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Finite Element Simulations for the Sustainable CFRP Retrofitted Hollow Square Columns

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ABSTRACT: This article describes the finite element analysis of concrete columns with a hollow square reinforced which restricted with a square Carbon-Fiber-Reinforced polymer (CFRP) tube. In this study, about sixteen square hollow core columns were investigated. These columns were classified into four sets. The set number one was the reference set which involved four unconfined reinforced columns with traditional steel helices and longitudinal steel bars. The columns of the 2nd category have a similar configuration as the set number one except that these columns were restricted outwardly by the CFRP tube. The columns of the set number were restricted outwardly by a CFRP tube and restricted inwardly by a steel tube. Finally, the columns of the 4th category do not have a steel reinforcement where they produced with only an outer CFRP tube and an inner steel tube. These columns were exposed to various loading conditions: concentric, eccentric (22 and 44) mm, and four bendings' points. It was investigated that the CFRP tube confinement faintly improved the columns' strength. Moreover, the use of a steel tube as inner confinement in the columns with a hollow section led to improve the structural performance and ductility.

KEYWORDS: Reinforced Concrete Column, Carbon-Fiber-Reinforced polymer CFRP, steel pipe

1 INSTRUCTIONS

In the last century, reinforced concrete (RC) was utilized widely over the world for construction (Z.S. Al-Khafaji and Falah 2020; Ali Abdulhussein Shubbar et al. n.d.). One of the most critical members is the column, which transfers loads from top member to bottom members and then to foundations [m1, m2]. Environmental impacts could lead to structural deterioration, which reduces the strength of the columns (Al-Khafaji et al., 2018; Al-Khafaji, Falah, et al., 2021). Despite the damaged column could be replaced with new structure, there are many techniques that could be applied to strengthen/retrofit the columns. In the last few decades, fiber-reinforced polymer (FRP) composite materials have been used commonly in repairing the damage of corroded structures. These materials are produced by a mixture of strong and stiff fibers in a polymer matrix (Hussain and Al-Khafaji 2021). These manufactured materials have high ratios for stiffness to weight, strength to weight, and have good resistance against environmentally and weathering conditions. The common approach is to utilized FRP composites to strengthen reinforced concrete structures. The utilization of FRP does not create greater stress concentration and has low maintenance for existing structures comparing with other repairing techniques. (ACI 2011) and ACI Committee 440 (*ACI*, 2017; Cromwell et al., 2011) observed that the strengthened structures with FRP have better durability in many environmental conditions compared with traditional ones. Also, the stiffness and flexural strength of reinforced beams with FRP are found to be enhanced (Esfahani, Kianoush, and Tajari 2007; Flexural Behaviour of Reinforced Concrete Beam with Hollow Core at Various Depth 2015). The shear strength of FRP reinforced structural members have been discovered to improve to a level where it practically works as an undamaged beam with improved resistance against cracking (Haddad, Al-Rousan, and Al-Sedyiri 2013; Mosallam and Banerjee 2007). Additionally, it has been found that the structural members reinforced with FRP including the joints of beam-column improve the seismic performance (Eslami and Ronagh 2013; Ozcan, Binici, and Ozcebe 2008; Pantelides, Okahashi, and Reaveley 2008).

Hollow concrete structures may be one option for optimizing the proportions of stiffness-mass and strength-mass, thus reducing the effect of weight on structures, which will ultimately minimize the total budget of the structure. For several new bridge piers using hollow structural elements have also been included (Abbas et al. n.d.; Hafedh, Hassan, and Falah 2020; Jabbar et al. 2021; Zhang et al. 2020). Previous literature demonstrated that hollow columns with a reasonable amount of transversal and longitudinal reinforcement; a sufficient concrete wall thickness; a small proportion between ultimate axial and axial load capacity; and a sufficient concrete strength have been found to conduct at flexural strength in a ductile manner (Al-Khafaji, et al., 2021; Yehia et al., 2022), similar to solid ones (Hsu and Liang 2003; G P Lignola et al. 2007; Gian Piero Lignola et al. 2007; Mo and Nien 2002; Pinto, Molina, and Tsionis 2003). Nevertheless, due to the unbalanced axial loading rate and a premature buckling of longitudinal reinforcement as a result of insufficient spacing of links or spirals, hollow RC columns may experience brittle mechanism. Consequently, in order to improve the cross-section performance of columns to conduct axial loads and minimize premature buckling of longitudinal reinforcement, external FRP confinement can be implemented on columns (M N S Hadi 2007; Muhammad N S Hadi 2006; G P Lignola et al. 2007; Gian Piero Lignola et al. 2007).

Recently, researches have shown that the improved structural performance of concrete-filled tube (CFT) systems including FRP confining tubes or steel, enhanced the gravitational and lateral load resisting system for the bridges, tall buildings, and pile footings (Fam and Rizkalla 2000; Xiao, He, and Choi 2005). The two usual kinds of CFTs that have been studied at both system and member levels are concrete-filled FRP tube (CFFT) and Concrete-filled steel tube (CFST) (Fam and Rizkalla 2000; Rousakis and Tourtouras 2014). According to (Dawood and ElGawady 2013; Fam and Rizkalla 2000; Naghibdehi, Sharbatdar, and Mastali 2014; Ozbakkaloglu 2013; Zaghi, Saiidi, and Mirmiran 2012) CFT systems represent noticeable properties in enhancing the structural performance and project constructability/ economy. Some studies (e.g., (H. Hu and Seracino 2014; Y. Hu 2011; Shirmohammadi, Esmaeily, and Kiaeipour 2015; Xiao, He, and Choi 2005)) have participated extra confinement supplied by FRP covers in the CFST system, in which the CFST is restricted by FRP jacket. The principle concern of many steel-concrete and reinforced concrete structures under harsh environmental conditions is durability (J.-Y. Wang and Yang 2012). (Kurt 1978) He reported that over $1 billion in the US is estimated to be spent on replacing and repairing of waterfront piling systems. This includes durability, the corrosion of steel tubes (Fam and Rizkalla 2000; Kurt 1978), brittle failure of FRP materials (J. Wang and Yang 2010), and potential long-term bond problems. (Kurt 1978; J.-Y. Wang and Yang 2012; J. Wang and Yang 2010) investigated the commercially available thermoplastic pipes for example, polyvinyl-chloride (PVC) pipes and high-density-polyethylene (HDPE) for enhancing the durability of reinforced structures.

