RC Frame Strengthened by CFRP laminates

H.R Aghaei[1] , M.Izadi Nia[2] and I.Elyasian[3]

[1]Ms structural Engineer, Civil Engineering Faculty of Islamic Azad University Najafabad branch, Iran
E-mail: Msc_h_Aghaei@yahoo.com
[2]Assistant Professor, Head Of Faculty,Civil Engineering Faculty of Islamic Azad University Najafabad branch,Iran
E -mail: Izadiniam2002@yahoo.com
[3]Ms Structural Engineer, Department of Civil Engineering, the University of Yazd. Young Research club Related to Azad University Iran E-mail: iman.elyasian@gmail.com

ABSTRACT :

After occurrence of recent earthquakes in the most of world parts, scientific committees for reducing natural disasters and research centers declared based performance design, investigation faults, retrofitting, rehabilitation, new researches are related to strengthening of structures, notice performance, importance of structure, surface of earthquake levels, considering economic and feasibility [4], . . . One of strengthening method of RC frames is using FRP laminates. Nowadays is running a lot of researches in case of using FRP bars and laminates for strengthening structural members but research about frame strengthened by FRP in Finite element is limited. This paper presents the numerical study to simulate the behavior of retrofitted reinforced concrete (RC) frames.

KEYWORDS: RC Frame-Finite Element Method-CFRP Laminate-Rehabilitation

1 INTRODUCTION

Modeling the complex behavior of reinforced concrete is a difficult task in the finite element analysis of civil engineering structures. Only recently have researchers attempted to simulate the behaviour of reinforced concrete strengthened with FRP composites using finite element method.[8,9]
The software package ANSYS was used for this study.
The use of externally bonded fibre-reinforced polymer (FRP) composite strips/sheets for the strengthening of reinforced concrete (RC) structures has become very popular in recent years. This popularity has been due to the advantages of FRP composites, including their high strength-to-weight ratio, corrosion resistance, Environmental and chemical resistivity, electo magnetic insulation, Impact resist, Limit thickness and easy application, Clean and smooth finished surface. . [1,2].
A recent technique for the strengthening of RC frame is to provide additional FRP reinforcement, commonly in the form of bonded external FRP strips/sheets . Over the last few years, several experimental studies have been conducted on this new strengthening technique [4], which has established its effectiveness. While experimental methods of investigation are extremely useful in obtaining information about the composite behavior of FRP[3,5,10] and reinforced concrete, the use of numerical models such as the one presented in this paper helps in developing a good understanding of the behavior at lower costs

Objective and scope
1- How can we strengthen RC frame by FRP laminates?
2-What is effect of strengthening in joints of frame?
3- How does more thickness affect on concrete surface?
4- What is the best orientation of alignment for major direction of Fiber in columns, beams and joints?

2 Numerical Model

In this research we modeled RC frame with one span and 2 stories with columns by 35×35 cm and beams by 30×35cm dimensions and height of columns is 3 m and center to center of Columns is 5m under vertical and lateral loads calculated and considered according loading instructions of Iran 2800 code (Building and housing research center) [11]
At first farme modeled without longitudinal reinforcements then rebars added without FRP laminates then CFRP laminates added to beams, columns and joints of frame eventually analyzed strengthened frame.
In next step amount of lateral load increases by 2 coefficients of primary calculations according 2800 draft, with this new loading strengthened and unstrengthened frame analyzed.
In frame reinforced concrete modeled by Solid65 element [9], 4 columns,2 beams,4 joints meshed appropriately . CFRP laminates modelled by Shell43

