INTENSIFY THE STRENGTH OF SHORT RC COLUMNS BY CARBON FIBER REINFORCED POLYMER (CFRP)

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CERTIFICATE

This is to certify that the work presented in this project report / thesis on **"INTENSIFY THE STRENGTH OF SHORT RC COLUMNS BY CARBON FIBER REINFORCED POLYMER (CFRP)"** is entirely written by the following students / themselves / himself / herself under the supervision of **ENGR: DR. GOHAR NADEEM.**

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“Failure is a part of innovation, perhaps the important part”

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DEDICATION

This study is dedicated to our parents and instructors, who have been our sources of encouragement and strength during times of discouragement. We express our unwavering thanks for their continuous support in moral, spiritual, emotional, and financial aspects. To our mentor, friends, and classmates who provided their assistance and insightful advice during the process of doing this research. We concluded by expressing our gratitude to the divine being, ALLAH ALMIGHTY, for bestowing upon us the fortitude, cognitive prowess, safeguarding, aptitudes, and an extended lifespan.

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ABBREVATIONS

CFRP	Carbon Fiber Reinforced Polymer
FRP	Fiber Reinforced Polymer
RC	Reinforced Concrete

ABSTRACT

This research aims to offer a cost-efficient alternative for reinforcing square reinforced concrete (RC) short columns by utilizing Carbon Fibre fiber-reinforced polymer (CFRP) sheets. Recently, there has been an increase in the utilization of externally bonded fiber-reinforced materials. Polymers, namely Fiber Reinforced Polymers (FRP), have gained significant popularity in civil engineering for many applications, such as wrapping concrete columns. This is mostly because to their exceptional strength-to-weight ratio and remarkable corrosion resistance. An important application of fiber-reinforced polymer (FRP) composites is the use of wraps or jackets to restrict reinforced concrete (RC) columns to improve their strength and flexibility. They bolster the column's strength by effectively confining the column material, hence preventing failure under significant pressure. Given the exorbitant expense associated with Carbon Fibre Reinforced Polymers, it can be financially impractical to completely encase the column with CFRP sheets. To reduce expenses, it is advisable to only encase the concrete columns in the most crucial areas. Therefore, it is necessary to analyze the cost efficiency of CFRP sheets in order to reduce material expenses and provide an economical solution.

This research aims to investigate the cost-efficient utilization of CFRP sheets through the application of partial wrapping technology as an alternative to complete wrapping. Fifteen square reinforced concrete (RC) short columns measuring 6” x 6” x 20.5” were subjected to concentric compressive loads. The columns were evaluated under two conditions: fully wrapped and using a partial wrapping technique with four different patterns. The results were compared in terms of strength, strain, and cost between columns that were covered and those that were not wrapped.

The subsequent chapters of this thesis go into the research findings and provide comprehensive analyses of partially wrapped columns, focusing on their strength, strain, and cost.

Chapter-01 INTRODUCTION

1.1 BACKGROUND

Building damages can occur due to several factors, such as seismic activity, inundation events, and inadequate upkeep, resulting in structural strain, deterioration, and compromised foundations[1]. Following the occurrence of a seismic event with a magnitude of 7.6 on the Richter scale in Muzaffarabad-Azad Kashmir on October 8th, 2005 [2], and another event with a magnitude of 7.7 on the Richter scale in the Awaran Kech region of Balochistan on September 24th, 2013 [3], there has been a heightened need to reinforce the existing structures in Pakistan that remain intact or have sustained moderate damage [4]. This surge in demand stems from the desire to enhance the structural integrity of these buildings throughout the country. Reinforced concrete beams can fail in two main ways: flexural failure and shear failure [5]. The former situation arises when the applied load surpasses the ability of the beam's materials to withstand bending, whereas the latter situation arises from a lack of shear resistance between the various materials of the beam. The common failure modes of reinforced concrete (RC) include: (a) failure due to shear sliding, (b) failure due to flexure, (c) failure due to diagonal tension, (d) failure due to diagonal compression (resulting in the crushing of web and/or boundary elements), and (e) failure due to hinge sliding [6].

The occurrence of column failure plays a significant role in the collapse of construction structures, thereby necessitating the development of specific strengthening techniques and design principles [7]. Steel jacketing is a highly effective method for enhancing existing reinforced concrete columns [8]. Section enlargement is a commonly employed method for reinforcing various reinforced concrete columns. Section enlargement refers to the application of an additional layer of concrete around an existing structural member, such as a footing, column, or beam [9]. The utilization of CFRP has seen substantial growth in its application within the building and civil engineering sectors [10]. CFRP materials have commendable mechanical strength and ductility; nevertheless, their utilization is hindered by their substantial cost. In the realm of structural engineering, it is common practice to employ a CFRP wrap that encompasses the full length of a column [11]. However, this approach has been found to be cost-prohibitive. This study aims to investigate the effects of varying configurations of CFRP sheets by conducting a comparative analysis of the obtained results. CFRP sheets have emerged as a viable method for enhancing the structural integrity of various components [12]. This study aims to investigate the effectiveness of CFRP sheets in reinforcing square-reinforced concrete

(RC) short columns. The focus is primarily on evaluating the strength enhancement and cost-effectiveness achieved by employing different configurations of CFRP sheets to wrap around the columns.
The primary objective of this study is to evaluate the enhancement of both strength and ductility in reinforced concrete (RC) short columns by the use of external confinement using CFRP sheets and epoxy resins. In order to fulfill the objective, a total of 10 reinforced concrete (RC) short columns were utilized in an experimental study, with their behavior being evaluated under compressive loading conditions. A number of distinct characteristics were observed during our investigation of the behavior of RC short columns that were externally constrained by various reinforcement techniques.

1.2 PROBLEM STATEMEMT

The degradation of structures can occur due to various factors, including the natural process of aging, the deterioration of concrete materials, alterations in building usage and load demands, corrosion in reinforcement elements, construction errors, and particularly in structures designed to withstand seismic events. There are primarily two alternatives available for enhancing the performance of existing structural components over their life cycle. The first option involves replacement, while the second option involves reinforcing the components by utilizing wraps or jackets made of either FRP or steel jacketing. A complete replacement of a structure is generally not a viable solution due to the significant costs associated with materials and labor, the adverse environmental impacts, and the annoyance caused by the ongoing usage of the structure. Therefore, it is often more advantageous to enhance or renovate the structure, utilizing various techniques for reinforcement. CFRP sheets have been widely recognized as an excellent method for enhancing the structural integrity of various materials. Although there has been much research conducted on the strength of CFRP wrapping on RC columns, the economic component of this technique has garnered relatively less attention from scholars. This study investigates the restrengthening of reinforced concrete (RC) columns, with a particular emphasis on achieving a balance between cost and strength, which is considered highly significant.

1.3 AIMS AND OBJECTIVES

The aim of this study is to identify the cost-effective approaches for utilization of CFRP to strengthen the modified columns. In order to achieves, the following objectives set:

1. To evaluate and compare the performance of short columns that are externally confined with various configurations of CFRP sheets under an axial compression load.
2. To explore cost-effective strategies for utilizing CFRP by investigating the application of different configurations on reinforced concrete (RC) columns.
3. To examine the failure modes exhibited by short columns that are externally confined with CFRP sheets.

1.4 SCOPE OF WORK

This study focused on the investigation of short reinforced concrete columns that were wrapped with CFRP material. The evaluation was conducted using several CFRP sheet configurations applied to reinforced concrete (RC) columns. Certain columns were fully enclosed, but others were covered with other arrangements. As the unexamined portion was retained for the sake of comparison, trends emerged. The load capacity and ductility of the columns were evaluated subsequent to the wrapping procedure. Ultimately, a comprehensive analysis is conducted to assess their relative merits in terms of stiffness, ductility, and mode of failure.

1.5 RESEARCH SIGNINFICANCE

The experimental investigation employed CFRP sheets to externally limit reinforced concrete (RC) short columns, resulting in several advantages as identified in this research study.

CFRP is a material of considerable expense, therefore rendering its cost-effectiveness a crucial factor in the context of economic structures.

By employing CFRP strips of different widths, as opposed to fully enveloping the entire length of the column, it is possible to achieve equivalent structural integrity while simultaneously reducing costs. In this specific research project, the focus is on the efficient utilization of CFRP.

1.6 THESIS OUTLINE

The documentation of this research investigation has been partitioned into 6 chapters. A concise depiction of each chapter is provided below.

CHAPTER # 01: The research has provided a comprehensive overview of the work conducted.

CHAPTER # 02: The primary aim of this review was to investigate various methodologies employed in the exploration of different techniques. The investigation pertains to the enhancement of the mechanical characteristics exhibited by diverse materials, as explored by multiple researchers, and the corresponding degree of improvement achieved. Enhancements in physical strength and potential modes of failure In addition, the cost-effectiveness of Various strengthening techniques were also examined in this review.

CHAPTER # 03: The research approach employed to achieve this study's objectives has been thoroughly elucidated, with a focus on delineating the many limits and limitations encountered. Additionally, this chapter provides further information regarding the materials utilized and a comprehensive description of the tests conducted. Furthermore, the discussion also encompasses the observations derived from the experimental testing program.

