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Behavior of GFRP Sheet Wrapped Rectangular RC Column Under Axial Loading

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Abstract

Over the past few decades, the deterioration of the reinforced concrete (RC) infrastructure has been rapid. There is an urgent need to develop the most cost-effective and efficient methods for repairing or replacing existing RC structures. The aim of this research was to gain an understanding of the axial response of RC rectangular columns with external bonded glass fiber reinforced polymer (GFRP) sheets. A total of 12 rectangular columns were constructed and tested using an axial compression test method. The columns were divided into three groups; three control columns, and three groups of GFRP wrap types (1-layer, 2-layer and 3-layer). The experimental results demonstrated that the addition of GFRP to the columns significantly improved their strength and ductility compared with the control columns. Furthermore, this study shows that the effect of adding layers of GFRP wrap to the rectangular columns is not linear. Specifically, the optimal configuration for improving both the axial loading capacity, as well as ductility of the rectangular columns, is using 2 layers of GFRP wrapping, which provided an 18.15% increase in the ultimate loading capacity of the GFRP wrapped column compared to the control column. The ultimate load of columns wrapped with 1 layer or with 3 layers of GFRP increased by 6.25% and 1.35%, respectively. The failure mode of controlled columns is typically dominated by a brittle concrete crush; conversely, the failure mode of GFRP-wrapped columns is often ductile due to GFRP rupture. The two-layer GFRP wrap configuration was found to be the best balance of structural performance and cost, and that the additional layers of GFRP wrap confer diminishing returns.

Keywords: RC Columns, Retrofitting, GFRP Wrapping, Confinement, Axial Loading, Structural Strengthening**.**

1. Introduction

The global infrastructure is being faced with many new and unprecedented challenges specifically surrounding the age of current reinforced concrete (RC) structure and ageing of the environment and service load requirements associated with these structures. Rectangular-shaped RC (reinforced concrete) columns, as the main structural support for all buildings and bridges, are very vulnerable to deterioration, due to an abusive environment and improper or deferred maintenance of the materials that make up these structures [1]. This ecological deterioration results in a decrease in load-carrying capacity, a loss of ductility and degradation in overall structural safety. Therefore, it is vital that effective and efficient rehabilitation plans are developed for these aged RC Structures.

Conventional strengthening methods (e.g., steel jackets, concrete overlays, and section enlargement) are limited in many ways. They traditionally have had the following specific limitations: they have been susceptible to corrosion, they have added significant weight to the structural system, they have caused architectural limitations, and they have created a long construction period. Because of the challenges associated with these limitations, many researchers are now working towards the development of advanced materials which will provide improved performance and longevity and ease of application [2].

FRP Composite Materials, including glass fiber, are an advanced approach to rehabilitation in structures [3]. Glass fiber-reinforced polymers are highly effective solutions, due to their low cost, high strength-to-weight ratio and very good resistance to various environmental conditions (corrosive). Also, the unique directional nature of glass fiber composites makes them ideal for providing significant lateral support to concrete elements, thereby significantly increasing the axial load bearing and ductility of concrete components [3]. Furthermore, when using glass as the jacket of the concrete core it applies ductile support around the core thus preventing crush and changing from brittle mode to ductile mode when failed.

While many experimental studies have demonstrated that FRP confinement is effective for circular columns [1]. It becomes increasingly complicated for rectangular sections because of the variable confinement created in addition to the stress concentrations at the corners. Although research conducted by Kumutha et al [4]. Raval and Dave [1]. has supported the premise that wrapping GFRP around rectangular columns will cause them to perform better than before; however, determining how many total layers are optimal has been less researched than other aspects of that topic area. Another uninvestigated aspect involves "over confinement", where once you reach a certain point of added layers, the return from these additional layers becomes less effective and/or even counterproductive due to high stiffness along with sensitivity to imperfections created during production.