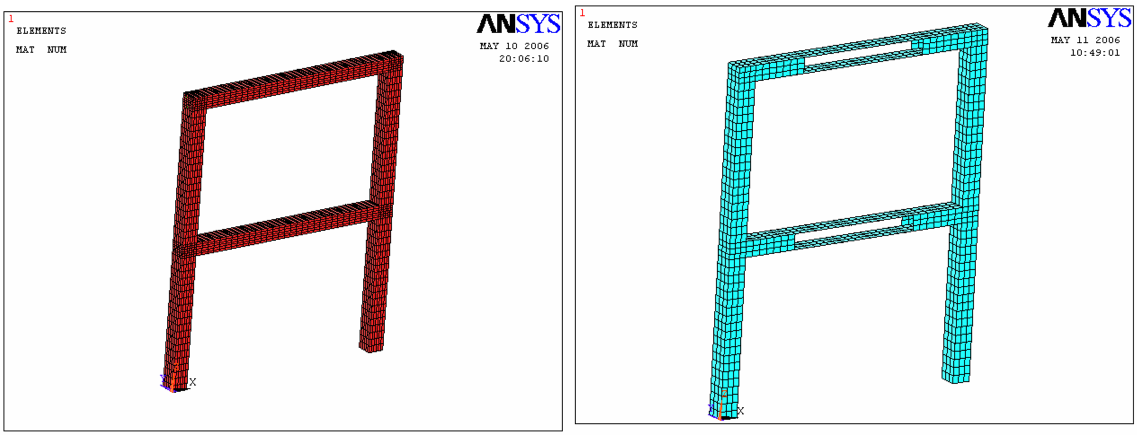

Figure-1 Frame element meshes Frame strengthened by CFRP Laminates

Longitudinal reinforcements modeled by Link8 element, for columns we used 8ϕ22 for beams 6ϕ22. Bars did not have any cut off and those were continuous and there were longitudinal bars at joints. transverse reinforcement modeled by smeared techniques in solid65 (concrete elements) With application vertical load monotonically by try and error process, load steps of loading is submitted below

pressure = 0.5kg /cm2 = 1750 kg/m Step-1
pressure = 0.75kg /cm2 = 2625 kg/m Step-2
pressure = 0.9kg /cm2 = 3150 kg/m Step-3
pressure = 1.1kg /cm2 = 3850 kg/m Step-4
pressure = 1.25kg /cm2 = 4375 kg/m Step-5
pressure = 1.35kg /cm2 = 4725 kg/m Step-6
pressure = 1.43 kg /cm2 = 5000 kg/m Step-7

F'c = 287kg/cm2 Concrete strength of 28 days
Fy = 3000 kg / cm 2 Tensile strength of bar
Failure criteria of concrete is William-Wrankle 1975
Shear transition coefficient for open crack is 0.24 and for closed crack is 0.98

Tensile strength of concrete is approximately $\frac{1}{10}$ compressive strength

We did not apply druker-pruger criteria because of not considering concrete confinement and its complexity. In this criteria we involve with internal friction angle and concrete bonding.Earthquake loads divided to 2 parts.one part is compressive (+) an other part is tensile (-) and put on other face of frame . we applied horizental and lateral load like vertical load step by step . CFRP lamintaes properties applied from research in reference [9]

Table-1 Laterla load applied to Frame

Storey	Step-1	Step-2	Step-3	Step-4	Step-5	Step-6	Step-7
Second	0.5 kg/cm2	0.7	0.9	1.1	1.28	1.38	1.43
	612.5kg	857.5	1102.5	1347.5	1568	1690.5	1750
First	0.25	0.35	0.45	0.55	0.64	0.64	0.715
	306.3	428.8	551.3	673.75	784	845.3	875

Table-2 CFRP laminates properties [9]

FRP composite	Elasticity modulus Mpa (ksi)	Major Poisson's ratio	Tensile Strength Mpa (ksi)	Shear Modulus Mpa (ksi)	Thickness of each ply mm (in)
CFRP	$E_x = 62,000(9000)$ $E_y = 4800(700)$ $E_z = 4800(700)$	$\nu_{xy} = 0.22$ $\nu_{xz} = 0.22$ $\nu_{yz} = 0.3$	958(138)	$G_{xy} = 3270(474)$ $G_{xz} = 3270(474)$ $G_{yz} = 1860(270)$	1.0(0.040)

3 Analysis Investigations

In this section follow to find differences between concrete strength effects, changes in FRP laminates thickness, fiber orientation to alignment of structural members . . .
We assumed RC frames have low strength of required in design so we retrofit it by CFRP laminates
Table-2 Comparison between Un strengthened control RC frame by various concrete strengths