CHAPTER # 04: The findings of this experimental study within the context of this research endeavor have been presented and deliberated upon. The discourse pertaining to experimental findings mostly centers around the response of load-imposed displacement, failure modes, and the enhancement of ductility. Furthermore, it is important to consider the concept of fracture energy. Furthermore, the theoretical calculation of the ultimate load using the American Concrete Institute (ACI) standards. The recommended equation is also addressed within the contents of this chapter.

CHAPTER # 05: The primary findings derived from the outcomes of this investigation, as well as suggestions for future research pertaining to the study, are provided.

CHAPTER # 06: Study focuses on enhancing the structural integrity of short Reinforced Concrete (RC) columns through the utilization of CFRP materials. This initiative is in accordance with the Sustainable Development Goals (SDGs).

Chapter-02 LITERATURE REVIEW

2.1 Introduction

It is widely acknowledged that reinforced concrete constructions are generally favored over steel buildings [13]. There are several factors contributing to this phenomenon, including the ease of accessing concrete materials in comparison to steel and the relatively lower cost of concrete when compared to steel. Reinforced concrete (RC) structures demonstrate favorable performance when subjected to seismic loading; nevertheless, they also manifest increased base shear as a consequence of their substantial self-weight [14].

However, for optimal performance, it is imperative that reinforced concrete (RC) structures are designed and erected in a meticulous manner [15]. However, the occurrence of such incidents is primarily attributed to substandard craftsmanship, untrained workforce, corrupt practices, and various other contributing factors. Currently, there is a significant amount of research being conducted with the aim of enhancing the capacity and lifespan of existing structures. Various methods for strengthening have been proposed, with the utilization of FRP composite material being the predominant approach to enhance column capacity [16]. These materials function as a restraining mechanism when applied to the column, enhancing its load-bearing capacity and facilitating larger deflections. This chapter serves as a complete evaluation of contemporary scholarly works concerning the behavior of different reinforced concrete (RC) structural elements when subjected to axial load. The comprehension of the ductility behavior of columns has witnessed a growing advancement due to the examination of experimental data and scholarly investigations. These endeavors have provided valuable insights into the influence of several elements, including limitation and axial load level. The acquisition of this knowledge has led to significant progress in the development of design code requirements and performance-oriented seismic design techniques for confining reinforcement [17]. This chapter presents a comprehensive survey of seismic studies done on columns made of FRP -confined concrete.

2.2 Columns

Columns are load-bearing components that mostly undergo axial compression. Columns are essential load-bearing components that offer structural support for vertical forces arising from the floors and roof of a building. These loads are then transferred by the columns to the foundations of the structure. Columns can be categorized into two kinds depending on the existence or lack of bending moment.

2.2.1 Concentrically Loaded Columns

As represented in Figure 2.1, refer to columns that experience solely axial load, with a minor unintentional displacement of the load resulting in a significantly reduced bending moment.

2.2.2 Eccentrically Loaded Columns

As depicted in Figure 2.1, refer to columns that experience a load applied at an eccentric distance, leading to a combined effect of axial compression and bending moment.

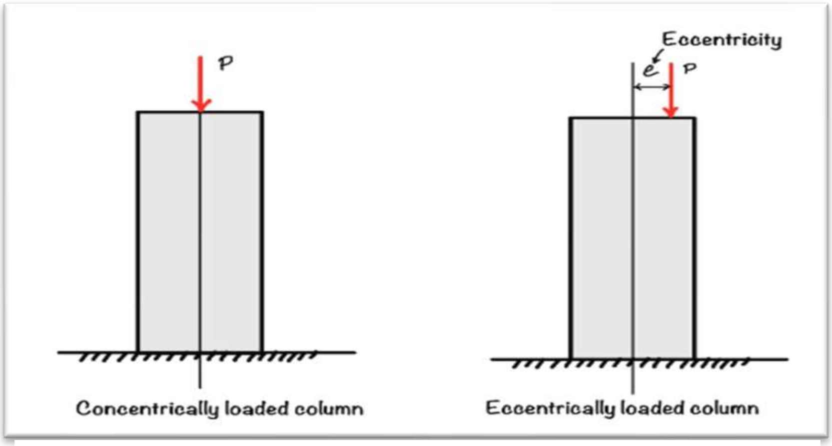


Figure 2.1 Concentrically and Eccentrically Columns

2.2.3 Short Columns / Struts

The low slenderness ratio of these columns avoids instability, buckling, and second-order effects. Second-order effects come from multiplying first-order column deflections and axial forces to amplify first-order moments. Column structural integrity depends primarily on material qualities and cross-sectional profile geometry.

2.2.4 Slender/Long Columns

Depending on their slenderness ratio and first-order lateral displacement, these columns may be weaker than shorter ones. Moment magnification may result from second-order processes.

2.3 Properties of RC Columns

Strength: The concrete can endure significant amounts of compressive force. Rebar enhances the tensile strength.

Stiffness: pertains to the capacity of a material or structure to withstand deformation when exposed to a load, hence maintaining stability.

Ductility: refers to the capacity of a material to tolerate substantial deformation without experiencing failure, hence providing a certain degree of advance notice before it collapses.

Fire Resistance: Concrete exhibits a considerable degree of fire resistance, effectively safeguarding the steel reinforcement.

Durability: With appropriate design and maintenance, it can endure for numerous years.

2.4 Failure modes of reinforced concrete (RC) columns

Buckling is a phenomenon that occurs in slender columns when they experience quick bending or bowing due to compression. Typically found in elongated, slender structures lacking adequate horizontal reinforcement [18]. Crushing is the result of the concrete being subjected to compressive stress that exceeds its strength. The occurrence can be attributed to either excessive loads or substandard concrete quality. Shear failure refers to the failure of a column caused by diagonal tension loads, typically occurring near connections. The occurrence can be attributed to insufficient shear reinforcement or elevated shear forces. Rebar Fracture is the phenomenon happens when the steel reinforcing bars fail due to the application of excessive tensile stress. Possible causes include rust, excessive load, or inadequate detailing. Bond failure refers to the separation of the concrete and rebar, resulting in a decrease in both strength and stiffness. Arising from corrosion, insufficient concrete covering, or substandard construction methods.

2.5 Strength Enhancing Techniques

In seismically active areas, reinforced concrete structures are strengthened considerably. This approach uses many materials, which can be classed.

Reinforcement with Steel: Steel plates or bars can strengthen and stiffen structural components. Steel jacketing or FRP wraps often do this.

Concrete Jacketing: Adding concrete to a structural member can improve its mechanical strength and durability. This material improves structural components like columns, beams, and slabs.

Carbon Fiber Reinforcement: Carbon fibre sheets or strips can improve load-carrying capacity, especially in flexural sections like beams and columns.

Post-Tensioning: Tensioned cables or tendons are added to structural parts to increase their load-bearing capacity.

External Prestressing: Increasing structural strength by applying external forces to induce compressive stresses is common, especially in bridge structures.

Strengthening with Composites: Fiber-reinforced composites like (FRP) or (GFRP) can improve structural component strength and endurance.

Shear Strengthening: Shear reinforcement, external steel plates, and fibre wrapping increase beam and slab shear capacity.

Column Jacketing: Encasing columns in concrete or steel increases their axial load capacity and confinement.

The best strengthening method relies on structural factors, materials, and environmental circumstances. Experienced structural engineers evaluate each project's conditions and recommend the best approach.

2.6 Fiber Reinforced Polymers (FRP)

FRP composites are made by fusing two materials. The component contains fibres, which are long strips of fiberglass, aramid, or carbon [19]. The composition includes polymer matrix. The chemical binds components securely. Fibre reinforced polymer is made from individual strands. You may buy these binders easily. Plastics like epoxy, vinyl ester, and polyester are thermosetting. Structures made of FRP have higher strength and stiffness. Additionally, they offer Previous discussions have covered longitudinal axial strength and transverse shear strength.

Property	Description
Physical Properties	
Density	Lightweight
Color	Variable, depending on the type of polymer used
Thermal Conductivity	Low
Electrical Conductivity	Non-conductive
Mechanical Properties	
Tensile Strength	High
Compressive Strength	High
Flexural Strength	High
Modulus of Elasticity	High
Impact Strength	Variable, depending on the type of reinforcement
Fatigue Resistance	Good
Chemical Properties	
Corrosion Resistance	Excellent
Chemical Resistance	Resistant to many chemicals
UV Resistance	Good
Moisture Resistance	High
Temperature Resistance	Good at moderate temperatures

Table 2.1 Properties of FRP

2.6.1 Properties of FRP (Physical, Chemical, and Mechanical)

CFRP, GFRP, and AFRP are fiber-reinforced composites used to strengthen structures. These entities are different and serve different objectives. The qualities and features of a FRP material depend on many parameters, including fibre volume, type, resin, fibre orientation, dimensional effects, and quality control procedures during manufacture.

2.6.2 Types of FRP

CFRP, GFRP, and AFRP are known for their efficiency and mechanical properties. Due of its benefits, aerospace, automotive, and construction industries are interested in FRPs [20]. Insulation, high tensile strength, and fatigue resistance distinguish this material from steel and aluminum [21]. FRP has several shapes and lengths for purposes. FRP bars, plates, and sheets are used in engineering.