Previous researches on CFPTs have been only partial to axial compression tests (Jiang, Ma, and Wu 2014). The materials of PVC representing noticeable mechanical characteristics in comparison to other normal olefin plastics purpose (Al-Baghdadi, Shubbar, and Al-Khafaji 2021; Zainab S Al-Khafaji, Majdi, Shubbar, Nasr, Al-Mamoori, Alkhayyat, et al. 2021; Al-Mamoori et al. 2021; Falah et al. 2021; Marshdi et al. 2021; A. Shubbar et al. 2021; A A Shubbar et al. 2022), illustrate a remarkable proportion of the cost to performance, particularly significant durability (Kurt 1978; J. Wang and Yang 2010). (Nowack, Otto, and Braun 1995) Investigated the soil-buried PVC pipes dug up after six decades of dynamic usage and showed that there is no deterioration and have an extra life expectation of five decades. The steel tube has only 0.45-0.6% thermal conductivity; this offers an unchanging condition of curing for the concrete core in order to satisfy high durability and performance (J. Wang and Yang 2010). Investigation on RC-filled-PVC tubes under severe environments showed that no deterioration in ductility and strength of reinforced concrete-filled PVC samples (Gupta and Verma 2014). The results of testing on reinforced concrete-filled PVC tubes mixed in saturated salty water for 180 days indicated that the chemical and microstructure of the PVC jacket remained approximately similar after subjecting to salty water (Gupta and Verma 2014). The enhanced durability of PVC material permits possible applications of this system for a varied range of structural systems subjected to the severe environment including the environments of saline and marine.

Lingala et al. (Gian Piero Lignola et al. 2008) carried out an analytical and experimental investigation on CFRP restricted concrete columns with a hollow square cross-section. From this study and under

eccentric and concentric loading conditions, it was observed that the ductility of columns is extremely improved and the strength is improved (Falah et al. 2020).
Hadi and Le (Hadi and Le 2014) carried out experimental research to study the behavior of hollow-core concrete columns covered by sheets of CFRP. These columns were covered by sheets of CFRP in three various combinations of covering orientations (0, 45, and 90 with respect to the circumferential direction). It was obtained that the ductility and strength of the concrete columns with the hollow section were improved for all covering configurations, but the increment in the strength was very low and the best ductility and strength results were found in the exclusively covered columns by sheets of CFRP in the direction of a hoop. The concrete columns with the hollow section can be restricted inwardly with a steel tube and could also be restricted outwardly with FRP to form a hybrid FRP-concrete-steel member. Teng et al. (Teng et al. 2007) found that the ductility and strength of FRP restricted hollow concrete columns could be increased by utilizing an inner steel tube.
Although, many studies have been conducted on the behavior of hollow columns, the research on the behavior of hollow square columns retrofitted by CFRP needs to be conducted further because the relevant research is insufficient. The aim of the paper is to provide a conceptual theoretical framework based on hollow concrete column with square cross-sectional area, which is not well common since most researches that related to confined column studies the columns with circular cross-sectional area. On the other hands, preparing columns experimentally required at between 28- 90 days preparing and testing the columns, therefore, this kind of research is considered time and money saver for both students and academics.

2 FINITE ELEMENT ANALYSIS (F.E.A)

In this article, a three-dimensional nonlinear numerical analysis has been utilized using the ANSYS platform to investigate the validation of the numerical modeling of the reinforced concrete columns, which reinforced with CFRP and steel pipe subjected to compression. Sixteen reinforced concrete columns of 182*182 mm cross-section, and 800 mm length were simulated and investigated in this study, Figure 1. These columns are divided into four groups and each group consisted of four columns with and without warping as shown in Figure 1. In this section, the description of element types used for all materials used in ANSYS models is presented. These materials are: concrete, steel reinforcement and carbon fiber reinforced polymer (CFRP).

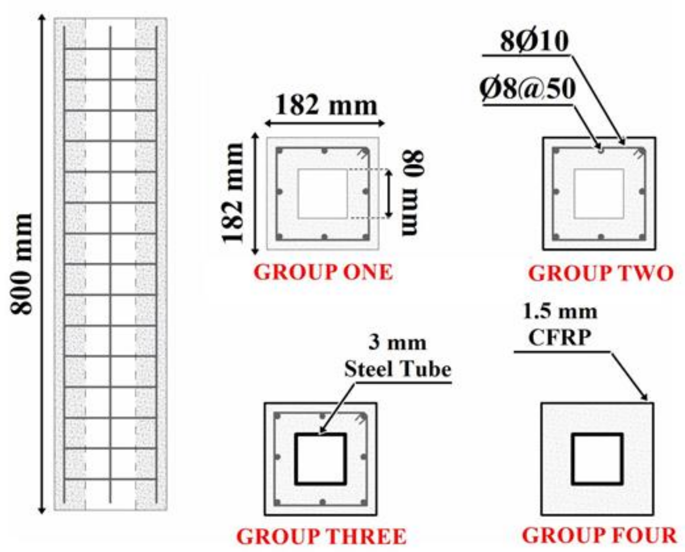
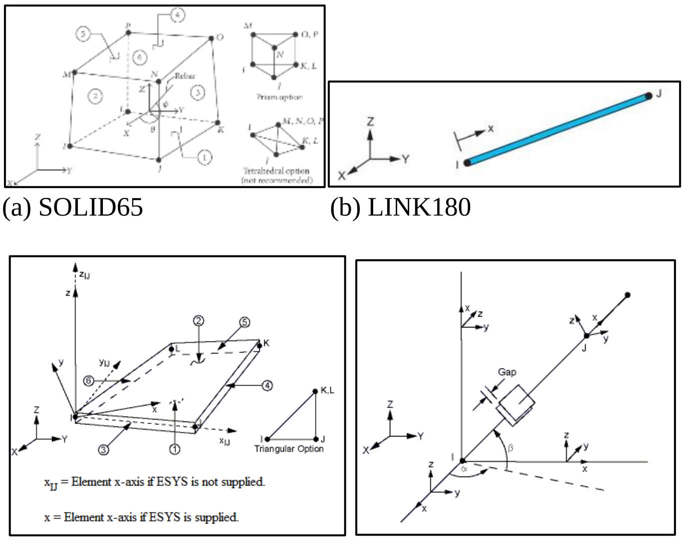


