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Modeling of Rectangular Reinforced Concrete Columns Strengthened Externally Using CFRP Sheets by Finite Element Analysis

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Abstract

The behavior of RC concrete columns of rectangular shape wrapped with "CFRP" has not been studied extensively, so a RC concrete column with dimensions of 150 X 300 X 500 mm has been modeled and a nonlinear analysis was made using the finite element method (FEM). Three dimensional eight-node brick element (SOLID65) was used to represent the concrete; three-dimensional Spar (3D) element (LINK180) represented the steel and using a three-dimensional shell element (SHELL81) to represent the "CFRP" composites and epoxy resin. The experimental data were used taking into account the axial capacity and orientation of the fibers.

In this study, the results of the ANSYS program (Release 2020 R2 ACADIMIC) were compared with the practical and theoretical data, as the results showed a significant improvement in the ductility and axial capacity of" CFRP" strengthened columns compared to the unstrengthened columns. Ones when strengthened the columns by one layer the axial load capacity was increased 4.2 %, three layers 30%, Moreover 77% when strengthened by five layers.

Keywords: Carbon Fiber Reinforced Polymer, Rectangular Columns, Confined concrete, Non-linear

1. Introduction

Fiber Reinforced Polymers (FRP) are materials composed of fibers combined with a polymeric matrix. They appear as an alternative in relation to conventional materials for strengthening and rehabilitation of structures. FRP is lightweight, non-corrosive and has high tensile strength. In fabric format, the FRP can be used to wrap the structure to promote strengthening. Fibers and resins are expensive if compared to traditional materials; however, they allow strengthening of the structure in a relatively short time and demand a lower degree of structure intervention. In addition to this, it is possible to apply them in places with difficult access (ACI 440.2R-08). In recent years, FRP composites are used as externally bonded reinforcement to concrete structures for essentially two purposes: to provide confinement to concrete subjected to compression (jacketing system), and to improve bending and/or shear strength of a reinforced concrete flexural member such as beam, slab, etc. The confinement pressure provided by the FRP increases continuously with the lateral strain of concrete because of the linear elastic stress-strain behavior of FRP, in contrast to steel confined concrete in which the confining pressure remains constant when the steel is in plastic flow. Failure of FRP-wrapped concrete generally occurs when the hoop rupture strength of the FRP is reached (Hajsadeghi, Alaee, Shahmohammadi, 2010)

The cost of rebuilding the concrete structure compared to its repair and reinforcement is very high. For this reason, we must understand modern technologies and study them in a way that enables us to choose the best decisions, to save money and time. A 3D model of a rectangular concrete column reinforced with CFRP layers was developed externally using ANSYS software and compared the theoretical solution using experimental equations with the practical solution and the ANSYS solution. In addition, studies of the change of some parameters such as the effect of CFRP thickness, and the direction of roll angle with respect to CFRP layers. In some previous studies, the bonding between reinforced concrete and CFRP layers is assumed ideal, while in the current study the epoxy resin layers that were simulated with Shall 181 represented this bonding, where the lower layers adhering to the concrete column body were given the properties of the Epoxy resin and the rest of the layers properties The CFRP. Do the results of analyzing the rectangular concrete column in this way give us close and logical results if compared with the laboratory and theoretical results, and what is the effect of the thickness of the concrete column and the orientation of the fire on the strength and elasticity of the column?

2. Literature Review

In confinement, using CFRP notably reduced concrete cover spelling and delayed concrete core crushing. This study dealt with the assessment of compressive behaviour of 18 short, square and low- strength concrete columns confined with both externally bonded CFRP and conventional transverse reinforcement. The studied parameters were steel ratio (2.8% and 5.6%) and configuration of transverse steel reinforcement, as well as carbon fiber volumetric ratio (0.3% and 0.5%). Test results also showed that the mean value in concrete peak strength for the columns with greater volumetric carbon fiber ratio (0.5%) was 17% higher than those of columns with the smaller volumetric carbon fiber ratio (0.3%), and 79% higher than those of columns without carbon fiber reinforcement (Carrilloa &Valencia-Minab & Bojórquez, 2019). The distribution of compressive stresses in the cross section of the column indicated that for centered load, circular cross sections had uniform distribution and for square and rectangular sections, parabolas and concentrates next to the rounded corners defended the effective confined concrete. For eccentric load, the effective confined region moves to the most confined edge, thus, this did not reduce the gain for Square and rectangular columns, but is unfavourable for circular columns (OLIVEIRA & CARRAZEDO, 2019). Loading capacity and strains of square reinforced concrete (RC) columns, strengthened with external carbon fibre reinforced polymer (CFRP) sheets, were tested and evaluated. Results clearly demonstrate that composite wrapping can enhance the structural performance of RC columns in terms of both maximum strength and ductility. The effects of test parameters are evidenced and compared (A. Benredjem1 & N. Chikh, 2018).