- Carbon (CFRP)
- Glass (GFRP)
- Aramid (AFRP)

Property	GFRP	CFRP	AFRP
Physical Properties			
Density	1.5 - 2.0 g/cm³	1.5 - 1.6 g/cm³	1.4 - 1.45 g/cm³
Color	Transparent, various colors	Black or dark gray	Yellowish-brown
Thermal Conductivity	Low	Very Low	Low
Electrical Conductivity	Non-conductive	Non-conductive	Non-conductive
Mechanical Properties			
Tensile Strength (MPa)	200 - 1400	1500 - 7000	700 - 1500
Compressive Strength (MPa)	200 - 1200	1500 - 7000	300 - 1000
Flexural Strength (MPa)	200 - 700	1500 - 7000	500 - 1200
Modulus of Elasticity (GPa)	30 - 80	70 - 230	70 - 140
Impact Strength (kJ/m²)	20 - 100	5 - 50	30 - 80
Fatigue Resistance	Good	Excellent	Good
Chemical Properties			
Corrosion Resistance	Good	Excellent	Good
Chemical Resistance	Resistant to many chemicals	Resistant to many chemicals	Resistant to many chemicals
UV Resistance	Good	Excellent	Moderate
Moisture Resistance	High	High	High
Temperature Resistance (°C)	-50 to 80	-200 to 250	-150 to 250

Table 2.2 Types of FRP

2.6.3 Factors Affecting FRP Properties

Various things might impact the characteristics of FRP materials. Some of them are mentioned below.

External Factor	Description
Temperature	Extreme temperatures change mechanical characteristics and dimensional stability due to thermal expansion/contraction. High temperatures may soften or degrade polymer matrix.
Humidity and Moisture	Absorption of moisture can alter mechanical qualities, dimensional stability, and degradation over time. Humid areas require sealing and coating..
UV Radiation	Extended UV exposure degrades the polymer matrix, weakening it and losing its colour. UV-resistant coatings or additives reduce this effect, especially outdoors.
Chemical Exposure	Hard chemicals can affect FRP's chemical resistance. Materials must be chosen based on the chemical environment to avoid degradation.
Abrasion and Wear	Over time, abrasion or wear can modify FRP surface characteristics. Wear-resistant coatings or materials may be needed.
Mechanical Loading	Static and dynamic mechanical loads affect FRP construction fatigue resistance and durability.
Biological Factors	Biological agents like fungi and bacteria can biodegrade FRP. Some applications require biologically resistant formulations.
Electromagnetic Fields	Certain electromagnetic fields may affect FRP's electrical characteristics. Electrical conductivity-critical applications require consideration.
Weathering Conditions	Hurricanes, earthquakes, and other natural calamities can damage FRP components. Such applications require proper design.
Vibration and Shock	Shocks and vibrations can damage FRP constructions' fatigue resistance and performance. Vibration-prone environments may require damping or design changes.
Maintenance Practices	Regular maintenance or lack thereof can affect FRP component lifetime and performance. Performance requires regular inspection and repairs..
Environmental Exposure	Saltwater and industrial contaminants might affect FRP degradation and performance.
Installation Conditions	Poor installation can cause stress concentrations and other structural difficulties in FRP components. Installation must be done correctly.
Dynamic Loading and Impact	Collisions and strong impacts can create abrupt stress and damage to FRP structures, impacting their structural integrity and performance.

Table 2.3 Factor Affecting FRP Properties

2.7 Flexural Strengthening

No matter the type, externally bonded FRP systems perform similarly to internal steel reinforcement [16], [22]. Longitudinal fibres at the tension face bottom increase a beam's positive moment capacity and rigidity. These elements can also reinforce slabs and withstand punching shear to increase their flexural capacity[23]. Strengthen aperture slabs. application of FRP is depicted in Figure 2.2.

Figure 2.2 Flexural reinforcement of RC beams with FRP sheets

2.7.1 Axial Enhancement

FRP strengthening can also limit concrete parts, especially circular ones. By surrounding the column with FRP and compressing it axially, this is achieved [24]. This application may use FRP reinforcement. Similar to spiral reinforcement or internal steel ties. FRP "jackets" can increase the axial load-bearing capacity and radial expansion of certain columns. Reinforcement may improve column ductility. Please refer to Figure 2.3 for visual representation.

Figure 2.3 Column Axial Enhancement with FRP sheets

2.7.2 Shear Strengthening

Shear strengthening entails the utilisation of FRP systems with primary fibres oriented perpendicular to potential shear cracks, often in a vertical manner within a concrete beam. Vertical fibre external stirrups have the potential to enhance shear capacity by 2 kips per inch of depth. The section has been referenced. Alternatively, FRP strips or sheets can be attached in a 'U' configuration around the edge. The top and bottom of a beam are reinforced to increase shear resistance. It can also morph. Unreinforced masonry walls become shear walls [25].

2.8 FAILURE MODES OF FRP

FRP-reinforced concrete members have more failure modes than non-FRP-reinforced ones. To account for diverse failure loads and behaviours, engineers must examine all anticipated failure modes.

2.8.1 Failure of Bond

At contact, externally bonded FRP material abruptly detaches from the concrete substrate. As shown in Figure 2.4, bond failures are brittle and occur before the fiber-reinforced polymer (FRP) sheet reaches full strength [26].

Figure 2.4 Debounding of FRP sheets

2.8.2 Delamination

This is delamination of FRP laminate layers, not bond failure. Plate end debonding causes concrete cover delamination or separation at the beam's end, commonly where the FRP sheet/strip ends. This failure spreads to the beam centre [27]. The breakdown above extends across the tensile reinforcement and gradually detaches the concrete coatings.

Degradation Reduced reinforced concrete mechanical functionality The mechanical properties of FRP materials used to reinforce beams are often affected by external factors.

2.8.3 FRP Composite Wrapping Limitations

- There are questions about the durability of FRPs due to poor long-term performance data.
- The issue of fire resistance is important.
- Limited knowledge of materials and methods.
- Deformed concrete parts may experience steel bar corrosion.
- There is insufficient laboratory and field information on structural activities, such as shear-lag from more fiber composite wrap layers.

2.9 CARBON FIBRE REINFORCED POLYMER (CFRP)

In our research study, we intend to utilize carbon fiber reinforced polymer sheets as a means of reinforcing columns. To conduct a comprehensive examination, it is vital to possess a fundamental comprehension of the physical and chemical features of CFRP sheets.

CFRP make composites. Matrix and reinforcement make up the composite material [28]. Carbon fibres strengthen CFRP. Epoxy resin, used in matrix materials, glues the reinforcements together. Two components determine the material properties of CFRP. Reinforcement, defined by stress and elastic modulus, gives CFRP strength and stiffness [29]. CFRP has anisotropic strength compared to steel and aluminium [30]. Despite their widespread use in aerospace, automotive, civil engineering, sports goods, and a growing number of consumer and technical applications, CFRPs have high manufacturing costs [31]. These materials' high strength-to-weight ratio and stiffness may explain this desire.

2.9.1 Properties

CFRP characteristics depend on carbon fibre arrangement and polymer matrix carbon fibre ratio. Two formulae that incorporate carbon fibre and polymer matrix properties can determine composite materials' net elastic modulus [32]. The equations above apply to carbon fibre reinforced plastics. The subsequent equation is

$$\boldsymbol{Ec = VmEm + VfEf}$$

Potential and kinetic energy are added to indicate energy conservation.

In composite materials with fibres parallel to the load, this statement is true. The composite's total composite modulus (Ec) depends on various elements, including the matrix and fibre volume percentages (Vm and Vf) and their elastic moduli (Em and Ef).

The following equation can be used to calculate the composite material's elastic modulus when the fibres are perpendicular to the load:

$$\boldsymbol{Ec = Vm/Em + Vf/E}$$

2.9.2 CFRP Fracture Toughness

CFRP fractures due to debonding, fibre pull-out, and CFRP sheet delamination. Epoxy-based CFRPs have a strain to failure of less than 0.5% [33]. CFRPs bonded with epoxy present unique failure detection issues for engineers due to their strength and elastic modulus [34]. The current project is complicated by fragmented brittle mechanics in these materials, which causes catastrophic failure. To increase the mechanical properties of CFRPs, epoxy materials are modified and other polymer matrices are investigated. A specific chemical has higher quantities. PEEK, or polyetheretherketone, is tougher than materials with equal elasticity. In several academic fields, modulus and strength are important. PEEK is harder to process and costs more.

2.9.3 Limit of Fatigue

CFRP has a good strength-to-weight ratio, but it lacks a fatigue endurance limit. A theoretical framework cannot rule out stress cycle failure. While steel and other structural metals and alloys have well-defined fatigue endurance limitations, composites' complicated failure mechanisms make CFRP fatigue failure prediction and design difficult [35].
Thus, engineers may need to include large safety margins when designing CFRP applications with high cyclic loads. For component dependability during operation, this is done.

2.9.4 Environmental Impacts

Most CFRPs and other polymer-based composites are affected by temperature and humidity, which can have serious implications. CFRPs are corrosion-resistant, but moisture at a wide range of temperatures can degrade their mechanical capabilities, especially at the matrix-fiber interface. Moisture plasticizes the polymer matrix but not the carbon fibres. Impermeability to jet fuel, lubricant, and rainwater is engineered into engine fan blade epoxy matrix. Composite components also have external coating to reduce UV radiation [36].

