ANALYTICAL MODELING OF ECCENTRICALLY LOADED RC COLUMNS CONFINEDWITH FRP

Nabil M. A. Hussian
(Ph.D)
College of Engineering
Al-Nahrain University
E-mail\\ abilali75@yahoo.com

Ali M. Lafta
(M.Sc)
College of Engineering
Al.Muthanna university
E-mail\\ alicivel@yahoo.com

ABSTRACT

This paper presents an analytical research on behavior of columns confined with FRP subjected to axial load and uniaxial bending moment, by using finite element method and ANSYS-14.To indicate the accuracy of this program, five reinforced concrete columns strengthened with carbon fibers from the experimental testing of previous researches are re-analyzed by ANSYS program.The results showed that the percentage of experimental ultimate load to analytical ultimate load are (99.4, 99.6, 99.8, 97.5 and 97.2) %,and there is a reasonable agreement between the load-deflection curves for experimental and analytical results for all studied columns. The effects of important parameters on the ultimate load and the ductility of the column are studied.The results showed that the ultimate load and the ductility areincreased by 60.3% and 118.8% as the compressive strength increased from 22 MPa to 40Mpa.The study shows, that the increasing in CFRP layers lead to increasing in the ultimate load and the ductility of the column, The maximum increasing in the ultimate load and ductility for the column are 78% and 69.4% respectively.The results showed that ,the ultimate load and the ductility are increased by 24.1% and 23% respectively when the percentage of steel area is increased from 1% to 4%.Finally, loads with several eccentricities from the center of the column are studied, the results show a significant reduced value in the ultimate load for confined column by 51% at load eccentricity value equal to 125mm.While the column ductility reduced to 42% for the same load eccentricity.

Keywords :column, CFRP, strengthen, eccentrically load, FEF, ANSYS-14

نمذجة تحليل الاعمده الخرسانية المسلحة المحملة لا مركزيا والمقواه بألياف البوليمر

الخلاصة

يقدم هذا البحث دراسة نظرية لسلوك الاعمدة المقواة بألياف الكاربون ومعرضه لحمل مركزي وعزم انحناء احادي المحور، وباستخدام طريقة العناصر المحددة,تم استخدام برنامج ANSYS-14 ليحاكي تصرف سلوك الاعمدة ، لبيان دقة البرنامج تم التحليل العددي لخمسة اعمدة من الفحوص المختبرية لبحوث سابقة حيث بلغ نسبة الحمل الاقصى المختبري الى الحمل الاقصى المستخرج من التحليل هو (99.4، 99.6، 99.8، 97.5، 97.2) % مع توافق معقول لمنحني العلاقة بين القوة والتشوه بين الفحص المختبري والتحليلي لجميع الاعمدة المدروسة, تم دراسة تأثير العوامل المهمة للأعمدة الخرسانية. وجد ان هناك زيادة في قوة التحمل للعمود ومطيليته بنسبة 60.3% و 118.8 % على التوالي عند زيادة مقاومة الانضغاط من 22 الى 40 نيوتن/مم2. ويستنتج ايضاً ان زيادة عدد طبقات الـ (CFRP) تؤدي ايضا الى زيادة

*Received at 2 / 4 / 2014 *Accepted at 28 /5 /2014

مقاومة العمود القصوى ومطيليته ، حيث وجد ان اعلى مقاومة قصوى ومطيلية مستحصلة للعمود كانت بنسبة 78% و69.4%على التوالي. أظهرت النتائج ان المقاومة القصوى للعمود ومطيليتهازدادت بنسبة 24.1% و23 % على التوالي عند زيادة نسبة مساحة حديد التسليح من 1% الى 4%.اخيرا تمت دراسة تأثير عدة قيم للامركزية الحمل، أظهرت النتائج انخفاض المقاومة القصوى للأعمدة بنسبة 51%عند انحراف مقداره 125 مم بينما انخفضت المطيلية بنسبة 42% .

Introduction

Eccentric loads are common for columns in buildings with other types of structures. Columns that are in the border of buildings, especially corner columns and columns near opening are usually subject to a combination of axial load and bending moment, thus creating an equivalent eccentric load.Two types to confine the column,External confining by using FRP composite sheets or jacket and internal confiningwith steel spiral, The confining causes three-axial state of stress in cross-section of compressed members and reduces the increase of transverse strains.Fundamental difference between members confined with internal and external confinement is that in case external confining the whole cross-section is strengthened and composite material works elastically till failure, whereas in case of the internal confinement only the core of cross-section work elasticity and the concrete in cover failure before core concrete[1].

Finite Element Formulation

In the present study, powerful nonlinear three-dimensional finite element analysis software ANSYS-14is used for analysis of RC columns strengthened with CFRP composites and subjected to axial load and uniaxial bending moment.
In the present research, the nonlinear finite element analysis is carried out using solid65 brick elements to represent the concrete,LINK180 3-D spar element to model the reinforcing steel, SHELL181 quadratic-order membrane shell to model CFRP. Stresses and strains are observed at the integration points. Cracking, yielding and crushing patterns are thus determined from the stress and strain values at these points.

