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Suitability of GFRP wrapping in high strength concrete short circular columns

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ABSTRACT

A major part of the civil engineering infrastructure will need significant repairs. The innovative rehabilitation and strengthening methods for reinforced concrete structures, especially with composite materials, has taken a large portion of the research work in the field of repair and restoration of structural elements. Also, some of these techniques were used to strengthen columns by confinement with composite enclosure. This paper investigates the strengthening of High Strength Concrete short circular columns using Glass Fiber Reinforced Polymer [GFRP] sheets. The main variables of the work are the slenderness ratio of the columns and the number of layers of GFRP wrapping. Column specimens of three different slenderness ratios [3, 6 and 9] each wrapped with 3 and 4 layers of GFRP fabric was considered for the study. Another set of unwrapped columns serves as the reference. The diameter of the columns is 150 mm. The columns were tested under uni-axial compressive loading until failure. The test results show that the load carrying capacity as well as the ductility capacity of the columns improved with the increasing slenderness ratio and number of layers of GFRP wrapping.

Introduction

Fiber reinforced plastic [FRP] materials are very often utilized in the form of bars, strips or sheets for retrofitting or strengthening of reinforced concrete members subjected mainly to axial or flexural and shear forces. In the case of RC columns the most common use of these materials is based on external wrapping with flexible layers of FRP sheets. (Rizkalla et al., 2009) connection of FRP sheets to reinforced concrete members proves to be effective with epoxy resin and adopting adequate over-lap length obtained by wrapping the FRP on itself. This reinforcing technique can determine enhancements of strength and strain capacities due to the lateral restraint (confinement effect) exercised by FRP. (Saravanan et al., 2012) the behavior of compression members, the main parameters considered in researches 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. (ACI, 440.2r, 2002) FRP system wrapped around a column provides passive reinforcement to the column. However, once the concrete dilates and begins to crack and weaken, the FRP reinforcement provides confinement for the concrete. (Hadi et al., 2004) used enveloping wrap provides more confinement than a longitudinal or spirally wrapped steel rebar. It is important to note that external FRP reinforcement should only be utilized as tensile reinforcement since the compressive properties of the same are not reliable. (Bambole et al., 2011, Papia et al., 2008, Li et al., 2003) found that Shape of cross section, corner radius, grade of concrete, FRP volumetric ratio are some of the important factors that affect the confinement effectiveness of FRP wraps. In case of circular columns, the whole cross sectional area is effectively confined because the confining pressure is uniformly distributed along the perimeter. (Beitleman et al., 2000, 2001) studied the thickness of the confinement increases, the integrity of the system improves leading to higher strength of the specimens, with the wrap having no damage even after the failure of the column. Similar studies were also conducted on columns made of plain cement concrete, i.e., the internal steel reinforcement was replaced by external confinement using Glass-FRP. The confined columns exhibited improved strength and ductility compared to the unconfined ones. (Lu et al., 2006) confinement modulus and confinement strength of FRP are considered to be the two main factors affecting the performances of FRP-confined concrete columns. (Arwikar et al., 2007) when exposed to outdoor conditions, GFRP sheets gained strength due to the increase in the strength of epoxy due to cross-linking of bonds in it. The effects of environmental conditioning on confinement of concrete with GFRP jackets are much less severe than those found on the mechanical properties of the GFRP material alone. (Jamwal et al., 2005)When the FRP-wrapped concrete is subjected to an axial compression loading, the concrete core expands laterally. This expansion is resisted by the FRP wrap, and therefore the concrete core is changed to a three dimensional compressive stress state. In this state, performance of the concrete core is significantly influenced by the confinement pressure.(Hadi, 2006) Eccentricity of loading reduces the load carrying capacity of the columns. (Mirmiran et al., 1997) Carbon FRP confined columns failed explosively, while Glass FRP confined specimens showed adequate warning in the form of white patches on FRP surface at the time of initiation of failure. (Ferrier et al., 2009) showed that the use of FRP confinement changed the failure mode, from brittle shear failure to ductile bending failure, for completely wrapped columns. Also ductility was increased due to transfer to the embeddings, creating a hinge by advanced yielding of longitudinal reinforcements. Failure of FRP confined concrete is indeed initiated by tensile rupture of the FRP wraps at strains close to [or exceeding] the coupon failure strain (Tim et al., 2010) Corrosion products occupy greater volume than the original material inducing expansive forces in concrete which leads to the spalling of cover reinforcement degradation. (Sarafraz1 et al., 2008) combination of FRP jacketing and Near Surface