2.9.5 Uses of CFRP in Civil Engineering

In structural engineering, CFRP is common. Academic studies of its building benefits have shown its cost-efficiency in various real-life circumstances. It improves concrete, masonry, steel, cast iron, and timber structural stability [37]. This material can improve the longevity of an existing building or replace steel from the start of a project in the industrial sector. In civil engineering, externally bonded CFRPs can be divided into various kinds. Classified into three distinct divisions.

2.9.5.1 New construction strengthening

Civil engineers use finite element analysis (FEA) to design new infrastructure projects. FRP composite structures have proven durable and resistant to environmental damage. FRP is used in innovative architectural projects in pre-stressing tendons, reinforcing bars, grid reinforcement, and dowels [38].

2.9.5.2 Repair/Rehabilitation Strengthening

Damaged or deteriorated structures are often restored and refurbished with FRP. Many reinforced concrete and masonry structures degrade or become unsuitable for occupancy due to usage, applied loads, design configuration, substandard building materials, or natural disasters.

Increasing numbers of reinforced concrete structures have reached their operational lifespan due to environmental variables and increased loads. Because to concrete and reinforcement degradation, the observed phenomena occurs. The structures above show signs of structural insufficiency or functional obsolescence, and many require considerable repairs. This application benefits from fiber-reinforced plastic sheets or plates' high strength-to-weight ratio, good fatigue behaviour, and excellent corrosion resistance. Recently, FRPs have become more popular in civil engineering. The new approach has great potential for improving the structural integrity of damaged concrete components. FRPs may be implemented quickly and easily, reducing labour expenses and project expenditures.

2.9.5.3 Architectural Uses

FRP has many uses specified by architects. The above constructions have siding, cladding, roofing, flooring, and partitions. In civil engineering, reinforcing methods are becoming more popular. In many situations, this method is used to increase the load-bearing capacity of decaying structures like bridges that were designed to withstand much lower service loads. There are also methods to improve earthquake resilience and repair damaged structures. Many prefer strengthening since rebuilding the faulty structure costs more than CFRP strengthening.

> In flexural applications for reinforced concrete constructions, CFRP commonly doubles or triples section strength. But the stiffness increase is usually only 10%. Due to the substance used in this application, this happens. The material's ultimate tensile strength of 3000 MPa exceeds mild steel by more than tenfold. The material has a rigidity range of 150 to 250 GPa, slightly lower than steel. Therefore, the material is only used in small cross-sections. Incorporating localised zones of high strength and moderate stiffness into a material will increase its strength while maintaining its stiffness.

CFRP can stiffen reinforced concrete by wrapping fibre around the desired area. Wrapping bridges or building columns with materials improves ductility [39]. This improves seismic resilience. Due to its cost-effectiveness, seismic retrofitting is popular in earthquakeprone areas. Pre-stressing materials made of CFRP are strong [40]. Compared to steel, CFRP pre-stressing material is lightweight and corrosion-resistant [41]. Specialized applications, especially offshore, can use CFRP because to its properties [42].

2.10 PAST RESEARCH USING CFRP SHEETS

1. Performance of CFRP Wrapped Square Reinforced Concrete Columns Subjected to Eccentric Loading.

This study examined how Carbon Fiber Reinforced Polymer affects square columns under eccentric loading. Fields use square or rectangular columns, and loading may not be concentric. This study studied CFRP's effect on square column strength to simulate field conditions. The effect of CFRP layers and eccentricity. We researched. Wollongong University School of Civil, Mining, and Environmental Engineering laboratories [43].

The study used 12 short 200mm x 200mm x 800mm high strength reinforced concrete square columns. The columns' four sides were rounded to prevent premature failure and allow enough CFRP wrap confinement.

The columns were separated into four groups:

- Group 1: Three unwrapped columns.
- Group 2: Three fully wrapped columns with one CFRP layer.
- Group 3: Three columns are entirely wrapped in three layers of CFRP.
- Group 4: Three columns are totally wrapped with two horizontal and one vertical layers.

Test Setup: Twelve columns failed compression. Use of the Denison 500-tonne compression tester. Levelling column end surfaces spreads weight. A loading mechanism in Figure 2.6 and new high-strength steel plate loading heads in Figure 2.5 eccentrically loaded the column.

Figure 2.6 Actual testing method

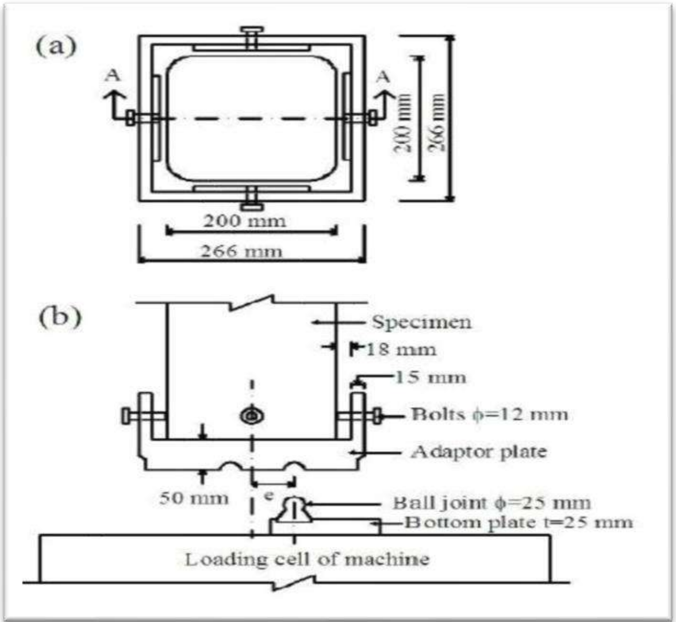


Figure 2.5 Standard testing mechanism setup

Results and Conclusion: Columns lacking CFRP wrapping experienced failure, resulting in concrete cover peeling off, tyre rupture, and longitudinal steel buckling. CFRP-wrapped columns failed with a violent burst as load approached maximum value. Load decreased but displacement increased.

It was found that eccentric loading reduces column load capacity.

CONCLUSION: CFRP wrapping delays concrete and reinforcement rupture, increasing column load capacity. Increased column ductility. Increased CFRP layers improve column load capacity and performance.

2. Structural Performance of Concrete Columns Wrapped with CFRP Sheets.

Compressive strength was measured on square reinforced concrete columns reinforced with CFRP. Transverse and axial tests of 48 axially compressed specimens to failure. We investigated column slenderness, wrap layers, and concrete strength. Ultimate strength, stiffness, and ductility were assessed using compressive, axial, and hoop strains to assess specimen stress-strain relationship [44].

Methodology: A study compared NSC-25 MPa with HSC-60 MPa concrete. Use of unidirectional SikaWrap-230C carbon-fiber sheets. Manufacturer promises 4300 Mpa CFRP strength and 238 Gpa tensile modulus. Fibre has 0.13mm thickness and 1.8% elongation. Composite columns were encased with Skiadur-330 epoxy. Eight- and twelve-mm transverse and longitudinal reinforcement. The longitudinal reinforcement was 500 Mpa and the transverse 235 Mpa.

Test procedure : Continuous uniaxial compression was applied to specimens until failure. The load was 0.24 MPa/s.We measured axial and lateral strains with extensometers. One square-framed lateral linear variable differential transducer (LVDT) was placed mid-height on specimens. Three vertical LVDTs measured average axial stresses. Sulphur mortar caps were on both ends of all CFRP-wrapped columns before testing. Figure 2.8 shows the specimen being tested..

Figure 2.7 Confined CFRP Specimen Failure

Conclusions and Results:

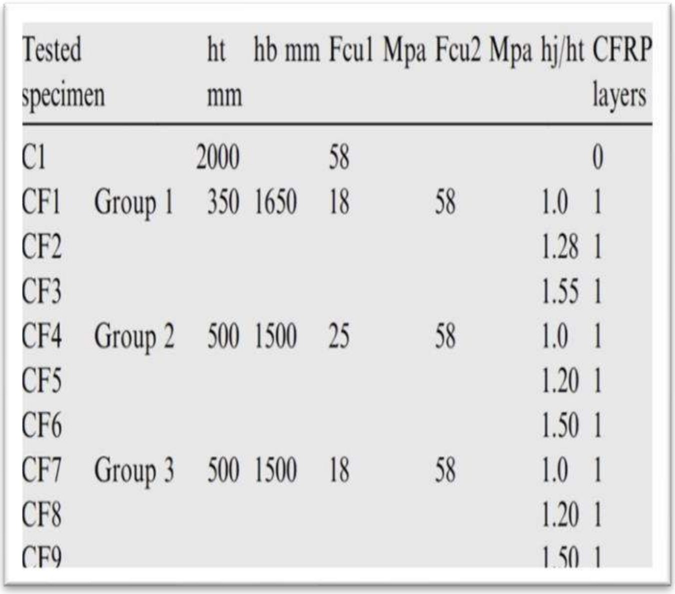
- All CFRP specimens failed explosively.
- Increased CFRP sheets improve column compressive strength, although at a slower rate than deformation capacity, which is proportional to CFRP strengthening ratio.
- CFRP confinement increased strength and stress in low-strength concrete specimens compared to high-strength equivalents

CFRP confinement decreases bearing and deformation capacity as concrete strength increases.

