Behavior of Biaxially loaded R.C. Columns Retrofitted by Ferrocement jacketing

Mahmoud Elsayed[1*], Alaa Elsayed[2]

[1] *Assistant Professor, Dept. of Civil Engineering, Faculty of Engineering, Fayoum University, Fayoum, Egypt*
[2] *Associate Professor, Dept. of Civil Engineering, Faculty of Engineering, Fayoum University, Fayoum, Egypt*
**E-mail: mms03@fayoum.edu.eg*

Abstract - *In this study, the finite element analysis FEA was utilized to numerically investigate the behavior of biaxially loaded RC columns wrapped by ferrocement jackets. The 3-D nonlinear finite element program ANSYS 14.5 was used to analyze and examine a total of twenty-five proposed models. The numerical results showed good agreement with the available experimental ones which served as a verification for the numerical model. The varying parameters considered were mortar strength, the number of layers of expanded wire mesh, and ferrocement thickness. The numerical results indicated that, in general, ferrocement jackets achieved a good efficiency in strengthening biaxially loaded R.C columns. All the wrapped specimens had higher ultimate loads and stiffness than that of the unwrapped column.*

***Key Words*:** Strengthening, Ferrocement, Biaxially loaded columns, ANSYS

1. INTRODUCTION

The behavior of reinforced concrete structures and their failure modes have been extensively studied in structural engineering. Rehabilitation of existing structure is becoming the main part of construction activities. Failure of the most important structure element, such as the column, generally leads to a total collapse of the building. There are many alternative techniques to be used in strengthening RC columns. Ferrocement is one of these systems. Ferrocement is a form of reinforced concrete using closely spaced multiple layers of mesh embedded in mortar layer [1]. Ferrocement has been currently used as a strengthening technique for concrete structures due to its ease of application, availability of its raw materials, and low cost [2-8]. Abdullah and Takiguchi [9], investigated an experimental test to study the efficiency of ferrocement confinement for repairing both circular and square R.C. columns under combined axial and lateral loading. Test results proved that applying external wrapped of ferrocement improves the ductility and strength of columns. Kaish et al [10] studied the influence of using ferrocement laminate in wrapping cylindrical plain concrete specimens, subjected to concentric loads. Kaish et al [11], Mourad, and shanng [12], and Xiong et al [13] reported that confinement R.C columns by ferrocement overlays lead to a significant enhancement in failure loads and improve ductility. El-Kholy and Dahish [14] proposed a method to be used expanded metal mesh as confinement configuration in addition to regular tie reinforcement. Kazemi and Morshed [15] studied experimentally the behavior of shear deficient of short concrete columns wrapped by ferrocement. The results demonstrated that ferrocement encasement increases both shear strength and ductility capacity. Moshiri et al [16], Juntanalikit [17], and Pham et al [18] wrapped RC columns by CFRP under different loading modes. Kumar and Patel [19] carried out an experimental investigation to study the behavior of plain cement concrete (PCC) circular columns retrofitted by stainless steel wire mesh. Belal et al [20] and Tarabia and Albakry [21] carried out laboratory programs and numerical analysis to investigate the behavior of R.C columns strengthened by steel jacket technique. Irshidat [22] studied the effectiveness of utilizing carbon fiber/epoxy composites in strengthening (RC) columns under axial loads. Hasan et al [23] presented an experimental study to investigate the efficacy of using NSM rebar and CFRP laminate in strengthening R.C columns subjected to cyclic loading. Punurai et al [24] carried out an experimental and numerical investigation on CFRP wrapped RC slender columns under both of axial load and biaxial bending.

2. Objective of the Research

In some cases the column having axial load acting in such a way that the load is eccentric about the both axes in the plane of the column, it is called biaxially loaded column. The main objective of the present work herein is to evaluate the effectiveness of using ferrocement overlays in strengthening biaxially loaded RC column. To fulfill this goal, 3-D finite element analysis will be suggested using ANSYS 14.5 [25] package to carry out parametric studies with respect to the main properties of the ferrocement strengthening.