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Mounted [NSM] FRP rods improves the flexural capacity of damaged as well as un-damaged columns. FRP jacketing is provided after embedding the FRP rods in grooves made close to the surface. (Jin et al., 1997) even though the initial stiffness of specimens repaired with FRP is lower than that of the original specimens; the rate of deterioration of stiffness of the former under large reversed cyclic loading was lower than the latter ones. FRP increases the compressive strength of short columns to an extent between 1.5 and 3 times of the ordinary columns. But, with increasing slenderness effects can prohibit the column from attaining maximum strength and the column may become susceptible to instability (Hu et al., 2007) for any slenderness ratio, the greatest increase in capacity of confined columns is mainly achieved by a two-thirds increase in concrete strength. An increase in concrete strength produced a greater increase in the axial capacity of the column compared to the increase produced in its bending capacity (Zaki et al., 2011, Lin et al., 2004). On the other hand, the increase of fiber thickness and fiber strength produced a greater increase in the bending capacity compared to the increase in the axial capacity (Hsu et al., 2008).

The present work is limited to the study over short circular columns. Short columns of different heights were considered and the combined effect of slenderness ratio and the confinement provided to them by wrapping with GFRP sheets on them were studied.

Materials And Methods

An experimental investigation was conducted on 3 sets of column specimens having a diameter of 150 mm with each set comprising of 3 specimens with slenderness ratios of 3, 6 and 9 respectively. Out of these, 2 sets of columns were wrapped with Chopped Strand Mat GFRP with different thickness for each slenderness ratio and the remaining one set of specimens serves as the reference. The longitudinal reinforcement consisted of 6 bars of 10 mm diameter and internal ties of 8 mm diameter at a spacing of 150 mm.

Material Properties

The concrete used for casting the specimens was designed for a compressive strength of 50 MPa with a mix ratio of 1: 1.35: 2.19: 0.35: 0.8% [Cementitious materials : Fine aggregate : Coarse aggregate : Water : Super plasticizer by weight of binding materials]. The Cementitious materials comprises of Cement [62%], Fly Ash [30%] and Silica Fume [8%]. The mix achieved a characteristic compressive strength of 52 MPa. The reinforcing steel had yield strength of 415 MPa.

Preparation of Specimens

The moulds used for casting the specimens were made by folding tin sheets into circular shape. Circular clamps having inner diameter of 150 mm were used for firmly holding the circular shape and to provide the required size to the moulds and hence to the specimens. One clamp was provided for every 30 cm [1 ft] height of the mould. In order to ensure adequate cover, cover blocks were placed appropriately and the prepared steel reinforcement cage was placed inside the mould, positioned in such a way that adequate cover was obtained from all sides. The prepared concrete mix was poured into the moulds in layers providing sufficient compaction to the concrete using needle vibrator to avoid honey combing. The specimens were de-moulded carefully after ensuring complete setting of concrete and cured for 28 days under standard conditions.

Wrapping with GFRP

The cured specimens were prepared for wrapping with GFRP. 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 fiber 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.

