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DUCTILITY BEHAVIUOR OF HIGH STRENGTH CONCRETE COLUMNS WITH GFRP WRAPS

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ABSTRACT

The paper presents the results of a study on the performance of Glass Fibre Reinforced Polymer (GFRP) wrapped high strength concrete columns under uni-axial compression. The columns had slenderness ratios of 8, 16, 24 and 32. Chopped Strand Mat GFRP was used with 3 mm and 5 mm thicknesses. The columns were tested under monotonic axial compressive loading up to failure. The deflections were noted for each load increment. The HSC columns with GFRP wrapping exhibited improved performance in terms of strength and ductility capacity.

Keywords: Deformation; GFRP; high strength concrete; strength

1. INTRODUCTION

Existing reinforced concrete columns may be structurally deficient for several reasons: substandard seismic design details, improper transverse reinforcement, flaws in structural design, and insufficient load carrying capacity. Over the last few years, there has been a worldwide increase in the use of composite materials for the rehabilitation of deficient reinforced concrete structures. One important application of this composite retrofitting technology is the use of fiber reinforced polymer (FRP) jackets or sheets to provide external confinement to reinforced concrete columns when the existing internal transverse reinforcement is inadequate. Reinforced concrete columns need to be laterally confined in order to ensure large deformation under load before failure and to provide an adequate load resistance capacity.

In the case of a seismic event, energy dissipation allowed by a well-confined concrete core can often save lives. On the contrary, a poorly confined concrete column behaves in a brittle manner, leading to sudden and catastrophic failures. With the development of technology, the use of high-strength concrete has proved to be popular in terms of economy, superior strength, stiffness and durability. With the increase of concrete strength, the ultimate strength of the columns increases, but a relatively more brittle failure occurs. The

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lack of ductility of high-strength concrete results in sudden failure without warning, which is a serious drawback. Several research scholars have shown that addition of compressive reinforcement and confinement will increase the ductility as well as the strength of materials effectively. Concrete, confined by transverse ties, develops higher strength and to a lesser degree ductility [1].

The application of FRP in the construction industry can eliminate some undesirable properties of high-strength concrete, such as its brittle behavior. FRP is particularly useful for strengthening columns and other siructural elements[2]. Focusing attention on the behavior of compression members, the main parameters investigated in literature [3–7] are the type of FRP material (carbon, glass, aramid, *etc*.) and its manufacture (unidirectional or bi-directional wraps), the shape of the transverse cross-section of the members, the dimensions and the shape of specimens, the strength of concrete, and the types and percentages of steel reinforcements.

The present paper deals with the analysis of experimental results, in terms of load carrying capacity and strains, obtained from tests on circular concrete columns, reinforced with external E-glass fiber composite. The pricipal study parameter was slenderness FRP confined columns.

2. MATERIALS AND METHODS

An experimental investigation has been conducted on 12 column specimens having 150 mm diameter and slenderness ratios of 8, 16, 24 and 32. The longitudinal reinforcement consisted of 6 bars of 8 mm diameter and internal ties consisted of 6 mm diameter bars at 115 mm spacing. Out of the 12 columns, one reference column was tested without any wrapping and the remaining 8 columns were wrapped with CSMGFRP with different thickness for each slenderness ratio.

2.1 Material properties

The concrete used for casting the specimens was designed for a compressive strength 60 MPa. The mix ratio adopted was 1:1.73:2.51:0.34:0.8% (cement: Fine aggregate: Coarse aggregate: Water: Hyperplastizicer percentage by weight of binder). The characteristic compressive strength achieved was 63.64 MPa. The steel used for longitudinal reinforcement was ribbed steel with yield strength of 450 MPa and mild steel with yield strength of 300 MPa was used for the internal ties. The properties of GFRP are presented in Table 1.

2.2 Preparation 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 the pipes were covered with polymer sheets to avoid any leaks. Cover blocks were placed at appropriate places to ensure adequate cover to the reinforcement. The interior of the pipes was 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 designed 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 moulds without any damage and cured in a standard manner for a period of 28 days.

