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Follow effect of low cost glass fibre reinforced polymer (GFRP) on the performance of concentrically loaded concrete column

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Abstract. (FRP) plays a major role in the strengthening of existing structures due to the age of the structure or natural calamities like earthquakes, floods, cyclones, etc. For reducing the size of structural members, the FRP wrapping assists to achieve the performance of the structure. Concrete is widely used due to its advantages and FRP is added to improve its quality in terms of strength. A study has been conducted on 21 cylinders based on their slenderness ratio. The slenderness ratios in the columns were 8, 16, and 24. At thicknesses of 5 mm and 7 mm, two types of wrap materials (UDCGFRP) and (WRGFRP)] were employed. Up to the point of failure, the columns were subjected to monotonic axial compressive force. The column's yield loads, and ultimate load, were deduced from the load-deflection curves. The overall, uni-directional cloth provided the most effective confinement and led to a highly desirable failure mechanism, which was a gradual process.

Keywords: concrete column, GFRP, mechanical strength, polymer, steel reinforcement cage, slenderness ratio.

Classification numbers: 2.9.4, 5.1.1, 5.4.5.

1. INTRODUCTION

FRP composite materials generally consisting of carbon, aramid or glass fibres in a polymeric matrix have been used successfully in new construction as well as in the repair and rehabilitation of existing structures [1 - 3]. Increases in service loads, changes in usage patterns, and degradation of the structure owing to natural or man-made flaws in the design or construction stages may need strengthening of reinforced concrete buildings. The geometry, aesthetics, and usability of the construction are minimally impacted by the use of FRP. Fibres in

FRP can have tensile strengths of over 3,000 MPa (compared to 400 MPa for reinforcing steel). FRP, unlike steel, does not exhibit plastic yielding and instead behaves linearly elastic until it fails [4 - 6]. FRP reaches a maximum strain in the range of 1.5 to 5 %. FRP composites are used as external reinforcement in the rehabilitation of Reinforced Concrete (RC) beams and slabs; they increase the strength (ultimate limit state) and the stiffness (serviceability limit state) of the structure [7, 8]. The structural application of FRP is motivated by requirements for anti-earthquake strengthening, higher service loads, smaller deflections, or simply the need to complement deficient steel reinforcement [9].

Today's FRP composites are largely made up of two materials: fibres and a resin matrix. The fibres supply the strength, while the resin matrix keeps them in place and distributes the stress evenly. The adhesives also protect and attach the fibres to the surface, allowing the load to be transferred from the framework to the fibres. E-Glass, Carbon, and Aramid fibres are the most commonly utilized. One of the best resins has been discovered to be epoxy.

The process of putting resin and reinforcing fibres in a mould by hand or using hand tools is known as hand layup. Each layer of reinforcement should be well saturated in resin before being layered one on top of the other. This procedure is repeated until the desired thickness has been reached. By gently rolling each layer with a rubber roller, one may ensure that air packets are removed from the completed composite. The strengthening RC columns are in-situ FRP wrapping [10 - 12]. In a wet lay-up procedure, unidirectional fibre sheets or woven fabric sheets are impregnated with polymer resins and wrapped around columns. The column can be completely wrapped in FRP sheets, partially wrapped in continuous spirals of FRP strips, or partially wrapped in distinct rings [13 - 15].

The current status of FRP is utilized mostly in beams to take care of flexural and shear behaviour. Improving the strength and minimising the grade of concrete by wrapping it with FRP composites leads to better strength and reduces buckling behavior. This report studies the impact of externally bonded WRGFRP and UDCGFRP laminates on the test column strength, deformation and ductility to investigate the GFRP laminates composite action at various load levels and comprehend the cracking and failure mechanisms involved.

2. EXPERIMENTAL PROGRAMME

Experimental investigations were carried out on column specimens having different slenderness ratios, wrap thicknesses and wrap materials. The longer specimens were tested on the loading frame and short stubs were tested on Compression Testing Machine and manual readings were recorded [14, 15].

