Comprehensive Analysis of Square Short and Slender RC Columns Wrapped with Carbon-Fiber Reinforced Polymer Sheets under Uniform Compression

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Abstract: ***Strengthening and retrofitting of old and existing structures is a major area of research for some time now. This paper focuses on the strengthening of the columns with Carbon-Fiber Reinforced Polymer sheets wrapped around them. The conventional methods of retrofitting and strengthening such as steel jacketing needs space and time. A lot of past researches have established that CFRP is a good substitute for the old methods for short columns. This work verifies the usability of CFRP for both short and slender columns of square cross sectional area. The columns were loaded axially in a quasi-static manner. The ultimate load and stress resistance of the short columns were found to have enhanced by 75% if doubly wrapped and for the same the long column produces an increase of 124.5% which is satisfactory. In this regard the cost of the short column goes up by 35-50% and 50-75% for long column depending upon singly or doubly wrapped.***

1. Introduction

It is known that the strength of R.C.C structures reduces with time. Different researches have been carried out to retrofit or strengthen the existing structures. With increase in the cost of construction materials it becomes relevant to develop new economic methods to strengthen the existing structures so as to extend the life of the structure. On this urge, Carbon Fiber either in the form of reinforcement or sheets has given a significant competition to other substitutes. Enough amount of studies have shown that Carbon fiber reinforcements enhances the quality of retrofitting whereas CFRP sheets demand further researches to establish it better substitute to heavy retrofitting techniques.

In this research work, the main focus has been on columns, an important structural member who transfers the load from the beam or slab to the sub structure and thus its strength is vital for the existence of any structure. With steady growth in research based on strengthening of existing and new columns, Carbon Fiber Reinforced Polymer (CFRP) has found its own significance. Several previous works on short and slender columns show that CFRP delivers serious results in delaying failure with significant increase in load.

It is also well known that failure mechanism of columns depends upon its slenderness ratio. The greater the slenderness the more bending property is infused into the column due to which while working on strengthening it becomes important to consider the ratio of effective length to least radius of gyration effectively known as slenderness ratio.

In accordance to IS 456:2000, when effective length to lateral dimension is less than 12, it is considered to be a short column, if otherwise, long column.

This research focuses on increase of strength of short and slender columns. CFRP due to its high strength to weight ratio does not significantly affect the dead weight of the column. The CFRP sheets are wrapped to enhance the loading resistance of Reinforced concrete columns. The factors affecting the effectiveness of externally wrapped CFRP sheets include the type of concrete used, number of wraps and loading conditions.

Keeping economy of the work in view, this work also intends to provide a clear data on increase of percentage confinement of column by CFRP versus increase in Load bearing capacity of the column. This will help in retrofitting of existing columns while restricting the cost to a desired value. There is a need to keep the cost in check as a new construction by demolishing old and existing structures would cost significantly higher. Here we try to give a much cheaper solution as a substitute to what can be a very exhausting and expensive method.

Researches on slender columns are significantly low in comparison to short columns, which hereby, make it relevant to carry forward the little work on slender columns, ahead. CFRP has proved its competence to improve crushing strength of short columns whereas its merit on delaying the bending failure is yet to be verified extensively.

Objectives of study

1) To find if Carbon fiber Reinforced Polymer (CFRP) can be a sustainable alternative to other retrofitting methods.
2) To understand the variation of cost and percentage wrap of the CFRP on the columns and see if the numbers suggest significant variation.
3) To verify the results of past researches on short column suggesting increase in crushing strength of CFRP sheet wrapped short columns.
4) To provide significant data on the usability of CFRP sheets in case of slender columns to resist bending.

Scope of study:

In the recent past, a number of researches have concluded that the failure of structures such as Bridges and Residential buildings happened due to failure of piers and columns. This makes the study on columns and increasing its strength an important topic of discussion and research.

In this regard alternatives to conventional retrofitting and strengthening techniquesare encouraged.