Table 1: Properties of glass fibre reinforced polymer (GFRP)

Sl.No	Type of fibre in GFRP	Thickness (mm)	Tensile strength (MPa)	Ultimate elongation (%)	Elasticity modulus (MPa)
1.	Chopped Strand Mat	3	126.20	1.60	7467.46
2.	Chopped Strand Mat	5	156.00	1.37	11386.86
3.	Uni-Directional Cloth	3	446.90	3.02	13965.63
4.	Uni-Directional Cloth	5	451.50	2.60	17365.38
5.	Woven Rovings	3	147.40	2.15	6855.81
6.	Woven Rovings	5	178.09	1.98	8994.44

2.3 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 all 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 ensure proper adhesion of FRP to the exterior of concrete. The specimens were wrapped with GFRP fabrics of appropriate fibre type by applying the resin on the surface of the specimens, wrapping them with FRP fabric and applying measured quantities of resin to the application of successive layers of FRP fabric and resin. The wrapped surfaces were gently pressed with a rubber roller to ensure proper adhesion between the layers and proper distribution of resin. Figures 1-3 show the application of FRP wrap on the surface of the column specimen. Figure 4 show the test set-up with instruments.

Figure 1. Air-cleaning under progress

Figure 2. Wrapping under progress

Figure 3. Wrapped specimens

Figure 4. Test set-up

3. TEST SPECIMENS

The test specimen comprised of 12 column specimens having 150 mm diameter with slenderness ratios of 8, 16, 24 and 32. The longitudinal reinforcement consisted of 6 bars of 8 mm diameter and internal ties consisted of 6 mm diameter bars at 115 mm spacing. Out of the twelve columns, one reference column was tested without any wrapping and the remaining columns were wrapped with CSMGFRP with different thickness for each slenderness ratio. The specimen designations, slenderness ratios, geometrical details and wrap details are provided in Table 2.

Table 2: Specimen details

Sl No	Details of specimens	Diameter (mm)	Height (mm)	Type of GFRP(mm)	Thickness of GFRP (mm)	Nominal slenderness
	S8R0	150	300	-	0	8
	S8CSM3	150	300	CSM	3	8
	S8CSM5	150	300	CSM	5	8
	S16R0	150	600	-	0	16
	S16CSM3	150	600	CSM	3	16
	S16CSM5	150	600	CSM	5	16
	24R0	150	900	-	0	24
	S24CSM3	150	900	CSM	3	24
	S24CSM5	150	900	CSM	5	24
	S32R0	150	1200	-	0	32
	S32CSM3	150	1200	CSM	3	32
	S32CSM5	150	1200	CSM	5	32

4. TEST SET-UP

Testing of specimens having heights of 300mm, 600 mm, 900mm and 1200mm was carried out in a loading frame of 2000KN 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. Figure 4 shows the instrumentation adopted for the columns. The specimen was placed with capping at both ends. The load was applied in increments using the loading jack. Axial compression was measured using two dial gauges placed at top and bottom of the specimen.

5. RESULTS AND DISCUSSION

The ultimate loads, deformations experienced by the test specimens are presented in Table 3.The stress strain curve for all specimen shown in Figure 5.

Table 3: Ultimate loads, stresses and strains for tested columns

Specimen designation	Ultimate load (kN)	Ultimate deflection (mm)	Ultimate stress (MPa)	Ultimate axial micro-strain (me)	Deflection ductility	Energy ductility
S8R0	1150	2.93	65.08	9766.67	1.47	1.74
S16R0	1080	3.01	61.12	5016.67	1.43	1.66
S24R0	1000	3.29	56.59	3655.56	2.01	3.23
S32R0	900	3.45	50.93	2875.00	1.99	3.42
S8CSM3	1220	3.02	69.04	10066.67	1.67	1.99
S16CSM3	1140	3.16	64.51	5266.67	1.90	2.43
S24CSM3	1050	3.56	59.42	3955.54	2.43	3.84
S32CSM3	990	3.62	56.02	3016.67	2.46	4.26
S8CSM5	1300	3.32	73.56	11066.67	1.79	2.17
S16CSM5	1200	3.46	67.91	5766.67	2.12	3.05
S24CSM5	1175	3.89	66.49	4322.22	2.76	4.48
S32CSM5	1025	4.02	58.00	3350.00	3.02	5.50