Material Representation

In the present research work, the finite element method has been used as a general method of stress and deformation analysis. The finite element method is usually used to find approximate solutions for structures having complicated shapes and loading arrangement.

1.Concrete Brick Element

The concrete is represented by SOLID65 isoparametric brick element as shown in Fig. (1).The most important aspect of this element is the treatment of nonlinear material properties in three dimensional with or without reinforcing bars (rebar).The element is defined by eight nodes having three degrees of freedom at each node, translations in the nodal x, y, and z directions. This solid element is capable of cracking (in three orthogonal directions), crushing, plastic deformation, and creep [2].

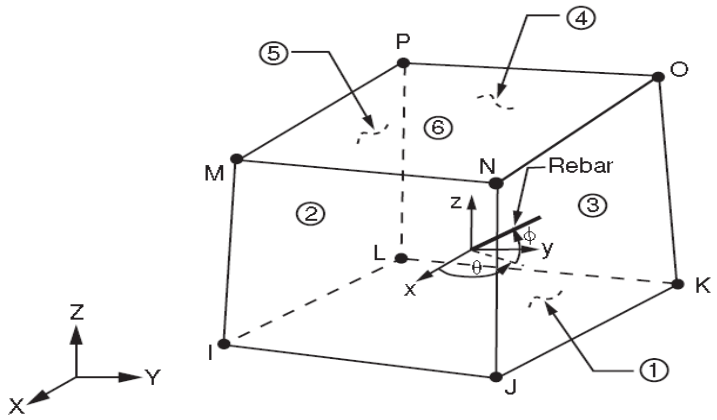

Fig. (1): Brick element with 8-nodes SOLID65[2].

2. Reinforcement Representation

Analysis of reinforced concrete structures using the finite element method requires a simple, yet accurate way of representing the reinforcement. Three alternative representations have been usually used to simulate the reinforcement in this type of analysis, which are [3]:

i) Embedded reinforcement.

ii) Smeared reinforcement.

iii) Discrete reinforcement.

In the present study, the discrete representation is used for the analyses carried out in the work.LINK180 which has been used to model the reinforcement is a bar (or truss) element which may be used in a variety of engineering applications. This 3-D spar element is a uniaxial tension-compression element with three degrees of freedom at each node, as shown in Fig. (2) [2].

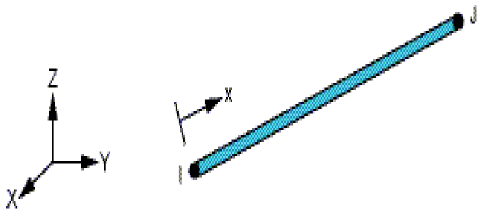

Fig (2): LINK180 – 3-D spar [2].

3. CFRP Reinforcement Representation

The 4-node quadratic-order membrane shell element (SHELL181) shown in Fig. (3) is used in the present work to model the CFRP. This element has six degrees of freedom at each node: translations in the x, y, and z directions, and rotations about the x, y, and z-axes. (If the membrane option is used, the element has translational degrees of freedom only), in this study the membrane option is used [2].

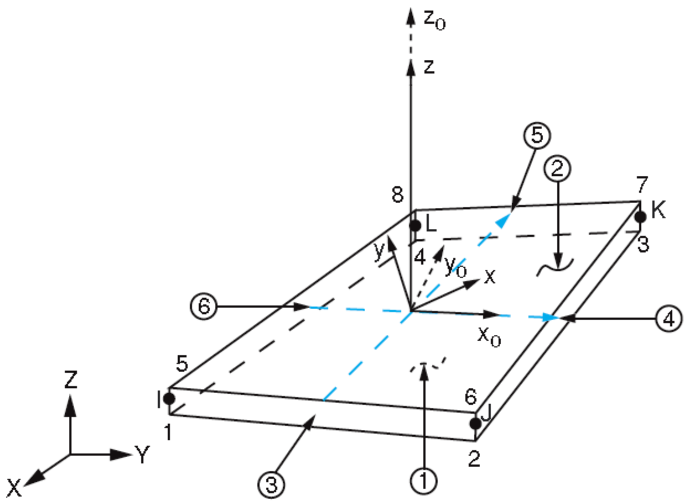

Fig. (3): SHELL181element [2].

The command Shell Section is used to represent the CFRP layer thickness, fibers orientation, numbers of layers and nodes section offset while, the command merge nodes is used to merge the shared nodes between the concrete and the CFRP layers and made the tying between them as a perfect bond.

4. Steel Plate Representation

SOLID45 is used for the 3-D modeling of solid structures, the element shown in Fig. (4) is defined by eight nodes having three degrees of freedom at each node; translations in the nodal x, y, and z directions. This element was used to model the steel plate [2].

