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Strengthening Of RC Circular Column Wrapped With Carbon Fiber Reinforced Polymer (CFRP)

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ABSTRACT: Carbon fiber reinforced polymers (CFRP) are very attractive to use in civil engineering applications due to its high strength, high durability, corrosion resistance, potentially high elasticity and high tensile strength criteria. This paper deals with Experimental and analytical studies of different parameters on concrete column wrapped with carbon fiber reinforced polymer (CFRP) are taken and investigated. Wrap thickness (l Layer), fiber orientation and the combinations of them were investigated. The results demonstrated significant enhancement in the compressive strength, stiffness and ductility of the CFRP- wrapped concrete column as compared to unconfined concrete column. An analytical model for ultimate stress and strain of confined concrete has been proposed.

KEYWORDS: CFRP, Concrete Column, FRP

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I.INTRODUCTION

Concrete is the most widely used construction material. Because of its specialty of being cast in any desirable shape, it has some serious deficiencies which, but for its remarkable qualities of resilience, flexibility, and ability to redistribute stress, would have prevented its use as a building material. Plain concrete is weak in tension and has limited ductility and little resistance to cracking. Micro cracks are present in concrete and because of its poor tensile strength; the cracks propagate with the application of load, leading to brittle fracture of concrete. In the past two decays, the use of carbon fiber reinforced polymer (CFRP) as an externally wrapping have achieved considerable popularity for the strengthening and repair of concrete structures. The CFRP wrapping have been used successfully for retrofitting and strengthening of existing structures and deficient reinforced concrete columns to increase the axial strength, shear strength, and increase the stiffness and deflection. In this application, the CFRP sheet mainly wrapped around the columns with fiber oriented mainly in the circumferential (hoop) direction. The fiber confines the cover concrete and increase the strength and stiffness. Reinforced concrete columns need to be laterally confined in order to ensure large deformation under applied loads before failure and to provide an adequate bearing capacity.

When the CFRP wrapped concrete column is subjected to an axial compressive loading, the concrete core expands laterally. This expansion is resisted by the CFRP and therefore the concrete core is changed to a three dimensional compressive stress state. In this state the performance of concrete core is significantly influenced by the confinement pressure. Many investigations have been conducted into the behaviour of CFRP- wrapped concrete column subjected to a Uniaxial compressive load, it will established that fibers should be aligned along the concrete core. In practice, however, almost all the columns are subjected to an eccentric axial load which can be resolved into a uniaxial compressive and bending moment.

1.1 MANUFACTURING PROCESS OF CFRP

The process for making carbon fibers is part chemical and part mechanical. The precursor is drawn into long strands or fibers and then heated to a very high temperature with-out allowing it to come in contact with oxygen.



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Without oxygen, the fiber cannot burn. Instead, the high temperature causes the atoms in the fiber to vibrate violently until most of the non-carbon atoms are expelled. This process is called carbonization and leaves a fiber composed of long, tight

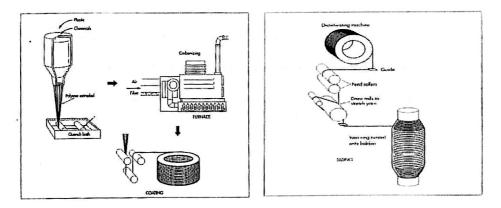


Fig. 1 shows the manufacturing process of Carbon Fibers.

The fibers are coated to protect them from damage during winding or weaving. The coated fibers are wound onto cylinders called bobbins inter-locked chains of carbon atoms with only a few non-carbon atoms remaining. Here is a typical sequence of operations used to form carbon fibers from polyacrylonitrile.

- Spinning, Stabilizing, Carbonizing, Sizing
- **1.2** Advantages of Carbon fiber reinforced polymer
 - Light weight, Corrosion resistant, High strength with a high fatigue resistant life, Can be installed with a minimal crew and common equipment

1.3 FRP CONFINEMENT OF CONCRETE

In FRP confined concrete the concrete core expands laterally when it is subjected to an axial compression load. This expansion of the concrete core is confined by the FRP jackets and thus transforms the concrete core to a 3-D compressive stress condition. The 3-D compressive stress condition serves to significantly increase the compressive strength and the ductility of brittle concrete. Compared with other cylindrical columns, FRP confined concrete columns behave uniquely when subjected to an axial compression load. The FRP begins to confine the concrete shortly after the unconfined concrete strength is reached. It then reverses the direction of the volumetric response, and the concrete responds through large and stable volume contraction. As a result, the stress-strain curve is characterized by a distinct bilinear response with a transition zone at a stress level near the strength of unconfined concrete. The axial stress-strain behavior of the FRP confined concrete.