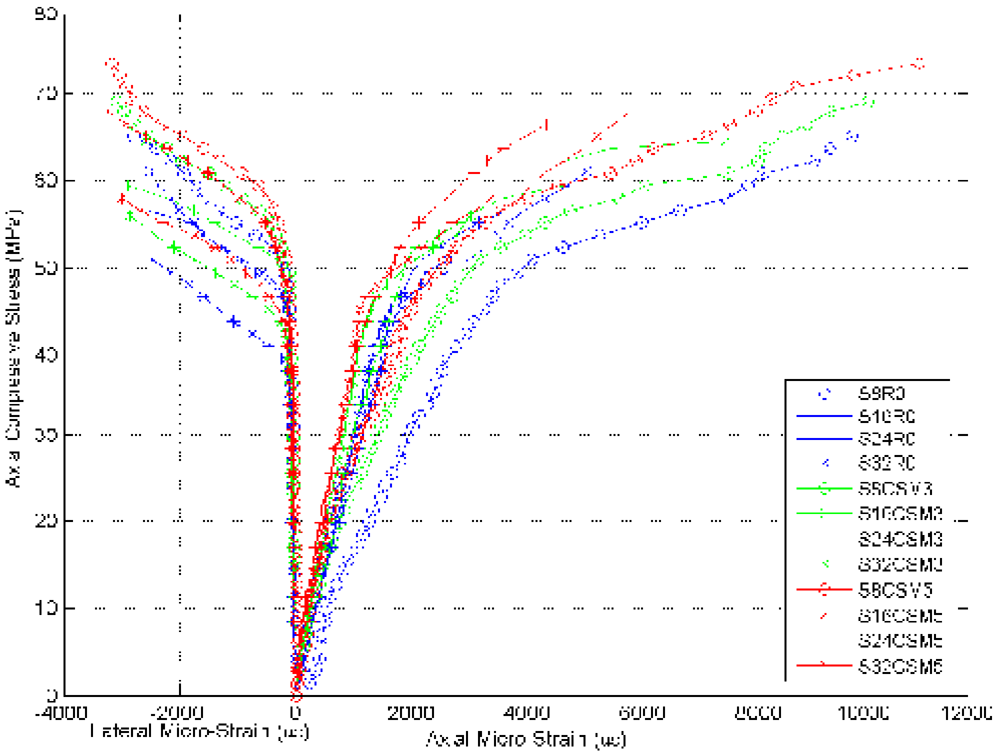

Figure 5. Stress-strain curves for columns with CSMGFRP wrap

5.1 Effect of slenderness ratio on ultimate stress

Slenderness ratio had a measurable influence on the ultimate stresses reached by the GFRP wrapped reinforced concrete columns. The ultimate stress increased as the slenderness ratio was decreased. The unwrapped columns with slenderness ratios of 24, 16 and 8 showed increase in ultimate stress by 11.11%, 20.01% and 27.78% over the columns having slenderness ratio of 32. The columns with 3 mm thick GFRP wrapping showed lower levels of increase in ultimate stress than the columns with 5 mm thick GFRP wrap. The columns with 3 mm thick CSMGFRP wrapping showed 6.07% to 23.24% increase; those wrapped with 5 mm thickness of CSMGFRP showed 14.64% to 26.83% increase in ultimate stress. The effect of slenderness on ultimate stress is presented in Figure6.