Conventional methods of jacketing including the post tensioning techniques provide satisfactory results but contain some serious drawbacks. The drawbacks are as follows:

- Steel add to the dead weight of the columns which may to enhancement of seismic loads.
- These construction methods are huge and time taking in nature and may result in disruption in traffic flow.
- Increase in mass may increase the stiffness of the structure which in turn can reduce the time period and consequently leading to destruction.
- The use of these conventional techniques also affects the aesthetics.

As the conventional methods contain the above serious drawbacks researches around the world have focused on substitute. In this regard Carbon Fiber polymer has emerged as a serious contender.

2. Materials

Cement:

43 grade of OrdinaryPortland Cement conforming to IS 8112:2013, *"ORDINARY PORTLAND CEMENT-SPECIFICATION"*, was used.

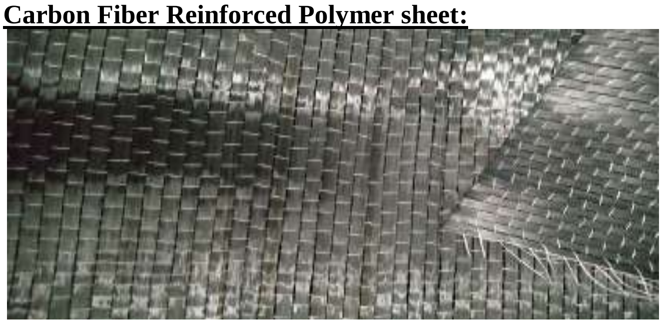
Aggregates:

a) Fine aggregates conforming to IS383:1970, *"specifications for coarse and fine aggregates from natural sources for concrete"* was used.
b) Coarse aggregates conforming to IS383:1970, *"specifications for coarse and fine aggregates from natural sources for concrete"* was used.

Water:

Normal portable water fit for drinking purpose was used to prepare fresh concrete.

Carbon Fiber Reinforced Polymer sheet:



CFRP are generally of two kinds, Uni-directionally woven and Bi-directionally woven. In this research Uni directional CFRP has been used. The mechanical properties of the 230GSM- Uni directional Carbon Fiber Sheet were:

Characteristics	Value	Tolerance	Test Method
Weight(g/m^2)	230	± 3%	ASTM D3801
Width(mm)	500	-0/+10mm	ASTM D3774
Dry Fabric Thickness(mm)	0.25	± 0.03mm	ASTM D1777

Note: The cost of the above CFRP sheet was 900INR per sq.m.

Epoxy Adhesive:

Epoxy resins are used for high strength bondage in civil engineering and thus epoxy adhesive the following properties were used:

Viscosity	Density	Gel Time	Full Cure time
9000-12000 MPas	1.15-1.20 g/cc	2 hours	24 Hours

Note: All the above values are taken at 25^{0}C. The cost of the Epoxy adhesive was 1120INR per Kg.

3. Literature Review

KatrniaGajdosova and JurajBilcik,studied the performance of slender rectangular reinforced column wrapped with CFRP in two manners of which the first included conventional CFRP sheet jacketing with full scale testing. The second of which had a new retrofit of near surface mounted CFRP strips conforming that the effect of CFRP was predominantly more when the columns are shorter. This study also concluded that the longitudinal fibers in CFRP strips wrapped over concrete are more effective and enhances the flexural load carrying capacity of slender columns. A synergic approach of NSM and CFRP wrapping produced the best results.

Mohhamad R. Irshidat, Mohammed H. Al-Saleh, Mahmoud Al-Shoubaki investigated the use of Carbon fiber reinforced epoxy composites modified with carbon nano tubes in strengthening the reinforced columns by wrapping them with fiber sheets blended with neat epoxy or CNTs modified epoxy. Under concentric axial loading the test results concluded that the wrapped columns gained a strength of 24%, maximum displacement of 109% and toughness of 232% with respect to unwrapped RC column.

PranayRanjan, PoonamDhimanstudied a particular problem statement of a building in Patna, Bihar. The paper focuses on the design of the RC jacketing, steel jacketing and FRP jacketing of the same column and their cost variation. According the study Fiber reinforced polymer jacketing is least economical whereas steel jacketing costs least. The paper concludes that the use of FRP Jacketing offers several advantages over the RC and SFRC Jacketing but it is slightly expensive.