3. Finite Element Analysis

3.1 Finite element modelling

The ANSYS 14.5 finite element package was utilized to study the efficiency of strengthening biaxially loaded R.C. columns with ferrocement jacket. Three types of elements are employed to simulate the models. The 3-D solid element (SOLID65) was used to model both the concrete and the ferrocement mortar. The element is defined by eight nodes having three degrees of freedom at each node. The element is capable of cracking and crushing. The internal reinforcement is modeled using 3-D spar element (LINK8), this element allows the elastic - plastic response of the reinforcing bars. The solid element (SOLID45) was used to model the wire-mesh laminates. This element is similar to the solid element SOLID 65 in its isoperimetric properties. The element plasticity, creep, stress stiffness, and large deflection capabilities. Table 1 shows martial properties for concrete, steel reinforcement, mortar, and wire mesh. Fig. 1 shows the geometry, node locations and the coordinate system for elements SOLID65.

3.2 Verification of the Numerical Analysis

In order to confirm the validity of the numerical model to perform the behavior of RC columns wrapped by ferrocement, verification of the finite element predictions with available experimental results has been verified. The analysis investigations were carried out on five R.C. columns in two phases as follows; Phase1; 3 R.C. columns with and without ferrocement jackets (C1, C2, and C2) tested experimentally under pure axial load by Sabea [26]. All specimens of size 1000 mm height and square cross section of 150 mm side, with main reinforcement 4 Φ10 mm and stirrups Ø 6 @ 160 mm. Phase 2; two R.C. columns (C4 and C5) subjected to the eccentric mode of loading examined by Kaish [11]. The columns with length 600 mm and cross section 100X100 mm, and the reinforcements of the column are 4 Φ8 as main reinforcements and Ø 5 @ 100 as link bars. The details of the verification specimens are shown in Fig. 2. A comparison between the predicted and the experimental results are given in Table 2. It can be seen from these results that the predicted values are in a good agreement with the experimental ones and the finite element modeling is quite accurate in representing the tested column specimens. Thus the ANSYS package can be used to extend the work for studying the behavior of biaxially loaded R.C. columns strengthened with ferrocement overlays.

3.3 Finite Element Modelling of Column Specimens

An extensive description of the finite element method of numerical modeling of RC columns has been carried out. A finite element model was developed to simulate the biaxially loaded RC columns wrapped by ferrocement. All specimens have 150 X150 mm in cross section and 1000 mm in height and were reinforced with 4Φ10 mm as longitudinal reinforcement and have 6 mm smooth bars as link bars. The concrete strength was considered as 30 MPa. Fig. 3 shows the details of tested column model. In all investigated models, a vertical displacement was incrementally imposed on the column. The magnitude of the displacement was applied at the upper quarter of the column to simulate biaxially loaded. The rigid plate was placed at the top of the column in the finite element models (as in the actual specimens). Element SOLID45 was used to model that rigid plates, with elastic modulus equal to 2,000,000 MPa and poisson's ratio of 0.3. Fig. 4 shows the loading and boundary conditions of the control column model.

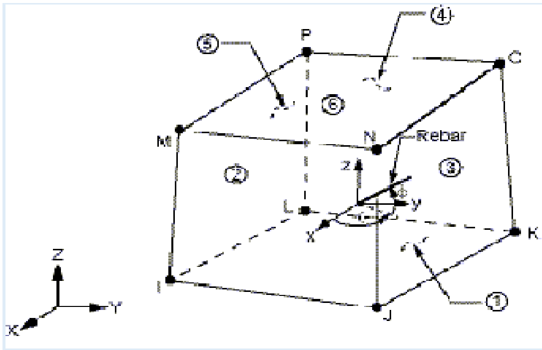
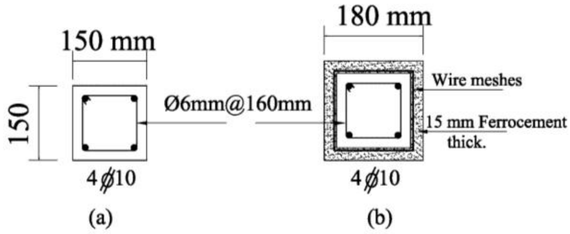


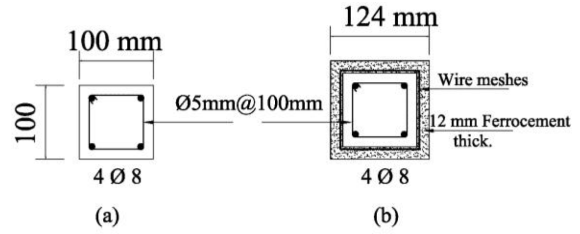
Fig -1: Node Locations and Coordinate System of SOLID65