3. MATERIALS

Normal strength concrete, ribbed tor steel bars for longitudinal reinforcement, mild steel for lateral ties and GFRP were used [16 - 18]. The mix ratio for the design strength of 30 MPa was 1:1.91:2.99:0.5 and its characteristic compressive strength of 38.43 MPa. Longitudinal reinforcement was made of 415 MPa high yield strength deformed steel bars, whereas lateral ties were made of Fe 250 grade mild steel bars. Uni-Directional Cloth (UDC) and Woven Rovings (WR) were used for the research. The iso-phthalic resin was used to wrap the material. WR had fibres running at 45° to the longitudinal axis of the fabric, UDC had fibres oriented at 0° to the longitudinal axis of the fabric. All the fibres had a fibre distribution of 450 GSM. There are various types of unsaturated polyester resins available in the market. The iso-phthalic polyester resin was used for the preparation of the FRP (layers of glass). In a vinyl monometer, iso-phthalic polyester resin is dissolved in linear long-chain polymers. Propylene/ethylene glycol and maleic anhydride combine to form an unsaturated iso-phthalic polyester resin. For the research, “Isophthalic Polyester Resin under the trade name Hetron® was used along with the curing method through a free radical polymerization process using a catalyst, such as methyl ethyl ketone peroxide (MEKP), in the presence of a promoter or accelerator”**.** Resin was used to bind the glass cloth and to make the desired thickness and it served as a matrix between the concrete and glass cloth and not with the reinforcement/steel. The epoxy was used to bond between the concrete and glass, and the unsaturated polyester resin to bond different layers of glass. If we use only one type of resin, debonding will occur, so two types of resin must be used. A comparison of typical properties for epoxy adhesive, concrete and steel is given in Table 1.

Table 1. Typical properties of epoxy adhesives, concrete and steel.

Property	**Cold-curing epoxy adhesive**	**Concrete**	**Mild steel**
Density (kg/m^3)	1100 - 1700	2350	7800
Elasticity modulus (GPa)	0.5 - 20	20 - 50	205
Shear modulus (GPa)	0.2 - 8	8 - 21	80
Poisson’s ratio	0.3 - 0.4	0.2	0.3
Tensile strength (MPa)	9 - 30	1 - 4	200 - 600
Compressive strength (MPa)	55 - 110	25 - 150	200 - 600
Shear strength (MPa)	10 - 30	2 - 5	200 - 600
Tensile strain at rreak (%)	0.5 - 5	0.015	25
Approximate fracture energy’s (J/m^2)	200 - 1000	100	10^6 - 10^5
Water absorption: 7-days - 25 ºC (%)	0.1 - 3	5	0
Co-efficient of thermal expansion (10^{-6}/ºC)	25 - 100	11 - 13	15 - 10
Glass transition temperature (ºC)	45 - 80	-	-

Table 2. Properties of GFRP.

S. No.	Type of Fibre	Thickness (mm)	Tensile strength (MPa)	Ultimate elongation (%)	Elasticity modulus (GPa)
1	Uni-directional cloth	5	446.90	3.02	13.96
2	Uni- directional cloth	7	451.50	2.60	17.36
3	Woven roving	5	147.40	2.15	6.85
4	Woven roving	7	178.09	1.98	8.99

GFRP wrapping was prepared by applying the resin on the slenderness surface of the reinforced concrete column and laying up the FRP fabric using the measured quantity of resin [9, 19]. FRP wrap of the required thickness was achieved by applying multiple layers of mat around the column specimens [20 - 22]. The properties of the GFRP wraps used for the present investigation are presented in Table 2.

The test specimens consisted of RC columns with a diameter of 150 mm, reinforced with six rods, 8 mm diameter ribbed tor steel bars and 6 mm diameter steel ties at a spacing of 115 mm c/c. The columns had varying heights of 300, 600 and 900 mm. The specimens were classified based on their slenderness ratio [18, 23, 24 - 26]. Two types of slenderness ratios were adopted for the work, i) the nominal slenderness ratio which ignores the presence of steel and FRP in the column section, ii) the effective slenderness ratio, which considers the presence of both steel reinforcement and FRP wrapping. The specimen designations, slenderness ratios, geometrical details and wrap details are provided in Table 3.

Table 3. Specimen details (150 mm in diameter).

SI. No.	Specimen designation	Height (mm)	Type of GFRP	Thickness of GFRP (mm)	Nominal slenderness
1	S8R0	300	-	0	8.00
2	S8UDC5	,,	UDC	3	8.00
3	S8UDC7	,,	UDC	5	8.00
4	S8WR5	,,	WR	3	8.00
5	S8WR7	,,	WR	5	8.00
6	S16R0	600	-	0	16.00
7	S16UDC5	,,	UDC	3	16.00
8	S16UDC7	,,	UDC	5	16.00
9	S16WR5	,,	WR	3	16.00
10	S16WR7	,,	WR	5	16.00
11	S24R0	900	-	0	24.00
12	S24UDC5	,,	UDC	3	24.00
13	S24UDC7	,,	UDC	5	24.00
14	S24WR5	,,	WR	3	24.00
15	S24WR7	,,	WR	5	24.00

Figure 1. PVC pipes cut-to-size for casting.