Table-3 Comparison between Un strengthened RC frame by various concrete strengths

units of stress kg/cm2	RC Frame with out FRP Laminate f'c=287kg/cm2		RC Frame with out FRP Laminate f'c=144kg/cm2	
X displacement	1.44 cm		2.89cm	
	Min tensile	Max compressive	min	max
1principalstress	-97	27.4	-44	19.2
2 principal stress	-189	21	-110	15.1
3 principal stress	-241.5	5	-178.2	11.2
X stress min & max	-236	31.2	-171.3	228
Stress intensity	0.824	255.4	2	163. 2
X plastic strain	-0.561E-3	0.941E-4	-0.0032	0.432E-3
Equivalent plastic strain	0.197E-4	0.0021	0.416E-4	0.432E-2

In Table-3 observed in ultimate failure point compressive strength of concrete received near to ultimate strength and in some directions is extended that it shows concrete crush in these regions, either negative tensile stresses is extended tensile rupture strength of concrete and illustrated that concrete is cracked there , al though frame with more concrete ultimate strength in collapse time has less deflections
Thus with strengthen RC frame with CFRP laminates and comparison of different results we submit suitable methods and solutions for strenghening RC frames with CFRP against earthqaukes.
For preventation of brittle and sudden failure mode of delamination and debonding we wraped columns entirely and beams covered completely to ¼ span length in both sides [7]

Table-4 conclusion from analysis of strengthened frame

units of stress kg/cm2	Frame with 0.5 cm CFRP thickness f'c=287kg/cm2		1.11 cm
X displacement	min	max	
1 principal stress	-74	21.5	Stress in concrete
	-74	442.6	Stress in CFRP
2 principal stress	-190	19.2	Stress in concrete
	-190	92	Stress in CFRP
3 principal stress	-240	5.2	Stress in concrete
	-73.9	5.2	Stress in CFRP
X stress min & max	-191.5	18.1	Stress in concrete
	-673	442.6	Stress in CFRP
Stress intensity	2.8	241	Stress in concrete
	57.0	708.1	Stress in CFRP
X plastic strain	-0.5E-3	0.71E-4	Strain in concrete
Equivalent plastic strain	0	0.002293	Strain in concrete

Corresponding Table-5 is observed incensement in thicknesses of CFRP is negligible but it is proved with ascending thickness or plies (layers) with complete bonding internal stresses of concrete and FRP laminate are reduced, so FRP layer fail later