Test Specimens

The test specimens comprises of 3 sets of column specimens having a diameter of 150 mm with each set comprising of 3 specimens with slenderness ratios of 3, 6 and 9 respectively. Out of these, 2 sets of column specimens were wrapped with Chopped Strand Mat (CSM) GFRP with different thickness for each slenderness ratio and the remaining one set of specimens serves as the reference. The details of the test specimens are given in Table1

Test Set Up

Testing of specimens having heights of 450 mm and 900 mm was carried out in a Universal testing machine of 1000 kN capacity and those of height 1350mm was carried out in a loading frame of 2000 KN capacity. The instruments used for testing included deflectometers having a least count of 0.01mm. 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.

Table I. Details of test specimens

Sl.No.	Specimen Details	Diameter [mm]	Height [mm]	Type of GFRP [mm]	Thickness of GFRP [mm]	Slenderness ratio
1.	C1S3G0	150	450	-	0	3
2.	C2S3G3	150	450	CSM	3	3
3.	C3S3G4	150	450	CSM	4	3
4.	C4S6G0	150	900	-	0	6
5.	C5S6G3	150	900	CSM	3	6
6.	C6S6G4	150	900	CSM	4	6
7.	C7S9G0	150	1350	-	0	9
8.	C8S9G3	150	1350	CSM	3	9
9.	C9S9G4	150	1350	CSM	4	9

Fig 1. A set of specimens

Fig 2. Test Set up

Results

The test results are presented in Table 2 and the load deflection curves for all specimens are shown in Figure 5.

Table 2 Test Results

Specimen Designation	Ultimate Load (kN)	Ultimate Deflection (mm)	Ultimate Stress (MPa)	Ultimate Strain	Deflection Ductility
C1S3G0	144	3.48	8.15	0.992266667	1.27
C2S3G3	224	4.28	12.68	0.990488889	1.41
C3S3G4	265	5.01	15.00	0.988866667	1.43
C4S6G0	373	4.22	21.12	0.994488889	1.30
C5S6G3	554	5.73	31.36	0.991488889	1.44
C6S6G4	843	6.48	47.73	0.989555556	1.50
C7S9G0	501	4.53	28.36	0.993407407	1.38
C8S9G3	752	5.26	42.57	0.992281481	1.50
C9S9G4	1009	6.77	57.12	0.990074074	1.63

In this analytical investigation, Lateral critical buckling loads of layered composite beam are determined by using ANSYS finite elements program. ANSYS finite elements procedures are figured. Firstly, analyzing type is determined. After loading layer numbers, thickness, angles and the mechanical properties to the program; the geometrical model is formed. The columns are meshed for finite elements procedure in the program. In the meshing process, the smaller dimension of elements provided more accurate results.