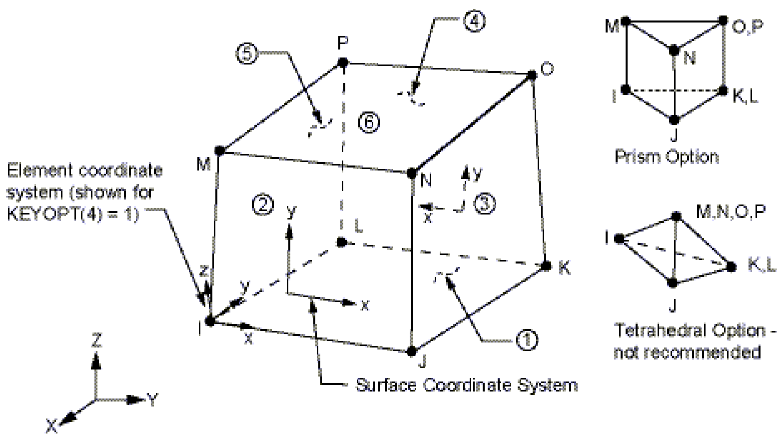

Fig. (4): Solid45 Element[2].

Modeling of Concrete in Compression

The finite element code ANSYS-14 program requires the uniaxial stress-strain relationship for concrete in compression. Numerical expressions, equations (1 and 2),are used along with equation (3), to construct the uniaxial compressive stress-strain curve for concrete as [2]:

$$f = \frac{E_c \varepsilon}{1 + \left(\frac{\varepsilon}{\varepsilon_\circ}\right)^2} \quad (1)$$

$$\varepsilon_\circ = \frac{2 f_c'}{E_c} \quad (2)$$

$$E_c = \frac{f}{\varepsilon} \tag{3}$$

where: f = stress at any strain ε
ε = strain at stress f
ε_0 = strain at the ultimate compressive strength f'_c

$E_c = 4700\sqrt{f_c'}$ based on the ACI 318M-11 equation[4].

Fig.(5) shows the simplified compressive uniaxial stress-strain relationship that was used in this study.

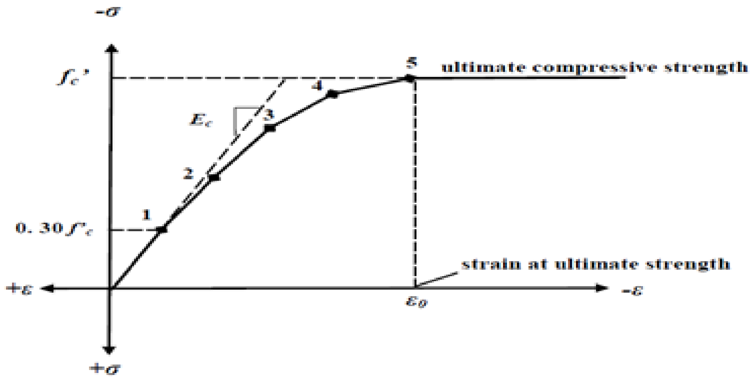

Fig. (5) : Simplified compressive uniaxial stress-strain curve for concrete[2].

Modeling of Concrete in Tension

Until the crack, initial tangent modulus $E_c$is used to find the maximum positive (tensile) stress. After the cracking in the concrete takes place, a smeared model is used to represent the discontinuous macro crack behavior. This cracked concrete can still carry some tensile stress perpendicular to the crack, which is termed tension stiffening. In this study, a simple descending line is used to model this tension-stiffening phenomenon as shown in Fig. (6)[5].

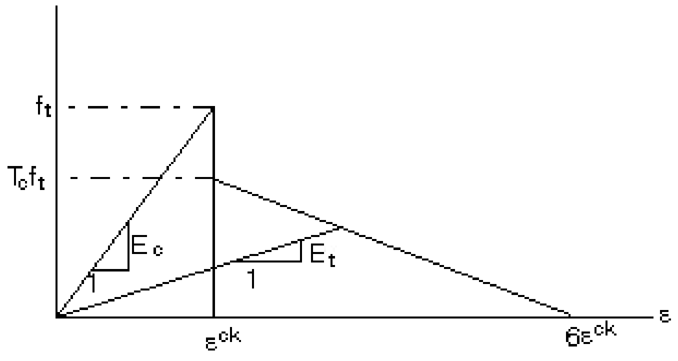

Fig. (6) : Tension stiffening model [2].

Modeling of Steel Reinforcement

The mechanical properties of steel in compression are well known and understood. Steel is a homogeneous material and the stress-strain behavior can be assumedidentical in tension and compression. Steel bars in reinforced concrete members are normally long and relatively slender and therefore they can be generally assumedcapable of transmitting axial forces only. The uniaxial stress-strain behavior of reinforcement is simulated by an elastic-linear perfect plastic model, as shown in Fig. (7)[6].