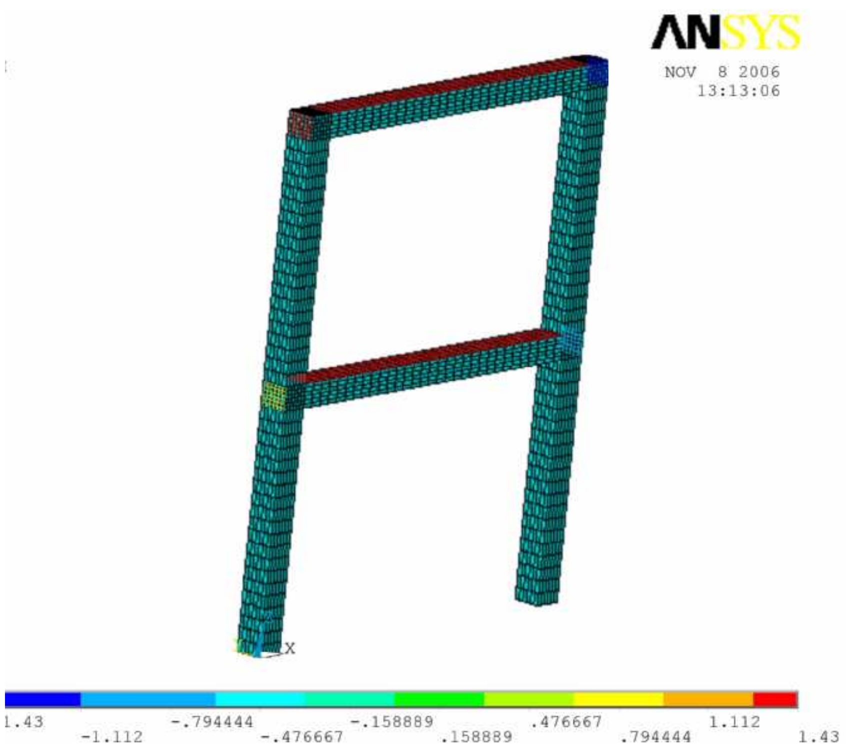

Figure-2 lateral and gravitational schemes imposed on frame

Table-5 Comparison of CFRP thickness incensement in strengthened RC frame

Units of stress kg/cm^2	Frame with 0.5 cm CFRP thickness		Frame with 1 cm CFRP thickness		Frame with1.5 cm CFRP thickness		F'c=144 kg/cm^2
X displacement	1.95 cm		1.65 cm		1.41 cm		
	Min	max	min	max	min	max	
1 principal stress	-48.8	18.9	-49.8	19.8	-50.3	15.2	Stress in concrete
	-48.8	448.5	-49.8	222	-50.3	177.6	Stress in CFRP
2 principal stress	-116.1	11.1	-121. 7	10.9	-116.2	9.4	Stress in concrete
	-345.4	58.9	-296.8	47.6	-265.3	38.6	Stress in CFRP
3 principal stress	-167.1	12.4	-163.8	13.6	-160.3	11.1	Stress in concrete
	-1101	12.4	-910.4	13.6	-806.2	11.1	Stress in CFRP
X stress min & max	-122.1	33.1	-117.2	33	-115.4	28	Stress in concrete
	-1101	448.4	-910.3	221.8	-805.9	167.4	Stress in CFRP
Stress intensity	2.4	159	0.462	158.1	0.52	159.9	Stress in concrete
	1.65	1119	0.462	128.7	0.27	823.3	Stress in CFRP
X plastic strain	-0.001312	0.393E-3	-0.0011	0.344E-3	-0.001	0.306E-3	Strain in concrete
Equivalent plastic strain	0	0.004222	0	0.003952	0	0.003917	Strain in concrete

Table-6 Lateral imposed load according Twice amount of 2800 Calculations

storey	Step-1	Step-2	Step-3	Step-4	Step-5	Step-6	Step-7
second	1 kg/cm^2	1.5	1.8	2.2	2.56	2.76	2.86
	1225 kg	1837.5	2205	2695	3136	3381	3500
First	0.5	0.75	0.9	1.1	1.28	1.38	1.43
	612.5	918.75	1102.5	1347.5	1568	1690.5	1750

3.2Effects of various concrete strength

One of important fault and lack in RC frame is poor constructed quality of concrete that is related to many parameters such as man powering, concrete curing, machinery for construction

Table -7 results from analysis of Un strengthened and strengthened frame imposed by Twice amount of 2800

Calculations for F'c=287 kg/cm2

Units of stress kg/cm2	Un strengthened Frame		Strengthened RC Frame by FRP laminates		F'c=287 kg/cm2
X displacement	3.09 cm		2.38cm		
	Min	max	min	Max	
1 principal stress	-96.8	31.3	-94.8	29.3	Stress in concrete
			0	599.7	Stress in CFRP
2 principal stress	-188	216	-183	20	Stress in concrete
			-293.1	81.6	Stress in CFRP
3 principal stress	-250.5	9.8	-284	8	Stress in concrete
			-846.9	0	Stress in CFRP
X stress min & max	-243.2	30.9	-275	28.1	Stress in concrete
			-846.9	599.7	Stress in CFRP
Stress intensity	2.4	282	0.98	262	Stress in concrete
			0	848.2	Stress in CFRP
X plastic strain	-0.0012	0.46E-3	-0.94E-3	0.23E-3	Strain in concrete
Equivalent plastic strain	0.15E-4	0.0033	0.16E-4	0.0022	Strain in concrete