The specimens were prepared by casting them in polyvinyl chloride pipe moulds of 150 mm diameter. The pipes were cut to size and embedded in a lean concrete base. The reinforcement cage was placed into the pipe with appropriate covers on all sides and at the bottom. The specimens were then cast as per mix design. After the concrete gained sufficient strength, the pipes were removed by cutting them into two pieces. Figure 1 shows the pipes after cutting. The specimens were removed from the mould without any damage and cured in a standard manner for a period of 28 days.

Steel reinforcement cages were prepared for each specimen with six bars of 8 mm diameter as longitudinal reinforcement and 6 mm diameter mild steel ties spaced at 115 mm c/c. Figure 2 shows the reinforcement cages prepared for the casting work.

Figure 2. Steel reinforcement cage for casting the column specimens.

The cured specimens were wrapped with GFRP after grinding the surface using a grinding wheel followed by compressed air to blow off any dust and dirt. Figure 3a shows sample specimens with ground exterior surfaces and Figures 3b and 3c show the application of GFRP in layers. By applying resin to the surfaces of the prepared specimens, wrapping them in GFRP fabric with proper resin fabric ratio. The required thickness was achieved by layering GFRP cloth and resin on top of each other [27 - 29]. To achieve appropriate adhesion between the layers and resin distribution, the wrapped surfaces were lightly pushed with a rubber roller [30, 31]. The GFRP wrapped specimens were air cured for a period of seven days.

(a) (b) (c) (d)

*Figure 3***.** GFRP wrapped specimens: (a) After grinding, (b) Receiving layer of GFRP with epoxy resin, (c) Cured specimens, and (d) Receiving another layer of GFRP

4. EXPERIMENTAL SETUP

Figure 4. Instrumentation: (a) Column specimens (S8), (b) Column specimens (S16 and S24).

The load was applied in equal increments of 5 kN to specimens with 600 mm and 900 mm heights on a loading frame with a capacity of 50,000 kN [32 - 24]. In Figure 4a, compressive loads in regular increments of 10 kN were applied to specimens with a height of 300 mm on a Compression Testing Machine (CTM) with a capacity of 2,000 kN. Figure 4b shows, on a loading frame, the instrumentation for columns with 600 mm and 900 mm heights. On the steel platform of the loading frame, a hydraulic loading jack was installed. Capping was applied to both ends of the specimen. Two dial gauges were used to measure axial compression.

The specimens having slenderness ratios of 16 and 24 (height 600 mm and 900 mm) were tested on a loading frame of 50,000 kN capacity. The load was applied at uniform increments of 5 kN. For each load increment, readings were taken from all dial gauges. The mode of failure of the specimen and the location of failure were noted for each specimen. Specimens having a slenderness ratio of 8 (height 300 mm) were tested on a CTM with a capacity of 2,000 kN. The load was applied at uniform increments of 10 kN. Readings from dial gauge and lateral, longitudinal extensometers were noted.

4.1. Failure modes

Typical failures of the tested specimens are presented in Figure 5. The failures indicate that UDCGFRP wrapped columns show less catastrophic failure than CSMGFRP or WRGFRP wrapped columns.

Figure 5. Different modes of failure.

5. RESULTS AND DISCUSSION

5.1. At yield point

The yield loads for GFRP wrapped columns were much higher than those reached by the unwrapped columns. The yield loads for columns with higher slenderness ratios were lower, indicating that the slenderness ratio had an influence on the behaviour of GFRP wrapped reinforced concrete columns at the yield level [35 - 37]. The greater the height, the larger the deflections, which was justified by the fact that the strain levels reached by the more slender columns were lower than those reached by the less slender columns. The lateral strain readings were least affected by the variations in slenderness ratios and the variations in lateral strains were very marginal. The thickness of the GFRP wrap had a considerable influence on all properties at the yield level with the values being higher for more thickness of wrapping. Wrapping material was also a major parameter that influenced the yield behaviour of the columns. Generally, columns with UDCGFRP wrapping showed a higher yield load.

The yield point performance of the GFRP wrapped reinforced concrete columns are presented in Table 4 and Figure 6.

Table 4. Yield load (150 mm in diameter).