1.4 SCOPE

The objectives is to increase the capacity of column, and therefore the strengthening measures aims at enlarging the cross sectional area or at enhancing the compressive strength of concrete by applying a confining action. The present study is to investigate the performance of RC circular columns with carbon fibre reinforced polymer wrap. The influence of key parameters such as materials properties, stiffness of CFRP wrap and concrete strength will be critically assessed. An analytical model for evaluating the structural capacity of CFRP wrapped circular column will also proposed.



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OBJECTIVES

- To study the mechanical behavior of CFRP oven.
- To study the effects of various wrap thickness on strength and ductility of concrete cylinders confined with CFRP composites.
- To study the stress- strain behavior of concrete cylinders confined with CFRP composites.
- To propose an analytical Modeling and to compare the experimental results with that of an analytical study on Finite element model.
- To propose the design methodology for the concrete column wrapped with CFRP.

II. METHODOLOGY

- We have studied the performance of strengthened columns using wrapped CFRP.
- M40 grade of concrete was used. •
- The resin ratio is constant.
- Linear and lateral strains were obtained and stress strain plot were drawn.
- An experimental tool has been developed and this was validated to that of the experimental results.

III. EXPERIMENTAL INVESTIGATIONS

3.1. Material Used

3.1.1 Cement:Cement used for all specimens was ordinary Portland pozzolona cement of 53 grade. This is conforming to IS 269-1976.

3.1.2. Fine Aggregate:The fine aggregate used for all specimens was conforming to IS-383-1970. It was sieved through 2.64mm sieve used.

3.1.3 Coarse aggregate: The coarse aggregate conforming to IS-383-1970 used in hard broken granite stone obtained from quarries in and around Chidambaram. The size of aggregate used wad 12mm to 20mm.

3.1.4 Water:Portable water was used for mixing concrete and curing the specimens.

3.1.5 Steel: In all columns have the internal tensile reinforcement as $6 \text{mm}\Phi$ and compression Reinforcement as 12mm D. The tension and compression reinforcement was Fe 415 grade, the clear cover of top, bottom and sides are kept as 40m.

3.1.6 Concrete: Ordinary Portland Pozzolona Cement from a single lot was used for the study. The physical properties and tests of cement are carried out in accordance with procedure laid down in IS- 1489. The maximum size of aggregate shall be 20 mm and the size of fine aggregate ranges between 0 and 4.75 mm. After casting, the specimens need to be allowed to cure in real environmental conditions for about 28 days so as to help the concrete to stabilize its own properties like compressive strength and modulus of elasticity. The strength of concrete under axial compression is determined by loading 'standard test cubes' (150 mm size) and cylinder (150mm Φ) failure in a compression testing machine, as per IS 516: 1959. The test specimens are generally tested after a curing period of 28 days.

3.1.7 Formwork: The columns were cast in PVC mould of Diameter 150mm, two halves of the pipes are fitted using circular clamps and fixed by bolds and nuts. The bottom is placed over a firm base plate and fixed properly by clamps. For casting columns, the inner surface of the PVC mould was applied by oil.

3.1.8 Carbon fibers:Carbon fibers have high tensile strength and young's modulus, but also a high specific strength compared to steel and glass fibers. The carbon fibers are in different forms like sheets, fabrics, strips and tendons. These carbon fibers have diameters ranging from 5 to 10 micrometers and have a characteristics charcoal colour. Carbon fiber has a two dimensional atomic structure creating different properties longitudinally and transverse direction. Along the longitudinal axis of the fiber the modulus and strength are high as opposed to the transverse axis which provides little of either strength or modulus. These fibers exhibit high durability in high temperature and moisture environments when subjected to fatigue loading.