P.Paultre, M.Boucher-Trudeau, R.Eid, N Roy in their research underlined that deficient columns used in bridges can be provided extra enhanced strength or can be upgraded by the use of surface fiber reinforced polymer sheets. As the work focuses on the columns used in bridges, the columns are loaded with cylic flexure. Under cylic flexure loading the behavior of the confined columns revealed that FRPs can be effective even in cyclic flexural loading.The results also showed that the addition of CFRP increases the ductility and energy dissipation. For the columns with transverse steel reinforcement spacing and lower axial load the results are more pronounced.

4. Methodology

Experimental Program:

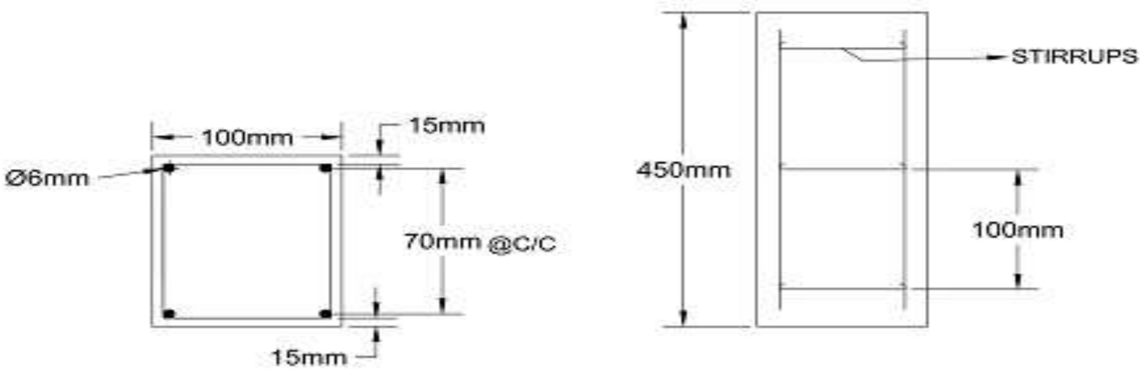
1) Specimen layout

A total of 16 specimens were prepared in accordance with the need of the research. Eight specimens were prepared as experimental models of short columns and other half were for long columns. As the research focuses on behavior of both short and slender columns the experimental set up was prepared to fulfill the needs of the research.

Details of column specimen/Model:

- *Short Columns:-*

The columns were reinforced with 4nos of 6mm diameters plain bars with stirrups at a distance of 100mm each.M20 concrete was used.The columns were cured for 28 days.



SHORT COLUMN SPECIMEN

Specifications of the Model Specimens of Short Column:

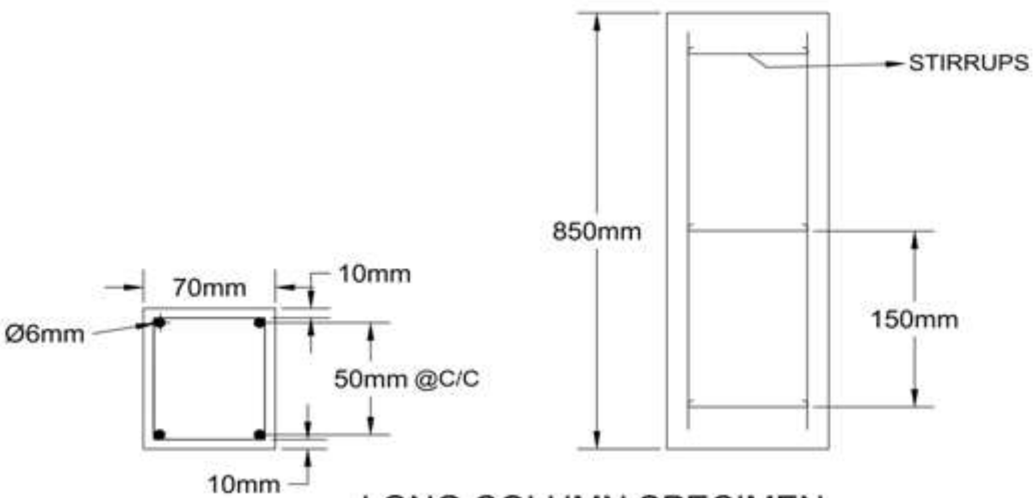
No. of specimen prepared	Height of the specimens (mm)	Width of the specimen (mm)	Cross sectional area of the specimens(mm^2)	Slenderness ratio of the specimen
8	450	100	10,000	4.5

2) Long Columns

The columns were reinforced with 4nos of 6mm diameters plain bars with stirrups at a distance of 150mm each.M20 concrete was used. The columns were cured for 28 days.