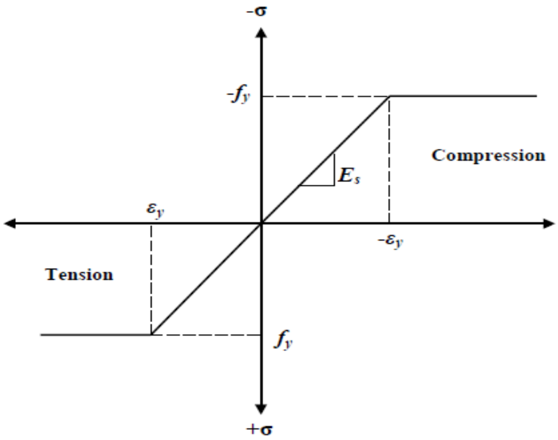

Fig. (7) :Stress strain relationship of steel bar [6].

Modeling of Carbon Fiber Reinforced Polymers (CFRP)

The behavior of CFRP materials is linear elastic to failure. Ultimate elongation strains are considerably higher than steel yielding strains. This results in ultimate tensile strengths that are typically between four to nine times the yields stresses of steel. Failure is sudden and brittle with no load carrying capacity after failure. Typical stress-strain relation of CFRP is shown in Fig. (8)[7].

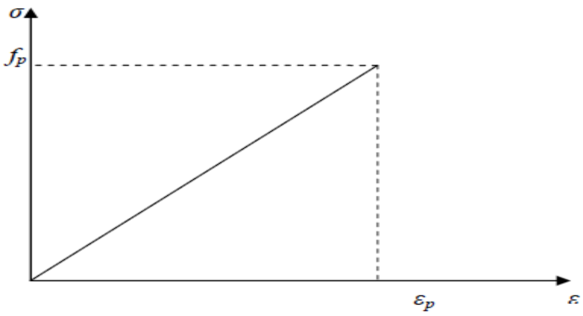

Fig. (8) : Stress-strain Relation of CFRP [7]

Verification Study

In order to check the validity and accuracy of the finite element models with their materials properties of reinforced concrete columns strengthened with CFRP, the details of five experimental reinforced concrete confined with CFRP and subjected to eccentrically loaded are remodel and analysis with ANSYS-14, then the results compared with the results of the same experimental model, each example deals with a particular aspect of behavior and are as follows:

1. Reinforced concrete column (C1-1) strengthened with wrapped CFRP sheets tested by Taranu, N. et al. [8].

The experimental ultimate load is (2147 kN) while, thenumerical ultimate load is (2133.8kN).The ratio of the experimental ultimate load to the analytical ultimate load value is (99.4%), as shown in Fig. (9).

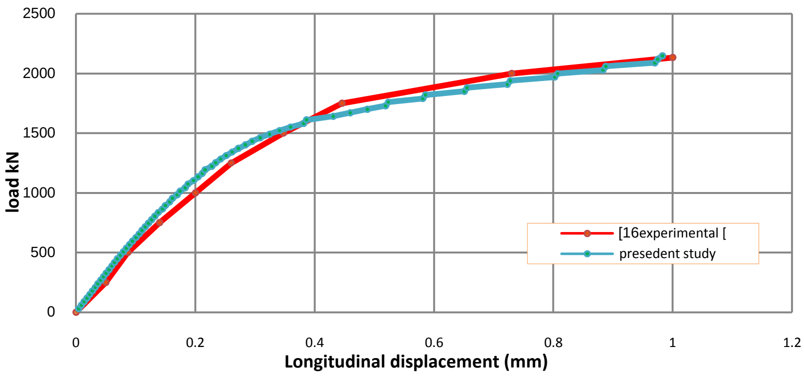

Fig. (9):Experimental and numerical load-longitudinal displacement for column specimen (C1-1).

2**.**Reinforced concrete column (C2-2) strengthened with wrapped CFRP sheets tested Taranu, N. et al. [8].

The experimental ultimate load is (2481kN), while the analytical ultimate load is (2490 kN). The ratio of the experimental ultimate load to the analytical ultimate load value is (99.6%), as shown in Fig. (10).

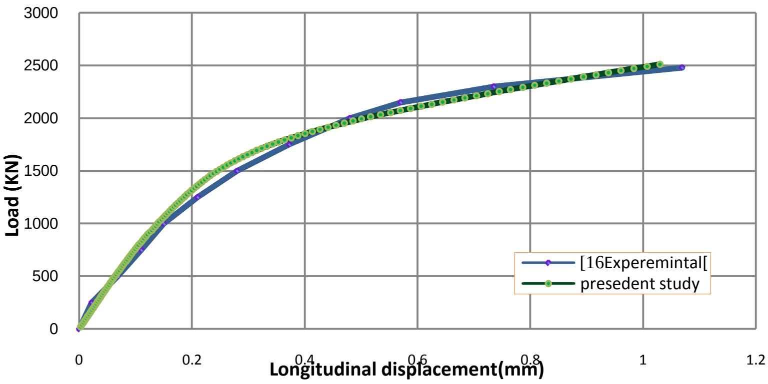

Fig. (10) : Experimental and numerical load-longitudinal displacement for column specimen (C2-2).

3**.**Reinforced concrete column (S200-L2T) strengthened with wrapped CFRP sheets tested by Sadeghian,P.et al. [9].

