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Confinement of High Strength Concrete (HSC) Columns with Fibre Reinforced Polymer Wraps

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***Abstract*— This paper presents the results of an experimental study on high strength concrete columns with external GFRP wraps. A total of seven specimens of 150 mm diameter and 300 mm height were cast and tested. One specimen was used as reference and the remaining six specimens were wrapped with three GFRP materials having different thickness. The columns were tested under uni-axial compression up to failure. Necessary measurements were taken for each load increment. The HSC columns with GFRP wrapping exhibited improved performance in terms of strength, deformation, ductility and energy absorption.**

***Keywords*—** Ductility, Energy absorption, GFRP, High strength concrete,

I. INTRODUCTION

Concrete with strength higher than 40 MPa is generally referred to as high strength concrete. Some basic concepts relating to strength and ductility have been introduced in ACI code with respect to the compression member (American Concrete Institute, 1999). With developments in technology, the use of high strength concrete members has proved to be most promising in terms strength, stiffness, durability and economy (Raviz and Saatcioglu, 1997). As the strength of concrete increases, it becomes more brittle. The lack of ductility of high strength concrete columns can result in sudden failure. Several research works have proved that the strength and ductility can be improved by the use of spiral confinement, rectangular and circular lateral ties (Yong *et al.*, 1988). In recent years, external wrapping has been identified as an effective method of confining concrete. Among the various materials available for the purpose, FRP has proved to be more beneficial. The application of FRP in the construction industry can eliminate the brittle behavior of high strength concrete. FRP is particularly useful for strengthening columns and other unusual shapes. Several research studies have been reported on improving the strength and ductility of normal strength columns. Only limited literature is available on enhancing the ductility of high strength concrete columns. Hence an attempt has been made to investigate the strength and ductility performance of high strength concrete columns with external GFRP wrapping (Demer and Neale, 1999; Mirmiran and Shahawy, 1997; Hadi and Li, 2004).

1.1 Research significance: In recent years. ductility has becomes an important design parameter for better performance under varying environments. In particular, ductility of column places a crucial load in the event of the earthquakes. Ductility can be important by internal confinement or external confinement. High strength concrete columns inherently lack ductility. In this research an attempt is made to study the strength deformation response of HSC columns utilizing the technique of external confinement with fiber reinforced polymer composites.

II. EXPERIMENTAL INVESTIGATION

An Experimental investigation was conducted on seven column specimens having 300mm height and 150mm diameter. Six bars of 8mm diameter for longitudinal reinforcement and 6mm diameter mild steel ties spaced at 115mm for lateral ties were used for all columns. Out of the seven columns, one reference column was tested without any wrapping and the remaining six columns were wrapped with GFRP of varying configuration and thickness. The details of the specimens are presented in Table I.

TABLE I. SPECIMEN DETAILS

Sl No	Detail of specimens	Diameter (mm)	Type of GFRP (mm)	Thickness of GFRP (mm)
1.	S8R	150	-	0
2.	S8CSM3	150	CSM	3
3.	S8CSM5	150	CSM	5
4.	S8WR3	150	WR	3
5.	S8WR5	150	WR	5
6.	S8UDC3	150	UDC	3
7.	S8UDC5	150	UDC	5

2.1Material Properties: M60 concrete was used for casting the specimens. The mix ratio adopted was 1:1.73:2.51:0.34:0.8 % (cement: fine aggregate: Coarse aggregate: Water: Hyperplastizicer). The characteristic compressive strength achieved was 63.64 MPa. The concrete composition is presented in Table II. The steel used for longitudinal reinforcement was ribbed steel with yield strength of 450 MPa and that for lateral ties was mild steel with an yield strength of 300 MPa. The properties of glass Fibre Reinforced Polymer (GFRP) is presented in table III.

TABLE II. CONCRETE COMPOSITION

Sl. No	Materials	Quantity
1.	53 Grade cement (kg /m^3)	450
2.	Fine aggregate(kg /m^3)	780
3.	Coarse aggregate(kg /m^3) 20mm 10mm	 680 450
4.	Water(kg /m^3)	160
5.	Silica fume(kg /m^3)	25
6.	Hyper plasticizer(Glunium B223)	0.8 % by weight of binder

2.2 Preparation and Casting of Specimens: The specimens were prepared by casting them in asbestos cement pipe moulds. After sizing, the pipes were placed firmly in position using a lean mix mortar at the base. The bottom faces of pipes were covered with polymer sheets position to avoid any leakage. Cover blocks were placed at appropriate locations to ensure adequate cover to the reinforcement. The interior of the pipes were applied a liberal coat of lubricating oil to prevent concrete from adhering to the asbestos cement pipe. Steel reinforcement cage was prepared for each specimen according to the requirements. The reinforcement cages were placed into the asbestos cement pipe formwork and positioned in such a way that pre- determined cover was available on all sides. The concrete mix was filled into the moulds in layers. Adequate compaction was carried out using needle vibrator to avoid honey combing. The specimens were removed from the moulds without any damage and cured in a standard manner for a period of 28 days.