Specifications of the Model Specimens of Long Column:

No. of specimen prepared	Height of the specimens (mm)	Width of the specimen (mm)	Cross sectional area of the specimens (mm^2)	Slenderness ratio of the specimen
8	850	70	4900	12.14



LONG COLUMN SPECIMEN

These specimens were swaddled with Carbon Fiber-Reinforced Polymer Sheets in three different manners. To study economic parameters and gauge the strength enhancement of the columns with different percentage of CFRP wrapping, the columns were wrapped 65% (single layer), 100% (single layer) and 200% (double layer of complete wrap) of their surface area.

1. Test set-up

The specimens prepared were tested with axial loading under the Universal Testing machine (long column) and compression testing machine (short column). All the sixteen specimens were loaded in quasi-static manner. Firstly, the specimens with zero percentage of wrapping were tested and the ultimate loads were noted. Secondly, the specimens with 65% of wrapping were tested and the same procedures were applied to the 100% and 200% wrapped specimens. The ultimate loads of all the specimens were tabulated. The ultimate loads were converted to ultimate stress and the comparison was plotted.

For each percentage of wrap two specimens were prepared to negate any human error. A total of sixteen specimens were prepared. The details are provided below:

SC_x, where SC represents short column and x is the serial number of the specimen. For e.g. SC_1 is the first short column specimen.

Specimens SC_1 and SC_2were not wrapped up by the CFRP sheet. SC_3 and SC_4 were wrapped up in such a pattern that a 65% of the total surface area was wrapped by CFRP. Similarly, SC_5 and SC_6 were completely wrapped i.e. 100% of the surface area was covered by CFRP. Consecutively SC_7 and SC_8 were doubly wrapped i.e. 200% of the surface area was wrapped with CFRP.

Test setup for long column specimens

Short columns were tested in the compression testing machine.

End Conditions:

All the ends of both short and long columns were not restrained against rotation.

5. Results and Discussions

The above specimen layout and test set up were used to produce the results of the research work. Every column specimen underwent the axial loading and their ultimate loads were noted down and certain interpretations were drawn. As stated in the introduction part we, in this research work were interested in the ultimate load/stress that the specimen can resist and the increase in the cost of the CFRP wrapped specimens with respect to unwrapped specimen.

The ultimate load (P_{ult}) at which the columns fail has been tabulated. In addition to this Ultimate stress (σ_{ult}) has been used to evaluate the performance of the columns.

The result has been explained separately for Short specimen and Slender Specimen.

Result for Short Column Specimen:
The short column (slenderness ratio< 12) gave the following results:

S. No	Specimen Name	Percentage wrapping	P_{ult} (kN)	$\sigma_{ult}(P_{ult}/A)$ (MPa)	σ_{ult} Considered (MPa)
1	SC_1	0	230	23	22.1
	SC_2		221	22.1	
2	SC_3	65	274	27.4	27.4
	SC_4		281	28.1	
3	SC_5	100	322	32.1	31.85
	SC_6		318.5	31.85	
4	SC_7	200	403	40.3	40.3
	SC_8		408	40.8	

The above results can be interpreted in the following statements:

- On an average the 65% wrapped column(SC3 and SC4) showed an increase of 23.98% in the ultimate load/stress resistance with respect to 0% CFRP wrapped(SC1 and SC2) column specimen.
- The column specimen SC5 and SC6 which were fully wrapped (single layer) with CFRP sheets i.e. 100% wrapped showed the least growth of 38.47% in the ultimate load/stress with respect to 0% wrapped column specimen.
- The specimen doubly wrapped on the surface with CFRP sheets i.e. 200% wrapped columns produced the least enhancement of 75.21% in the ultimate load/Stress resistance with respect to 0% wrapped column specimen.