This research project will fill this void with a systematic experimental investigation. The study's main objectives include:

1. Assess the axial strength and behavior of Control RC Columns without retrofitting.
2. Quantify the increase in axial strength and ductility when retrofitting the Control RC Columns with either 1, 2 or 3 layers of Glass Fiber Reinforced Polymer (GFRP) Sheets.
3. Determine the optimal number of layers of GFRP sheets which produce the greatest increase in axial strength and enhance the failure mode performance of rectangular RC Columns.

2. Experimental Program

2.1 General

The Step-by-Step Testing (for example) was done to see how different types of retrofitting would affect the axial performance of retrofitted GFRP-C Type Columns. To perform this test the very first action taken was to have 12 identical pieces of columns (upon producing these specimens) produced in accordance with Standards IS 456 2000 [5]. A Concrete mix of M20 Category was produced for all 12 pieces of Column Specimens based on guidelines provided by the IS 10262:2019 [6]. By using these combination methods to produce the Column Specimens the test would result in consistency between the 12 columns produced. To achieve a specific Specified Compressive Strength of Concrete for the Retrofits, a 28-day curing period using Water was observed when producing each Column Specimen. The preparation for Retrofitting the Columns consisted of cleaning and smoothing the surfaces of the Columns to allow for better adhesion to the GFRP [7]. GFRP was applied using Manual Application Techniques, with layers of one layer, two layers and three layers being applied in order to gain an understanding of how multiple layers would affect Compressive Strength during Load Testing of the Columns. Once all 12 Column Specimens were fabricated Compression Testing was conducted on each Column Specimen using a Universal Load Testing Device to determine the ultimate Compressive Strength, Deformation Characteristics and Failure Modes for each Column Specimen [8].

2.2 Materials Properties & Test Results

The experimental program implemented a systematic evaluation of the effects of GFRP (Glass Fiber Reinforced Polymer) confining structures on concrete using the following characteristics of the Cement and aggregate used in this research. Concrete was designed to achieve a target mean strength of M20 grade as per Indian Standard IS 10262:2019 [6]. The materials used in constructing concrete were defined in accordance with the Indian Standard codes predominately to ensure that the materials met the required quality specifications and followed Indian Standard codes [9].

2.2.1 Cement: Cement used in the construction of concrete was Portland Pozzolana Cement (PPC) which is produced in accordance with Indian Standard IS 1489 (Part 1) [10]. The following tests were conducted to confirm the quality of cement using a Vicat Apparatus in accordance with Indian Standard IS 4031 [11]. The Standard Consistency Test yielded a standard consistency of 32%, an initial setting time of 35 minutes, and a final setting time of 315 minutes. The specific gravity of cement is 3.15. You can see in figure no.1

2.2.2 Fine Aggregate: Fine aggregate was obtained from natural sources and conformed to Zone-II of Indian Standard IS 383:2016 [12]. A Sieve Analysis was conducted in accordance with the standard sieve sizes using standard sieve sets to determine the

gradation and fineness modulus (2.62) of the fine aggregate. Specific Gravity and Water Absorption of the Fine Aggregate were determined using a Pycnometer in accordance with Indian Standard IS-2386 (Part 3) [13]. The Specific Gravity of the Fine Aggregate was found to be 2.74 and a negligible amount of water absorption. In fig no. 2 you can see pycnometer test

2.2.3 Coarse Aggregate: The materials used in the study included Coarse Aggregate, with a nominal size of 20 mm crushed stone aggregate, according to IS 383:2016 [12], as well as confirming the Specific Gravity and Water Absorption of the Coarse Aggregate using the Wire Basket Method, per IS 2386:2016 [13], which indicated Specific Gravities of 2.77 and 0.47%, accordingly. A Flakiness and Elongation Index Test was conducted with a Thickness Gauge to determine the Flakiness Index and a Length Gauge for the Elongation Index with results of 33 and 13%, respectively. In Fig no. 3 You can See

2.2.4 Reinforcement: The Reinforcement used was Fe 550 high-strength steel bars, comprising four 8 mm diameter longitudinal bars and 6 mm diameter transverse mild steel stirrups. The Concrete was made from a target grade of M20, with mix design and testing, as per IS 10262:2019 [6]. After testing 150 mm cubes in the Compression Testing Machine (CTM) as per IS 516:1959 [14], the compressive strength at 28 days was found to be 30.5 MPa. In figure no. 5 You can See reinforcement for column