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3.1.9. CFRP Tensile strength

The CFRP is to be used in this study for strengthening of columns and the mechanical properties of CFRP are obtained from appropriate tests prescribed as per ASTM Standards (ASTM -D 3916 -84). Tensile tests are carried out using a universal testing machine the results are shown in table

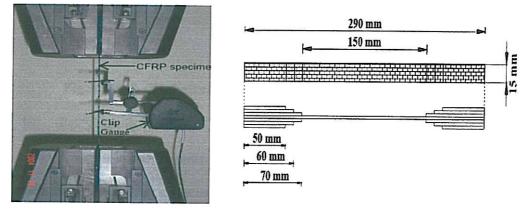


Fig .2 shows the tensile tests on CFRP carried out in universal testing machine

Table.1.shows the typical	l mechanical properties of CFR	Р
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Unidirectional advanced composite materials	Fiber content (% BY WT.)	Density (KG/M3)	Longitudinal tensile modulus	Tensile strength (MPa)
Carbon / Epoxy CFRP laminate	65-75	1600-1900	120-250	1200-2250

3.1.10 Physical properties of materials

Table -2: Specific gravity

S.No	Characteristics	value	Total Water Absorption
1	Specific gravity of cement	3.15	-
2	Specific gravity of FA	2.64	1.99%
3	Specific gravity of CA	2.72	3.645

Table -3: Physical properties of steel bar

S.No	Diameter of Bar	Yield s	strength	Ultimate	Percentage	of
		N/mm2		strength	Elongation (%)	
1	12mm	884.84		655.56	16.1	
2	6mm	442.42		612.7	32.9	



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Table-4: The Mix proportion

Water	Cement	Fine aggregate	Coarse aggregate
191.6 lits	450 Kg	596.9 Kg	1193.81
0.4	1	1.326	2.653

3.1.11 Specimen Details:

Dia of Specimen $=150 \text{mm}\phi$ Height of Specimen =1200 mm

Main Reinforcement =12mm ϕ - 6Nos

Stirrups $=6 \text{mm} \phi$ -120mmc/c CFRP =0.42 mmAxial load (Pu) =392.593 KN

3.2 TEST SPECIMEN PREPARATION:-

The planned experimental program consists of five columns of 1200mm length x 150mm Φ . Out of the five columns two are controlled specimen and three are wrapped with CFRP woven. Columns were wrapped with standard procedure indicated below

I.Surface Preparation. II. Putty Application, III. Primer Application, IV. Hand of saturate, V.CFRP sheet application



fig .3 shows Surface Preparation and cleaning of the specimen

3.3 TEST SETUP

- The specimen was capped at its top and bottom and axially placed on the column testing frame.
- LVDT placed at 120m degree a part to measure the lateral deflection of the concrete specimen at its mid height.
- Three deflectometer was placed vertically over the top and bottom of the cap to measure the axial compression(change in length)and one placed in center of the specimen.

An electrical strain gauge was placed horizontally at the mid height of the specimen to measure the lateral strain



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3.4 TESTING PROCEDURE:

- After the specimen was placed axially, the specimen was loaded through a hydraulic jack.
- Transverse deflection of the specimen taken from the out put received from LVDT s. Strain in the axial and the lateral direction was measured using the strain gauges on the specimen



Fig 4 show the Testing Arrangements and Instruments and Setup of Conventional Column



Fig. 5 Testing Setup CFRP Wrapped Specimen



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3.5 Experimental results and discussions

An experimental investigation was carried out on fie high strength concrete columns. The parameters included ultimate load, axial stress, and axial deflection.