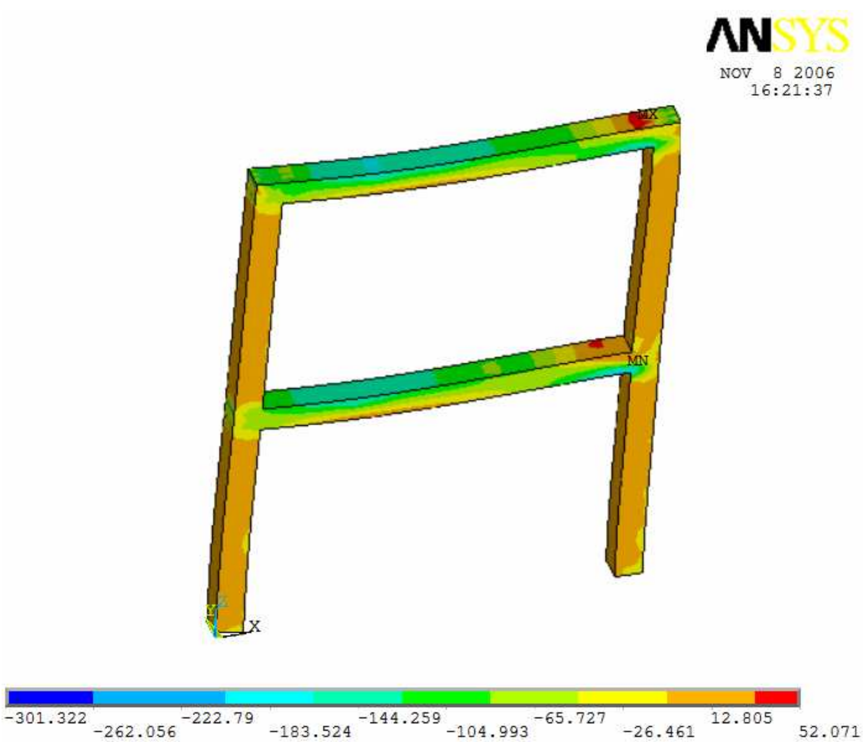

Figure -3 f’c=287 Kg/ cm2 and lateral load is imposed by code2800 coefficient 2
Plastic hinge Performance in beam (it illustrates weak beam- strong column philosophy)

Table -8 results from analysis of Un strengthened and strengthened frame imposed by Twice amount of 2800 Calculations for F'c=144 kg/cm2

units of stress kg/cm2	Un strengthened Frame		Strengthened RC Frame by FRP laminates		F'c=144 kg/cm^2
X displacement	7.14 cm		4.213 cm		
	Min	max	min	Max	
1 principal stress	-44.6	26.1	-39.3	25.6	Stress in concrete
			0	846.1	Stress in CFRP
2 principal stress	-108.5	18.7	-114	24.7	Stress in concrete
			-502	165.8	Stress in CFRP
3 principal stress	-136.8	3.1	-187.5	4.3	Stress in concrete
			-1344	0	Stress in CFRP
X stress min &max	-134.2	25.9	-169.7	23.8	Stress in concrete
			-1344	845.4	Stress in CFRP
Stress intensity	2.08	136.8	0.55	165.6	Stress in concrete
			1.7	1351	Stress in CFRP
X plastic strain	-0.006	0.58E-3	-0.0033	0.0013	Strain in concrete
Equivalent plastic strain	0.32E-4	0.0066	0	0.0049	Strain in concrete

We Observe because of strengthening ultimate strength and compressive stress reduces little but tensile stress increases some, in other expression cracking probability in section is increasing. FRP sheet is in passive mode (there is little stress in laminate), when concrete cracks and Reinforcement yielding is initiated and redistribution in section happens, eventually some of stress in reinforced concrete section transmits to FRP laminate.

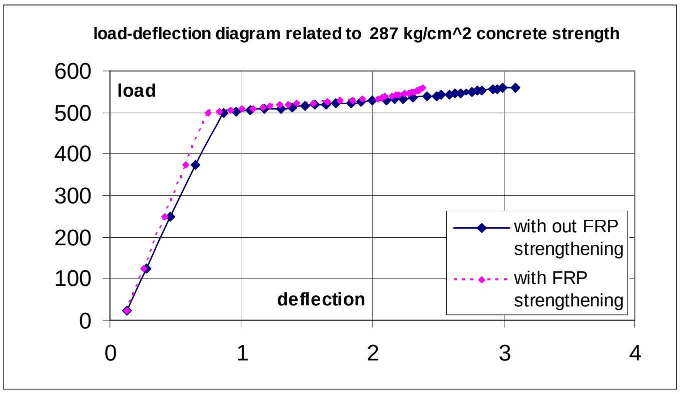

Figure- 4 Load-Deflection load for concrete strength with F’c=287 Kg/cm2 according twice amount of 2800 code calculations in Un strengthened and strengthened frame with FRP laminates