3. Finite Element molding of Strengthened RC Columns.

In this study a finite element model for rectangular RC column confined with FRP composites is developed. The model is simulated using ANSYS (Release 2020R2 Academic) finite element software Solid 65, Solid 186, Link 180 and Shell 181, elements are used to represent concrete, loading steel plates, main steel and stirrups reinforcing bars and carbon fiber (CFRP) composites with epoxy resin respectively. The geometry, node locations, and the coordinate system for ANSYS elements are shown in Figure (1)



Figure 1: Geometry Elements ANSYS

3.1. Material Properties

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Finite element models for CFRP wrap columns are presented. First, the material properties are identified, then are inserted in program software in this study, the ANSYS is used for modeling of concrete column, reinforcement, epoxy resin, and CFRP sheet. The nonlinear analysis is developed by means of ANSYS/STANDARD to simulate the nonlinear behavior of the confined column. After that the geometry of model is defined, and material properties should be introduced. First, elastic behavior of material is set. Hence, the elastic parameters such as: Young's modulus of concrete, E_c and Poisson's ratio,v are inputted. From experimental results E_c is calculated as $E_c = 4700\sqrt{f'_c}$ (ACI 8.5.1), where is given in MPa. The popular stress-strain relationship is used to make the uniaxial compressive simulation of the concrete column, which is given by the following relationships (Desayi, Prakash, and Krishnan 1964).

$f_r = 0.62\sqrt{f_c'}$	(1)
$\varepsilon_o = \frac{2f_c}{E_c}$	(2)
$f = \frac{\tilde{E}_{c}\varepsilon}{1 + (\frac{\varepsilon}{\varepsilon_{c}})^{2}}$	(3)

Where:

 f_c = stress at any strain ε_0 = strain at the ultimate compressive strength f'_c ε = strain at stress f_c f'_c = ultimate compressive strength f_r = uniaxial tensile strength

In this study, the cylindrical compressive strength of using concrete was 26.4 MPa and Poisson's ratio (v_c) of concrete was assumed to be 0.2 The shear transfer coefficient represents a shear strength reduction factor for subsequent loads that induce sliding (shear) across the crack face, [Chansawat et al., 2009]. Typical shear transfer coefficients range from 0.0 to 1.0, with 0.0 representing a smooth crack (complete loss of shear transfer) and 1.0 representing a rough crack (no loss of shear transfer), [ANSYS 2014]. For an open crack, the shear transfer coefficient varied between 0.05 and 0.50 in many studies of reinforced concrete structures, [Isenburg, 1993]. In this study, many analysis attempts had been done to determine the appropriate values of shear transfer coefficients used in this study for shear column models are 0.3 and 0.99 respectively the uniaxial cracking stress of concrete (tensile strength) is based upon the modulus of rupture. Modulus of rupture of concrete is a more variable property than the compressive strength from Eq. (1) (Mohammad H, 2015).

A value uniaxial crushing stress was taken (-1) for removes the crushing capability (Mechanical APDI Theory Reference.) Modified Hognestad mathematical model (See Figure (2)) has been used for the approximation of the stress-strain behavior of concrete. Equations (2) and (3) were used to predict the multilinear isotropic stress strain curve for the concrete. The multilinear curve was used to help with convergence of the nonlinear solution algorithm, [Wolanski, 2004]. Figures (3) shows the stress-strain relationship used in this study for ANSYS model respectively. The curve starts at zero stress and strain. Point 2, defined as $0.3f'_{c}$, and was calculated in the linear range. Points from 3 to 20 were calculated from Eq. (3) with ε_o obtained from Eq. (2). Strains were selected and the stress was calculated for each strain. Point 20 is at f'_c . After Point 19, perfectly plastic behavior of concrete was assumed. Software ANSYS requires input data for Material properties as shown in Table 1.