Figure 1 Details of columns

2.1 *Element type*

Numerous elements for simulating the behavior of CFRP-warped concrete members were applied. These components are commonly utilized in ANSYS, and past studies recommend them [1], [8-9], [12], [14-21]. A three-dimensional (3-D) SOLID65 element was adopted, see Figure 2 (a) and Table 1. This solid element has the capability of crushing in compression and cracking under tension. In addition, it incorporates steel reinforcing bars, which makes it ideal for RC modeling. The solid element has eight nodes; each of these nodes has three degrees of freedom from each direction. The element allows the treatment of nonlinear material properties. The concrete is capable of cracking (in three orthogonal directions), crushing, plastic deformation, and creep. To model the reinforcing bars, a 3-D element LINK180 was used, see Figure 2 (b) and Table 1. This spar is a uniaxial tension-compression element with two nodes and three freedom degrees at each node. The FRP sheet is represented by shell element SHELL41 (four nodes quadratic-order membrane) as shown in Figure 2 (c) and Table 1, this element have membrane (in-plane) stiffness but no bending (out-of-plane) stiffness with three freedom degrees in x,y and z-direction at each node. SOLID185 is used for modeling of steel pipe. It is defined by eight nodes having three freedom degrees at each node. The element has plasticity, hyperelasticity, stress stiffening, creep, large deflection, and large strain capabilities. Finally, the CONTAC52 element is assigned to the glue in the interfaces between concrete and CFRP warping. The element is capable of supporting only compression in the direction normal to the surfaces and shear (Coulomb friction) in the tangential direction. The element has three freedom degrees at each node as shown in Figure 2 (d) and Table 1.



(a) SOLID65 (b) LINK180

(c) SHELL41 (d) CONTAC52

Figure 2. Element types.

2.2 *Materials Models*

The materials of the structural elements used in the FE analysis in this study include concrete, steel reinforcing bars, CFRP, and steel pipe. The finite element models adopted have a number of parameters, which are summarized in Table 1. The Von Mises failure criterion was used to define concrete failure along with Willam and Warnke's constitutive model (Esfahani, Kianoush, and Tajari 2007; Falah et al. 2020; Hadi and Le 2014; Jiang, Ma, and Wu 2014; G P Lignola et al. 2007; Gian Piero Lignola et al. 2007), see Figure 3. For high strength concrete, the compressive uniaxial stress-strain relationship for concrete is described by a multi-linear isotropic stress-strain curve, Figure 4 (a), using the following expressions:

$$f_c = \varepsilon\, E_c \quad for \quad 0 \le \varepsilon \le \varepsilon_1$$

$$f_c = 0.6f'_c + \frac{0.4f'_c}{(\varepsilon_\circ - \varepsilon_1)}(\varepsilon - \varepsilon_1) \quad for \quad \varepsilon_1 \le \varepsilon \le \varepsilon_\circ$$

$$f_c = f'_c \quad for \quad \varepsilon_\circ \le \varepsilon \le \varepsilon_{cu}$$

where;

ε_1 =strain corresponding to $(0.6f'_c)$, defined by:-

$$\varepsilon_1 = \frac{0.6f'_c}{E_c} \quad \text{(Hooke's law)}$$

Valle and ***Büyüköztürk (1993)*** suggested peak strain ($\varepsilon_\circ$) for HSC as:-

$\varepsilon_\circ = 0.0025$

An elasto-plastic stress-strain relationship was considered for steel reinforcement, as shown Figure 4 (b). The modulus of elasticity of steel was considered to be 200,000 MPa (29,000 ksi), and Poisson's ratio was assumed to be 0.3.

CFRP composites is modeled using the orthotropic linear elastic model. The properties of the CFRP composites were considered the same in any direction perpendicular to the fibers. This means that the properties in the y direction were similar to that in the z direction. The Maximum strain failure criterion and maximum stress failure criterion were used, based on the longitudinal tensile strength and maximum strain of CFRP fabrics.

Table 1. Parameters of the columns' elements used in the FE Model

Material Type	Element Type	Characteristics
Concrete	Solid65	Compressive strength (fc')=36 MPa Poisson's ratio=2×10-1 Elasticity modulus =28200 MPa Ultimate strain=3 ×10-3 Tensile strength (ft'=18) Dilation angle= 36 Eccentricity= 0.1 k=0.667 fb0/fc0=1.16
Steel Reinforcement	Link180	Ø10, Ø8 Yield strength=560 MPa
CFRP	Shell41	Thickness=1.5mm Modulus of elasticity=165000 MPa Yielding strength (fy)= 2800
Steel pipe	Solid185	Elasticity modulus =200000 MPa Yielding strength (fy)= 460 MPa Poisson's ratio=3 ×10-1
Sikadur®-330 epoxy (glue) (Ghayyib et al. 2021)	Contac52	Tensile strength=30 MPa Tensile elastic modulus=4500 MPa Elongation=0.9% at 7-days.