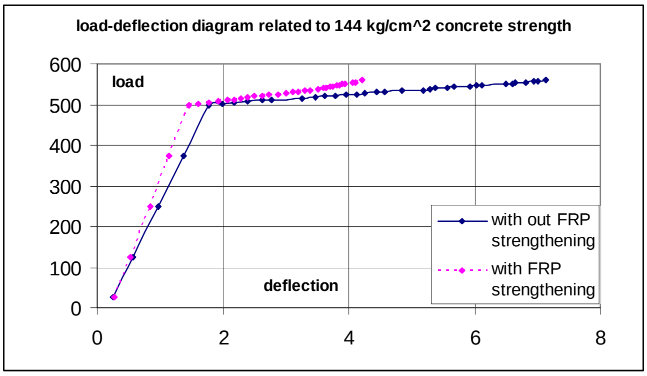

Figure- 5 Load-Deflection load for concrete strength with F'c=144 Kg/cm2 according twice amount of 2800 code calculations in Un strengthened and strengthened frame with FRP laminates

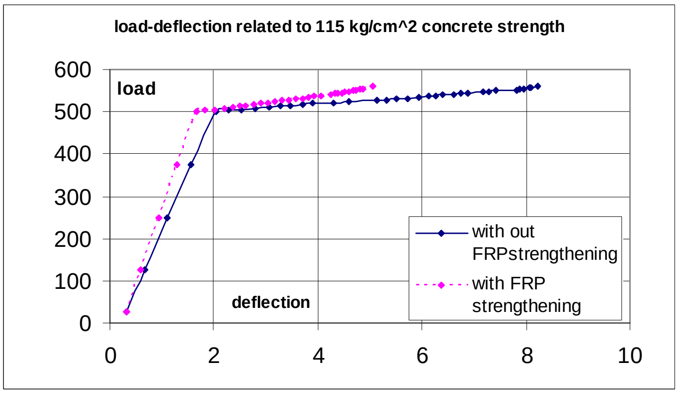

Figure- 6 Load-Deflection load for concrete strength with F'c=115 Kg/cm2 according twice amount of 2800 code calculations in Un strengthened and strengthened frame with FRP laminates

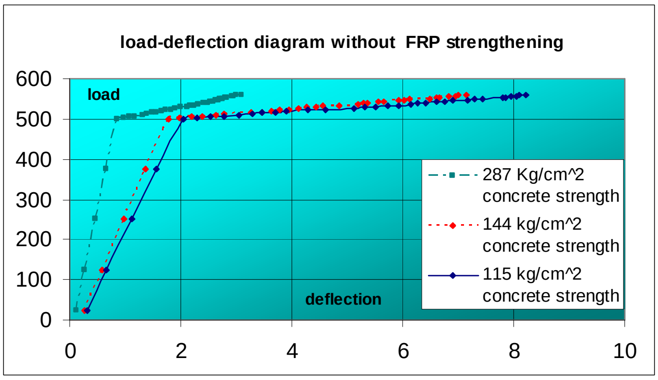

Figure-7 load-deflection for various concrete strength cm2 according twice amount of 2800 code calculations in Un strengthened frame

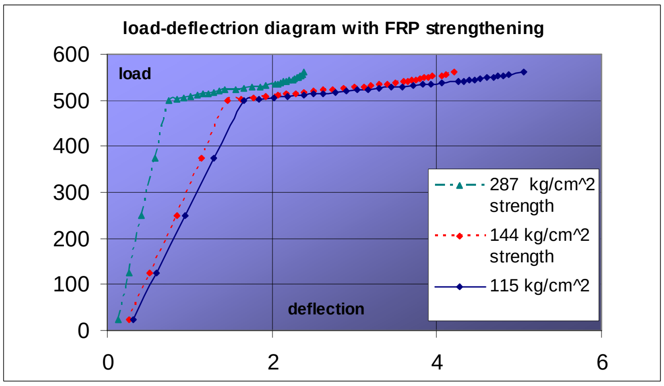

Figure-8 load-deflection for various concrete strength cm2 according twice amount of 2800 code calculations in Un strengthened frame

In figure 4 to 8 we observed with concrete ascending strength in Un strengthened or retrofitted form whole strength of frame is increased and deflection is decreased.
Convergence criteria is displacement and load increased statically and monotonically step by step to twice of amount of 2800 code calculations for earthquake(lateral load) recited in table-6 [6] and these pressures and loads increases for all frames. Further more we conclude with retrofitting by FRP laminates and more concrete strength we have less deflections.

