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(RESEARCH ARTICLE)

Performance evaluation of CFRP-wrapped columns under eccentric loading

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Abstract

Reinforced concrete (RC) columns are essential structural elements that primarily resist axial loads along with bending moments caused by eccentric loading conditions. In many existing structures, columns may experience deterioration, increased service loads, or design deficiencies, which can reduce their structural capacity and performance. Strengthening and rehabilitation of such columns are therefore necessary to ensure safety and durability. Carbon Fiber Reinforced Polymer (CFRP) has emerged as an effective strengthening material due to its high strength-to-weight ratio, corrosion resistance, durability, and ease of application. The present study investigates the performance of CFRP-wrapped reinforced concrete columns subjected to eccentric loading. Reinforced concrete columns of size 150 mm × 150 mm × 1200 mm were cast using M25 grade concrete. Each column was reinforced with four 12 mm diameter longitudinal bars and 8 mm stirrups spaced at 100 mm center-to-center. Different CFRP wrapping configurations were used to evaluate their effectiveness in strengthening the columns. Two types of strengthening techniques were adopted, namely full wrapping and strip wrapping using CFRP sheets of 0.42 mm thickness. The wrapping configurations included only middle span wrapping, one end and middle span wrapping, middle span and second end wrapping, and wrapping at both ends of the column. All specimens were tested under eccentric loading, and parameters such as ultimate load, axial stress, axial deflection, and axial strain were recorded and analyzed.

Keywords: Axial Stress; Axial Strain; Axial Deflection; Retrofitting of Structures; Full Wrap; Strip Wrap.

1. Introduction

Under strong seismic excitations, reinforced concrete bridge columns designed using earlier codes are commonly deficient in flexural ductility, shear strength and flexural strength. Various retrofitting techniques have been developed and the use of fiber-reinforced plastic/polymer (FRP) composite jackets has been widely applied to provide lateral confinement for enhanced strength and ductility. Among the FRP used for the retrofit of reinforced concrete columns, carbon fiber sheets (CFS) are widely used due to its high elastic modulus and tensile strength, the highest among the FRP composites. Several constitutive models governing the behavior of CFS-confined concrete under monotonic loading have been developed (Spoelstra and Monti 1999, Kawashima et al. 2000, Xiao and Wu 2000). On the other hand, very limited studies are available to assess its cyclic response. Kawashima et al. (2000), Chang et al. (2004), Haroun and Elsanadedy (2005), among others have experimentally investigated the performance of CFS wrapped reinforced concrete bridge columns under simulated seismic actions. Their results showed that the retrofitted columns had improved seismic performance. Although experimental studies were conducted to investigate the cyclic performance of CFS-retrofitted columns, there is a need to develop an analytical model which can simulate the experimental results. Also, development of an analytical model that can represent inelastic stiffness and energy-absorbing characteristics of the composite column is necessary for detailed analysis of such systems for practical applications such as in nonlinear static and dynamic analysis.

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1.1. Necessity of Strengthening Reinforced Concrete Elements:

For taking in consideration the necessity of strengthening RC elements we must analyse the situations that arise in practice where existing concrete structures or some of their components may, for a variety of reasons, be found to be inadequate and in need of repair and/or strengthening. The situations in which the reinforced concrete slabs require the intervention for repairs or strengthening are the following [1]:

- Repairing damaged/deteriorated concrete slabs to restore their strength and stiffness.
- Corrosion of the reinforcement.
- Limiting crack width under increased (design/service) loads or sustained loads.
- Retrofitting concrete members to enhance the flexural strength and strain to failure of concrete elements requested by increased loading conditions such as earthquakes or traffic loads.
- Rectifying design and construction errors such as undersized reinforcement.

1.2. Carbon Fiber Reinforced Polymer

Among the available strengthening techniques, Carbon Fiber Reinforced Polymer (CFRP) wrapping has gained widespread acceptance due to its high tensile strength, corrosion resistance, lightweight nature, and ease of application.