The experimental ultimate load is (490kN), while the numerical ultimate load is (491kN). The ratio of the experimental ultimate load to the analytical load is (99.8%), as shown in Fig. (11).

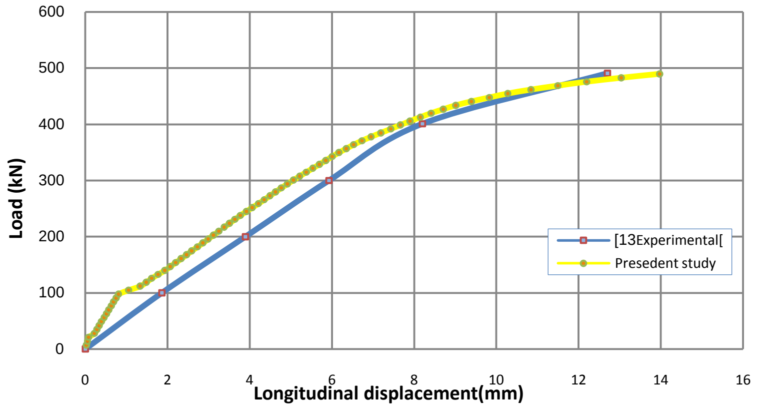

Fig. (11) : Experimental and numerical load-longitudinaldisplacementforcolumn specimen (S200-L2T).

4.Reinforced concrete column (ES4) strengthened with CFRP sheets tested by Quiertant, M.et al. [10].

The experimental ultimate load is (1482 kN), while the numerical ultimate load is (1520kN). The ratio of the experimental ultimate load to the analytical load is (97.5%), as shown in Fig. (12).

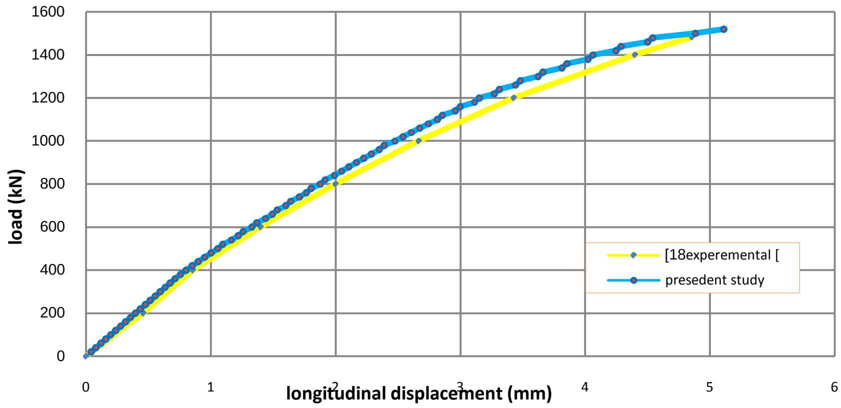

Fig. (12) :Experimental and numerical load-longitudinal displacement for column specimen (ES4)

5.Reinforced concrete column (ES2) strengthened with CFRP sheets tested by Quiertant, M.et al. [10].

The experimental ultimate load is (1262 kN), while the numerical ultimate load is (1298kN). The ratio of the experimental ultimate load to the analytical load is (97.2 %),as shown in Fig. (13).

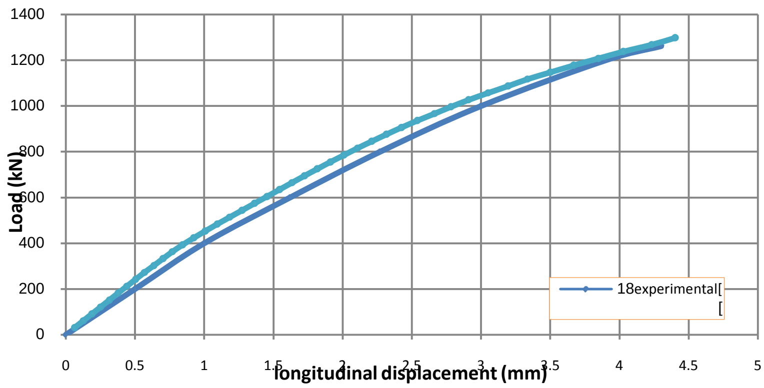

Fig. (13) : Experimental and numerical load- longitudinal displacement for column specimen (ES2)

Parametric Study

The following sections display the influence of the most important parameters that affecting on the ultimate load and the ductility of RC columns strengthened with CFRP subjected to axial force with uniaxial bending. It is very important to mention that when one parameter is varied; all other properties of the system will be held constant in order to isolate the effects of the other parameters.

1.Effect of Compressive Strength of Concrete

The column specimen (C1-1) was selected to study the effects of compressive strength of concrete on the ultimate load and the ductility of RC.To conduct this study, ten values of compressive strength for confined column are selected (22,24,26,28,30,32,34,36,38 and 40 N/mm2) in addition to the control column (without CFRP layers) for each value of compressive strength,the study show the following resulting which illustrated in Table(1).