Figure 2: Uniaxial Stress-Strain Behavior of Concrete (Basappa & and Rajagopal, 2013)



Figure 3: Compressive Uniaxial Stress-Strain Curve for Concrete ANSYS Model

In addition, material properties of steel reinforcement used for ANSYS column models, define material as a bilinear models recommended in several previous researches requires the Yield Stress (f_y), as well as the Hardening Modulus (tangent modulus of the plastic region) of steel to be defined Elastic Modulus (E_x), also defined Poisson's Ratio (v_x). In this study, two types of steel reinforcing bars were used with diameters of 8 mm and 12 mm. the yield stress (f_y) and strain (ε_y) of the bars with diameters of 8 mm and 12 mm, were 476 Mpa and 0.0024, 339 Mpa and 0.0017, respectively, Elastic Modulus (E_x) was 200000Mpa. The Poisson's ratio of the steel reinforcement (v_x) was 0.3, Table 2 shown properties FE model foe steel reinforcement. The bond between steel bars and concrete is considered perfect. Surely, as the CFRP behavior is orthotropic, the CFRP material is inputted as a linear elastic orthotropic material in the model. Without a doubt, it is necessary to introduce properties of the CFRP for every course independently; the mechanical properties of the CFRP that were used in this study are shown in Table 3. A local coordinate system for the CFRP shell element was defined where the x direction is the same as the fiber direction, while the y and z directions were perpendicular to the x direction. The elastic modulus in the fiber direction of the unidirectional CFRP material used in the experimental studies was specified by the manufacturer, major Poisson's ratio was assumed, and then, the elastic modulus in directions perpendicular to the fiber direction, minor Poisson' ratio, and shear modulus were predicted using Rule of Mixture.

$$G_{xy} = \frac{E_{x}E_{y}}{E_{x} + E_{y} + 2\nu_{xy}E_{x}}$$
(4)

Where:

 G_{xy} = Shear modulus in the xy plane

 $E_{\rm x}$ = Elastic modulus in the x direction

 E_y = Elastic modulus in the y direction

 v_{xy} = Major Poisson's ratio

Equation (4) shows the relationship between elastic and shear moduli (ANSYS 1998). The bond between concrete and CFRP by epoxy resin which mechanical properties show in Table 4 is simulated as shell181 element. The base and loading plates were modelled with the mechanical properties of steel shown in Table 5.

Element Type	Material Properties				
Solid 65	Linea	r Isotropic			
	E_{x}	23294.12(Mpa)			
	PR_{xy}	0.2			
	Multi-lin	iear Isotropic			
	Point	Strain	Stress (Mpa)		
	1	0	0		
	2	0.00034	7.92		
	3	0.00044	10.16		
	4	0.00054	12.23		
	5	0.00064	14.16		
	6	0.00074	15.96		
	7	0.00084	17.6		
	8	0.00094	19.08		
	9	0.00104	20.4		
	10	0.00114	21.57		
	11	0.00124	22.58		
	12	0.00134	23.46		
	13	0.00144	24.19		
	14	0.00154	24.8		
	15	0.00164	25.3		
	16	0.00174	25.8		
	17	0.00184	25.98		
	18	0.00194	26.19		
	19	0.00204	26.32		
	20	0.00214	26.39		
	21	0.0022	26.4		
	Open shear	Coefficient transfer	0.3		
	Closed shear	Transfer coefficient	0.99		
	Uniaxial cracking	Stress	3.18		
	Uniaxial crushing	Stress	-1		
	Biaxial crushing	Stress	default		
	Hydrostatic	Pressure	default		
	Hydro biaxial	Crushing stress	default		
	Tensile crack	factor	default		

Table 1: Material Properties of Concrete FE Model

Element Type	Material Properties		
Link 180	Linear Isotropic		
	E_{χ}	200000Мра	
	PR_{xy}	0.3	
For Φ 12 mm	Bilinear isotropic		
	Yield stress	339 Мра	
	Tangent modulus	339 Мра	
	Cross-section		
	Area of link	$113 mm^2$	
For Φ 8 mm	Bilinear isotropic		
	Yield stress	476 Mpa	
	Tangent modulus	476 Mpa	
	Cross-section		
	Area of link	$50.24 \ mm^2$	