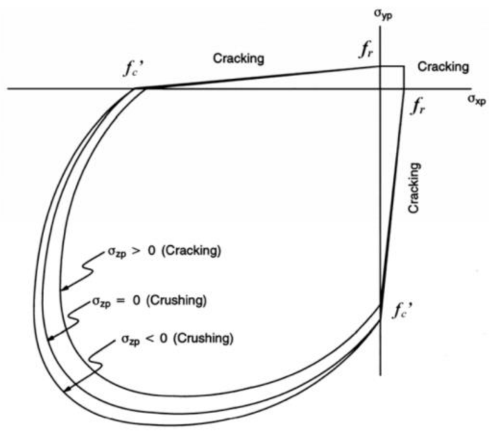


Figure 3. Von Mises failure criterion

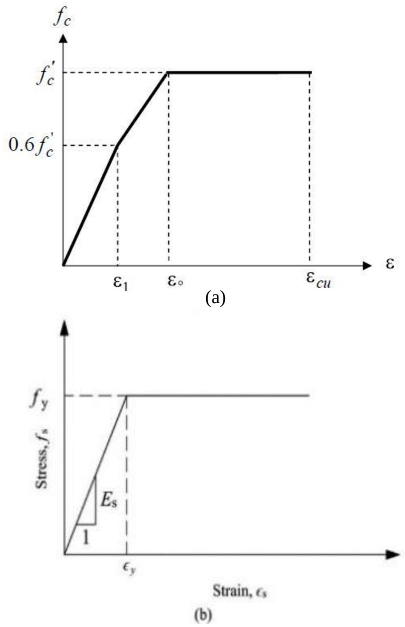


Figure 4. Stress-strain diagrams: (a) concrete, and (b) steel.

2.3 *Column Geometry and Meshing*

A total of sixteen RC columns made of HSC and NSC, having a height of 800 mm and an outer cross-section of 182x182 mm and inner cross-section of 80x80 mm were simulated and tested using ANSYS software. Short columns were designed to avoid additional bending moments due to slenderness. These columns were divided into 4 groups according to the parameters studied, see Table 2. The first group consists of 4 hollow square columns prepared by normal reinforced concrete with (8Ø10) as a main steel bars and (Ø8@50) secondary reinforcement. The second group consists of 4 hollow square columns with the same materials as group 1, but the columns in this group have 1.5 mm thickness of CFRP as an outer strengthening around for the whole column. The third group consists of 4 hollow square columns with the same materials as group 1, but the columns in this group have 1.5 mm thickness of CFRP as an outer strengthening around for the whole column, in addition to 3 mm thickness steel tube as internal strengthening for the column. The fourth group consists of 4 hollow square columns with the same materials as group 1, but the columns in this group, prepared without steel bars and have 1.5 mm thickness of CFRP as an outer strengthening around for the whole column, in addition to 3 mm thickness steel tube as internal strengthening for the column.

The proper meshing can be selected when the deflection did no increase or increased slightly. However there is no specific mesh size for the selected sample, which is depending on the places of reinforcement, cover of concrete and supporting zone.

To obtain good results, a rectangular mesh is recommended by (3-28) and (3-3). Therefore, the mesh is set up such that square or rectangular elements are to be created. Steel loading and supporting plates were meshed as solid elements in such a way that its nodes were oriented with adjacent concrete solid elements. In the finite element modeling, mesh density is considered as an effective parameter to obtain better results accuracy with economical computation time. In this study, an appropriate mesh density was selected, when any increase in the mesh density became ineffective on the results accuracy. The overall mesh of the concrete column model is shown in Figure 5.

Four loading scenarios were adopted in this research as shown in Figure 6, which were concentric loading load, eccentric loading with an eccentricity (e) of 22 mm, eccentric loading with an eccentricity (e) of 22 mm, and four-point bending.

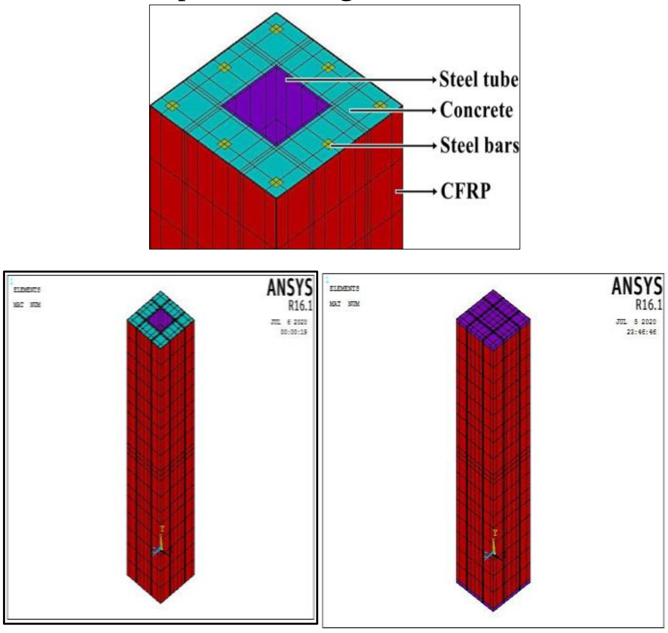


Figure 5. The overall mesh of the concrete column model.

2.4 *Model validation*

The validation is conducted to quantitatively identify the compatibility between the model's expectations, and the material environment described by experimental observations. In this part, to analyze the impact of load eccentricity on the hollow square columns, the theoretical model built in this study is compared with the measured columns in investigation (Hadi and Le 2014; Kusumawardaningsih and Hadi 2010). As well as investigate the other strengthening cases, the author suggested some cases related to the use of steel plate in addition to using CRFP (G P Lignola et al. 2007). Details of columns configuration are shown in Table 2. Figures 6 and 7 show the experimental and numerical predicted models.

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Table 2. Details of columns configuration.