3. Partial Strengthening of R.C Square Columns Using CFRP

The study investigated how CFRP affected partially strengthened RC square columns in regions with poor workmanship or other conditions. Concrete column tops are often fragile due to poor construction or quality control. This study evaluated how top-only CFRP wrapping strengthens columns [45].

Methodology: We tested ten 2.0 m square columns with a 200 · 200 mm cross section. One control specimen has 58 Mpa concrete strength (fcu), whereas the other nine are divided into three groups. The main factors were upper poor concrete strength (18–25 Mpa), upper part height (35–50 cm), and jacketed column/top part height (1.0–1.55). Figure 2.8 exhibits longitudinal reinforcement (grade 36/52) and stirrups on all specimens. Table 2.4 lists specimen attributes.



Tested specimen		ht mm	hb mm	Fcu1 Mpa	Fcu2 Mpa	hj/ht	CFRP layers
C1		2000		58			0
CF1	Group 1	350	1650	18	58	1.0	1
CF2						1.28	1
CF3						1.55	1
CF4	Group 2	500	1500	25	58	1.0	1
CF5						1.20	1
CF6						1.50	1
CF7	Group 3	500	1500	18	58	1.0	1
CF8						1.20	1
CF9						1.50	1

Table 2.4 Column specimen details

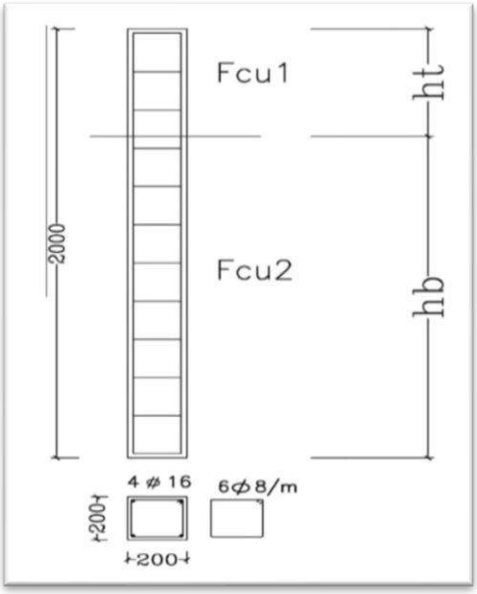


Figure 2.8 Configuring Columns

Test preparations : 500-ton hydraulics loaded all columns. Measure longitudinal strain with LVDTs at the column's top and bottom. The fiber strain was measured with 20mm electrical strain gauges.

Figure 2.9 Testing Column

Decisions and Results: The maximum load each test specimen can take is indicated in Fig 2.10.

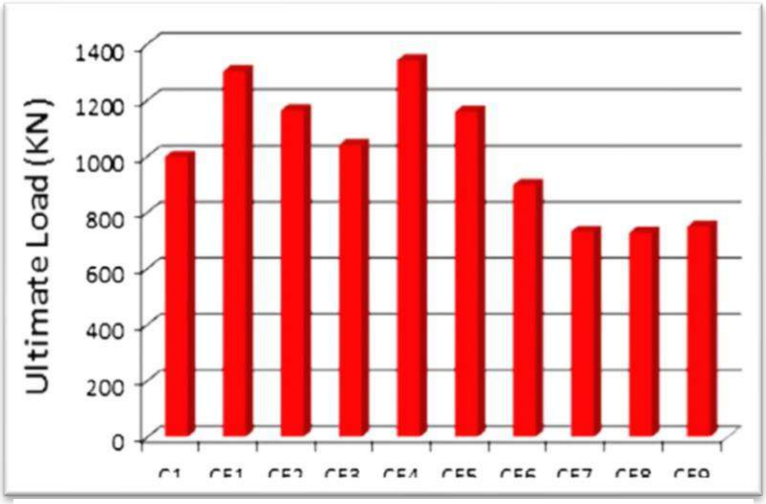


Figure 2.10 Ultimate Load Graph

- Partial strengthening of square columns with inferior upper concrete is possible. Wrapping the bad area with one CFRP layer is important.
- Increasing jacket height (hj/ht) increases wrapped column ductility without increasing ultimate load.
- As higher part concrete strength falls, confined part corner radius must increase.

4. Strengthening of Concrete Columns with CFRP [46]

This research aimed to examine the impact of CFRP-enhanced reinforced columns.

We analyzed four 250x250x1500 mm reinforced concrete columns. The first series had non-strengthened RC columns, the second CFRP laminate strips before testing, and the third CFRP sheets. CFRP laminate strips and sheet reinforced final columns. See Figure 2.11.

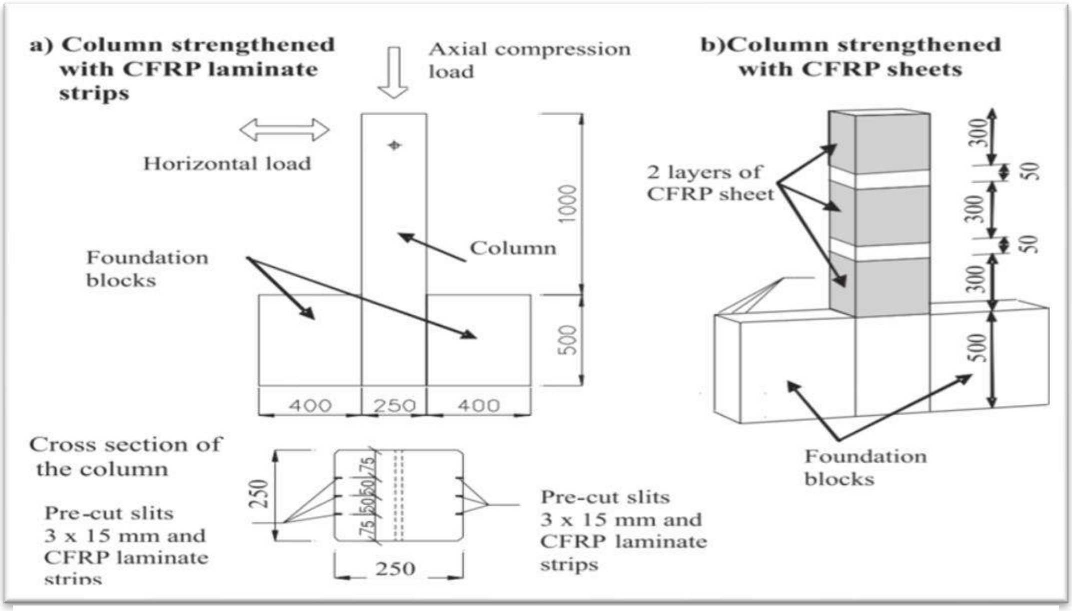


Figure 2.11 Test specimens

Test setup: Each specimen consists of a column secured to foundation blocks. Columns received constant vertical loads of 250, 450, 650, 750, and 850 kN. Linear variable displacement transducers (LVDTs) measure column horizontal and footing vertical displacement. The horizontal force was the same height as LVDT1.

Results: The columns collapsed due to concrete compression face crushing. 15–20 mm deflection was recorded near the collapse. When columns were strengthened for a 250 kN vertical load, the load carrying capacity increased:

- 10% of columns enclosed in CFRP plywood.
- About 26% of columns are strengthened with CFRP laminate ribbons.
- Improved 32% of columns using CFRP laminate strips and sheets.

The load carrying capacity of columns loaded with 650 kN vertical load increased on average:

- CFRP laminate strips reinforced − 9% of columns.
- Increased column strength by 18% using CFRP laminate strips and sheets.

CONCLUSIONS: NSM strengthening may increase bending concrete column load capacity. Unconfined eccentrically loaded columns' compression-side concrete crushed. Pre-peak load, constrained columns behaved normally. After compressing the concrete, the confined columns ruptured the FRP confining jacket at mid-height..

5. Performance Analysis of CFRP Composite Strips Confined RC Columns under Axial Compression

The issue is cement/aggregates. Local commercial Portland cement was used for binding. Discussing steel reinforcement. Reinforcement was 415 N/mm2 commercial HYSD bars. Mixtures of cement and cement are called "concrete". The concrete mix proportions were based on IS aggregated characteristics to reach 25 N/mm2 strength. Fiber and matrix components of composites are discussed. SIKA India Inc.'s unidirectional carbon fiber Sikawrap-230 C strengthened the column in this investigation. We picked carbon fiber for mechanical and durability. Fiber stiffness was 230 GPa and tensile strength 4300 MPa, according to the manufacturer [47].

Making specimens. Seven 800-mm-tall, 125-mm-diameter columns were erected. Except for the reference column, three columns of the six specimens were externally constrained with 50 mm x 20 mm CFRP strips. Three more columns were externally constrained by 40 mm CFRP strips of the same width.

Axial Loading Experiment. A 2000 kN compression testing machine was used to axially crush column specimens. To match its centerline with the machine axis, the column component was carefully placed on the supports. Linear voltage displacement transducers (LVDTs) detected column axial and lateral deformation, while a 2000 kN load cell monitored load. The 16-Channel Data Acquisition System saved data from the load cell and LVDTs. With the help of an electronic jack, the columns were loaded and tested till failure. Failure, axial deformation, and ultimate load were observed experimentally.