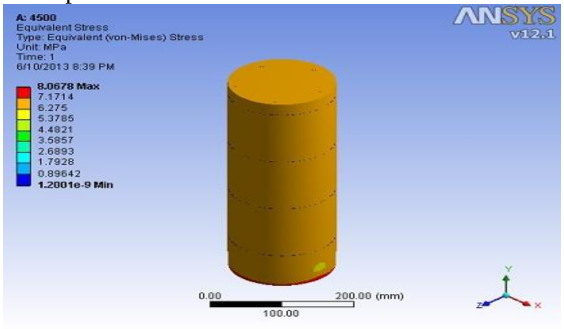

Fig 3 Equivalent Stress Chart of 450 mm unconfined column

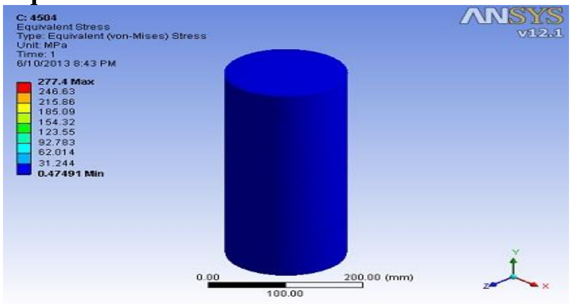

Fig 4 Equivalent Stress Chart of 450 mm confined column

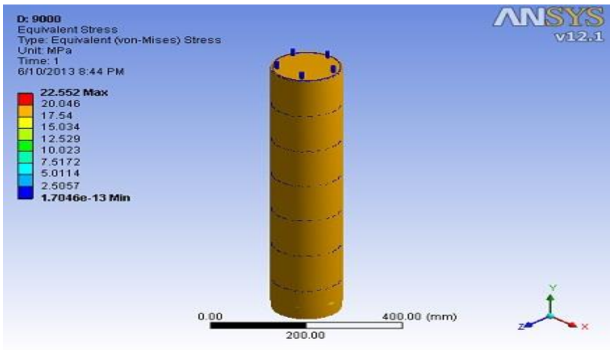

Fig 5 Equivalent Stress Chart of 900 mm unconfined column

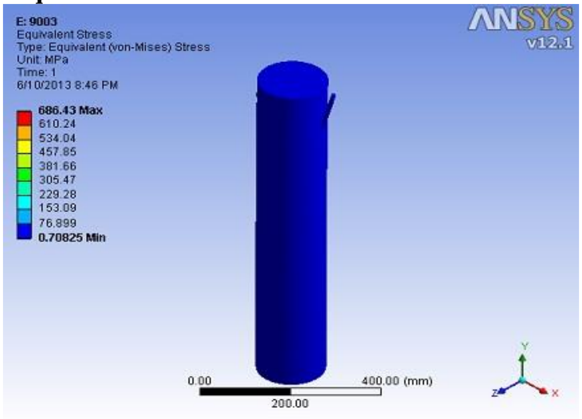

Fig 6 Equivalent Stress Chart of 900 mm confined column

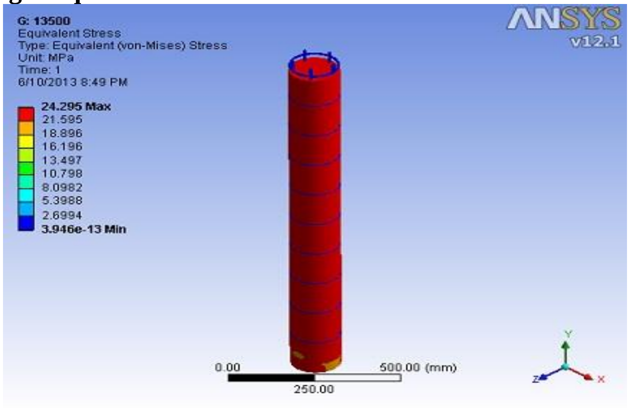

Fig 7 Equivalent Stress Chart of 1350 mm unconfined column

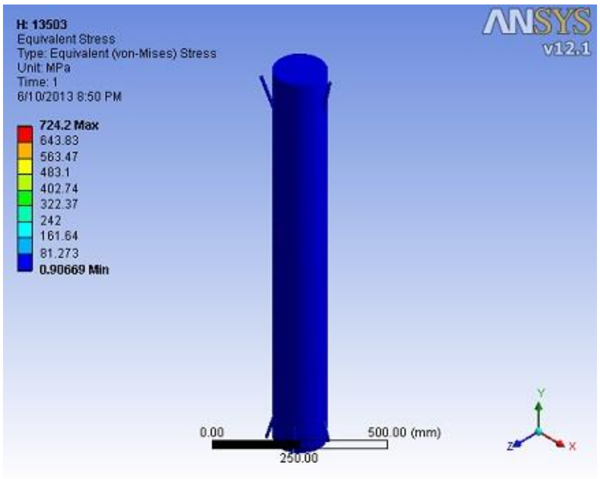

Fig 8 Equivalent Stress Chart of 1350 mm confined column

Discussion of results

Effect of slenderness ratio and confinement on ultimate load and ultimate stress

Slenderness ratio had a notable increase on the ultimate load and ultimate stress attained by the confined as well as unconfined column specimens. The ultimate load increased with increase in the slenderness ratio of the specimens. The unconfined specimens with slenderness ratios 6 and 9 showed an increase of 160% and 248% respectively over the specimens with slenderness ratio of 3. Similarly, columns with 3 mm thick GFRP wrap showed an increase of 145 % and 236%; and those with 4 mm thick GFRP wrap exhibited 218% and 280% increase in the ultimate load over the specimens with slenderness ratio of 3. The effect of slenderness ratio on the ultimate stress is presented in Figure 9. The effect of slenderness ratio on the ultimate load is same as that on the ultimate stress.