specimen 1		specimen 2			S	pecime	n 3	sp	ecimen	4	specimen 5			
Load (kN)	Axial Stress (Mpa)	Axial Deflect ion from Dial	Load (kN)	Axial Stress (Mpa)	Axial Deflecti on from Dial	Load (kN)	Axial Stress (Mpa)	Axial Deflecti on from Dial	Load (kN)	Axial Stress (Mpa)	Axial Deflec tion from Dial	Load (kN)	Axial Stress (Mpa)	Axial Deflecti on from Dial
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	1.41	0	25	1.41	0	25	1.41	0.06	25	1.41	0	25	1.41	0
50	2.83	0.02	50	2.83	0.01	50	2.83	0.13	50	2.83	0.01	50	2.83	0
75	4.24	0.04	75	4.24	0.04	75	4.24	0.19	75	4.24	0.02	75	4.24	0
100	5.66	0.07	100	5.66	0.06	100	5.66	0.26	100	5.66	0.03	100	5.66	0.01
125	7.07	0.11	125	7.07	0.08	125	7.07	0.3	125	7.07	0.04	125	7.07	0.02
150	8.49	0.15	150	8.49	0.13	150	8.49	0.35	150	8.49	0.05	150	8.49	0.03
175	9.9	0.2	175	9.9	0.16	175	9.9	0.4	175	9.9	0.06	175	9.9	0.04
200	11.3	0.25	200	11.3	0.18	200	11.3	0.48	200	11.3	0.08	200	11.3	0.05
225	12.7	0.32	225	12.7	0.24	225	12.7	0.53	225	12.7	0.12	225	12.7	0.06
250	14.1	0.38	250	14.1	0.29	250	14.1	0.58	250	14.1	0.16	250	14.1	0.07
275	15.6	0.45	275	15.6	0.35	275	15.6	0.65	275	15.6	0.19	275	15.6	0.08
300	17	0.49	300	17	0.38	300	17	0.7	300	17	0.24	300	17	0.09
325	18.4	0.53	325	18.4	0.42	325	18.4	0.77	325	18.4	0.27	325	18.4	0.1
350	19.8	0.58	350	19.8	0.47	350	19.8	0.83	350	19.8	0.31	350	19.8	0.12
375	21.2	0.6	375	21.2	0.5	375	21.2	0.88	375	21.2	0.35	375	21.2	0.14
400	22.6	0.63	400	22.6	0.54	400	22.6	0.94	400	22.6	0.38	400	22.6	0.16
425	24.1	0.68	425	24.1	0.59	425	24.1	0.99	425	24.1	0.41	425	24.1	0.18
450	25.5	0.72	450	25.5	0.62	450	25.5	1.06	450	25.5	0.44	450	25.5	0.2
475	26.9	0.78	475	26.9	0.65	475	26.9	1.11	475	26.9	0.46	475	26.9	0.24
500	28.3	0.83	500	28.3	0.69	500	28.3	1.17	500	28.3	0.5	500	28.3	0.26
525	29.7	0.89	525	29.7	0.73	525	29.7	1.21	525	29.7	0.55	525	29.7	0.28
550	31.1	0.92	550	31.1	0.81	550	31.1	1.26	550	31.1	0.59	550	31.1	0.32
575	32.5	0.99	575	32.5	0.88	575	32.5	1.3	575	32.5	0.64	575	32.5	0.36
600	34	1.14	600	34	0.92	600	34	1.35	600	34	0.66	600	34	0.39
625	35.4	1.27	625	35.4	0.99	625	35.4	1.4	625	35.4	0.7	625	35.4	0.4
650	36.8	1.39	650	36.8	1.16	650	36.8	1.46	650	36.8	0.75	650	36.8	0.42
			675	38.2	1.31	675	38.2	1.52	675	38.2	0.79	675	38.2	0.45
						700	39.6	1.58	700	39.6	0.82	700	39.6	0.48
						725	41	1.63	725	41	0.84	725	41	0.5
						750	42.4	1.72	750	42.4	0.87	750	42.4	0.52
						775	43.9	1.84	775	43.9	0.9	775	43.9	0.53
						800	45.3	1.97	800	45.3	0.95	800	45.3	0.56
						825	46.7	2.22	825	46.7	0.98	825	46.7	0.58
									850	48.1	1.05	850	48.1	0.63
									875	49.5	1.12	875	49.5	0.68
									900	50.9	1.19	900	50.9	0.73