2.2.5 GFRP System: Concrete structures are frequently strengthened with Glass Fiber Reinforced Polymer (GFRP) systems (illustrated in Figure 6.), which consist of glass fibres embedded in a polymer resin. As a standard GFRP product, sheets are adhered to the concrete substrate during construction. The resin, which is usually epoxy, serves to impregnate and mechanically bond the fibres together [15]. It distributes loads equally, thereby assuring proper mechanical bonding between fibres & resin and between the GFRP system and the concrete. See Table 1. key mechanical characteristics that demonstrate how this material is both strong in tension, lightweight and has excellent resistance to corrosion; therefore, it performs well in different environments and under various loading conditions.

Table 1. Properties of GFRP

Properties	Values
Density	1.2-2.1 g/cm^3
Coefficient of thermal Expansion	6-10 x10^{-6}/°C)
Thickness	0.5-1.5mm
Modulus of Elasticity	34-48 GPa

2.2.6 Primer & Saturant: According to ACI 440.2R-08 [15]. there are two important resin component that are vital to the installation of an FRP system. First is the primer, which is a low viscosity resin that is applied after the concrete has been prepared, but before the FRP is installed. The purpose of a primer is to allow the primer to penetrate into the pores of the concrete to allow for a better bond between the concrete and FRP which then seals the concrete and allows the saturating resin or other adhesive to adhere properly and provide the necessary mechanical bonding. The saturating resin of a wet-layup system is used to saturate the dry fibre sheets before they are placed into the FRP system [16]. The saturating resin provides the means to bond the fibres together and hold them in place, as well as transfer shear loads between the different fibres. In addition to being the means of bonding the individual fibres of the wet layup system, the saturating resin also serves as the bond between the primed concrete and the FRP composite system. In order for both materials to work properly, they must be compatible with each other and the concrete, and develop the required mechanical properties so that the composite will be effective in its intended use.



Fig 1. Vicat Apparatus



Fig 2. Pycnometer



Fig 3. Wire Bucket method

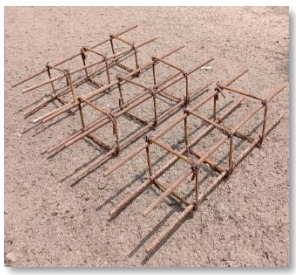


Fig 4. Reinforcement



Fig 5. Compressive Strength After 28 days



Fig 6. GFRP

3. Casting of Specimen

After finalizing the mix design, twelve identical reinforced concrete column specimens were produced. Before casting the columns, the inside surfaces of the 16 mm plywood moulds were treated with oil to allow for easy removal. The prepared reinforcement cage was made up of four longitudinal bars, all with a diameter of 8 mm; also, 6 mm diameter stirrups were placed at 135 mm centre-to-centre. The reinforcement cage was carefully placed in the middle of the mould. In order to provide adequate cover (concrete cover) over the reinforcement cage as outlined in the specifications, cover blocks with a thickness of 10 mm were placed on all four sides of the reinforcement cage. The M20 concrete used to cast the columns was poured into the mould layer by layer and was compacted with a tamping rod to remove any air voids and create a homogeneous material. The column specimens produced were cast at a size of 120X180X560 mm. you can see in the fig 7

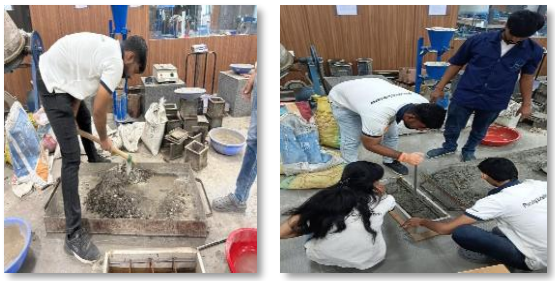


Fig 7. Casting of Column's

4. Application of GFRP Sheet & Epoxy Resin

They did the retrofitting with the hand lay-up method. They started by coating the surface with an epoxy primer. After that, they cut the GFRP sheets to fit, then saturated them with epoxy and wrapped them around the columns so that all fibres were pointed in the hoop direction. They applied one, two, and three GFRP layers to different sets of columns, so they could control saturation and force the air out from between the layers and create a good bond between the GFRP and the columns Experimental setup. You can see in fig no. 8