S. No	Specimen designation	Height (mm)	Yield load (kN)	Yield deflection (mm)	Lateral yield deflection
1	S8R0	300	410	0.70	0.06
2	S16R0	600	390	1.09	0.05
3	S24R0	900	380	1.63	0.05
4	S8UDC5	300	660	0.95	0.09
5	S16UDC5	600	600	1.84	0.08
6	S24UDC5	900	625	2.64	0.08
7	S8UDC7	300	690	1.28	0.12
8	S16UDC7	600	640	2.01	0.10
9	S24UDC7	900	635	2.60	0.09
10	S8WR5	300	500	0.69	0.07
11	S16WR5	600	450	1.30	0.06
12	S24WR5	900	510	2.02	0.06
13	S8WR7	300	600	1.29	0.13
14	S16WR7	600	670	2.30	0.09
15	S24WR7	900	590	2.47	0.07

The effect of the thickness of the GFRP wrap on the yield stresses reached by the columns was calculated as the percentage of variation compared to the unwrapped column of the same slenderness ratio. The yield stress values for GFRP wrapped columns increased in proportion to the thickness of the GFRP wrap applied to the columns. All the columns with 7 mm thick GFRP wrap showed higher yield stresses compared to the corresponding columns with 5 mm thick wrapping of the same material. The yield stresses reached by UDCGFRP wrapped columns were generally higher than those for columns with WRGFRP wrap material.

The yield stress of GFRP wrapped reinforced concrete columns was affected by the type of GFRP wrap material, viz., UDCGFRP and WRGFRP. The effect of the GFRP type on yield stress was calculated by taking the WRGFRP as the reference wrap material. The variations in yield stress values were calculated for other wrap materials of the same thickness. The yield stress values exhibited by UDCGFRP wraps were very close to those exhibited by the WRGFRP wrap of the same thickness.

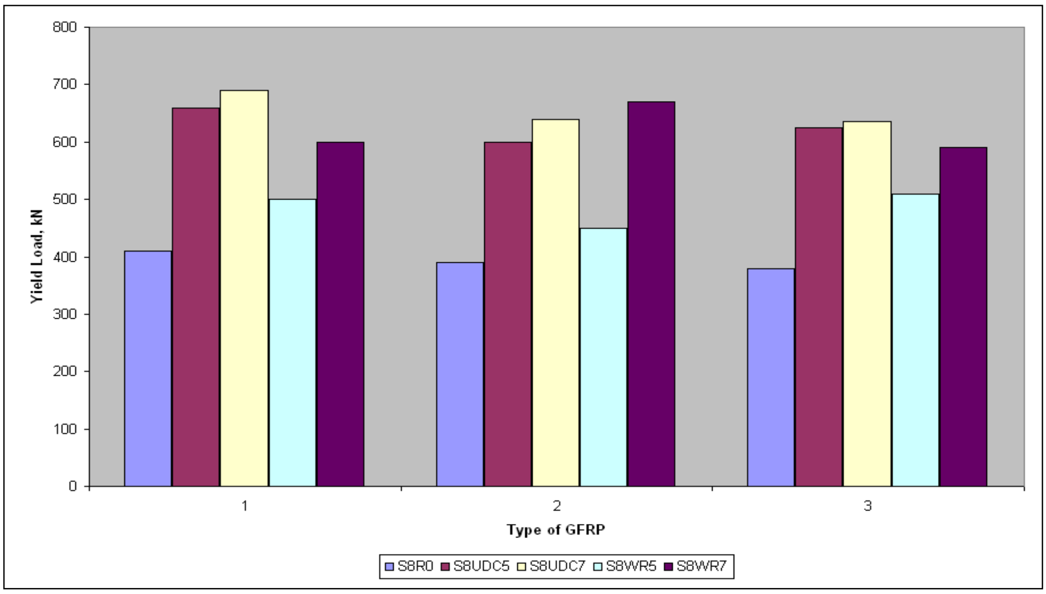

Figure 6. Yield load with different types of GFRP and thickness.

5.2. At ultimate point

The ultimate point performance of GFRP wrapped columns revealed the impact of the GFRP wrap material on stress and strain values. The stress and strain values at the ultimate point were more influenced by GFRP wrapping than those at the yield point. The yield point marked the beginning of the GFRP's participation in resisting applied loads, while the ultimate point marked the wrapping mechanism's collapse once its capacity had been exhausted. Table 5 and Figure 7 show the maximum loads attained by the experimental specimens. Ultimate stress values were highest in the reinforced concrete columns with UDCGFRP covering.

The slenderness ratio had a measurable influence on the ultimate stresses reached by the GFRP wrapped reinforced concrete columns [38 - 40]. The effect of the slenderness ratio on ultimate stress was very clear and monotonically increased as the slenderness ratio decreased.