Table (1): Effect of compressive strength on ultimate load of columns.

f`c (MPa)	ultimate load (kN)	% benefit of increase f`c
22	1662	control
24	1782	7.2
26	1865	12.2
28	1972	18.7
30	2047	23.2
32	2216	36.9
34	2323	39.8
36	2438	46.7
38	2532	52.4
40	2664	60.3

It is seen that the unconfined and confined RC columns show increased in its ultimate strength as the compressive strength (f`c) increased. Thus, two remarks can be made. The first one, that the effect of the compressive strength value is an important on the strength capacity of the columns, as shown from the result the strength capacity is increased by about (7.0% - 60%)as the compressive strength increased from 24MPa to 40MPa .The second remark is that, the effect of increasing the compressive strength has a little bit effect on the strength capacity of the confined CFRP columns than the unconfined RC columns , where for

unconfined column the approximately benefit rate is 7.3% for each 2 MPa increasing in compressive strength of concrete, while the rate benefit of the confined column is 6.7%.
To study the effect of the compressive strength of column concrete on the ductility.The most common measures of ductility is (the energy absorbed by the element or structures as given by the area under the force deformation diagram) [11]. The force may be load, moment or stress while the deformation could be elongation, curvature, deflection or twist. In this study the load used as a force and the longitudinal displacement as a deformation, to calculate the area under the curve, (AutoCAD) program release 2010 is used, this program given the area with accuracy 100 %. In this study the load –longitudinal displacement curves are drawn as shown in Fig. (14) for confined column with one CFRP layer , and the area under curve is listed in Table(2).

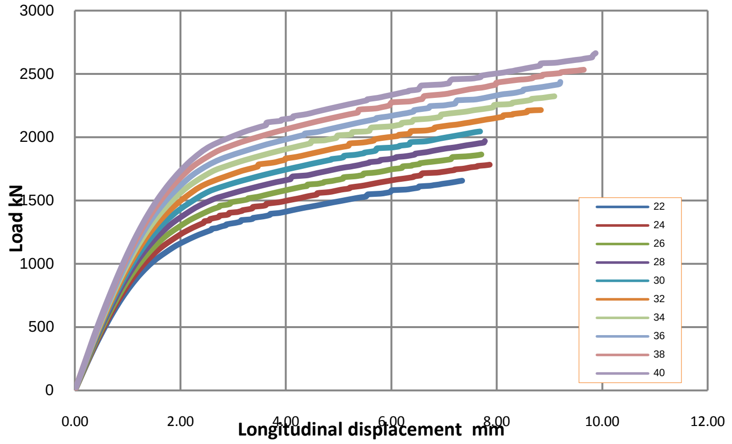

Fig. (14): Load –longitudinal displacement for confined column with compressive strength of concrete ranged from (22 to 40) MPa.

Table(2): Area under load –longitudinal displacement curve for confined column.

f`c MPa	Area under curve	% Benefit
22	9214	control
24	10585	14.9
26	11000	19.4
28	11623	26.1
30	11981	30.0
32	15020	63.0
34	16241	76.3
36	17134	86.0
38	18907	105.2
40	20162	118.8

It can be observed from Table (2) that the ductility of the column increases as the compressive strength increased ,the increasing percentage of the ductility is about (14.9 to 118.8)% as the compressive strength increases from(24 to 40)MPa.

2.Effect of Confining Column with Different Numbers of CFRP Layers.

A column specimen (C2-2) was selected to study the effect of confining column with different numbers of CFRP layers on the ultimate load and the ductility of RC.To conduct this study ,four numbers of layers are selected in this research (1, 2, 3 and 4) layers as well as unconfined column as a control column the study show the following resulting which illustrated in Table(3).

Table (3): Effect of confining column with different numbers of CFRP layers in ultimate loads.

Numbers of layers	0	1	2	3	4
Ultimate load (kN)	1588	2325	2512	2655	2820
% of benefit	control	46	58	67	78

As the general remark from this table is that the strength capacity is increased as the confinement effect (No.of CFRP layers) increased. To study the effect of CFRP layers on the ductility of RC columns, the load-longitudinal displacement for columns with different CFRP layers number are drawn in Fig. (15) and the ductility percentage is tabled in Table (4).

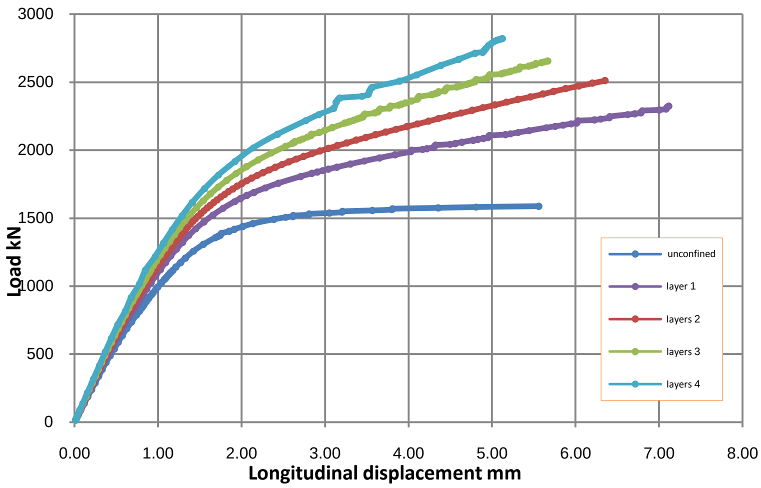

Fig. (15): Load –longitudinal displacement for different numbers layers of CFRP.

