93	0.95	0.77	0.91	0.95	2 Layer Sq
Col 6	80	97.84	111.30	102.03	95.07	0.82	0.72	0.78	0.84	3 Layer Sq
Col 7	82	115.58	120.17	119.77	109.26	0.71	0.68	0.68	0.75	4 Layer Sq
Col 8	83	88.23	106.49	92.42	87.38	0.94	0.78	0.90	0.95	2 Layer Ex with 25 Str
Col 9	93	104.19	112.37	112.58	106.87	0.89	0.83	0.83	0.87	2 Layer Ex with 30 Str
Col 10	106	112.17	115.31	122.66	116.61	0.95	0.92	0.86	0.91	2 Layer Ex with 40 Str

IV. CONCLUSION

This experimental study is carried out to analyze the behavior of reinforced concrete square columns strengthened using a Ferro-cement jacket. Based on test results, observations, and discussions, the following 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 54% as compared to the specimen strengthened with two-layers of expanded wire mesh. Also, the results showed that using expanded wire mesh was better than Using square wire mesh.

4- Using two layers of expanded wire mesh with 40 MPa mortar strength exhibited an increase in the ultimate load capacity of 51% than that with 25 MPa mortar strength.

5- The ductility index for column strengthen by three layers of expanded wire mesh was better than that strengthened by three layers of square wire mesh.
6- We concluded from the experimentally and theoretical results, that the values of the modified Egyptian code give a better value of the ultimate load-carrying capacities than the values obtained from all the modified equation codes.
7- We suggest changing and adjusting the modified equations to be more agreement with the experimental results.

REFERENCES

[1]. Abdullah and K. Takiguchi, “An investigation into the behavior and strength of reinforced concrete columns strengthened with ferrocement jackets,” Cement and Concrete Composites, vol. 25, no. 2. pp. 233–242, 2003.
[2]. Abeer. M. Erfan, H. H. Ahmed, B. A. Mina, and T. A. El-Sayed, “Structural Performance of Eccentric Ferrocement Reinforced Concrete Columns,” Nanosci. Nanotechnol. Lett., vol. 11, no. 9, pp.1213–1225, 2020.
[3]. Maharashtra Engineering Research Institute, Nashik. (2018) "WRD Handbook "Ferrocement Technology" . First Edition, Chapter No.1 , 2018.
[4]. American Concrete Institute (ACI), (2008). "Building Code Requirements for Structural Concrete" American Concrete Institute. (ACI 318-08) and Commentary (ACI 318R-05). Detroit.
[5]. Sayan Sirimontree & Boonsap Witchayangkoon & Krittiya Lertpocasombut,(2015)." Strengthening of Reinforced Concrete Column via Ferrocement Jacketing". American Transactions on Engineering & Applied Sciences. Volume 4 No.1 ISSN 2229-1652 ISSN 2229-1660, pp 39-47.
[6]. Abdullah and K. Takiguchi, “An investigation into the behavior and strength of reinforced concrete columns strengthened with ferrocement jackets,” Cement and Concrete Composites, vol. 25, no. 2. pp. 233–242, 2003.
[7]. S. A. Majeed and M. N. Mahmood, “Flexural Behavior Of Flat And Folded Ferrocement Panels,” AL-Rafdain Eng. J., vol. 17, no. 4, pp. 1–11, 2008.
[8]. B.Kondraivendhana and Bulu Pradhan, “Effect of ferrocement confinement on behavior of concrete,” Constr. Build. Mater., no. 23.3, pp. 1218–1222, 2009.
[9]. Ornela Lalaj, (2015), “Recent perspectives for ferrocement" Res. Eng. Struct. Mat. Vol. 1 ISSN .1, pp 11-23.
[10]. Kaish A. B. M. A& Alam, M. R. & Jamil, M. & Waheed, M. A., (2013). "Ferrocement Jacketing for restrengthening of Square Reinforced Concrete Column under Concentric Compressive Load". Procedia Engineering, 54 (0), 720-728.
[11]. Kim, J.-K. & Lee, S.-S., (2000). "The behavior of reinforced concrete columns subjected to axial force and biaxial bending". Engineering Structures, 22 (11), 1518-1528.
[12]. Mansur, M. & Paramasivam, P., (1985). "Ferrocement under combined bending and axial loads". International Journal of Cement Composites and Lightweight Concrete, ISSN 7 (3), pp 151-158.
[13]. Mourad, S. & Shannag, M., (2012). "Repair and strengthening of reinforced concrete square columns using ferrocement jackets". Cement and Concrete Composites,Vol 34 ISSN (2), pp 288-294.
[14]. Egyptian Code for Design and Construction of Reinforced Concrete Structures (ECP 203- 2017).
[15]. Canadian Code Short Columns Case (0) by Ramzi Almahayri 2010.

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