Group name		Outer cross-section (mm)	Inner Cross-section (mm)	CFRP warping	Inner steel tube	Steel reinforcement	Loading condition
Group one	A1	182x182	80x80	Without	Without	8Ø10 main reinforcement and Ø8@50 secondary	Central load
	A2						Eccentricity = 22mm
	A3						Eccentricity = 44 mm
	A4						Four point bending
Group two	B1	182x182	80x80	CFRP =1.5 mm thickness	Without	8Ø10 main reinforcement and Ø8@50 secondary reinforcement	Central load
	B2						Eccentricity = 22mm
	B3						Eccentricity = 44 mm
	B4						Four point bending
Group three	C1	182x182	80x80	CFRP =1.5 mm thickness	3 mm steel tube	8Ø10 main reinforcement and Ø8@50 secondary reinforcement	Central load
	C2						Eccentricity = 22mm
	C3						Eccentricity = 44 mm
	C4						Four point bending
Group four	D1	182x182	80x80	CFRP =1.5 mm thickness	3 mm steel tube	Without	Central load
	D2						Eccentricity = 22mm
	D3						Eccentricity = 44 mm
	D4						Four point bending

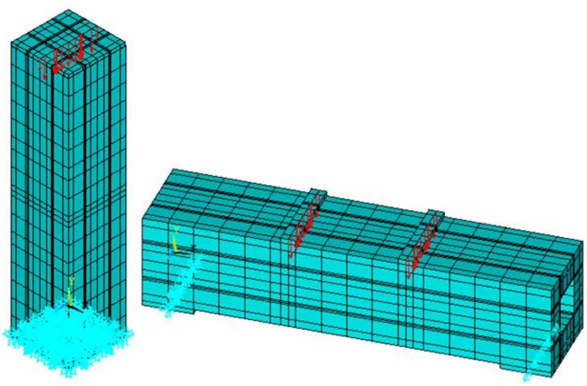

Figure 6. Geometry of the numerical model for columns.

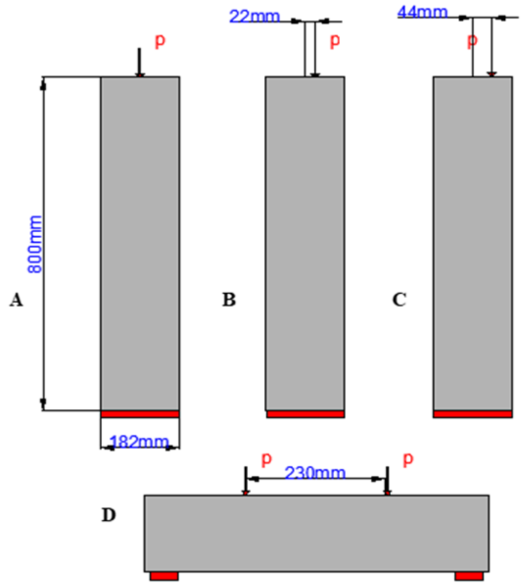

Figure 7. Typical setup of the loading tests, A) central load, B) Eccentricity= 22mm, C) Eccentricity= 44mm and D) Two-point load.

2.5 *Finite Element Idealization*

A finite element analysis needs to produce a meshing of the model. In other words, the model is dividing into many small elements. Loading, Meshing, and boundary conditions for beams are shown in Figures (5, 6 and 7).

3 RESULTS AND DISCUSSIONS

In this section, the results obtained from ANSYS are displayed for 16 columns divided according to strengthen in four groups. Because there has been no experimental program for this research to compare the results with, the effectiveness of the simulated models was verified through another research that contains experimental results as demonstrated in Figure (8) (Kusumawardaningsih and Hadi 2010). The comparison has shown that the FE models have accurately verified with experimental results. The load-deflection curves are demonstrated in Figure (9) and Table 3. Table 3, shows the differences between the ultimate load and the deflection for numerical and experimental work, and these differences appear as result of conditions of experimental works, which is not perfect in all cases such as the during the curing period the ideal temperature should be 25 degree centigrade, but in the real case may be higher to lower. As well as the compaction of concrete after mixing not well distributed for the pervious reasons the numerical show better results than experimental works.

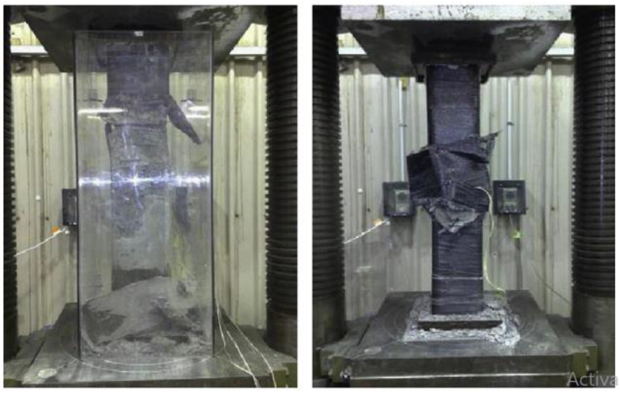

Figure 8. Comparative behavior of hollow square columns confined with CFRP.

3.1 *Designations*

CF: Carbon Fiber
A: refers to fc`=29.5 MPa
6, 8: Eccentricity (mm)

Table 3. Comparison between experimental and numerical ultimate load and deflection

Beam	Ultimate load (kN)			Deflection (mm)		
	Experimental	Numerical	Percentage Difference %	Experimental	Numerical	Percentage Difference %
CF6A	190	206	8.4	7.2	5.9	18
CF8A	125	133	6.4	7.5	6	20

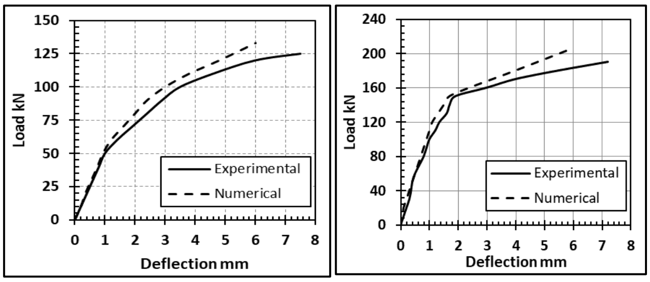

Figure 9. The relationship of Deflection-Load for a column (CF8A)