Table -1: Material Properties and Input Data of Element Types

Material	Element type	Material properties	
Concrete	Solid 65	Elastic modulus (Ex)	22162 MPa
		Uniaxial crushing stress (fcu)	30 MPa
		Uniaxial tensile stress (ft)	3.15 MPa
		Poisson's ratio (υ)	0.20
		Shear coefficient for open shear (ßt)	0.3
		Shear coefficient for closed shear (ßc)	0.85
Longitudinal bars	Link 8	Elastic modulus (Ex)	200000 MPa
		Yield stress (fy)	446 MPa
		Poisson's ratio (υ)	0.30
Transverse bars	Link 8	Elastic modulus (Ex)	200000 MPa
		Yield stress (fy)	283 MPa
		Poisson's ratio (υ)	0.30
Mortar	Solid 65	Elastic modulus (Ex)	$4400\sqrt{fcu}$ MPa
		Uniaxial crushing stress (fcu)	40 and 60 MPa
		Uniaxial tensile stress (ft)	3.80 and 4.65 MPa
		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 45	longitudinal Elastic modulus	138000 MPa
		transverse Elastic modulus	85000 MPa
		Poisson's ratio (υ)	0.30
		Thickness	1.35 mm



Phase 1 by sabea [26]



Phase 2 by Kaish [11]

Fig -2: Column Specimen Details, (a) Non-Jacketed Column, and (b) Ferrocement Jacketed Column

Table -2: Comparison between Experimental and Numerical Results

Model	Fcu (MPa) concrete	Mode of Loading	No of wire mesh	fcu (MPa) Mortar	Ultimate Loads (kN)		EXp./Num.%
					Exp.	Num.	
C1	37	Concentric	----	----	612	582	105.2
C2	27	Concentric	1	42	813	832	97.7
C3	27	Concentric	3	42	880	900	97.8
C4	24.2	Eccentric	----	----	247	250	98.8
C5	24.2	Eccentric	1	37.2	323	336	96.2

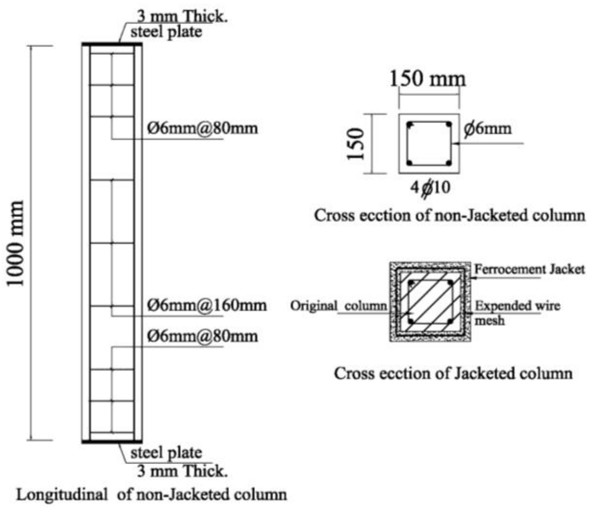


Fig -3: Dimensions and Reinforcement of the Column Model

4. Parametric Analysis

For the Parametric study, a total of twenty-five analytical models were constructed and analyzed. One un-confined column was kept as reference specimen and twenty-four confined specimens. The main varying parameters were the characteristic strength of the mortar layer, the thickness of mortar layer, and the number of ferrocement wire mesh. In this numerical analysis, four different thicknesses of the mortar layer, three different numbers of wire mesh, and two different types of mortar grade were considered. The studied parameters and classification of the investigated models are listed in Table 3.