Table 2: Material Properties Used for FE Model of Steel Reinforcement

Element Type	Description	Data
Shell 181	Tensile elasticity modulus	= 230 GPa, = 3 GPa
	Shear elasticity modulus	= 2064 GPa = 1136 Gpa
	Poisson's ratio	FALSE
	Tensile strength	= 3430 Mpa
	Ultimate rupture strain	0.015
	Nominal thickness	=0.165 mm/ply

Table 3: Mechanical Properties of CFRP Sheets FE Model

Element Type	nt Type Description	
Shell 181	Tensile elasticity modulus	=3Gpa
Ultimat	e elongation strain	0.025
compressive strengths		80 Mpa
Poisson's ratio		= 0.35
tensile strengths		= 50 Mpa
	Nominal thickness	=0.3 mm
Table 4. Machanical Properties of Enoug		

Table 4: Mechanical Properties of Epoxy

Material Properties	
Linear isotropic	
	200000Mpa
	0.3
	Material Properties Linear isotropic

Table 5: Material Properties Used For FE of Steel Plates

3.2. Specimens Geometry and Specification

In this study, specimen (columns) with dimensions and 150×300×500 mm was studied. The concrete cover and the corner's radius of 40 mm (see Figure 4). For specimen, four 12 mm steel bars were used as longitudinal reinforcement, and six 8 mm stirrups were used as the transverse reinforcements. Every specimen was fully wrapped with one, three, or five unidirectional FRP layers in transverse direction. The specimen identification labels are presented in Table 6. The primary letter in the mark represents rectangular cross segment. The next character represents the number of FRP layers used to externally confine the specimens.



Figure 4: FRP Wrap Rectangular Layout and Column's Cross-Section

Symbol of Model	Data	Number of Layers
NS-R-2-175-0-40	Experimental	0
R-1	Model	1
R-3	Experimental/Model	3
R-5	Model	5

Table 6: Specimens Specifications

3.3. Boundary Conditions, Loading and Solution

Due to the symmetry condition of the specimens, just a quarter of the specimens were modelled and the relating limit conditions were applied to *yz* and *zx* planes (see Figure 5/a). To reenact the steel plates at the finishes of the models, two plates were displayed with the mechanical properties of steel, in those zones. Pivotal stacking was applied on top surface of the stacking plate utilizing a client characterized stacking augmentation. The pivotal burden was applied to the top hubs of the stacking plate and the base plate (base plate) was fixed from displacement in x, y, and z headings. (Figure 5/b) shows the limited component model of the rectangular specimens containing symmetric conditions. Various union upgrade includes in ANSYS like programmed load venturing, line search, etc. Can be enacted to aid the arrangement with combining. In the current examination the programmed load venturing and the line search choices were used. The programmed load venturing choice permits ANSYS to decide the quantity of burden steps needed for an exact arrangement. Sub-steps are characterized to apply the stacking, steadily. Have been set time at end sub-step 5000 also can be activated time increment, the size of time step was 0.2, the minimum of time step 0.2 and the maximum of time step 0.1.



Figure 5: Modeling Steps of Studied Specimen

For prediction of ultimate strengths of CFRP jacketed specimens, the equations proposed by (ACI 440.2 -08). The compressive strength of confined concrete, f'_{cc} as shown in Eq (4), is given by-

$$f_{\rm cc}' = k_{\rm c} f_{\rm c}' \tag{4}$$

Where f'_c : the cylinder concrete compressive strength, k_c is a Factor depends on the biaxial state of stresses induced by the lateral confining pressures. This factor is given by:

$$\kappa_{c} = \alpha_{1}\alpha_{2}$$
(5)
Where α_{1} , α_{2} are given by
$$\alpha_{1} = 1.25 \left(1.8 \sqrt{1 + 7.94 \frac{F_{1}}{f_{c}'}} - 1.6 \frac{F_{1}}{f_{c}'} - 1 \right)$$
(6)
$$\alpha_{2} = \left[1.4 \frac{f_{1}}{F_{1}} - 0.6 \left(\frac{f_{1}}{F_{1}} \right)^{2} - 0.8 \right] \sqrt{\frac{F_{1}}{f_{c}'}} + 1$$
(7)

 α_1 and α_2 concrete strength enhancement , F_1 and f_1 are the maximum and minimum confining lateral stresses, respectively.