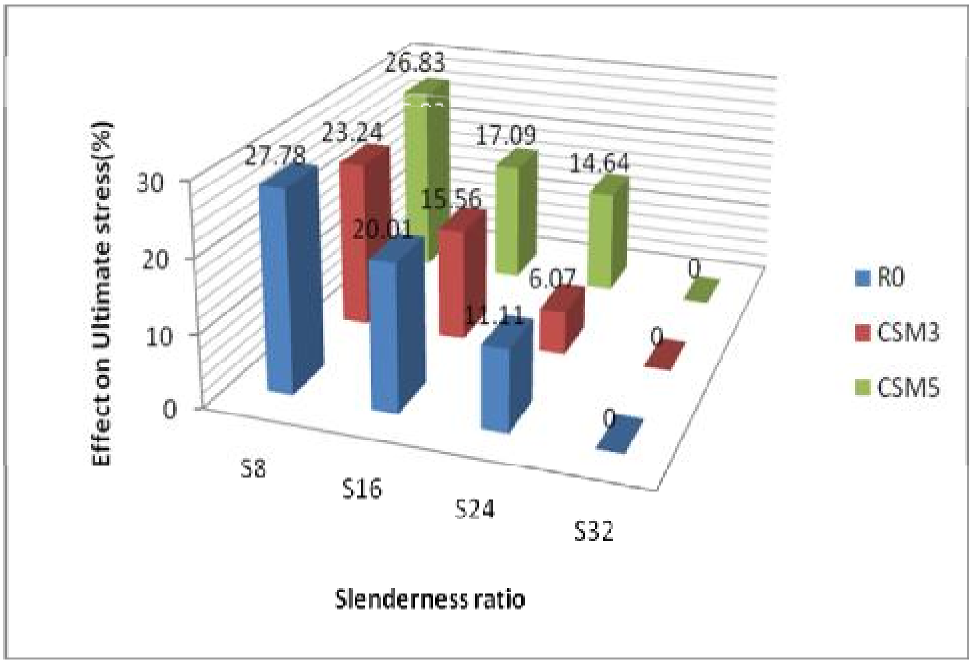

Figure 6. Slenderness ratio vs ultimate stress

5.2 Effect of slenderness ratio on ultimate axial strain

The axial strain for unwrapped columns showed maximum sensitivity to slenderness ratio, where the increases were in the range of 27.15% to 239.71% and were progressively higher for decreasing slenderness ratio. The columns wrapped with 3mm thick CSMGFRP showed increase in ultimate axial strains in the range of 31.12% to 233.70%, 5mm thick CSMGFRP showed increase in the range of 29.02% 230.35% in slenderness ratio from 24 to 8 when compared to the columns with slenderness ratio of 32. The effect of slenderness on ultimate axial strain is presented in Figure 7.