Table (4): Effect of confining column with different numbers of CFRP layers in the ductility.

Numbers of layers	0	1	2	3	4
Area under the curve	7326.1	12414.5	11633.1	10678.8	9867.5
% of benefit	control	69.4	58.8	45.8	34.7

The using of one layer of CFRP increased the ductility of RC column with a percentage of about 69%, while this percentage of ductility increment is decreased from 69% to 34% as the number of CFRP layers increased from one layer to four layers. It is clearly that, the percentage benefit decreased as the number of layers increased, this decreased in percentage benefit coming from the fact that, the CFRP is a brittle materials and the increasing of CFRP thickness made it more brittle.

3.Effect of Longitudinal Reinforced Steel Area

The column specimen (ES4) was selected to study the effects of longitudinal steel reinforcement area on the ultimate load and the ductility of RC.To conduct this study, four percentage of reinforced steel area with respect to column section area are selected in this study (1, 2, 3, and 4%) are used; the results of this parametric study are tabled in Table (5).

Table (5): Effect of longitudinal reinforced steel area on ultimate load of column.

% area of longitudinal reinforced steel to area of column section	ultimate load (kN)	% Benefit
1	1740	control
2	1880	8.0
3	2020	16.1
4	2160	24.1

From the above results, it is clear that, the ultimate load is increased as the steel percentage increased; the amount of the strength increased is about 24% as the steel percentage is increased 4%. To study the ductility effect of CFRP layers on the RC columns, the load-longitudinal displacement for columns with different numbers of CFRP layers are drawn in Fig. (16) and the ductility percentage is tableted in Table (6).

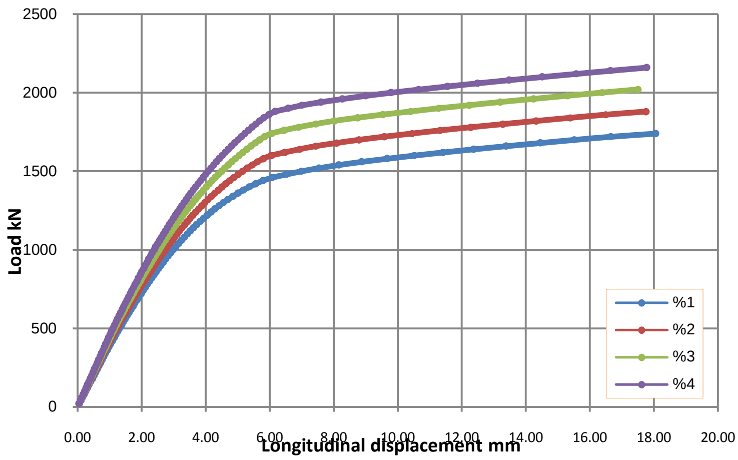

Fig. (16): Load –longitudinal displacement of confined column with several percentage area of reinforced steel.

Table (6): Effect of longitudinal reinforced steel area on the area under curve of the column.

% area of longitudinal reinforced steel to area of column section	Area under curve	% Benefit
1	25015	control
2	26576	6
3	28149	13
4	30664	23

It can be observed from Table (6) that the ductility of the column increases as the percentage of steel area increased, the increasing percentage of the ductility is about (6% to 23%) as the percentage of steel area increases from (2% to 4%).

4.Effect Of Eccentric Loads

For studying the effects of eccentric loads on column that strengthened with CFRP, a column specimen (C2-2) is selected for this purpose.To conduct this study, six eccentric load are selected in this study (25, 50,75 ,100 and 125 mm) as well as concentric load this identity to (e/h)equal to (0.083,0.166,0.25,0.33 and 0.416) respectively, the results of this parametric study are tabled in Table (7).

Table (7) Effect of eccentric loads on ultimate load of column.

The eccentricity of load (mm)	ultimate load (kN)	% losses of ultimate load as a result of eccentricity
0	4731	control
50	3197	32
75	2512	47
100	1927.5	59
125	1425	70

From the above results, the ultimate load is decreased as the eccentric load value increased, the amount of the strength decreased is about 32% to 70% as the eccentric load value is increased from 50 mm to 125 mm. To study the ductility effect of CFRP layers on the RC columns, the load-longitudinal displacement for columns with different CFRP layers number are drawn in Fig. (17) and the ductility percentage is tableted in Table (8).