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52.3 1.24

1.37

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0.85

52.3

53.8

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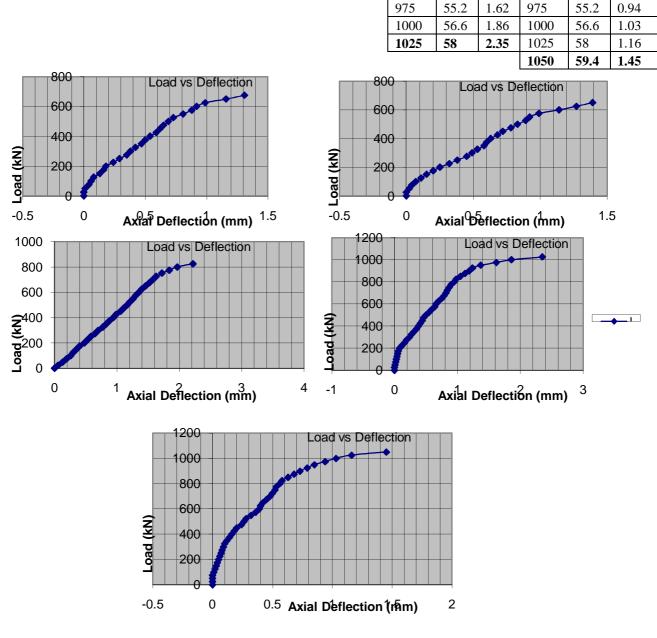
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IV.ANALYTICAL STUDY

4.1 ANSYS

One of the reasons for wide application of the finite element software is due to the availability of number of package programs. Today the most effective and commonly used software is ANSYS. They are mostly graphics oriented. The processor modules involve mathematical computations that requires large arithmetic operations i.e., number of crunching operations in the computer. ANSYS is a complete software package developed by ANSYS Inc – USA.



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It is used by engineers world wide in virtually all fields of engineering:

Structural ,Thermal,Fluid(Acoustics and Fluid analysis),Low and High frequency electromagnetic

4.1.1 Ansys Modeling

ANSYS modeling is generally performed by mapped meshing or free meshing. Mapped mesh modeling is a procedure in which meshes are generated in even order. Free mesh modeling is the one in which the meshes are generated in random. In this thesis work, mapped mesh modeling is adopted.

4.1.2 Methods of Modal Generation

•

The construction of a single planar or 3D finite element modal usually requires a variety of mesh generation techniques. Several mesh generation techniques, which are available in commercial programs, are as follows.

Single Node and Element Generation

Digitizing Input, Pattern generation, Region Generation, Dragging Generation

4.1.3 Mesh Generation

There are two methods of meshing: 1.Granular meshing, 2.Coarse meshing

Granular type of meshing is the one in which meshes formed are close to each other leading to increase in approximation of the result. Coarse meshing is that in, which meshes formed give results approximately. Generally coarse type of meshing of meshing is used as it gives better results in modeling of beams thus adopted totally there were 6929 nodes in the column model generation for analysis. Load, Young s modulus of concrete, dimensions of the specimen, volume ration was the prime inputs given. For these inputs the deflection at the mid span of the beam was obtained as output, he corresponding results of deformation and graphical representation are show in figure below.

Real constant number	Element type	Diameter in mm	Area in mm ²
1	Solid 65	-	-
2	Solid 46	-	-
3	Link 8	dia 12	50.265
4	Link 8	dia 6	28.274

4.1.4 Modelling of Column, Element type:

V. CONCLUSION

The element analysis of the concrete column wrapped with carbon fiber reinforced polymer (CFRP) are taken and investigated. The study considered the ultimate load carrying capacity, deflection and cracking pattern of the confined and confined Columns. Two set of reinforced concrete columns, in two column for control column and three columns for confined CFRP Columns. From the test results and calculated strength values, the following conclusions.

1. The ultimate load carrying capacity of the strengthened column is more than the controlled column.

2. Analytical analysis is also carried out to find the ultimate moment carrying capacity and compared with the experimental results.

3. Use of CFRP columns improves load carrying capacity, delay crack formation and energy absorption capability of column reinforced with CFRP.

4. The 80% damaged columns increases load carrying capacity. When strengthened with 1200mm height and 0.42mm thick of CFRP sheet in single layer for full longitudinal direction as compared with control column.