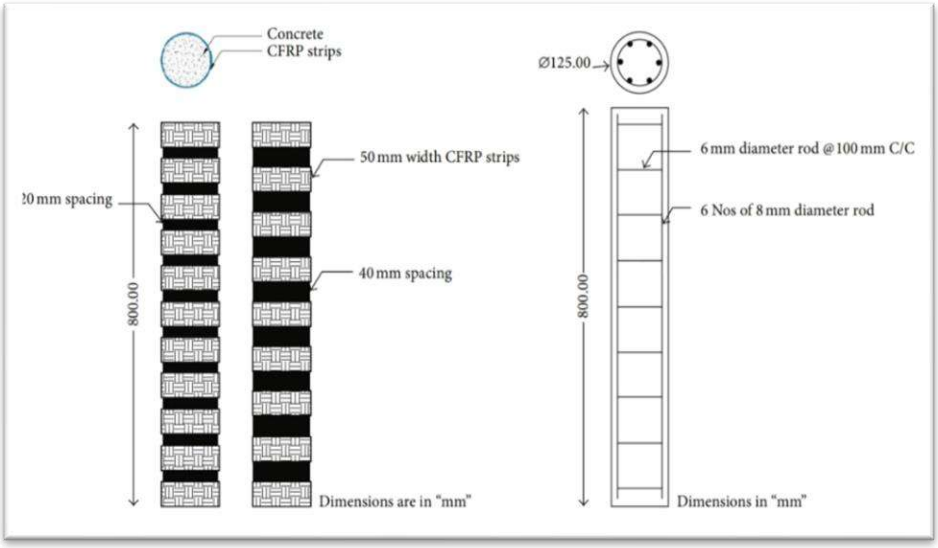


Figure 2.12 Column Configuration and wrapping pattern

Results and discussions: After linear behavior, the reference column cracked at the supports at 50% of its ultimate load. Additional loading caused larger and new compression cracks on all column sides. Concrete crushing caused support spalling at 252 kN load, resulting column failure. Brittle concrete caused a loud explosion. A column with 50 mm CFRP strips (NC-20-2 and NC-20-3) revealed no cracks in the unbonded area at 60% (155 kN) ultimate load, although severe resin withdrawal on the CFRP strips exterior caused a cracking sound. The columns collapsed from loading-related fiber rupture and concrete crushing.

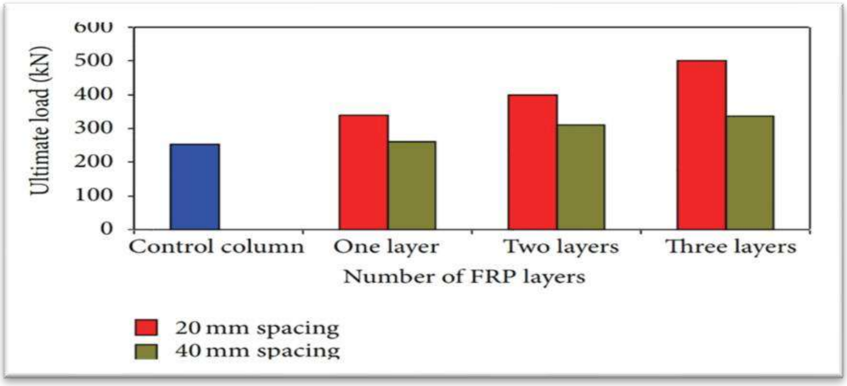


Figure 2.13 Load capacity

6. Behavior of CFRP Wrapped Reinforced Concrete Column under uniaxial compression.

The study employed experimental trials to assess the performance of reinforced concrete columns that were strengthened with carbon fibre reinforced polymer (CFRP) and exposed to uniaxial compressive stresses. This study investigated the performance of rectangular columns made of plain and reinforced concrete, which were enveloped with carbon fibre reinforced polymer (CFRP). The primary emphasis of this study is the application of uniaxial compressive stress and the evaluation of the effectiveness of CFRP wrap. Rectangular columns have the ability to be completely, partially, or sporadically covered. [48].

Uniaxial compressive loads was applied to ten reinforced concrete specimens measuring 24// (600 mm) in height and 6// (150 mm) × 12// (300 mm) in cross-section. Ten controls and six Carbon Fiber specimens were used. Wrapping CFRP. Two control samples were bare concrete. RCC two. Reinforcement info Six 0.5//" (1% steel) longitudinal and 0.44// transverse bars strengthened the specimens. Used a 7// (178 mm) center-to-center stirrup and 1// (25 mm) clear concrete top. Nominal concrete compressive strength Uniaxial compression test data of 4// diameter and 8// height cylinders yielded a 1:2.56:3.05 concrete mix ratio with w/c ratio, according to ASTM C39/C39M. In experiments, 0.6. This ratio compresses. Standard Pakistani building employs 3 ksi (21 MPa). Wrapped CFRP The CFRP wrapping patterns divided six specimens into three series. A pair per series. Series I reinforced concrete columns were fully CFRP, wrapped. Partial series II column wrapping at one-third specimen height. Series III included concrete columns with strips 2 inches apart and a 1-inch space between the top and bottom strips.

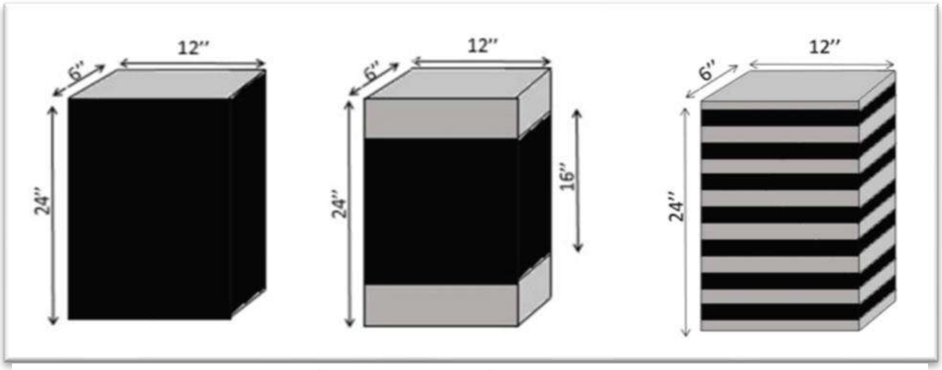
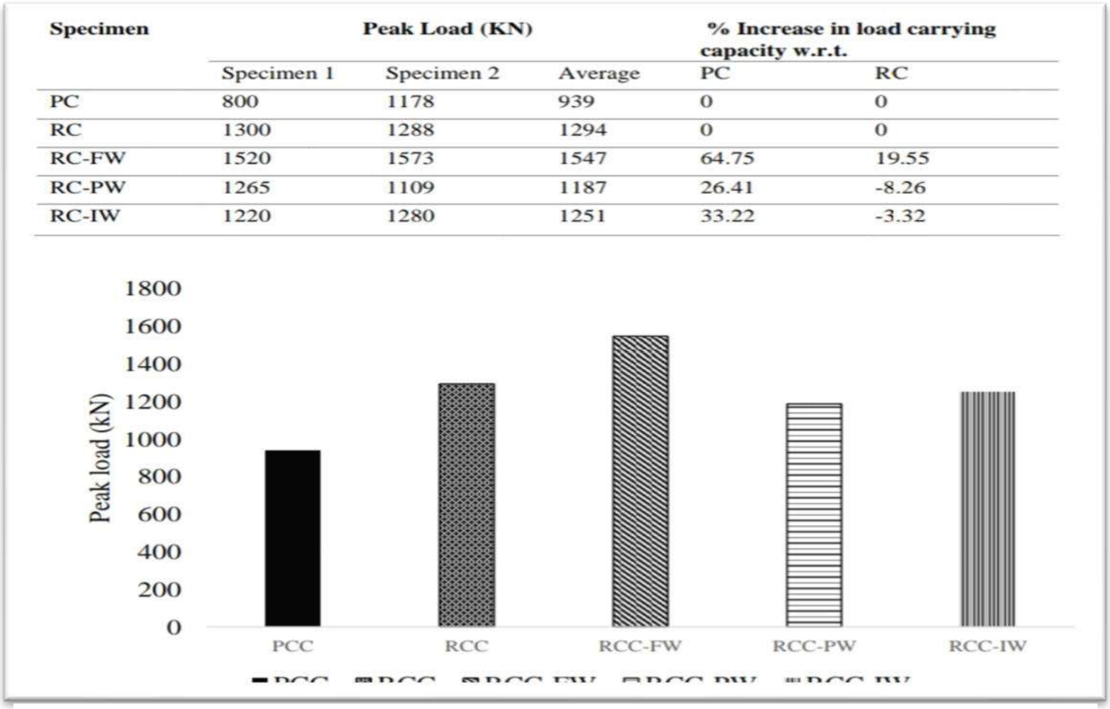


Figure 2.14 Wrapping pattern



Specimen	Peak Load (KN)			% Increase in load carrying capacity w.r.t.	
	Specimen 1	Specimen 2	Average	PC	RC
PC	800	1178	939	0	0
RC	1300	1288	1294	0	0
RC-FW	1520	1573	1547	64.75	19.55
RC-PW	1265	1109	1187	26.41	-8.26
RC-IW	1220	1280	1251	33.22	-3.32

Figure 2.15 Peak load

Results: Mode of failure

- PC-1,2: Concrete crushing. Localized failure was seen in the specimen's weaker area.
- RC-1,2: Concrete crushing and reinforcing yielding.
- RCFW-1,2: This specimen failed owing to CFRP rupture. Concrete cover crushed.
- RCPW-1,2: Unwrapped concrete crushing causes CFRP rupture.
- RCIW-1,2: CFRP rupture after column end concrete crushing.