Fig 8. Application of GFRP & Epoxy

5. Experimental setup and Testing Procedure

After the retrofitting procedure, all specimens that had been wrapped with GFRP had a 5-day curing time to allow all epoxy resin to polymerize and create a strong bond between the composite material and the concrete substrate. All twelve specimens (three control columns and nine retrofitted ones) were subjected to failure loads in uniaxial compression. The uniaxial compression test was performed using a Universal Testing Machine (UTM). During testing, the axial load was increased gradually at a constant rate and the maximum failure load recorded for each specimen. The testing setup was designed to allow for the application of uniaxial loads to each specimen, and the behaviour of the specimens was observed and recorded, including crack initiation, crack propagation, and eventual failure of the specimens. You can see in fig no. 9



Fig 9. Axial Load Testing On UTM

6. Results & Discussion

6.1 Failure Modes

The results of both the control and GFRP-wrapped RC columns have been obtained from axial load testing with the Universal Testing Machine (UTM). We took detailed notes throughout the testing of this data and examined it thoroughly to see how effective GFRP confinement is when used to increase the structural strength of the column. Also considered in this evaluation of performance enhancements were a number of things, such as the ultimate load capacity.

Observation Made During Testing:

6.2 Control Specimen (A0): The test was carried out on control specimens (A0) Under axial load in the UTM, the control specimens demonstrated a linear-elastic response at lower loads; however, as loads increased, fine vertical cracks were observed developing at stress concentration locations at the corners of the columns. With the continued increase in load, these cracks progressed rapidly to failure due to extensive concrete crushing and spalling. Failure was sudden and brittle with reinforcement dramatically exposed at failure and very little post-

peak resistance present. The strength, in MPa, for the control specimens can be found in Table 2.

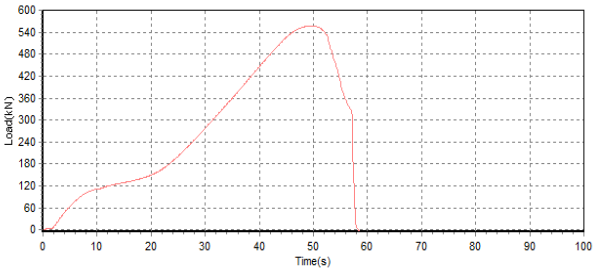


Fig 10. Load vs Time Graph

6.3 GFRP Wrapped Specimen (Single layer A1): The single-layer GFRP-wrapped specimens (A1) demonstrated a significantly higher level of ductility than the control specimens. The mode of failure of these specimens was horizontal cracking of the jacket and audible rupture of GFRP fibres. The initial ruptures occurred at a localised stress concentration point, usually in the lower corner of the column, and progressed through the GFRP jacket, with each successive rupture initiating a further line of weakness in the jacket, The confined concrete core of A1 specimens was crushed due to internal pressure but maintained its integrity better than A0 specimens due to the increased energy absorption capability associated with the active confinement provided by the single-layer GFRP jacket. The results of the tests conducted on the two specimen types can be seen in Table 2.

6.4 GFRP Wrapped Specimen (Double Layer A2): The axial load tests performed on the GFRP-Wrapped two-layer test specimens confirmed that the way loads were applied during testing had an advantageous effect on their structural behaviour as compared with either control or one layer wrapped columns (see Table 2). The columns were able to deform under load earlier than control specimens as well as those which were wrapped with only one layer, demonstrating greater stiffness and therefore the ability to support more weight before exhibiting visible signs of distress. At the conclusion of ultimate load testing of both two-layer and control specimens (see Table 2), fine horizontal cracks formed along the outside face of the outer layer of the two-layer GFRP-Wrap. Some of the outer layers also produced characteristic sound effects indicative of fibre. The outer layer of the GFRP wrap gave redundant confinement to the load so that loads could be redistributed to the intact fibres and allowed for the greatest increase in load capacity, which was observed in this study.