The figures and tables that previously presented give a comparative indication between numerical and experimental results related to deflection and load relationship. In general, this comparison demonstrates that the numerical models are stiffer than the experimental one. As well as the numerical analyses give a lower deflection and higher ultimate load. The following reasons might cause these variances:

- The numerical models assume that the concrete is fully homogeneous, but in reality, the producing of concrete is affecting by many conditions, so the concrete samples of the experiment are not perfectly homogeneous
- The compressive strength of the tested concrete cubes might not show the actual compressive strength.
- Meshing size can influence the structural response

3.2 *First Crack and Ultimate load*

The effect of CFRP layers on the Ultimate load behavior of hollow concrete column with a square sectional area under axial load has been observed by using the line graph presented in Figure 10 which clearly shows that the application of CFRP materials to the un-reinforcement and reinforcement concrete columns with Hollow Square cross-sectional is capable of increasing their strength. In condition of applying an axial load on the center of column samples, axial strength gain increases with using CFRP layer (Figure 10, and Figure 11). In sample B1 using of CRFP lead to increase both first crack load and ultimate load comparison with A1 sample, also strengthening the hollow part of columns by steel plate increased the first crack resistance and huge increment in the ultimate load as shown in sample C1. While in un-reinforcement sample with application of CFRP sheet externally and steel plate internally (D1) has a considerable increasing in both first crack load and ultimate load comparison with A1 sample.
On the other hand, applying an axial load on different eccentricity (22 and 44) mm from reinforcement concrete column samples center decrease both first crack and ultimate load for samples (A2 and A3) comparison with sample A1 with central load. The first crack load was (54.2 and 58) kN and ultimate load (245and 236) kN for samples (A2 and A3), respectively. However, the applying of either CRFP sheet alone as in group two or applying CRFP sheet with steel plate as in group three was led to decrease the effect of changing in load eccentricity. While in group four the changing in eccentricity in samples (D2 and D3) lead to decrease both first crack and ultimate load comparison with sample D1, which same behavior as group one sample, but with higher values.
The changing in the loading condition from one point load to two points load in samples (A4, B4, C4 and D4) cause a decrease in both first crack load and ultimate load comparison with samples (A1, B1, C1 and D1). From Table 4, it is well demonstrated that the changing in columns strengthening condition such

as using steel bars or not, using CFRP sheet alone or using both CFRP sheet and steel plate in reinforced concrete, and using both CFRP sheet and steel plate in unreinforced concrete have the same behavior in two points load condition.

3.3 *Deflection*

The deflection of columns under axial load is usually happened with increasing the applied load. Figure 10 and 11 demonstrate the axial load–deflection of hollow columns with and without CFRP confinement. Depending on Figure 10 and 8, hollow columns confined with CFRP sustained higher ultimate load and greater axial deflection compared to those without confinement. Columns confined with CFRP had more capability to sustain repeated large loadings (demonstrating an increased ductility) before they reached their ultimate load. After that, they would experience significant decreases in their ultimate load. These behaviours caused by the debonding between the layers of CFRP confinement and hollow columns, resulting in the rupture and failure of the CFRP and concrete composites. Whenever the column is subjected to deformation due to axial loading, the external bonding of CFRP strips provides sufficient restraining effect against elastic deformation and also delayed the local buckling and as a result, the ultimate strength capacity is increased. Application of CFRP causes an increase in effective thickness which reduces the width-to-thickness ratio of cross-sectional elements. This decrease in the slenderness of cross-sectional elements actually results in a delayed local buckling which ultimately enhances overall buckling strength of columns. Meanwhile, applying of steel plate around the hollow square sides increase the ultimate load as well as increase the deflection value before failure for both reinforced and un-reinforced columns.
Eight samples were tested under eccentric load two for each group, four of them with a 22 mm eccentric load and the other four with a 44 mm eccentric load. Figure 11 (b) demonstrates the deflection against the applied load of the samples tested under 22 mm eccentric load, all these columns failed in under lower compression load comparison with same columns tested under central load. As well as it could be observed that by applying CFRP, CFRP, and steel plate in strengthening hollow square columns increase the deflection with increasing the applied load. Four samples were tested under load eccentricity 44 mm. Figure 11 (c) illustrates the load-deflection curves of the tested samples, the deflection of samples with 44 mm characterized by increasing the deflection higher than the same samples with 22 mm eccentricity with decrease the ultimate load. It was observed that applying CFRP a column can withstand a higher load than an unconfined reinforced and un-reinforced concrete column, and the use of steel plate results in greater deflection as shown in the samples of groups (three and four).
And finally, samples with two-point load have the lowest deflection along with decreasing the ultimate load, where the increasing in the deflection against the applied was increased rapidly until failure as shown in Figure (11 c) this behavior regardless the strengthening condition with steel bar or without, with CRFP or with both CRFP and steel plate. From tested the eight eccentric loaded samples, it is seen clearly that applying CFRP the load has increased and applying steel plate the ductility of the specimen has also increased.

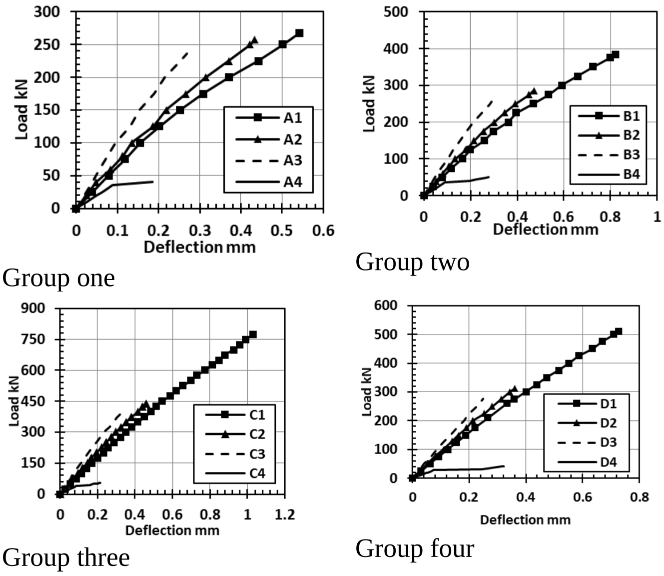

Figure 10. Load-deflection curve for each group.