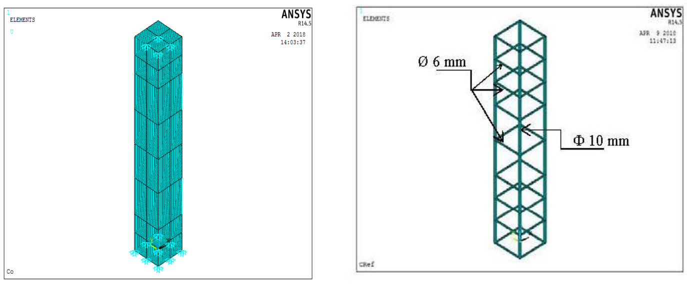


Fig -4: ANSYS Numerical Model

Table -2: Description of Numerical Models

Group	Model	Mortar Thickness (mm)	Number of Wire Mesh Layers	Characteristic Strength of Mortar (MPa)
Control	Co (Ref.)	-	-	-
Group 1	C1	15	1	40
	C2	20	1	40
	C3	25	1	40
	C4	30	1	40
Group 2	C5	15	2	40
	C6	20	2	40
	C7	25	2	40
	C8	30	2	40
Group 3	C9	15	3	40
	C10	20	3	40
	C11	25	3	40
	C12	30	3	40
Group 4	C13	15	1	60
	C14	20	1	60
	C15	25	1	60
	C16	30	1	60
Group 5	C17	15	2	60
	C18	20	2	60
	C19	25	2	60
	C20	30	2	60
Group 6	C21	15	3	60
	C22	20	3	60
	C23	25	3	60
	C24	30	3	60

5. Numerical Results and Discussion

The results obtained from numerical analysis of unwrapped and wrapped biaxially loaded RC columns are discussed in the following sections.

5.1 Ultimate load response and Initial Stiffness

The ultimate loads of the numerical models, as well as axial displacement and initial stiffness, are listed in Table 4. The initial stiffness was calculated from the slope of the tangent drawn to the load-displacement curve. Fig. 5 and 6 show a comparison of the gain percent in ultimate load capacities among different models. It can be observed that the wrapped specimens reported significant enhance in both ultimate loads and initial stiffness as compared to the reference column; such increase is about 136% and 103% respectively. This is due to the additional area of column section both ferrocement and reinforcing steels. This is primarily contributed to an improvement in biaxial loads resulting from ferrocement wrapping. The gain in ultimate load was found to increase with increasing both the ferrocement thickness and mortar strength. It can be demonstrated that volumetric ratio of ferrocement has a moderate influence on the efficiency of ferrocement jackets.

5.2 Biaxial load –displacement curve

Fig. 7 shows the relationships between biaxial loads and axial displacement for the proposed models of groups 1 to 6. It can be observed that the models showed in the analogous mode of failure. It is clearly shown from the load-displacement curves that both thickness and mortar strength is the vital factors affecting the performance of strengthened specimens. Numerical results showed that the suggested rehabilitation technique can increase the strength of columns with increasing mortar grade. In the uncracked stage represented by the first linear part of the load-displacement curves, the initial stiffness of all retrofitted specimens was higher than the one of the control specimen. Insignificant improve in initial stiffness was observed with increasing the number of wrapping rounds of wire mesh. The deformation capacity earlier than failure which shows the ductility of the column depends on ferrocement thickness, the strength of mortar. Increasing of ductility is caused by the efficient confinement of wire mesh and mortar cement composite.

5.3 Cracking patterns of numerical models

Fig. 8 shows a finite element cracking patterns of the numerical models. The numerical study showed that the unconfined column exhibits large deformations in concrete compared with the confined one. The cracked/crushed concrete elements were placed mainly near the head of the column. Generally, in all models, the cracks started at the elements adjacent to the column loading point and propagate with the increase of load.

Table -4: Numerical Results of the Strengthened Models

Group	Model	Ultimate load (kN)	Ultimate axial displacement (mm)	% Increment in ultimate load	Initial stiffness (kN/mm)	% Increase in initial stiffness
Control	Co (Ref.)	305	3.7	0.00	117	0.00
Group 1	C1	391	3.5	28.20	141	20.51
	C2	438	3.5	43.61	158	35.04
	C3	471	3.1	54.43	179	52.99
	C4	548	3.2	79.67	204	74.36
Group 2	C5	432	3.9	41.64	145	23.93
	C6	465	3.4	52.46	162	38.46
	C7	491	3.1	60.98	185	58.12
	C8	552	3.0	80.98	208	77.78
Group 3	C9	457	3.4	49.84	151	29.06
	C10	512	3.8	67.87	170	45.30
	C11	590	4.0	93.44	191	63.25
	C12	598	3.3	96.07	212	81.20
Group 4	C13	431	3.7	41.31	150	28.21
	C14	508	3.9	66.56	173	47.86
	C15	576	3.7	88.85	200	70.94
	C16	644	3.5	111.15	229	95.73
Group 5	C17	440	3.7	44.26	156	33.33
	C18	522	3.6	71.15	177	51.28
	C19	583	3.1	91.15	213	82.05
	C20	680	3.5	122.95	232	98.29
Group 6	C21	525	4.2	72.13	160	36.75
	C22	545	3.6	78.69	185	58.12
	C23	607	3.6	99.02	209	78.63
	C24	720	3.7	136.07	238	103.42