Advantages of Carbon Fiber Reinforced Polymer

- Light weight, Corrosion resistant, High strength with a high fatigue resistant life, Can be installed with a minimal crew and common equipment
- The major advantages of carbon fiber over traditional materials like steel, aluminum, wood and plastics include: High stiffness and strength. Lightweight. Corrosion resistance.
- High strength and high modulus

2. Materials and Methods

Most existing RC columns are subjected to combined axial load and bending rather than pure compression. Retrofitting guidelines under eccentric loading conditions are limited. CFRP is expensive; hence, optimal placement and partial wrapping strategies must be studied. There is a need to compare full wrapping versus strip wrapping under eccentric loads. Practical strengthening solutions must be identified for rehabilitation of existing columns.

2.1. Mix Proportions.

Table 1 The Mix proportion

Water	Cement	Fine aggregate	Coarse aggregate
191.6 lits	450 Kg	596.9 Kg	1193.81
0.4	1	1.326	2.653

- Column size = 150 mm × 150 mm × 1200 mm
- Total height (H) = 1200 mm
- Tension zone = H/6 = 200 mm
- Main bars = 4 no – 12T
- For full wrap Stirrups = 200 mm
- Strip width = 50 mm (8 No)
- Total wrapping length per specimen = 400 mm

- For strip wrapping, the total wrapped length (400 mm) will be achieved using multiple 50 mm wide strips.

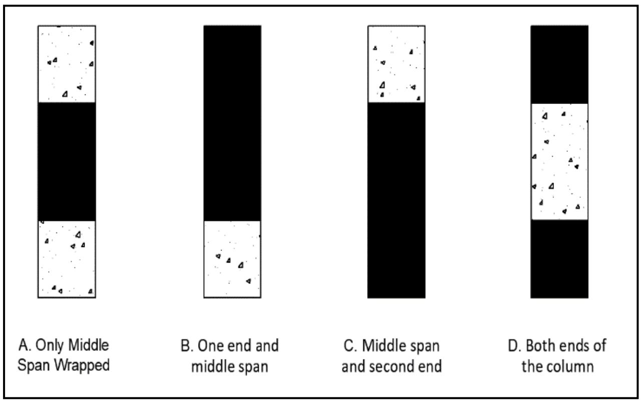

Figure 1 Wrap Details for Full wrap

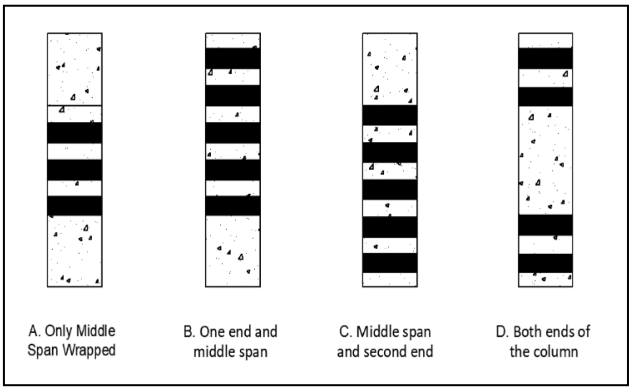

Figure 2 Wrap Details for Full wrap

3. Results and Discussion

3.1. Results for Full Wrap

The reinforced concrete columns were cast with M25 grade concrete and reinforced with four longitudinal bars of 12 mm diameter along with 8 mm diameter stirrups spaced at 100 mm center-to-center. The column specimens had overall dimensions of 150 mm × 150 mm × 1200 mm. After casting, the specimens were cured properly for 28 days before the strengthening process was carried out.

Table 2 Ultimate Failure Load of CFRP Full Wrapped Columns

Wrap Configuration	Specimen 1 (kN)	Specimen 2 (kN)	Specimen 3 (kN)	Average Load (kN)
Control Column (No CFRP)	305	312	309	308.67
Only Middle Span Wrapped	356	362	359	359
One End and Middle Span	381	387	384	384
Middle Span and Second End	372	378	375	375
Both Ends of Column	342	348	345	345