Conclusion

- CFRP-wrapped reinforced concrete specimens showed 65% and 20% better compressive strength compared to previous patterns and PC/RC columns. RC columns were stronger than partially and intermittently wrapped columns.
- Fully wrapped columns failed owing to concrete cover area crushing, although steel core concrete was spared.
- Partially and intermittently wrapped specimens behaved similarly. Due to concrete crushing in weaker column sections, both specimens failed, resulting in CFRP rupture. There was little concrete damage in the steel core.
- Two-thirds partial wrapping and intermittent wrapping do not increase specimen load carrying capacity and ductility.

7. Investigation on the Behaviour of Partial Wrapping in Comparison with Full Wrapping of Square RC Columns under Different Loading Conditions

Exterior-bonded FRP sheets boost load and strain capacity for RC columns. FRP cylindrical small-scale unreinforced concrete sample testing is comprehensive. More open than circular columns are square and rectangular. Form factor-adjusted circular columns are used in most rectangular section theoretical models. Massive carbon FRP-reinforced square and rectangular RC columns were tested for axial load. Important were FRP reinforcing quantity, cross-section side-aspect ratio, and corner radius of curvature. Fibre reinforced polymer confinement strengthens low-strength rectangular concrete columns. The strain efficiency factor and FRP hoop ultimate strain were lower than design specifications and flat coupon testing's material ultimate tensile strain. Experimental Program: Square and rectangular portions with rounded corners will be used to study FRP confinement efficiency. The experimental program centers compression testing on massive concrete prismatic specimens to imitate RC columns. The largest specimens are 2400 mm [49].

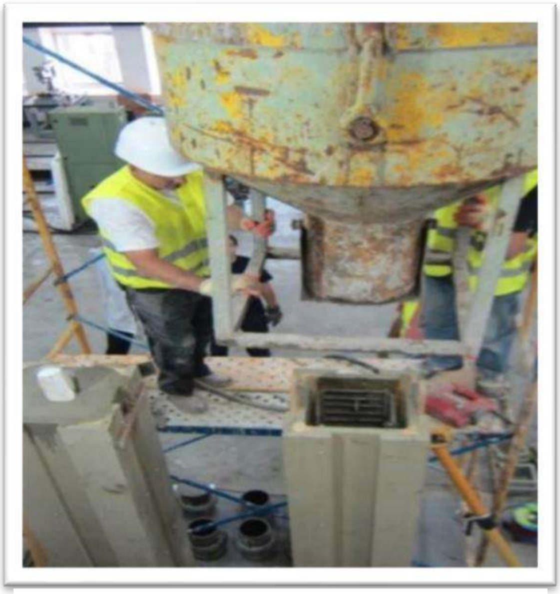


Figure 2.16 Concrete Filling

Experimental program variables include:

- Cross-section side-aspect ratio or concrete section side ratio (b/d). Testing included square (b/d = 1) and rectangular (b/d = 1.5 and 2) samples. A total of three sections were used: 300 × 300 mm (square), 250 × 375 mm2 (rectangular, b/d = 1.5), and 200 × 400 mm2 (rectangular, b/
- Corner radius of curvature. Round rectangular columns' corners before strengthening to prevent FRP jacket failure. This research employed 20- and 40-mm curvature radii.
- FRP reinforcement size. The specimens were strengthened with 2 or 3 CFRP layers.

Figure 2.17 Column testing

Results

- The unconfined concrete compressive strength (fco) was measured using cylindrical reference samples.
- The test's maximum axial load (Qmax).
- Peak load concrete axial stress or limited concrete strength (fcc). This is the difference between peak load (Qmax) and longitudinal steel reinforcement load divided by concrete net area. The load longitudinal steel bars carry is their area times their yield stress.
- fcc/fco or strength enhancement ratio of confined and unconfined concrete. Note that this preliminary research ignored existing steel stirrups.
- Ultimate axial strain (εcc). Average displacement sensor data yield axial stresses.
- The ultimate transversal strain (εf,eff) is the FRP effective strain. The average of four-side transversal measurements yields transversal deformations.
- The highest transversal strain (εfmax) measured by any gauge in the middle of the four faces.

Conclusion

- FRP confinement action increased concrete's ultimate axial strain by 0.009 (0.9%) to 0.014 (1.4%) in testing. Avoid large axial strains for practical applications. ACI and TR55 design guides limit concrete strain to 0.01.
- Failure happens rapidly and explosively due to jacket fiber tensile rupture at a strain value substantially lower than FRP coupon testing.
- Experimental data suggest that strain efficiency factor (εf,eff/εf) decreases with increasing cross section side-aspect ratio (b/d), however further testing is needed to confirm..
- Predictions of FRP-confined column capacity using three codes without safety factors are cautious for low-strength concrete columns with a side-aspect ratio (b/d) larger than 1.5.
- The TR55 guide forecasts matched experimental results better. The Concrete Society TR55 2012 technique, which considers The maximum strain and confined stiffness of FRP jackets are promising but need more research.

8. Strengthening of reinforced concrete short rectangular columns using FRP (Fakhry Fathy Tayel) 2021

Fiber reinforced polymers have been used to strengthen columns under impact stresses, according to previous studies. Repairing or strengthening structural components with FRP can avert collapse, infrastructure damage, and costly replacement. Good FRP materials can replace steel jackets to improve reinforced concrete structural components. Research shows that FRP materials can strengthen columns and support higher loads. The report recommends studying column impact loading situations. This study reviews RC column strengthening and repair strategies from the last two decades. Each method has been evaluated and new research areas identified to fill gaps. This study utilizes ‘repair’ to fix broken RC columns and ‘strengthening’ and ‘retrofitting’ interchangeably to enhance capacity. Overall, the study focuses on 'jacketing' RC columns for strengthening and repair.

Outcomes of study: Sheet and column were bonded using urethane. Both control and reinforced specimens with one or two polyester belt layers were examined. Strongened specimens were ductile, while controls were brittle. Strengthening improved the column's force-displacement behavior. Polyester fiber-reinforced polymers dissipated 184% more energy. Certain hybrid restoration techniques include high-performance materials that incorporate steel/FRP rebars or coatings. Specimens that were severely pre-damaged exhibited partial restoration of their flexural strength. Increasing the pre-damage of ancient RC columns using high-performance fiber-reinforced cementitious composite resulted in a decrease in specimen stiffness, hence enhancing their seismic performance.. Spilled steel-bar mortar. The strengthening procedure increased column ductility, strength, stiffness, and energy dissipation. Polymer-fiber HPFRC dissipated less energy than steel-fiber columns. Stronger retrofitted columns had fewer bending and diagonal shear cracks than unretrofitted ones. Strengthened columns improved hysteretic damping energy significantly.

Figure 2.18 Testing of Column

2.11 Past research literature conclusion

Through a thorough review of research on using CFRP sheets to strengthen columns. CFRP sheets improve column load-carrying capacity and performance, particularly capacity and displacement under continuous load. If columns collapse, this improvement allows safe evacuation.

However, a significant limitation of these research endeavors is the substantial financial burden associated with them. CFRP is an expensive material, making it economically impractical to completely encase a column, as has been done in previous studies. Therefore, a thorough CFRP material cost-effectiveness study is necessary. A decision was made to conduct a research study with several reinforced concrete (RC) column specimens. The columns were wrapped in various patterns, resulting in significant savings in both material usage and cost. Ultimately, we conducted tests on all of these columns subjected to compressive stress and subsequently compared the outcomes with those of a fully wrapped column in terms of strength, strain, and cost-effectiveness. A comprehensive examination of the aforementioned subjects can be found in the extensive analysis presented in chapters 3 and 4 of this thesis.

Chapter-03 RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter provides an overview of the experimental program that was developed for the purpose of this research study. The program encompasses the technique employed, as well as the comprehensive information regarding the specimen being examined and the strengthening materials utilized in this study, including their respective qualities.