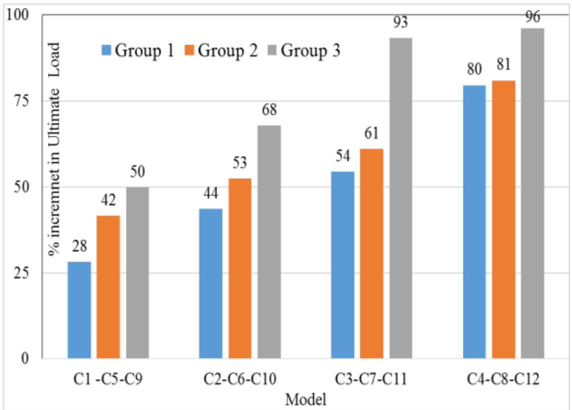


Fig -5: % Increase in ultimate loads for groups 1, 2, and 3

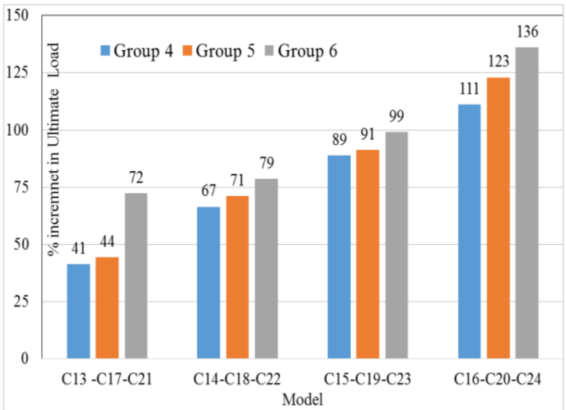


Fig -6: % Increase in ultimate loads for groups 4, 5, and 6

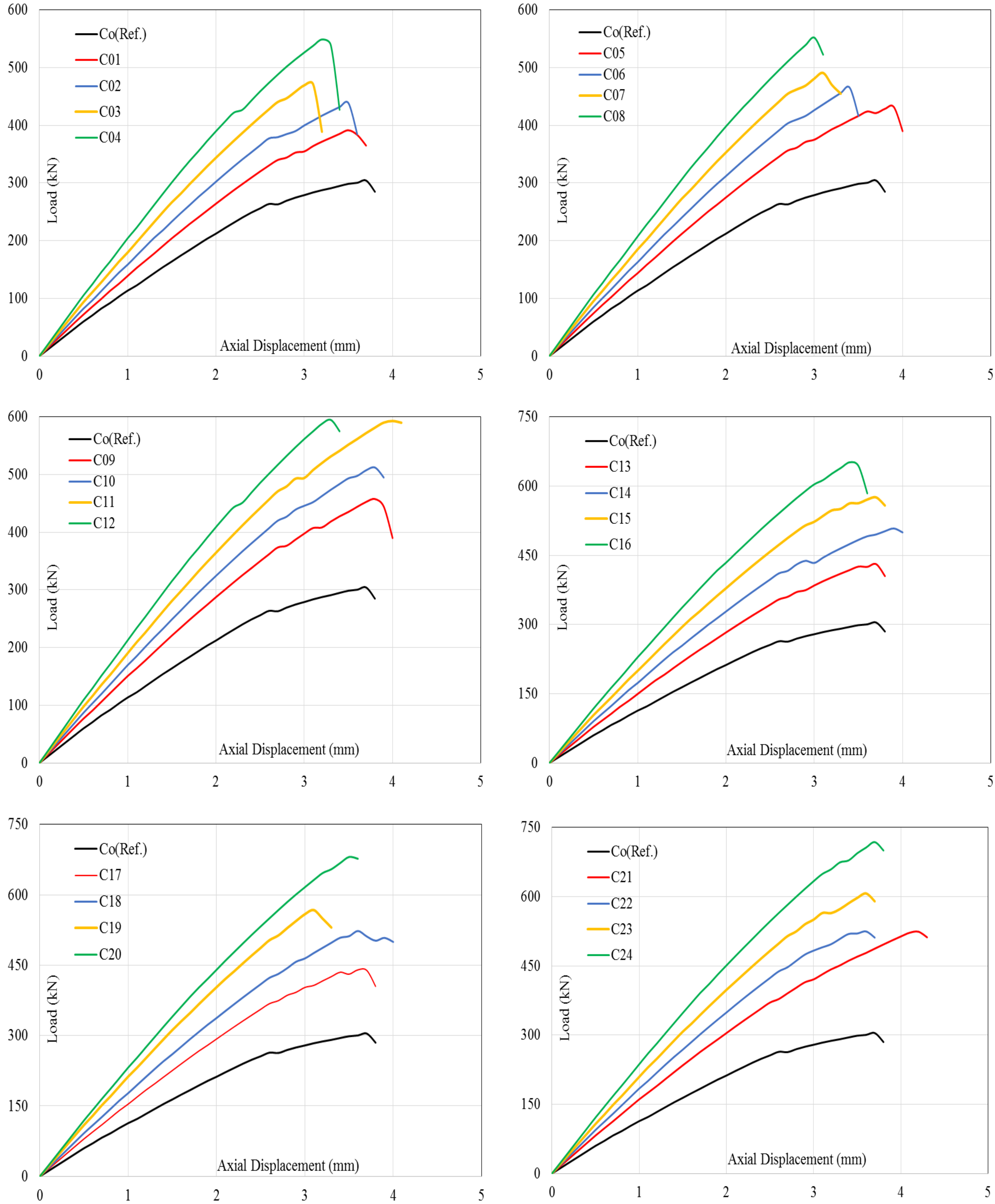


Fig -7: Load-Displacement Curves of Numerical Models

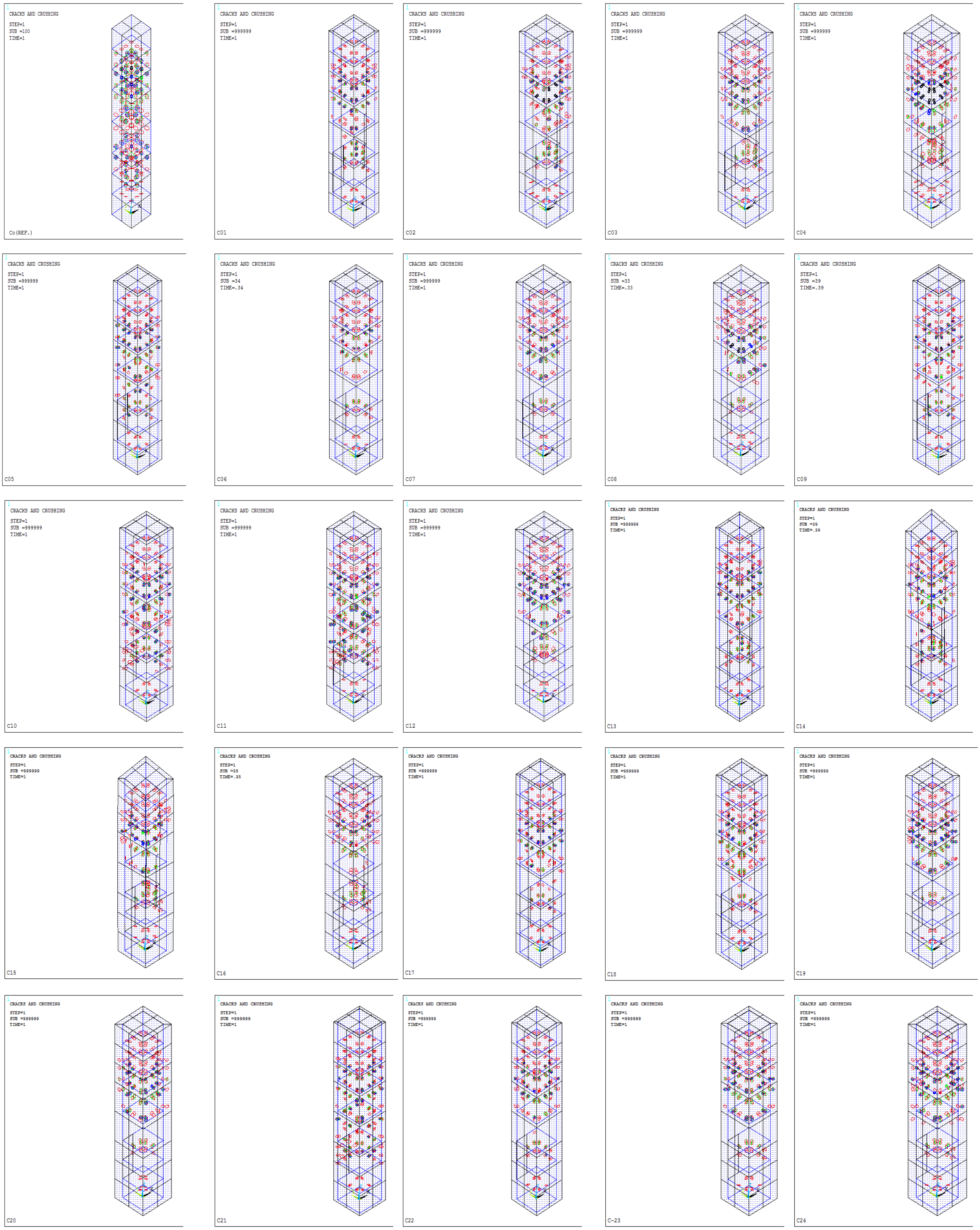


Fig -8: Cracking Patterns of Numerical Models

6. Conclusion

Ferrocement jackets were used as a strengthening technique for biaxially loaded R.C. columns. The efficiency of the proposed technique on the behavior of the columns was numerically investigated. The following conclusion was drawn based on the above results.

1. The technical characteristics of biaxially loaded R.C. columns ensure the efficiency of the rehabilitation using ferrocement jacketing.

2. Ferrocement jacketing can be used as an alternative technique for strengthening of RC columns economically as compared to steel jacket or carbon fiber polymer.

3. Specimen strengthened with high strength plastering mortar recorded a higher ultimate load and stiffness rather than that strengthened with normal plastering mortar.