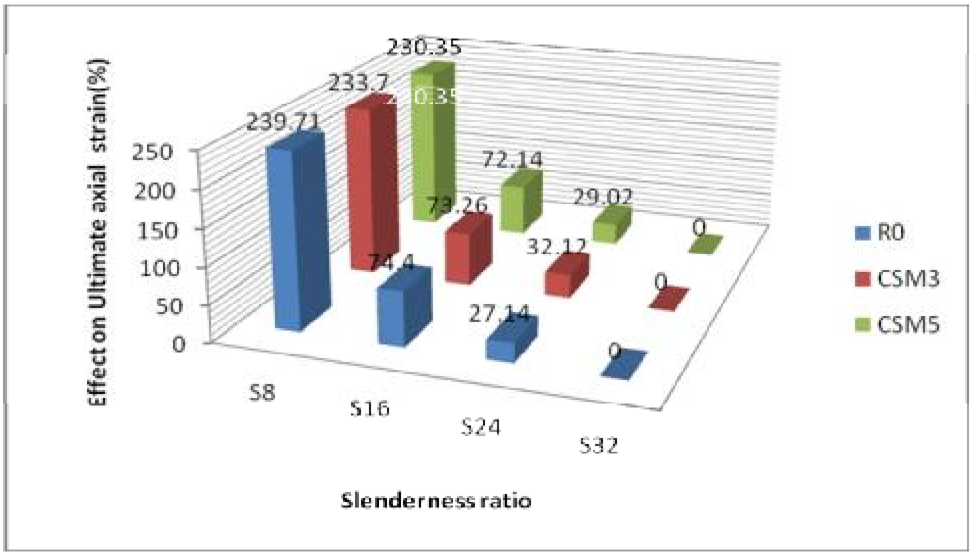

Figure 7. Slenderness ratio vs ultimate axial strain

5.3 Effect of slenderness ratio on ultimate lateral strain

The ultimate lateral strain attained by the unwrapped columns was 3.42%, 2.09% and 13.01% over for S24R0, R16R0 and S8R0 compared to the column S32R0. The ultimate lateral strain increased 7.69% for 3mm thick CSMGFRP wrap for columns with slenderness ratios in the range of 8 to 24, when compared to columns having slenderness ratio of 32. The ultimate lateral strain increased 0.6% to 8.47% for 5mm thick CSMGFRP wrap. The effect of slenderness on lateral strain is presented in Figure 8.

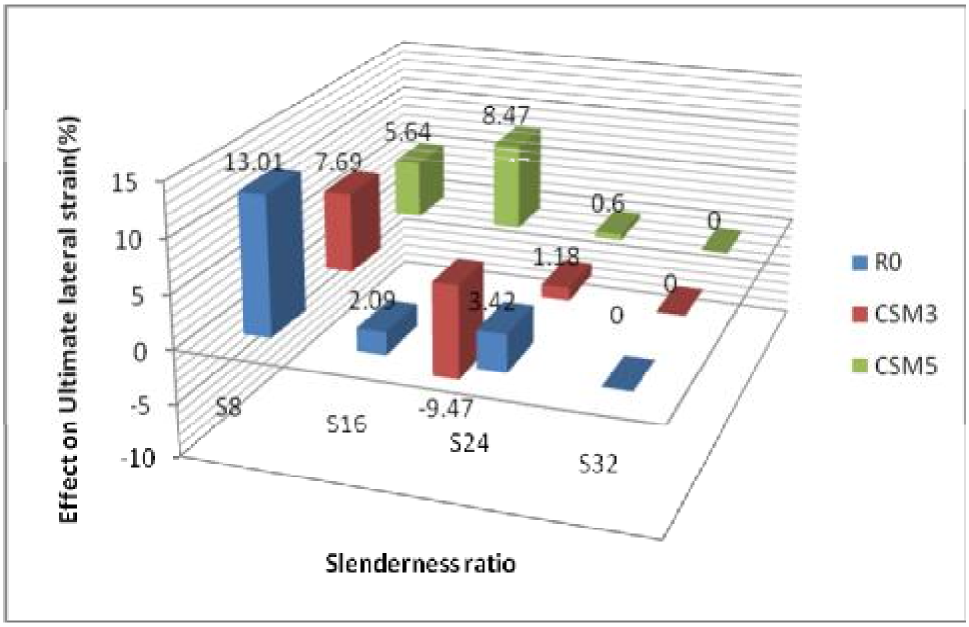

Figure 8. Slenderness ratio vs ultimate lateral strain

5.3 Effect of slenderness ratio on deflection ductility

The unwrapped columns showed sensitivity to slenderness ratio on deflection ductility, the decrease in 28.14% and 26.13% for the columns S16R0 and S8R0, the increase in 1.00% for the column S24R0 compared to the column S32R0. The columns exhibited decrease in deflection ductility up to 31.28% for 3mm thick CSMGFRP wrap. The columns decrease in deflection ductility up to 46.71% for 5mm thick CSMGFRP wrap. The effect of slenderness on deflection ductility is presented in Figure 9.