2.3 3 Wrapping with FRP: The cured specimens were prepared for wrapping with FRP. The surfaces of the specimens were ground with a high grade grinding wheel to remove loose and deleterious material from the surface. A jet of compressed air was applied on the surface to blow off any dust and dirt. Then, all surface cavities were filled up with mortar putty to ensure a uniform surface and to facilitate proper adhesion of FRP wrapping. The wrapped surfaces were gently pressed with a rubber roller to ensure proper adhesion between the layers and proper distribution of resin. Fig.1-2 show the application of FRP wrap on the surface of the column specimen

TABLE III. PROPERTIES OF GLASS FIBRE REINFORCED POLYMER (GFRP)

Type of Fibre in GFRP	Thickness (mm)	Tensile Strength (Mpa)	Ultimate Elongation (%)	Elasticity Modulus (Mpa)
Chopped Strand Mat	3	126.20	1.60	7467.46
Chopped Strand Mat	5	156.00	1.37	11386.86
Uni-Directional Cloth	3	446.90	3.02	13965.63
Uni-Directional Cloth	5	451.50	2.60	17365.38
Woven Rovings	3	147.40	2.15	6855.81
Woven Rovings	5	178.09	1.98	8994.44

Fig.1 GFRP Wrapping under Progress

Fig 2 GFRP Wrapped Specimen

III. EXPERIMENTAL SETUP

Testing of specimens having a height of 300mm was carried out in a loading frame of 2000 KN capacity. The instruments used for testing included deflecto meters having a least count of 0.01mm and a lateral extensometer with a least count of 0.001mm. The specimen was placed with capping at both ends. The load was applied in increments using a loading jack. Axial compression was measured using two dial gauges placed at top and bottom of the specimen.

IV. THE RESULTS AND DISCUSSION

The test results are presented in Table IV.

4.1 Stress-Strain Behaviour of GFRP Wrapped RC Columns

The stress-strain curves for all concrete columns (with and without GFRP wrapping) tested for the experimental investigations are presented in Figs.3.

TABLE IV. **TEST RESULTS AT ULTIMATE STAGE**

Specimen designation	Ultimate Load (kN)	Ultimate Axial Stress (Mpa)	Ultimate Axial Deflection (mm)	Ultimate Micro-Strain	Deflection Ductility	Energy Ductility	Energy Absorption per unit volume
S8R	1150.00	65.08	2.93	9766.67	1.47	1.74	2370.13
S8CSM3	1220.00	69.04	3.02	10066.67	1.67	1.99	2731.73
S8CSM5	1300.00	73.56	3.32	11066.67	1.79	2.17	3339.75
S8UDC3	1370.00	77.53	4.70	15666.67	2.51	3.05	5272.78
S8UDC5	1450.00	82.05	4.83	16100.00	3.77	5.22	5559.63
S8WR3	1270.00	71.87	3.92	13066.67	1.75	1.96	4225.40
S8WR5	1320.00	74.70	4.28	14266.67	3.29	4.32	4697.78

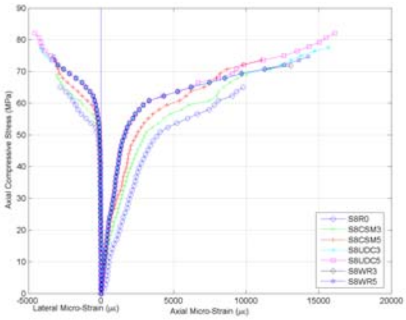


Fig.3 Stress -Strain Curves for all Columns

The stress-strain curves indicate the general trend that all the columns exhibit similar behaviour in the initial phase. The differences arising due to the variations in wrapping thickness and material are first exhibited in the form of different levels of yield stress, although the differences are not as high as those for ultimate stresses. The yield point on the stress-strain curve signifies the point at which the concrete core begins to crush. Until reaching the yield point, the concrete core is sound and resists much of the load applied on it.

The columns with UDCGFRP wrapping normally showed better stress-strain behaviour. The stress and strain level reached by UDCGFRP wrapped columns were higher than those reached by corresponding columns with CSMGFRP or WRGFRP of the same thickness. The columns wrapped with 3 mm thick CSMGFRP and WRGFRP showed similar stress-strain trends up to failure. But the behaviour of 5 mm thick WRGFRP wrapped column was better than that of 5 mm thick CSMGFRP wrapped column.