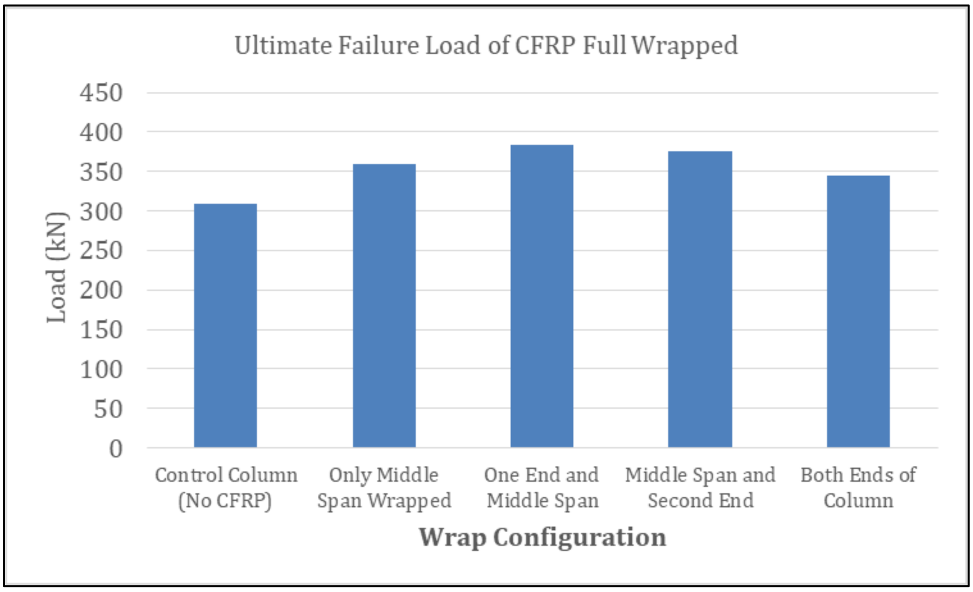

Figure 3 Ultimate Failure Load of CFRP Full Wrapped Columns

Three specimens were tested for each configuration and the average value was considered for analysis. The results indicate that the one end and middle span wrapping configuration achieved the highest load carrying capacity, followed by the middle span and second end configuration. Columns wrapped only at the middle span also showed significant improvement compared to the control column, while both end wrapping exhibited relatively lower strength enhancement.

Table 3 Average Axial Deflection

Wrap Type	Average Deflection (mm)
Control Column	0.6
Only Middle Span	0.71
One End + Middle Span	0.75
Middle Span + Second End	0.73
Both Ends	0.68

The results indicate that the one end and middle span wrapping configuration exhibited the highest axial deflection, indicating improved ductility and energy absorption capacity. The middle span and second end configuration also showed significant deformation capacity, while the both-end wrapping configuration exhibited comparatively lower deflection

3.2. Results For Strip Wrap

Table 4 Ultimate Failure Load of CFRP Strip Wrapped Columns

Configuration	Specimen 1 (kN)	Specimen 2 (kN)	Specimen 3 (kN)	Average Load (kN)
Control Column	305	312	309	308.67
Only Middle Span	332	338	335	335
One End + Middle Span	348	352	350	350
Middle Span + Second End	342	347	345	344.67
Both Ends of Column	320	326	323	323