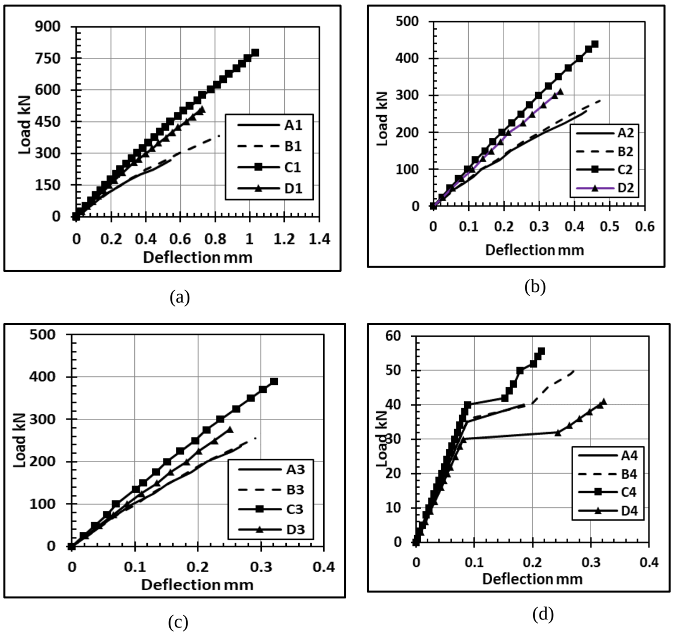

Figure 11. The effect of a typical setup of loading test

Table 4. Result for all columns (First Crack, Ultimate Load and Deflection)

Group name		First Crack (kN)	Ultimate Load (kN)	Ultimate Load Percentage%	Deflection (mm)	Deflection Percentage%
Group one	A1	75	276.5	------	0.463	------
	A2	54.2	245	-11.4	0.713	54.00
	A3	58	236	-14.6	1.148	147.95
	A4	22	40	-85.5	0.217	-53.13
Group two	B1	76	383.9	38.8	0.82	77.11
	B2	60	285	3.1	0.83	79.27
	B3	50	255	-7.8	1.23	165.66
	B4	25	51	-81.6	0.33	-28.73
Group three	C1	100	774.9	180.3	1.032	122.89
	C2	80	438.8	58.7	1.102	138.01
	C3	62	389.2	40.8	1.8	288.77
	C4	30	55.5	-80	0.247	-46.65
Group four	D1	100	510.6	84.7	0.726	56.80
	D2	80	311.8	12.8	0.97	109.50
	D3	61	276.8	0.1	1.65	256.37
	D4	23	41	-85.2	0.4	-13.61

3.4 *Influencing Parameters*

The influence of each parameter, in the present study, on the columns' behavior is studied. The results are presented in Figure 11 and discussed.

3.5 *Crack Propagation:*

The ANSYS program has the capability to record the propagation of crack at every applied load step. Where the patterns of cracks which have been gotten from the finite element analysis by using the Crack/Crushing plot option, as shown in Figure 12.

3.6 *Stress and modes of failure:*

In the axial column vertical deflection is more at the free end where load is applied as shown in Figure13. As eccentricity increases the maximum value shifted towards the eccentricity and also the maximum value increases because of the bending effect. As eccentricity increases the horizontal deflection increases as shown in (A2, B2, C2 & D2) samples. Tension increases at the opposite side of the eccentricity. Also Figure13 shows that increasing the eccentricity from 22 mm to 44mm the free side of the column samples failed at lower load than 22mm eccentricity or centrically load, the same behavior happened for all selected samples regardless the strengthening condition that selected. While the failure mode was shown in Figure 14.

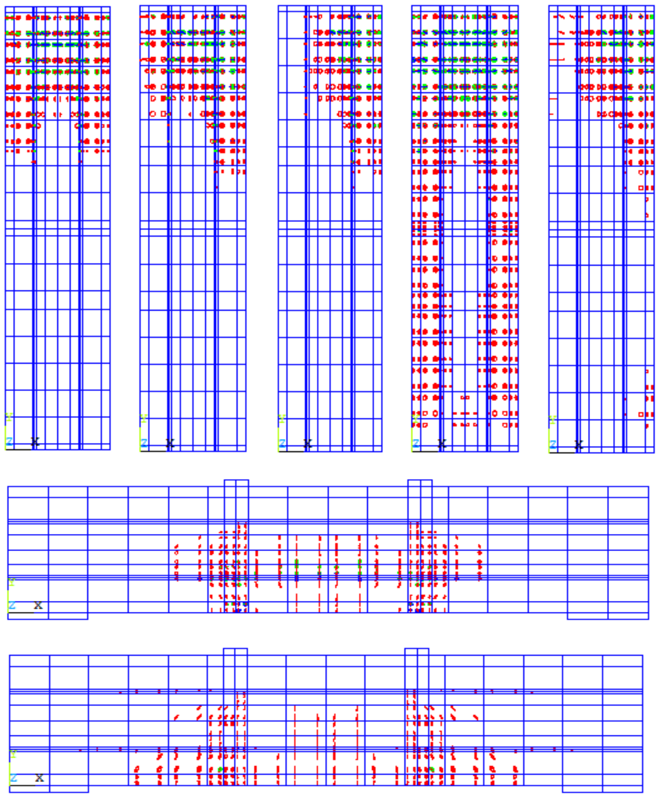

Figure 12. Crack propagation at ultimate load in the columns.