The columns with 5 mm thick GFRP wrapping showed lower levels of the increase in ultimate stress than the columns with 7 mm thick GFRP wrap. The influence of the slenderness ratio on ultimate stress value for 7 mm thick wrapping was almost similar for all types of wrap materials. The overall observation is that the slenderness ratio was influential on the ultimate stress values reached by reinforced concrete columns, whether they were wrapped with GFRP or not and that the reduction in slenderness ratio led to an increase in ultimate stress value.

The thickness of GFRP wrapping was the single most influential parameter on the ultimate stress values reached by the GFRP wrapped reinforced concrete columns [41 - 43]. The highest levels of influence on ultimate stress values were shown by UDCGFRP wrapped columns. The effectiveness of UDCGFRP in providing enhanced strength levels for confined concrete was clearly exhibited by the level of the increase in ultimate stress values [44 - 46]. The columns with 7 mm thick UDCGFRP wrapping showed the highest levels of the increase in ultimate stresses. Variations in the thickness of the GFRP wrap resulted in corresponding variations in ultimate stress values and these two were directly related [47 - 49].

Table 5. Ultimate load (150 mm in diameter).

S. No	Specimen designation	Height (mm)	Ultimate load (KN)	Ultimate deflection (mm)	Ultimate lateral expansion (mm)
1	S8R0	300	530	2.65	0.55
2	S16R0	600	490	3.45	0.41
3	S24R0	900	455	4.24	0.36
4	S8UDC5	300	1090	10.12	2.75
5	S16UDC5	600	1075	18.18	2.75
6	S24UDC5	900	1068	24.97	2.58
7	S8UDC7	300	1480	13.74	4.54
8	S16UDC7	600	1410	21.68	3.58
9	S24UDC7	900	1155	29.81	3.31
10	S8WR5	300	890	5.91	1.92
11	S16WR5	600	870	10.21	1.68
12	S24WR5	900	720	17.59	1.74
13	S8WR7	300	1179	15.85	1.23
14	S16WR7	600	1058	10.94	3.14
15	S24WR7	900	920	16.39	2.71

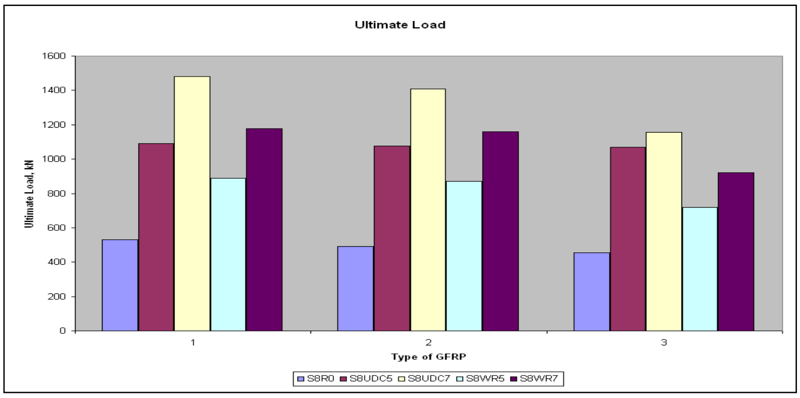

Figure 7. Ultimate load with different types of GFRP and thickness.

The ultimate stress values reached by columns wrapped with different types of wrapping materials, viz., UDCGFRP and WRGFRP, were influenced by the type of the GFRP wrap used. The results clearly indicate the fact that UDCGFRP provided the most effective confinement to the reinforced concrete columns [50, 51].

6. CONCLUSIONS

The following conclusions have arrived from the experimental investigation:

The specimens wrapped with WR fibre GFRP having a nominal slenderness ratio of 24 failed with moderate warning.

The specimens wrapped with UDC fibre GFRP having a nominal slenderness ratio of 24 showed a very high level of ductility.

The UDC wrapped specimens had sustained load carrying capacity. As the UDC wrap for columns with a slenderness ratio of 24 began to fail, it showed up glassy patches indicating the failure of the resin, followed by very small radial openings, which opened out to the side in which the column deflected laterally.

The lateral deflection seen at the midpoint of the UDC wrapped column due to the application of axial load was an indicator of the ability of UDC to effectively confine the column and keep it intact for a long time after the actual failure occurred.

The specimens having slenderness ratios of 8 and 16 and wrapped with WRFRP failed by the rupture of the FRP wrap, which initiated at the top or bottom, and went up to the mid height of the specimens in most of the cases.

In the case of UDC FRP wrapped specimens having slenderness ratios of 8 and 16, the failure was due to the perceived gradual reduction of axial stiffness rather than the rupture of the wrap.

In the overall context, uni-directional cloth provided the most effective confinement and led to a highly desirable failure mechanism, which was a gradual process.

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Declaration of competing interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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