4. The ferrocement thickness has a great influence on the amount of gain in load carrying capacity, and stiffness of strengthened columns.

5. The proposed numerical model gives acceptable results compared with the available experimental ones, thus it can be utilized effectively in the investigation of R.C. columns with the different biaxial mode of loading.

6. The better roughening surface of the column and the bond between the mortar and old concrete surface must be ensured to achieve the suitable strength of wrapped columns.

7. Wrapping columns with ferrocement jackets containing two layers of wire mesh encapsulated with 25 mm high mortar strength could be adopted in strengthening biaxially loaded columns.

REFERENCES

[1] ACI Committee 549. Guide for the design, construction and repair of ferrocement. American Concrete Institute, Re-approved; 1999.

[2] Hani H., N, Husam N. Experimental and analytical investigation of ferrocement–concrete composite beams. Cement & Concrete Composites, Vol. 26, 2004, pp. 787–796.

[3] Kondraivendhan B, Pradhan B. Effect of ferrocement confinement on behaviour of concrete. Construction and Building Materials, vol. 23(3), 2009, pp.1218–1222.

[4] Kubaisy AI M, Jumatt MZ. Crack control of reinforced concrete members using ferrocement tension zone layer. J Ferrocement, vol. 35, 2005, pp. 490–499.

[5] Paramasivam P, Lim CTE, Ong KCG. Ferrocement application in structural upgrading-an overview. J Structure Engineering ASCE, vol. 32, 2005, pp. 27–31.

[6] Fahmy E.H Shaheen Y.B and Korany Y.S. Repairing Reinforced Concrete Beams by Ferrocement. Journal of Ferrocement, vol. 27, 1997, pp. 19-32.

[7] Fahmy E.H Shaheen Y.B and Korany Y.S. Use of Ferrocement Laminates for Repairing Reinforced Concrete Slabs." Journal of Ferrocement. Vol. 27, 1997, pp. 219-232.

[8] Xiong GJ, Chen XH, Chen LQ, Yang JZ, Li GY. Hybrid modified ferrocement under sustained load in flowing sulphuric acid solution. Cement & Concrete Composites, vol. 26 (1), 2004, pp. 81–86

[9]Abdullah, and Takiguchi. An investigation into the behavior and strength of reinforced concrete columns strengthened with ferrocement jackets. Cement & Concrete Composites, vol. 25, 2003, pp. 233–242.