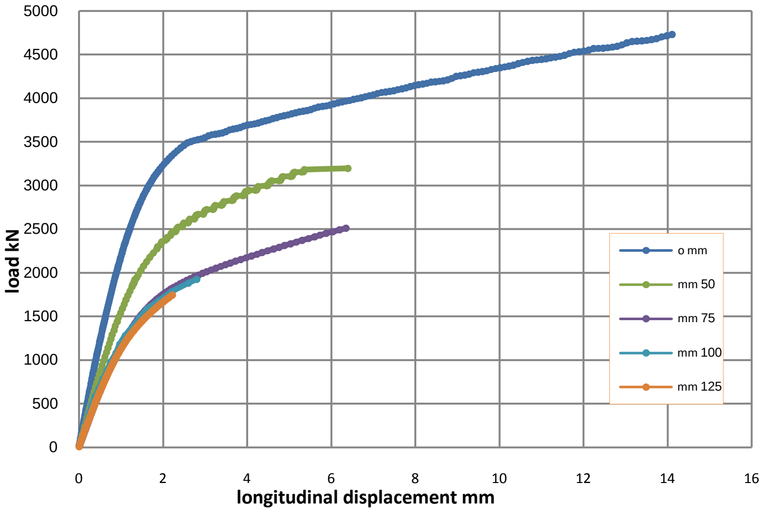

Fig. (17): Load-longitudinal displacement for confined column with different eccentricity of load

Table (8) Effect of eccentric loads on ultimate load of column.

The eccentricity of load (mm)	Area under curve	% losses of ductility as a result of eccentricity
0	53887	control
50	15674	71
75	11633	78
100	5000	91
125	2429	95

It can be observed from table (8) that, the ductility of the column decreased as the eccentric load value increased, the decreasing percentage of the ductility is about (71% to 95%) as the eccentric load value increased from (50mm to 125mm).

Conclusions

The following conclusions can be drawn from this work:

1. Effect of Compressive Strength of Concrete

The numerical results show, when the compressive strength of column concrete changed from 22MPa to (24, 26, 30, 32, 34, 36 and 40)MPa, the ultimate load are increased by(7.2, 12.2, 18.7, 23.2 36.9, 39.8, 46.7, 52.4 and 60.3) %respectively. Theresearch also showed that, the ductility of the column increases by (14.9, 19.4, 26.1, 30.0, 63.0, 76.3, 86.0, 105 and 118.8) %respectively for the same compressive strength of concrete above.

2. Effect of Confining Column with Different Numbers of CFRP Layers(Thickness of CFRP).

The research shows that when unconfined column strengthen with (1, 2, 3 and 4) layers of CFRP,the ultimate load increasing by (46, 58, 67 and 78) % respectively and the ductility increased to (69.4, 58.8, 45.8 and 34.7) %respectively.

3. Effect of Longitudinal Reinforced Steel Area

The results show that when the percentage area of reinforced steel increasing from 1% to (2, 3 and 4) % respectively, the ultimate load increasing to (8, 16 and 24.1) % respectively .The increasing of percentage steel of column effected also on the column ductility, the results showed that the ductility increasing to (6, 13and 23) % respectively.

4. Effect of Eccentric Loads

The results show that when the eccentricity (e) increased from 0 mm to(25, 50, 75, 100 and 125)mm the ultimate load of column decreased to (14, 32, 47, 59 and 70) % respectively. This parametric also effected the column ductility and led to decreasing the ductility to (71, 78, 91 and 95) % respectively.

References

1. Hadi M, N.S.,(2006),"Comparative study of eccentrically loaded FRP wrapped columns", Journal of Composite structures, pp127–135.
2. ANSYS,(2011), "ANSYS Help",Release 14.
3. Kwak H. and Filippou C.F.,(1990),"Finite element analysis of reinforced concrete structures under monotonic loads",a report from California Department of Transportation,124pp.
4. ACI Committee 318,"Building Code Requirements for Structural Concrete (ACI 318M-11) and Commentary ACI 318R-11 ", American Concrete Institute (ACI), Farmington Hills, MI 48331, 509pp.
5. Hussian N.M,(2005)"Analysis and Optimum Design of Large Reinforced Concrete Domes", Ph. D. Thesis, University of Nahrain, pp. 1-185.
6. Zaki M.K.,(2011)", Investigation of FRP strengthened circular columns under biaxial bending ",Engineering Structures journal, pp1666–1679.
7. Hoque M. M.,(2006), "3D Nonlinear Mixed Finite-element Analysis of RC Beams and Plates with and without FRP Reinforcement", MS Thesis, University of Manitoba, Canada, 106 pp.
8. Taranu N., Cozmanciuc C. and Oltean R.,(2011)," experimental study of reinforced concrete columns confined with composite membranes",Bul. Inst. Polit. Iasi, pp33-45.
9. Sadeghian P., Rahai A. and Ehsani M.,(2010)," Experimental Study of Rectangular RC Columns Strengthened with CFRP Composites under Eccentric Loading",Journal Compos. Constr., pp443-450.
10. Quiertant M., Clement J.,(2011)",Behavior of RC columns strengthened with different CFRP systems under eccentric loading" ,Construction and Building Materials, 452–460.
11. MacGREGOR J. G.,(1974),"Handbook of concrete engineering", MacGraw Hill, pp. 229-247.