Table -9 results from analysis of Un strengthened and strengthened frame imposed by Twice amount of 2800 Calculations for F'c=115 kg/cm2

units of stress Kg/cm2	Un strengthened Frame		Strengthened RC Frame by FRP laminates		F'c=115 kg/cm^2
X displacement	8.22 cm		5.06 cm		
	min	max	min	max	
1 principal stress	-42.7	11.8	-32.9	10.3	Stress in concrete
			0	955.1	Stress in CFRP
2 principal stress	-87.7	5.4	-96.7	8.3	Stress in concrete
			-597.2	237.8	Stress in CFRP
3 principal stress	-133.7	8.2	-141.6	4.2	Stress in concrete
			-1680	0	Stress in CFRP
X stress min &max	-114.2	11.9	-127.3	10.1	Stress in concrete
			-1680	953.9	Stress in CFRP
Stress intensity	4	124.8	0.71	127.8	Stress in concrete
			0.61	1691	Stress in CFRP
X plastic strain	-0.0078	0.0031	-0.0044	0.001	Strain in concrete
Equivalent plastic strain	0.46E-4	0.194	0.44E-4	0.008	Strain in concrete

3.3 Effects of arrangement **and orientation of columns wrapping Scheme by FRP**
While we apply FRP laminates in format of Wrap perpendicular to column alignment has better behavior and ductility to application them parallel by column longitudinal axis
If we modeled this by confinement effects of columns we would discover better special in circular and elliptical columns.

Table-10 Evaluation of fiber direction in strengthened frame

F'c=115kg/cm^2 units of stress kg/cm2	Strengthened frame with 0.5 cm FRP laminate wrap surrounding column		Strengthened frame with 0.5 cm FRP laminate Parallel to column axis	
X displacement	2.3 cm		2.51 cm	
	min	max	min	max
1 principal stress	-39.7	14.7	-31	18.7
	0	377.8	0	433

2 principal stress	-94.3	6.3	-93.4	8.7
	-425.2	86.2	-470	60
3 principal stress	-102.7	1.7	-149.1	4.3
	-1289	0	-1276	0
X stress min &max	-80.2	15.1	-98.4	13.5
	-1289	377.5	-1276	433
Stress intensity	1.7	128.2	1.8	131.2
	0.8	1316	0.43	1283
X plastic strain	0.0019	0.0008	-0.0026	0.0006
Equivalent plastic strain	0..00002	0.007	0.000025	0.005

4 Conclusions:

- For shear strengthening of beams, we use jacketing and wrapping entirely system for inhabitation of destructive without control and soon mode like debonding special in two ends of beams and for flexural strengthening of RC beam, we use above and below laminates in whole of spans, for strengthening columns wrapping scheme is more effective and workability in circular or elliptical strengthened columns are better than rectangular or squared strengthened columns. Stress distribution in this case is uniformly thus we apply squared or rectangular un strengthened columns with scheme of circular or elliptical scheme and void space is filled by material like grout epoxy without shrinkage
- In RC frame, Joints should cover thoroughly because of prevent of local crushing effects caused by cyclic loads, stress concentration and reinforcement congestion. So we can reduce sudden failures
- Incensement in CFRP thickness does not have considerable effect in strengthening of frame but Fiber orientation has more effect and proposal is utilizing FRP scheme in wrapping and jacketing instead longitudinal reinforcements specially we model confinement by drucker pruger criteria
- With notice to load-deflection diagram we conclude that strengthening RC frame by CFRP laminates forbids large deflection against lateral loads and inhibit failure (collapse) and turn over of structure.
- Deflection reduction in strengthened to un strengthened mode limits to maximum 62 % and for tensile stress is restricted to 15% , so it is illustrated CFRP ‘s influence for concrete cracking postpone

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