6.5 GFRP Wrapped Specimen (Triple Layer A3): Three-layer glass fibre reinforced polymer specimens exhibit instant failure that is also very brittle. The very stiff and heavy outer jacketing restrains buildings to expand consistently laterally, which provides an early point of failure. In combination with an air between the layers, the behaviours led to a critical weakness. Therefore, the lack of strength increase (shown in Table 2) is evidence of the diminished return and possible negative effects of excessive confinement.

Table 2 Ultimate load carrying Capacity of Tested Column

Specimen Type	No. of GFRP Layers	Ultimate Load (KN)	Compressive strength (N/mm^2)
Control [A0]	0	539.66	24.98
GFRP-[A1]	1	573.41	26.55
GFRP-[A2]	2	637.66	29.52
GFRP-[A3]	3	546.95	25.31

6.6 Comparison Between Control and Retrofitted Columns: The comparative analysis definitively establishes that GFRP retrofitted columns exceed in performance the control specimens. The failure mode has evolved from a sudden, brittle failure due to compression and crushing of concrete to a gradual, flexible and ductile failure mode due to rupturing of the GFRP material. As indicated in Table 3, the optimum method for strengthening the specimen was achieved through the use of a 2-Layer GFRP Wrap, as it provided the maximum strength benefit. In contrast, there was little to no benefit observed for the 3-Layer Configuration, indicating the point at which confinement is ineffective. Furthermore, it is important to optimise the number of layers of GFRP for maximum structural benefit Strength enhancement you can see in the table number 3 which gives you idea after adding GFRP what percentage of strength are increased

Table 3. Strength Enhancement Due to GFRP Wrapping

Specimen Type	**No. of GFRP Layers**	**Strength Increase (%)**
Control- [A0]	0	0
GFRP [A1]	1	6.25
GFRP -[A2]	2	18.15
GFRP-[A3]	3	1.35

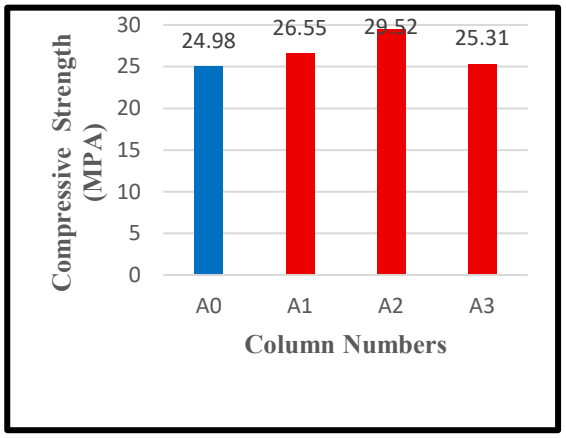


Fig 11. Compressive strength comparison for Control and retrofitted column

7. Conclusion: Externally bonded GFRP (Glass Fibre Reinforced Polymer) systems are very effective ways to significantly increase the performance and load carrying capacity of rectangular RC (Reinforced Concrete) columns. The two-layer GFRP wrap configuration represents the best of all available wraps and provides a maximum strength increase of 18.15% with a very well-balanced combination of both strength and ductility. The study also identifies the diminishing return phenomenon, in which three layers of GFRP sheet material only provided an additional 1.35% increase in ultimate strength compared to two-layer wraps. Excessive stiffness and construction errors caused by applying three layers led to diminished return gains. Confining the concrete with GFRP significantly changes the failure mode of the column. Instead of failing suddenly and catastrophically (brittle) under axial compression, the columns failed more gradually in a ductile manner, allowing the chance to identify the failure and respond. It is recommended that a two-layer GFRP system is the most effective and economical method of retrofitting rectangular RC columns. This research has the limitation that retrofitting of freshly constructed column is carried out in this instead of already loaded column as exist on site.

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