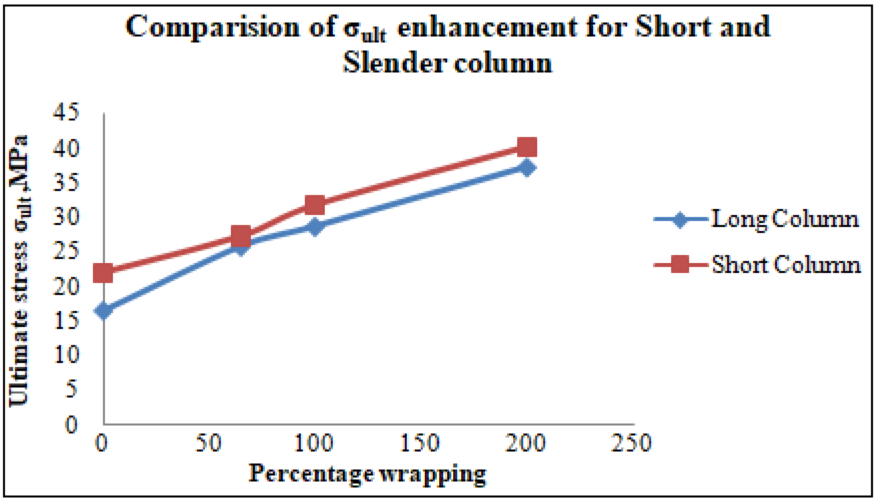
Result for Long Column Specimen

The short column (slenderness ratio>12) gave the following results:

S. No	Specimen Name	Percentage wrapping	P_{ult} (kN)	$\sigma_{ult}(P_{ult}/A)$ (MPa)	σ_{ult} Considered for calculation (MPa)
1	LC_1	0%	83	16.93	16.63
	LC_2		81.5	16.63	
2	LC_3	65%	138	28.1	25.91
	LC_4		127	25.91	
3	LC_5	100%	141	28.77	28.77
	LC_6		151	30.81	
4	LC_7	200%	198	40.40	37.34
	LC_8		183	37.34	

The above results can be interpreted in the following statements:

- On an average the 65% wrapped column (LC3 and LC4) showed an increase of 55.83% in the ultimate load/stress resistance with respect to 0% CFRP wrapped (LC1 and LC2)long column specimen.



- The long column specimen LC_5 and LC_6 which were fully wrapped (single layer) with CFRP sheets i.e. 100% wrapped showed the least growth of 73% in the ultimate load/stress with respect to 0% wrapped column specimen.
- The specimen doubly wrapped on the surface with CFRP sheets i.e. 200% wrapped columns produced the least enhancement of 124.5% in the ultimate load/Stress resistance with respect to 0% wrapped column specimen.

Failure pattern in the case of long columns has been shown in the figure below which suggest that the failure due bending was avoided.

Failure of long column specimens at the ends

6. Conclusions

The results obtained for the short and slender column specimen with the discussed test setup were analyzed keeping in view the pre decided objectives. The analysis concluded as enumerated below:

1) CFRP is a sustainable substitute to steel jacketing or other conventional methods as it consumes far lesser time and space than those conventional methods.
2) The enhancement in the ultimate load or stress of the short column verifies the past work suggesting that CFRP improves the load bearing capacity of the column by a significant margin.
3) In case of long columns, the increase in the ultimate load and stress value establishes the fact that Carbon fiber reinforced polymer sheets is capable of enhancing the strength and also delaying the failure, though the failure pattern remains the same.
4) The cost for preparing a short column specimen wrapped with 100% surface area wrapped with CFRP was 35%more than that of 0% wrapped specimen which in return resulted in a strength enhancement of around 40%. This cost went up to 50% for Long columns but the strength enhancement is 73% which is significantly encouraging.
5) The increase in cost went up to 50% in case of short column and 75% for Long column if doubly wrapped.
6) All the long column specimens were found to fail at supports indicating that failure due to bending was avoided as the resistance towards bending improved.

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