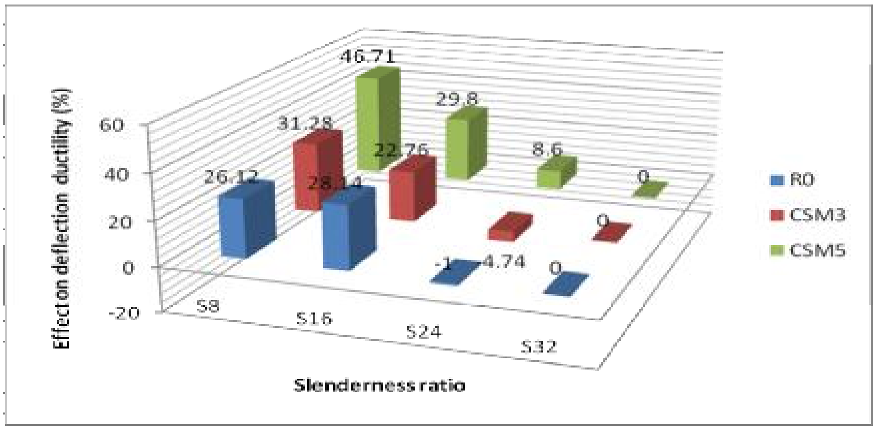

Figure 9. Slenderness ratio vs deflection ductility

5.4 Effect of slenderness ratio on energy ductility

Energy ductility for 3mm thick GFRP wrapped columns were lower for slenderness ratios of 24, 16and 8 compared to the columns having slenderness ratio of 32. Columns wrapped with 3mm thick CSMGFRP showed increase in energy ductility at 9.86% to 52.29% due to decrease in slenderness ratio. Columns wrapped with 5mm thick CSMGFRP showed increase in energy ductility at18.55% to 60.54% due to the decrease in slenderness ratio. The effect of slenderness on energy ductility is presented in Figure 10.

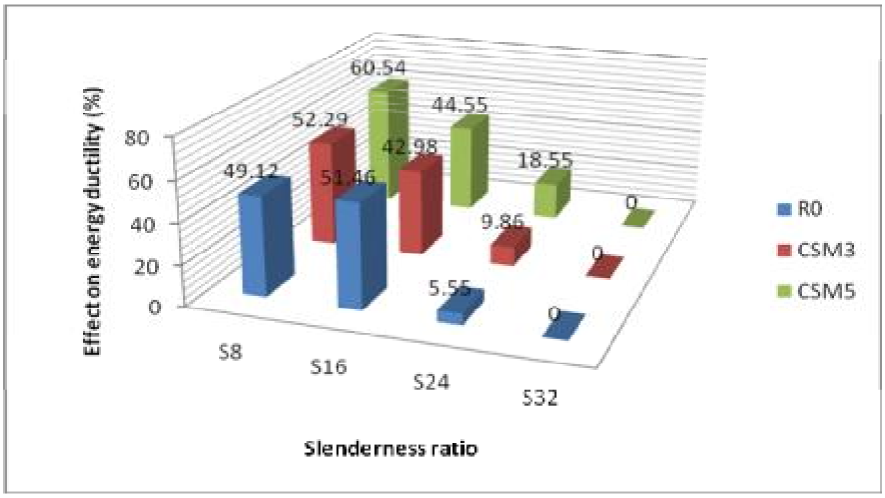

Figure 10. Slenderness ratio vs energy ductility

7. CONCLUSIONS

Based on the results obtained through the experimental investigation, the following conclusion are made

1. The unwrapped columns with slenderness ratios of 24, 16 and 8 showed increase in ultimate stress by 11.11%, 20.01% and 27.78% over the columns having slenderness ratio of 32.
2. The columns wrapped with 5 mm thick of CSMGFRP showed increase in ultimate stress up to 26.83%with decrease in slenderness ratio.
3. The columns with 5mm thick CSMGFRP showed increase in axial strain in the range of 29.02% 230.35% in slenderness ratio from 24 to 8 when compared to the columns with slenderness ratio of 32.
4. The ultimate lateral strain increased up to 8.47% for 5mm thick CSMGFRP wrap.
5. The columns wrapped with 5mm thick CSMGFRP showed decrease in deflection ductility up to 46.71% .
6. Columns wrapped with 5mm thick CSMGFRP showed increase in energy ductility up to 60.54% with a decrease in slenderness ratio.

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