The stress and strain levels reached by 3 mm thick UDCGFRP wrapped column and 5 mm thick WRGFRP wrapped column were very close, but the stress-strain paths followed by the two were different. The stress-strain curve for 3 mm thick UDCGFRP was very closely followed that of column with 5 mm thick UDCGFRP, but failed at lower stress value. The columns with 3 mm thick CSMGFRP and WRGFRP reached same stress levels, but the strain for CSMGFRP was lower. The stress and strain levels reached by 3 mm thick UDCGFRP wrapped column were higher than those reached by even 5 mm thick CSMGFRP and WRGFRP wrapped columns.

4.2 Ultimate stress: The thickness of GFRP wrap and types of wrapping material are the most influential parameters. The increase in ultimate strength was found to be 6.07% for specimen with 3mm thick CSM wrapping and 13.04% for specimen with 5mm thick CSM wrapping when compared to the reference column. The increase in ultimate strength was found to be 10.43% for specimen with 3mm thick WR wrapping and 14.98% for specimen with 5mm thick WR wrapping when compared to the reference column. The increase in ultimate strength was found to be 19.13% for specimen with 3mm thick UDC wrapping and 26.09% for specimen with 5mm thick UDC wrapping when compared to the reference column. Fig.4 shows the increase in ultimate stress when compared to the reference column.

The increase in ultimate strength was found to be 4.80% for specimen with 3 mm thick WR wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in ultimate strength was found to be 1.55% for specimen with 5 mm thick WR wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in ultimate strength was found to be 12.30% for specimen with 3 mm thick UDC wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in ultimate strength was found to be 11.56% for specimen with 5mm thick UDC wrapping when compared to the specimen with CSM wrapping of same thickness.

4.3 Ultimate Axial Deformation: The increase in axial strain was found to be 3.07% for specimen with 3mm thick CSM wrapping and 13.31% for specimen with 5mm thick CSM wrapping when compared to the reference column. The increase in axial strain was found to be 33.78% for specimen with 3mm thick WR wrapping and 46.07% for specimen with 5mm thick WR wrapping when compared to the reference column. The increase in axial strain was found to be a 60.48% for specimen with 3mm thick UDC wrapping and 64.45% for specimen with 5mm thick UDC wrapping when compared to the reference column. Fig.5 shows the increase in ultimate axial micro - strain when compared to the reference column.

The increase in ultimate axial deformation was found to be 29.87% for specimen with 3 mm thick WR wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in ultimate axial deformation was found to be 28.92% for specimen with 5 mm thick WR wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in ultimate axial deformation was found to be 55.63% for specimen with 3 mm thick UDC wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in ultimate axial deformation was found to be 45.48% for specimen with 5mm thick UDC wrapping when compared to the specimen with CSM wrapping of same thickness.

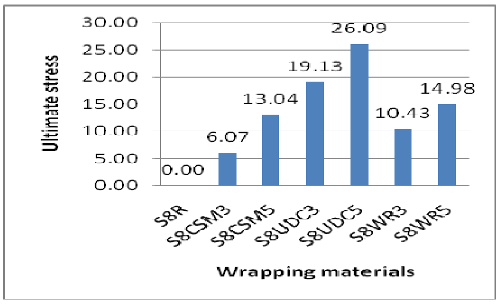


Fig 4. Ultimate Stress for Wrapped Specimens

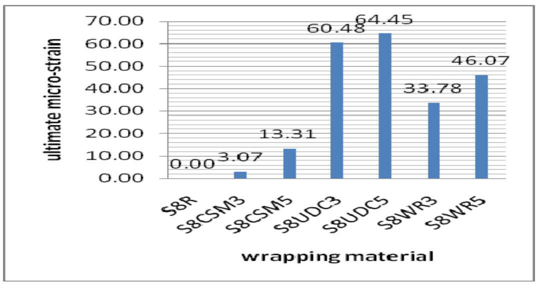


Fig.5. Ultimate Axial Micro- strain Wrapped Specimens

4.4 Deflection ductility: Deflection ductility was found to be 13.37% for specimen with 3mm thick CSM wrapping and 21.77% for specimen with 5mm thick CSM wrapping when compared to the reference column. Deflection ductility was found to be 19.05% for specimen with 3mm thick WR wrapping and 123.81% for specimen with 5mm thick WR wrapping when compared to the reference column. Deflection ductility was found to be 70.75% for specimen with 3mm thick UDC wrapping and156.46 % for specimen with 5mm thick UDC wrapping when compared to the reference column. Fig.6 shows the increase in ultimate deflection ductility when compared to the reference column.