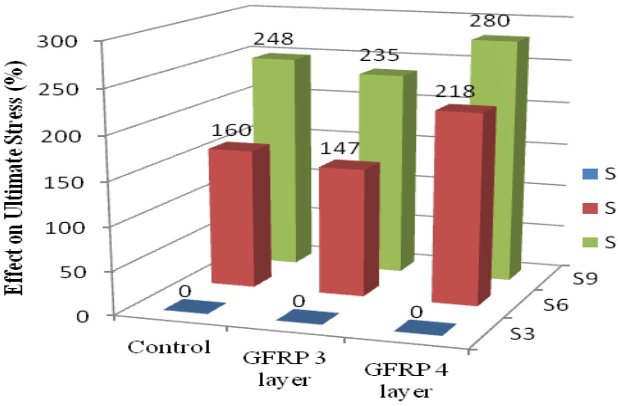

Fig 9. Slenderness Ratio vs Ultimate Stress

Effect of slenderness ratio and confinement on deflection

The deflection shown by the specimens increased with increase in the slenderness ratio. Also the GFRP confined specimens allowed for more deflection than the control specimens. This was due to the strength in the confinement provided to the specimens. The failure of the specimens is when the rupture of the FRP confinement occurs.

Effect of slenderness ratio and confinement on deflection ductility

Ductility characterizes the deformation capacity of members (structures) after yielding, or their ability to dissipate energy. In general, ductility is a structural property which is governed by fracture and depends on structure size. A measure of theductility of a structure may be defined by the displacement (deflection) ductility factor (μ), $\mu = \frac{\Delta u}{\Delta y}$, Δu = lateral deflection at the end of the post-elastic range, Δy = lateral deflection when yield is first reached

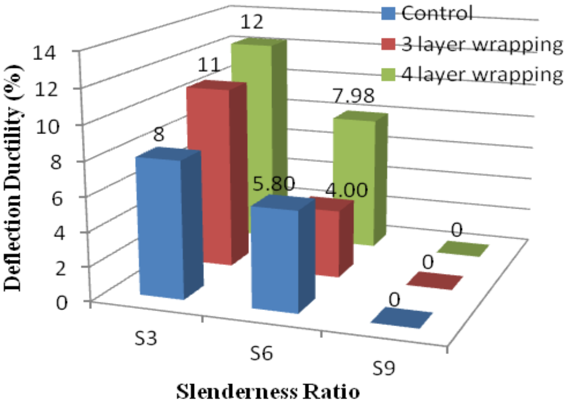

Fig 10. Slenderness Ratio vs Deflection Ductility

Slenderness raio had considerable effect on the deflection ductility of the unconfined columns, having a decrease of 5.80% and 8.0% for the columns C4S6G0 and C1S3G0 respectively compared to the column C7S9G0. The confined columns showed a decrease to about 11.0% for 3mm thick GFRP wrap and upto 12.0% for 4mm thick GFRP wrap. The effect of slenderness ratio on the deflection ductility is presented in Figure 10.