The lateral confining stresses induced by FRP jacket only in the x- and y-directions, $f_{1,jx}$ and $f_{1,jy}$, are:-

$$f_{1,jx} = \rho_{jx} 0.005 E_{\rm p} \tag{8}$$
$$f_{1,jy} = \rho_{jy} 0.005 E_{\rm p} \tag{9}$$

Where: E_p is the elastic modulus of the FRP jacket. The reinforcement ratios ρ_{iv} and ρ_{iv} are defined as:

$$\rho_{jx} = 2 \frac{t_j}{t_y}$$
(10)
$$\rho_{jy} = 2 \frac{t_j}{t_x}$$
(11)

 $t_{j} = t_{x}$ t_{j} , t_{x} , t_{y} are the nominal jacket thickness, overall column cross-section in x and y direction dimensions respectively. The lateral confining stresses induced by the steel hoops only in the x- and y-directions, $f_{1,sx}$ and $f_{1,sy}$, are

$$f_{1,sx} = \rho_{sx} f_{syh}$$
(12)

$$f_{1,sy} = \rho_{sy} f_{syh}$$
(13)
Where f_{syh} is the yield stress of the steel hoops.

$$\rho_{sx} = \frac{A_{t,x}}{sd_y}$$
(14)

$$\rho_{sy} = \frac{A_{t,y}}{sd_x}$$
(15)

 d_x , d_y are the distances between the centerlines of the perimeter hoop in the *x*- and *y*-directions, respectively. $A_{t,x}$, $A_{t,y}$ are areas of transverse steel reinforcement parallel to the *x*- and *y*-axis, respectively and s is the spacing between sets of hoops. The lateral confining stress acting upon area $A_{cc,j}$ due to both confining materials is equal to $f_{c,j} = f_{c,j} + f_{c,j}$

$$J_1 = J_{1,S} + J_{1,j}$$
 (10)

5. Numerical Simulation Results and Discussion

5.1. Validation of Numerical and Analytical Model (Comparison FE Results with Experimental Data and Theoretical Analytical)

Non-linear FE analysis of RC columns are strengthened with layers of CFRP under the static incremental loads. The stress and strain of the columns are measured. The validation of the FE analysis of the FRP-wrapped RC columns was checked with an experimental study reported by (Ilki et al, 2008).

Figure 6: shows a comparison between the stress-strain response of the control specimens obtained from the tests and that resulted from the FE analysis. In addition, the comparison of the finite element analysis (FEA) and the experimental results are presented in Table 7.

Table 8 and Table 9 were shown the comparison of the theoretical analytical and the experimental results are presented, which f'_{cc} and ε_{ccu} are the maximum compressive stress and strain of the confined columns, respectively. It can be seen that the FE analysis results are very close to the test results. In addition, theoretical analytical results are very close to the test results in rectangular specimens but far in circular samples, this means that the FE model is valid for predicting the behavior of specimens and can be used to conduct a parametric study.



Figure 6: Comparison of the Stress-Strain of the Finite Element Modelling and Experimental Tests

Specimens		R-3		
f'cc	Exp	40.6 Mpa	DIF 1.5 %	
	FE	40.0 Mpa		
ε _{ccu}	Exp	0.0336 mm/mm	DIF 0.9 %	
	FE	0.0339 mm/mm		