4.5 Energy ductility: Energy ductility was found to be 14.37% for specimen with 3mm thick CSM wrapping and 24.71% for specimen with 5mm thick CSM wrapping when compared to the reference column. Energy ductility was found to be 12.64% for specimen with 3mm thick WR wrapping and 148.27% for specimen with 5mm thick WR wrapping when compared to the reference column. Energy ductility was found to be 75.29% for specimen with 3mm thick UDC wrapping and 200.00% for specimen with 5mm thick UDC wrapping when compared to the reference column. Fig.7 shows the increase energy ductility when compared to the reference column.

The decrease in energy ductility was found to be a 1.50% for specimen with 3 mm thick WR wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in energy ductility was found to be a 99.08% for specimen with 5 mm thick WR wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in energy ductility was found to be a 53.27% for specimen with 3 mm thick UDC wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in energy ductility was found to be a 140.55% for specimen with 5mm thick UDC wrapping when compared to the specimen with CSM wrapping of same thickness.

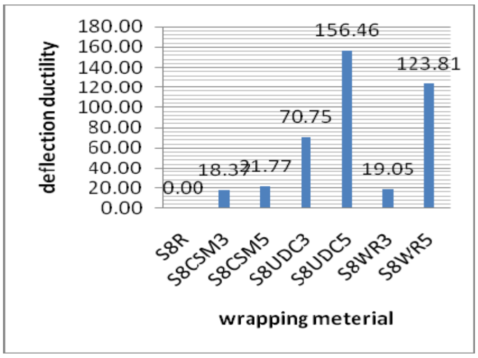
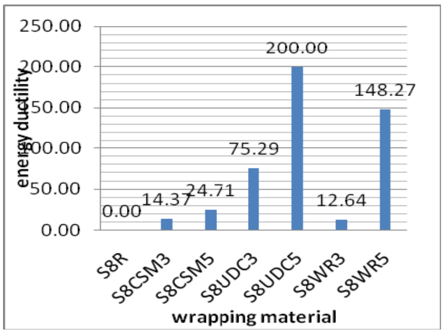


Fig.6.Deflection Ductility for Wrapped Specimens

4.6 Energy Absorption: Energy Absorption was found to be a 15.26% for specimen with 3mm thick CSM wrapping and 40.91% for specimen with 5mm thick CSM wrapping when compared to the reference column. Energy absorption was found to be a 78.28% for specimen with 3mm thick WR wrapping and 98.21% for specimen with 5mm thick WR wrapping when compared to the reference column. Energy absorption was found to be a 122.26% for specimen with 3mm thick UDC wrapping and134.57% for specimen with 5mm thick UDC wrapping when compared to the reference column. Fig.8 shows the increase energy absorption when compared to the reference column.

The increase in energy absorption was found to be 54.75% for specimen with 3 mm thick WR wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in energy absorption was found to be a 40.63% for specimen with 5 mm thick WR wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in energy absorption was found to be 93.00% for specimen with 3 mm thick UDC wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in energy absorption was found to be 66.50% for specimen with 5mm thick UDC wrapping when compared to the specimen with CSM wrapping of same thickness.



Eig.7. Energy Ductility for Wrapped Specimens

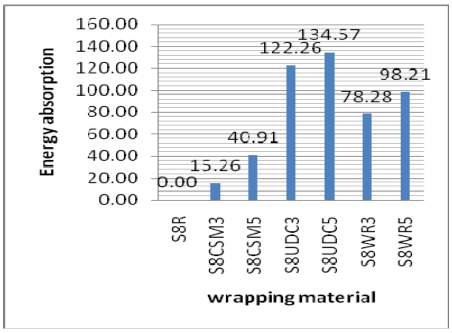


Fig.8. Energy Absorption for Wrapped Specimens.

V. CONCLUSIONS

Based on the results presented, the following conclusions are drawn:

- The GFRP significantly improved the ultimate stress, ultimate axial strain, deflection ductility, energy ductility and energy absorption..
- The maximum ultimate stress was increased by 26.09% for 5mm thick UDC wrapping when compared to reference column.
- The maximum ultimate axial strain was increased by 64.45% for 5mm thick UDC wrapping when compared to reference column.
- The maximum deflection ductility was increased by 156.46% for 5mm thick UDC wrapping when compared to reference column.
- The maximum energy ductility was increased by 200.00% for 5mm thick UDC wrapping when compared to reference column.
- The maximum energy absorption was increased by 134.57% for 5mm thick UDC wrapping when compared to reference column.

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