REFERENCES

- 1. M.N.S. Hadi*(2006) "Behavior of FRP wrapped normal strength concrete columns under eccentric loading" ACI structural Journal vol 72, PP 503-511.
- 2. R.Eid^a*, A.N. Dancy Gier^b (2006) "Confinement effectiveness in circular concrete columns" ACI structural Journal Vol. 28., PP 1885-1896.
- Omar Chaallal, M.ASCE¹; Munzer Hassan²; and Michel LeBlanc³ "Circular Columns Confined with FRP: Experimental versus Predictions of Models and Guidelines" Journal of Composites for Construction., ASCE/JAN/FEB 2006 vol.10 PP 4-12.



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- Omar Chaallal¹; Mohsen Shahawy²; and Munzer Hassan³ "CFRP Repair and Strengthening of Structurally Deficient Piles: Design Issues and 4. Field Application" Journal of Composites for Construction., ASCE/JAN/FEB 2006 vol.10 PP 26-34.
- S. P. Tastani¹; S. J. Pantazopoulo, M.ASCE²; D.Zdoumba³; V. Plakantaras⁴; and E.Akritidis⁵ "Limitations of FRP Jacketing in Confining Old-5. Type Reinforced Concrete Members in Axial Compression Issues" Journal of Composites for Construction., ASCE/JAN/FEB 2006 vol.10 PP 13-25
- R.Eid¹ and P.Paultre, M.ASCE² ., "Analytical Model for FRP- Confined Circular Reinforced Concrete Columns" Journal of Composites for 6. Construction., ASCE/ SEP/OCT 2008 vol.12 PP 541-551.
- Ahmed S.Debaiky, Ph.D., P.E.¹; Mark F.Green, Ph.D., "Modeling of corroded FRP-Wrapped Reinforced concrete Columns in Axial 7. Compression" Journal of Composites for Construction. ASCE/NOV/DEC 2007 vol.11 PP 556-564.
- 8. Athanasios 1. Karabinis¹; Theodoros C. Rousakis²; and Georgia E.Manolitsi² "3D Finite-Element Analysis of Substandard RC Columns Strengthened by Fibre-Reinforced polymer Sheets" Journal of Composites for Construction., ASCE/ SEP/OCT 2008 vol.12 PP 531-540.
- Amr Shaat¹ and Amir Z. Fam, M.ASCE² "Slender Steel Column Strengthened Using High -Modulus CFRP Plates for Buckling Control" 9 Journal of Composites for Construction., ASCE/ JAN/FEB 2009 vol.13 PP. 2-12
- Valerio Alecci, Ph.D¹., Silvia Briccoli Bati²; and Giovanna Ranocchiai³, "Study of Brick Mesonry Columns Confined with CFRP Composite 10. "Journal of Composites for Construction., ASCE/ MAY/JUN 2009 vol.13 PP. 179-187. 11. R. Eid¹; N.Roy²; and P. Paultre, M.ASCE³ "Normal- and High-Strength Concrete Circular Elements Wraooed with FRP Composites" Journal
- of Composites for Construction., ASCE/ MAR/APR 2009 vol.13 PP. 113-124
- Azadeh Parvin¹; Selcuk Altay²; Cem Yalcin³; and Osman Kaya⁴ "CFRP Rehabilitation of Concrete Frame Joints with Inadequate Shear and Anchorage Details" Journal of Composites for Construction., ASCE/ JAN/FEB 2010 vol.14 PP. 72-82
 Raafat EI-Hacha, M.ASCE¹; Mark F. Green, M.ASCE²; and Gordon R. Wight, M.ASCE³ "Effect of Severe Environmental Exposures on
- CFRP Wrapped Concrete Columns" Journal of Composites for Construction., ASCE/ JAN/FEB 2010 vol.14 PP. 83-93 14. Kang-Kyu Choi¹; and Yan Xiao² "Analytical Model of Circular CFRP Confined Concrete-Filled Steel Tubular Columns under Axial
- Compression" Journal of Composites for Construction., ASCE/ JAN/FEB 2010 vol.14 PP. 125-133
- J. F. Chen¹; J. Ai²; and T. J. Stratford³ "Effect of Geometric Discontinuities on Strains in FRP-Wrappaed Columns" Journal of Composites for 15. Construction., ASCE/ MAR/APR 2010 vol.14 PP. 136-145