Table 7: Comparison of the Finite Element Modelling and Experimental Data

Procedure	Calculations in SI metric units
Confining pressure due to the transverse steel rein-	$A_{t,x}$ = 2×50.25 =100.5mm2
forcement only.	$A_{t,y} = 2 \times 50.25 = 100.5 \text{mm}^2$
$\rho_{\rm sx} = \frac{A_{\rm t,x}}{cd} \tag{14}$	d_x =300-(40×2) +8=228mm
A_{ty}	$d_y = 150 - (40 \times 2) + 8 = 78 \text{mm}$
$\rho_{\rm sy} = \frac{s_{\rm sy}}{sd_{\rm x}} \tag{15}$	<i>s</i> = 175 mm
$f_{1,\rm sx} = \rho_{\rm sx} f_{\rm syh} (12)$	<i>s</i> = 167 mm
$f_{1,sy} = \rho_{sy} f_{syh} (13)$	$\rho_{\rm sx} = \frac{100.5}{175 \times 78} = 0.0074$
	$\rho_{\rm sy} = \frac{100.5}{175 \times 228} = 0.0025$
	$f_{1 \text{ sx}} = 0.0074 \times 476 = 3.52$
	$f_{1,sy} = 0.0025 \times 476 = 1.19$
	$\rho_{ix} = \frac{2 \times 3 \times 0.165}{150} = 6.6 \times 10^{-3}$
Confining pressure provided by the jacket.	$2 - \frac{2 \times 3 \times 0.165}{10} - 3.3 \times 10^{-3}$
$\rho_{jx} = 2\frac{\iota_j}{t} \qquad (10)$	$p_{jy} = \frac{-5.5 \times 10}{300}$
$2 - 2^{t_j}$ (11)	$J_{1,jx} = 0.0 \times 10^{-1} \times 0.005 \times 230000$
$p_{jy} = 2 \frac{1}{t_x} $ (11)	$J_{1,jx} = 7.59 \text{ Mpa}$
$f_{1,jx} = \rho_{jx} 0.005 E_{\rm p} (8)$	$J_{1,jy} = 5.5 \times 10^{-1} \times 0.005 \times 5000$
$f_{1,jy} = \rho_{jy} 0.005 E_{\rm p} (9)$	$J_{1,jy} = 0.045 \text{ Mpa}$
Calculate the compressive strength of the concrete.	$F_1 = max.(f_{1,jx}, f_{1,jy}) = 7.59 Mpa$
$f_{cc,j} = k_c f_c \qquad (4)$ $k_c = \alpha \alpha \qquad (5)$	$f_1 = min.(f_{1,jx}, f_{1,jy}) = 0.045 Mpa$
$\alpha_{1} = 1.25 \left(1.8 \sqrt{1 + 7.94 \frac{F_{1}}{f_{c}^{\prime}}} - 1.6 \frac{F_{1}}{f_{c}^{\prime}} - 1 \right) $ (6)	$\alpha_1 = 1.25 \left(1.8 \sqrt{1 + 7.94 \frac{7.59}{26.4} - 1.6 \frac{7.59}{26.4}} \right) -$
$\alpha_2 = \left[1.4 \frac{f_1}{F_1} - 0.6 \left(\frac{f_1}{F_1} \right)^2 - 0.8 \right] \sqrt{\frac{f_1}{f_c'}} + 1 \tag{7}$	1)= 2.25
	$\alpha_2 = \left[1.4 \frac{0.045}{7.59} - 0.6 \left(\frac{0.045}{7.59} \right)^2 \right]$
	$-0.8\left]\sqrt{\frac{7.59}{26.4}} + 1 = 0.58\right]$
	$k_{\rm c} = 2.25 \times 0.58 = 1.31$
	$f'_{cc,j}$ = 1.31×26.4=34.6 Mpa

Procedure	Calculations in SI Metric Units
Combined jacket and hoop confinement.	$f_{1,x} = 3.52 + 7.59 = 11.11$ Mpa
	$f_{1,y}$ =1.19+0.045= 1.24 Mpa
$f_1 = f_{1,s} + f_{1,j} \tag{16}$	$F_1 = max.(f_{1,x}, f_{1,y}) = 11.11 Mpa$
	$f_1 = min.(f_{1,x}, f_{1,y}) = 1.24 Mpa$
	$\alpha_1 = 1.25 \left(1.8 \sqrt{1 + 7.94 \frac{11.11}{26.4}} - 1.6 \frac{11.11}{26.4} \right) - 1.6 \frac{11.11}{26.4} -$
	1)=2.91
	$\alpha_2 = \left[1.4 \frac{1.24}{11.11} - 0.6 \left(\frac{1.24}{11.11}\right)^2\right]$
	$(-0.8]\sqrt{\frac{11.11}{26.4}} + 1$
	= 0.577
	$k_{\rm c} = 2.91 \times 0.577 = 1.68$
	$f'_{\rm cc,js}$ = 1.68×26.4=44.4 Mpa

Table 8: Derivation of the Dependable Concentric Compression Load in the Column UsingThe ACI 318 Building Code, in SI Metric Units

Specimens		R-3	
		40.6 Mpa	DIF 9.4 %
	Theoretical	44.4Mpa	

Table 9: Comparison	of the	Theoretical	Analvtical	and Ex	perimental	Data
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5.2. Parametric Study