The load deflection plots of the test specimens are given below:

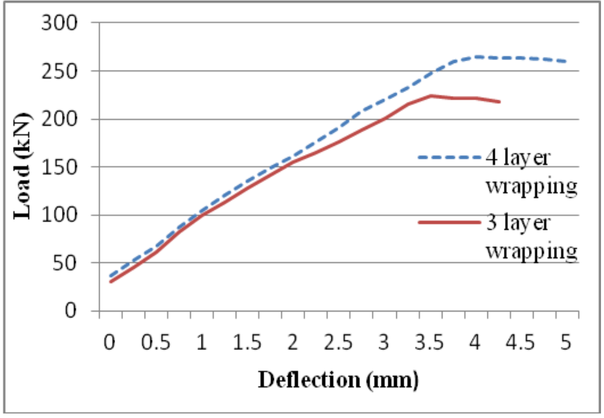

Fig 11 Load deflection plot for confined column of height 0.45m

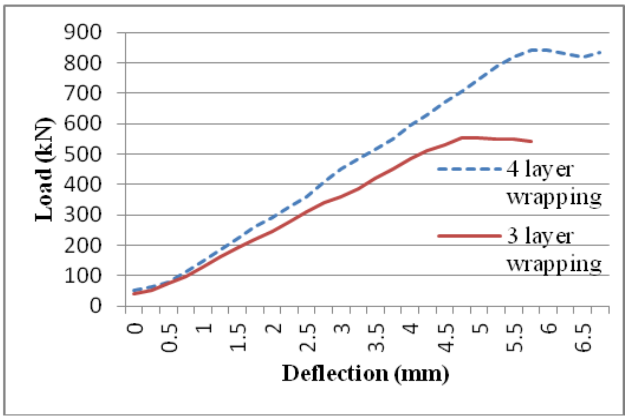

Fig 12 Load deflection plot for confined columns of height 0.9 m

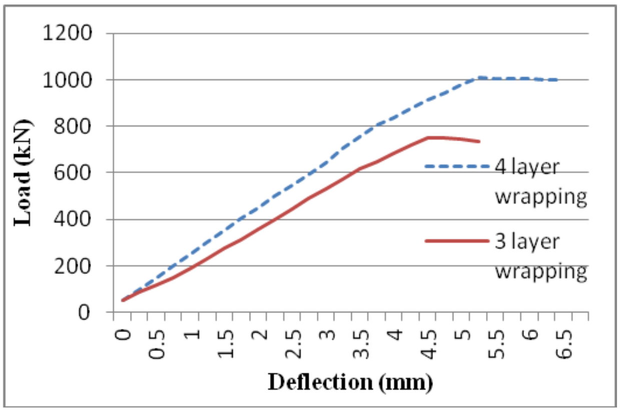

Fig 13 Load deflection plot for confined column of height 1.35 m

Comparison of results

Sl.No.	**Column Designation**	**Ultimate Load (kN)**	
		Experimental Value	**Analytical Value**
1	C1S3G0	144	141.43
2	C2S3G3	224	222.75
3	C3S3G4	265	266.95
4	C4S6G0	373	371.25
5	C5S6G3	554	565.71
6	C6S6G4	843	894.54
7	C7S9G0	501	485.50
8	C8S9G3	752	747.52
9	C9S9G4	1009	990.32

Conclusions

Based on the results obtained through the experimental investigation, the following conclusions were made.

1. As the slenderness ratio increases from 3 to 9, the ultimate load carrying capacity increases by about 250%.
2. When the specimens are confined with GFRP wrapping, the load carrying capacity is again enhanced. As the thickness of the wrap increases from 3mm to 4mm, the load carrying capacity increases by about 280%.
3. Similarly, the deflection on the unconfined and confined specimens increases with the increase in slenderness ratio from 3 to 9.
4. The unconfined columns exhibited a decrease in the deflection ductility upto 8.0% while the confined columns showed decrease upto 12.0%. Ductility increased with increase in slenderness ratio and thickness of GFRP wrap.
5. In the analytical analysis, the modeled specimens too exhibited similar behaviour with increase in the load carrying capacity with increase in the slenderness ratio from 3 to 9, and increase in thickness of GFRP wrapping from 3 to 4 mm.
6. The results obtained from analytical analysis using ANSYS and that from experimental work were very much comparable. Hence, the software proves to be reliable in the prediction of the behaviour of concrete specimens under specific loading conditions.

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