[10] Kaish, A.B.M., Jamil, M., Raman, S.N., and Zain, M.F.M. Axial behavior of ferrocement confined cylindrical concrete specimens with different sizes. Construction and Building Materials, vol. 78, 2015, pp. 50–59.

[11] Kaish, A. B. M., Alam, M.R., Jamil, M. and Wahed, M.A. Improved ferrocement jacketing for restrengthening of square RC short column. Construction and Building Materials, vol. 36, 2012, pp. 228–237.

[12] Mourad, S.M. and Shannag, M.J. Repair and strengthening of reinforced concrete square columns using ferrocement jackets. Cement & Concrete Composites, vol. 34, 2012, pp. 288–294.

[13] Xiong, G.J., Wu, X.Y., Li, F.F and Yan, Z. Load carrying capacity and ductility of circular concrete columns confined by ferrocement including steel bars. Construction and Building Materials, vol. 25, 2011, pp. 2263–2268.

[14] El-Kholy A. M., and Dahish, H.A. Improved confinement of reinforced concrete columns", Ain Shams Engineering Journal, vol. 7, 2015, pp. 717–728.

[15] Kazemi, M.T. and Morshed, R. Seismic shear strengthening of RC columns with ferrocement jacket. Cement & Concrete Composites, vol. 27, 2005, pp. 834–842.

[16] Moshiri, N., Hosseini, A., and Mostofinejad D. Strengthening of RC columns by longitudinal CFRP sheets: Effect of strengthening technique. Construction and Building Materials, vol. 79, 2015, pp. 318–325.

[17] Juntanalikit, P., irawattanasomkul, T., Pimanmas A. Experimental and numerical study of strengthening non-ductile RC columns with and without lap splice by Carbon Fiber Reinforced Polymer (CFRP) jacketing. Engineering Structure, vol. 125, 2016, pp. 400–418.

[18] Pham, T.M., Doan L.V. and Hadi M. N.S. Strengthening square reinforced concrete columns by circularisation and FRP confinement. Construction and Building Materials, vol. 49, 2013, pp. 490–499.

[19] Kumar, V., and Patel P.V. Strengthening of axially loaded circular concrete columns using stainless steel wire mesh (SSWM) – Experimental investigations. Construction and Building Materials, vol. 124, 2016, pp. 186–198.

[20] Belal, M.F., Mohamed H.M., and Morad S. "Behavior of reinforced concrete columns strengthened by steel jacket. HBRC Journal, vol. 11, 2015, pp. 201–212.

[21] Tarabia, A.M., and Albakry H.F. Strengthening of RC columns by steel angles and strips. Alexandria Engineering Journal, vol. 53, 2014, pp. 615–626.

[22] Irshidat, M.R.., Al-Saleh, M.H., and Al-Shoubaki M. Using carbon nanotubes to improve strengthening efficiency of carbon fiber/epoxy composites confined RC columns. Engineering Composite Structures, vol. 134, 2015, pp. 523–532.

[23] Hasan, Q.F., Tekeli H. and Demir F. NSM Rebar and CFRP laminate strengthening for RC columns subjected to cyclic loading. Construction and Building Materials, vol. 119, 2016, pp. 21–30.

[24] Punurai, W., Hsu, T., C., Punurai, S., Chen, J. Biaxially loaded RC slender columns strengthened by CFRP composite fabrics. Engineering Structures, vol. 46, 2013, pp. 311–321

[25] ANSYS, (2010). ANSYS User's Manual and Help Revision 14.5. USA.

[26] Sabea W. Strengthening of fire-exposed columns using ferrocement overlays. Master thesis (2011), Faculty of Engineering, Fayoum University, Egypt.

BIOGRAPHIES

Dr: Mahmoud Mohamed Elsayed is Assistant professor at the Department of Civil Engineering, Fayoum University, Egypt. His research interests are strengthening and repair R.C. structures and nonlinear analysis of reinforced concrete.

Assoc. Prof. Alaa Aly Elsayed is Associate professor at the Department of Civil Engineering, Fayoum University, Egypt. His research interests are repaired and rehabilitated structures, behavior of R.C. structures wit corroded bars.