5.2.1. Wrap Thickness Effect of CFRP

The confinement effect on the ductility of the specimens, the ductility ratios of all of the specimens were calculated. Ductility can be surveyed the ductility ratio, μ , which is defined by (Mohammad, Farshid & Amir, 2010):

 $\mu = \frac{\text{Ultimate displacement}}{\text{Elastic displacement}}$ (17)

Figure 8: show the stress-strain response of FE analysis results for the RC columns with three different wrap layers (one, three, and five). It is observed significant enhancement in the compressive strength and ductility of the columns compared to unstrengthen columns. With increasing of the number of layers, lateral confining pressure is increased. According to this Figure, that mean of load

Carrying capacities was increased 77%. Table 10 shows the ductility ratios of the specimens. The increasing proportions of ductility ratio (strengthened specimens to unstrengthened specimens) are provided in it. In addition, according to this Table the mean of ductility, ratios of rectangular specimens is 4.5 times of ductility ratios of unconfined specimens as it as mentioned, concrete is non-uniformly strengthened. Figure 9 shows distribution of the stress specimens, the shape of the cross section causes this phenomenon. In the specimens at any location of the cross section, different lateral pressure from FRP wrap is applied and therefore, the distribution of compressive stress becomes non-uniform

μ	Unstrengthened Ductility	Strengthened		Proportion
	Ratio (mm/mm)	Ductility Ratio		
		(mm/mm)		
R	1.54	R-1	4.35	2.82
		R-3	8.08	5.25
		R-5	9.03	5.86

Table 10: Ductility Ratios



Figure 7: Stress-Strain Curves of RC Columns



Figure 8: Contours of Axial Compressive Stress of Concrete Section of RC Column

5.2.2. Fiber Orientation Effect on Specimen

The effect of fiber orientation of FRP jacket on the stress-strain response of specimens R–3 is considered. The fire orientation 0°, 15°, 30°, and 45° with respect to horizontal were considered. Figure 9: show the effect of the fiber orientation on the stress-strain response of specimens R–3. it was observed that the hoop orientation of fibres (0°) results in the largest gain in ultimate stress, while the fibre orientation of $\pm 15^{\circ}$ leads to the largest ultimate strain.



Figure 9: Effect of Fiber Orientation on Stress-Strain Response of Specimen R-3

6. Conclusion

In the current study, FE simulation ANSYS and analytical model are used to evaluate the structural response of a CFRP-strengthened RC column. In addition, a parametric study consisting of three models (one, three, and five) CFRP layer is conducted. The following conclusions can be drawn from this model:

- 3-D finite element method results showed considerable increase in the axial compressive strength and ductility of the FRP-wrapped RC columns compared with the unstrengthened columns.
- when Increasing number of CFRP layers holding to the RC column soffit increases the stiffness of the column and increases its axial load capacity.
- RC column strengthening by bonding a single layer of CFRP to the tension face of the column increases rectangular column strength by 4.2%.
- RC column strengthening by bonding two layers of CFRP to the tension face of the column increases rectangular column strength by 30% and RC column strengthening by bonding three layers of CFRP to the tension face of the column increases rectangular column strength by 77%.
- The CFRP thickness has a significant effect on the strength and ductility of the columns so ductility ratio of rectangular are 4.5 times of ductility ratio of unconfined specimens.
- The gain in axial compressive strength was observed to be the highest in the columns wrapped with the hoop orientation; but the highest axial strain and ductility were observed in the columns wrapped with the fiber orientation of ±15° with respect to the horizon for rectangular column.

7. Recommendations

- In this study, the commercial Finite Element analysis software (ANSYS Academic 2020R2) was used in the analysis process. Comparative of studies Appling other available Finite Element software can be conducted to investigate which one can give more accurate results comparing with experimental investigations.
- In this study, the bond between concrete and CFRP fabric was Epoxy risen which simulate as layer (shell element). Although this simulation did not cause a significant error in the obtained results comparing with experimental investigations, the behavior of the concrete-CFRP bond and de-bonding issues can be concentrated analytically to get more accurate results especially regarding failure modes.
- In this study, The RC column external strengthening with CFRP was investigated. Strengthening with other available Fiber Reinforced Polymer (FRP) materials as Glass Fiber Reinforced Polymer (GFRP) can be concentrated to investigate the efficiency of the strengthening technique utilizing different materials with various properties.

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