3.7

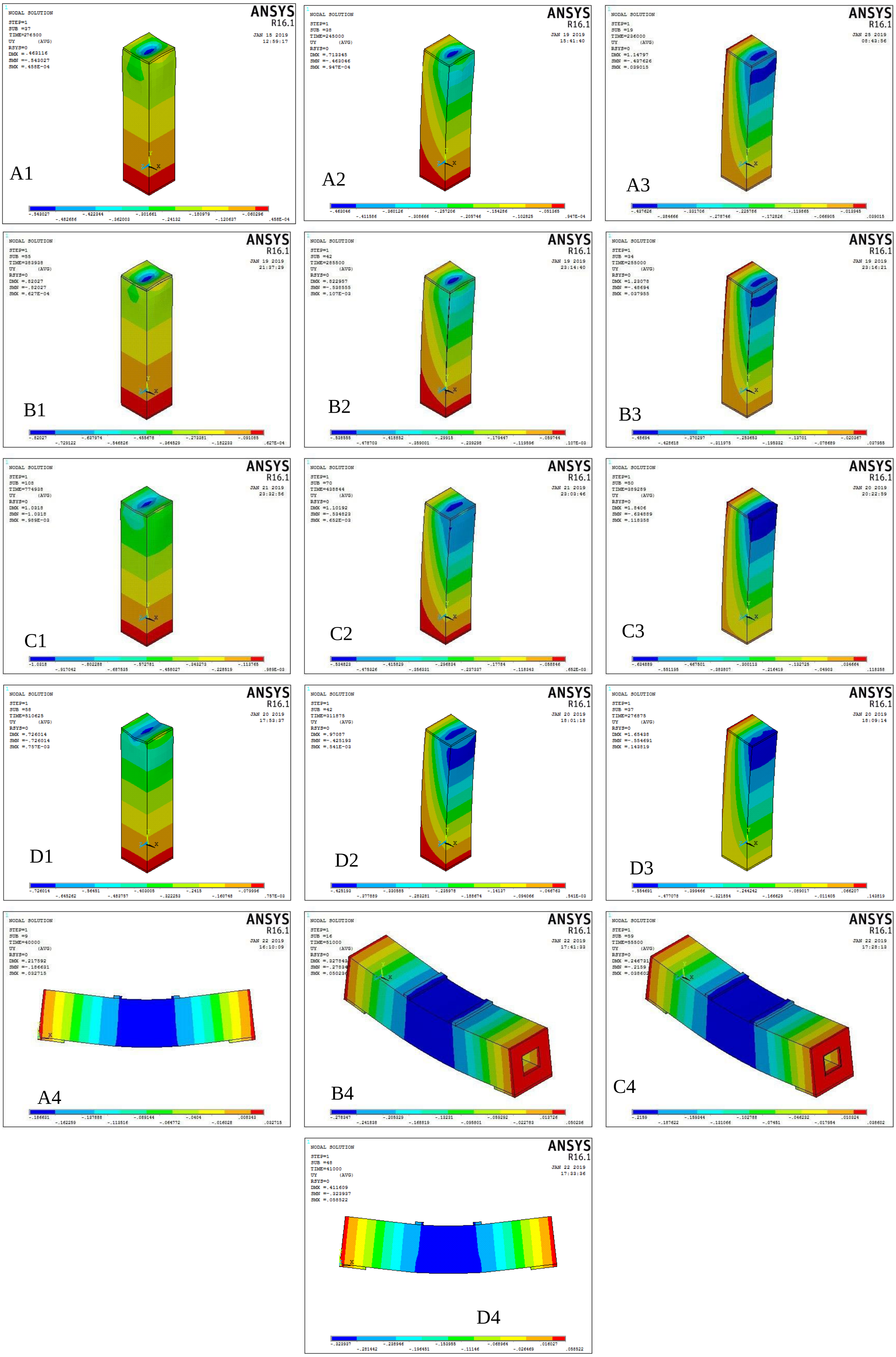

Figure 13. stress at ultimate load in the columns.

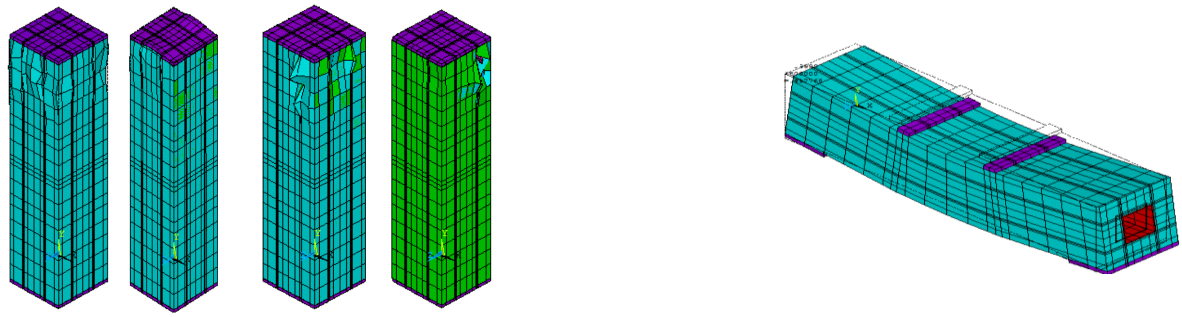

Figure 14. Failure's mode in the columns.

4 CONCLUSIONS

- CFRP strengthened the columns from outside, CFRP from outside and steel pipe from inner and strengthen columns without any reinforced that improved behaviour is observed with control columns.
- The increase in ultimate load when strengthened columns by CFRP by (38.8%), strengthened columns by CFRP and steel pipe by (180%) and when strengthened columns by CFRP and steel pipe by (84.7%) without any reinforced.
- The decrease in ultimate load when the applied load at four-point (bending) when compared with control column and increase in ultimate load when strengthened columns by CFRP by (27.5%) and (38.75%) when strengthened columns by CFRP and steel pipe when compared with a column without any strengthen.

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