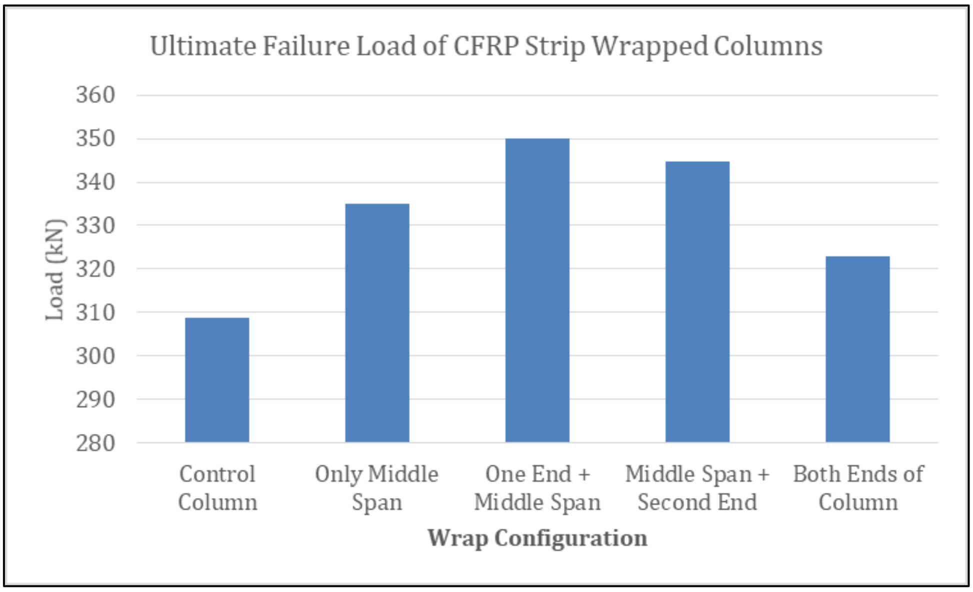

Figure 4 Ultimate Failure Load of CFRP Strip Wrapped Columns

Three specimens were tested for each wrapping configuration and the average value was calculated to ensure reliability of the results. The control column exhibited an average ultimate load of 308.67 kN. The columns strengthened with CFRP strip wrapping showed improved load carrying capacity compared to the control specimen. Among the different configurations, the one end and middle span wrapping configuration showed the highest ultimate load, indicating better confinement and structural performance. The results demonstrate that CFRP strip wrapping enhances the strength of reinforced concrete columns subjected to eccentric loading

Table 5 Average Axial Deflection

Configuration	Average Deflection (mm)
Control Column	0.6
Only Middle Span	0.63
One End + Middle Span	0.67
Middle Span + Second End	0.66
Both Ends	0.59

The control column recorded an average deflection of 0.60 mm. CFRP strip wrapping slightly increased the deflection, indicating improved ductility of the columns. The one end and middle span configuration showed the highest deflection (0.67 mm), followed by middle span and second end (0.66 mm), which indicates better deformation capacity due to effective confinement. The only middle span configuration showed moderate improvement (0.63 mm), while the both ends configuration recorded the lowest deflection (0.59 mm) among the strengthened columns. This shows that CFRP placement at the middle region is more effective in improving column deformation under eccentric loading.

2. Conclusion

The present experimental investigation was carried out to evaluate the structural performance of reinforced concrete columns strengthened with Carbon Fiber Reinforced Polymer (CFRP) under eccentric loading conditions. The study focused on comparing different CFRP wrapping configurations using both full wrapping and strip wrapping techniques. Based on the experimental results obtained from the testing of column specimens, the following conclusions are drawn.

- The experimental results demonstrated that strengthening reinforced concrete columns with CFRP significantly improves their load carrying capacity when compared with the control column.

- The control column exhibited the lowest ultimate load capacity, whereas all CFRP strengthened columns showed higher failure loads due to the confinement effect provided by the CFRP material.
- Among the full wrapping configurations, the one end and middle span wrapping configuration showed the highest ultimate load and axial stress, indicating that proper placement of CFRP at critical regions significantly enhances the structural performance of the column.
- The middle span and second end configuration also showed considerable improvement in load carrying capacity, confirming that CFRP confinement near the critical stress zones improves the resistance of the column under eccentric loading.
- The both-end wrapping configuration showed comparatively lower improvement in strength compared to other wrapping configurations, indicating that confinement only at the ends is less effective when eccentric loading produces higher stresses in the middle region.
- CFRP strip wrapping also improved the strength of the columns, although the increase in strength was slightly lower compared to full wrapping due to the discontinuous confinement provided by the strip configuration.
- The axial stress results showed that CFRP strengthened columns were capable of resisting higher stresses compared to the control column, demonstrating the effectiveness of CFRP in enhancing compressive resistance.
- The axial deflection and strain results indicated that CFRP strengthened columns exhibited higher deformation capacity, which reflects improved ductility and energy absorption characteristics.
- The experimental results confirmed that CFRP strengthening not only increases the load carrying capacity but also enhances the structural performance of reinforced concrete columns subjected to eccentric loading.
- From the overall comparison of different strengthening configurations, it can be concluded that CFRP wrapping at the middle span combined with one end provides the most effective strengthening strategy for reinforced concrete columns under eccentric loading.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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IS Codes

- **IS 456:2000** Code of Practice for Plain and Reinforced Concrete.
- **IS 10262:2019 –** Guidelines for Concrete Mix Design Proportioning.
- **IS 383:2016 –** Specification for Coarse and Fine Aggregates from Natural Sources for Concrete.
- **IS 12269:2013 –** Specification for Ordinary Portland Cement (OPC 53 Grade).