3.2 METHODOLOGY

The experimental study was conducted using the following technique, which was executed in the subsequent phases:

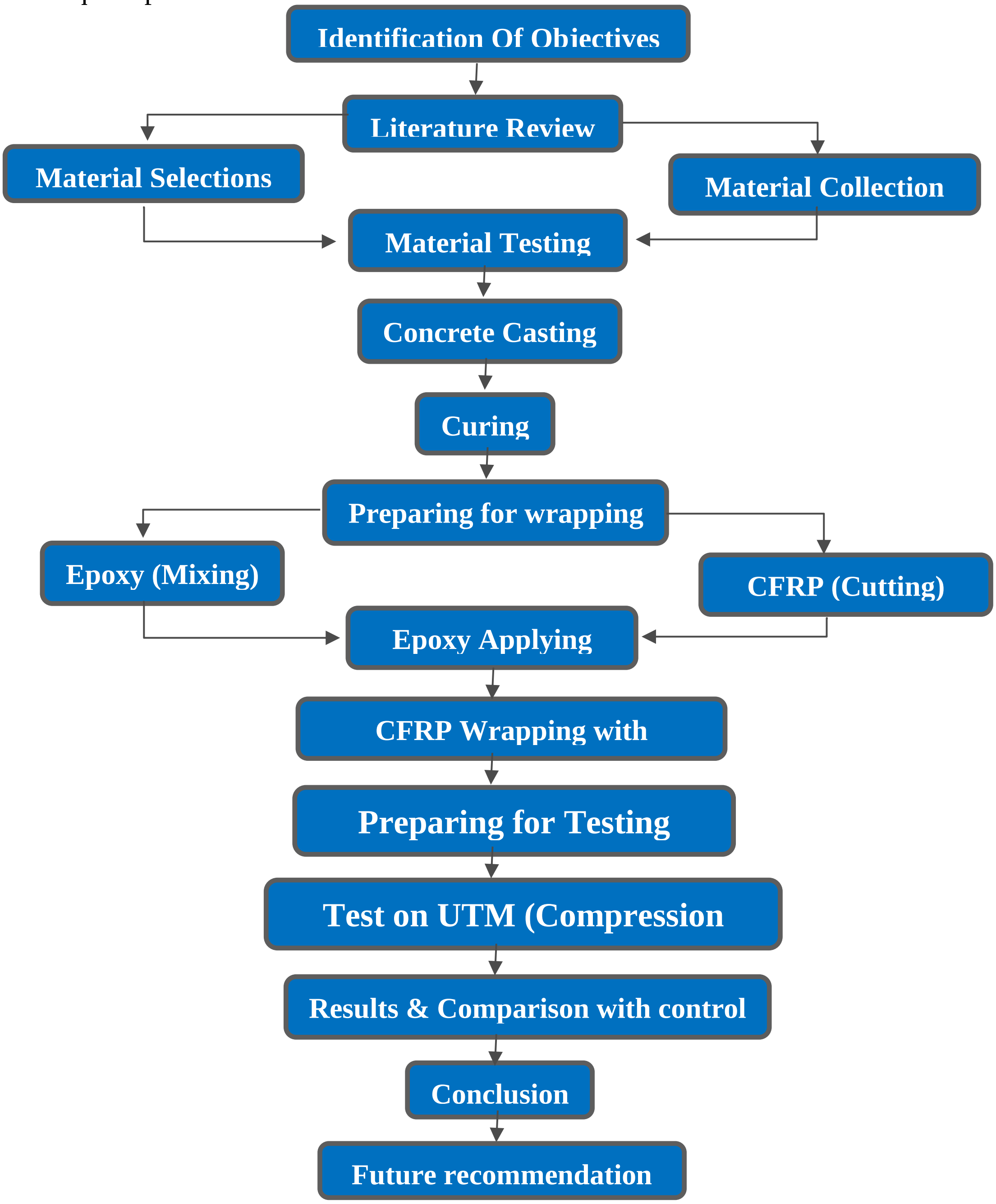


Figure 3.1 Flow chart

3.3 MATERIALS

The materials used in this experiment include Carbon Fiber-Reinforced Polymer (CFRP), Epoxy, Ordinary Portland Cement, Steel, Fine Aggregate, Coarse Aggregate, and Water.

3.3.1 Carbon Fiber-Reinforced Polymer (CFRP)

Imporient Chemical, PVT, Limited, a company based in Pakistan, has supplied the fundamental characteristics of the CFRP Wrap Hex 230C. Properties are mentioned in table 3.1, CFRP is shown in figure 3.2.

Figure 3.2 CFRP Wrap Hex 230C

Technical Data	
Fiber name	CFRP Wrap Hex -230 C
Fiber type	High strength carbon fibres
Fiber orientation	Unidirectional
Design thickness of fibre	0.12 mm (based on total carbon content)
Fiber density	1.78 g/cm^3
Fibre tensile strength	4,100 N/mm^2 (nominal)
Fibre tensile E-modulus	231, 000 N/mm^2 (nominal)
Areal weight	220 g/m^2 ± 10 g/ m^2
Fibre break strain	1.7% (nominal)

Table 3.1 Properties of CFRP

Approvals

- ICBO Evaluation Report ER 5558 (USA)
- SOCOTEC (France)
- Road and Bridges Research Institute, Poland, IBDiM No AT/99-04-0537

3.3.2 Epoxy (Chemdur – 300)

Chemdur 300 is employed as an adhesive within the context of this specific investigation. The product under consideration is a solvent-free, thixotropic epoxy resin-based impregnation system consisting of two components.

The essential properties of the Chemdur-300 were provided by Imporient Chemical, PVT, Limited, located in Pakistan. Properties are mentioned in table 3.2, Chemdur-313 is shown in figure 3.3.

Data	
Name	Chemdur - 300
Type	Epoxy Resin and hardening Agent
Formed colour	Greyish White
Mixed ratio	Comp A: Comp B = 5:1 (by weight)
Density	1.31 Kg / Lit (Mixture of A+B)
Storage conditions	Dry area between 5°C and 35°C.

Table 3.2 Data of Chemdur-300

Figure 3.3 Chemdur-300

3.3.3 Ordinary Portland Cement (OPC)

The cement used was Type I Ordinary Portland Cement (OPC) Grade 53 of one of the leading brands in Pakistan “Power Cement Ltd”.

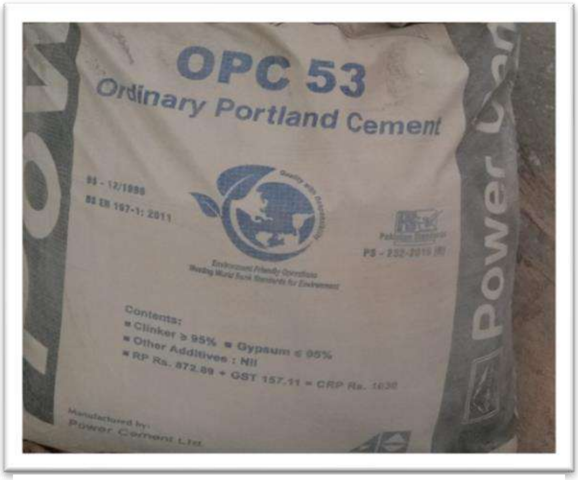


Figure 3.4 OPC Grade 53

Test on OPC performed in Material Testing Lab, CED at BUET Khuzdar.

Consistency test

- ➢ The penetration result was 6mm. Thus, it meets ASTM's 5-7mm recommendation.
- ➢ Water percentage: 27%. Thus, it meets ASTM recommendations of 25-30%.

Initial setting time

- Initial setting: 35 minutes. At least 30 minutes is recommended.

Final setting time

- Final setting: 6hrs (300 min). maximum 10hrs (600 min) is recommended.

Figure 3.5 Cement paste on Vicat's apparatus

Finess test

- The ASTM requirement is >90%, however the result was 92%.

Figure 3.6 Cement paste for fineness

Soundness test

- The ASTM requirement is <10mm, however the result was 1mm.

3.3.4 Steel

Mild steel of grade 60 is used.

Tensile tests on steel bars of grade 60 were performed on UTM in Material Testing Lab, CED at BUET Khuzdar.

Dia = 0.474 in (12mm) Area = 0.1765 in^2

	length (in)	*Δ* length (in)	Elongation (%)	Yield load (tonne)	Yield load (lb)	Yield strength (psi)	Ultimate load (tonne)	Ultimate load (lb)	Ultimate Strength (psi)
A	8	1	12.5	5	11023.1	62,453.8	7.7	16,978.5	96,195.5
B	8	1.1	13.75	4.9	10802.7	61,205.1	7.5	16,537.5	93,694.05
c	8	1.15	14.37	5	11023.1	61,205.1	7.6	16755.1	94,929.2
Average		**1.08**	**13.54**	**4.96**	**10934.9**	**61,954.1**	**7.6**	**16755.1**	**94,929.2**

Table 3.3 Yeild and ultimate strength

Measurement of diameter of steel bars by vernier caliper.

Figure 3.7 Dia of bar

Tensile test performed on UTM.

Figure 3.8 Test performed

3.3.5 Fine Aggregate

The fine aggregate utilized in this study was sourced from a wholesaler located in the Wadh tehsil of Khuzdar, Balochistan.

Sieve analysis of fine aggregate

Sieve size (mm)	Sample1 (g)	Sample2 (g)	Sample3 (g)	Average (g)	Retain %	C.Retain %	Passing %	Range %
4.75	30	10	30	23.23	1.16	1.16	**98.84**	**100**
2.36	20	20	20	20	1	2.16	**97.84**	**95-100**
1.18	50	50	50	50	2.5	4.66	**95.34**	**80-100**
0.6	340	260	270	290	14.5	19.16	**80.84**	**50-85**
0.3	1050	1130	1090	1090	54.5	73.66	**26.23**	**25-60**
0.15	250	300	310	283.2	14.16	87.82	**12.18**	**10-30**
0.075	190	210	190	196.66	9.8	97.62	**2.38**	**0-10**
pan	40	20	40	33.33	1.66	100	**0**	**0**

Table 3.4 Sieve analysis of fine aggregate

As per ACI, fine aggregates have an FM of 2.00 to 4.00. Our sieve examination yielded a fineness modulus of 2.8.

3.3.6 Coarse Aggregate

The coarse aggregate utilized in this study was sourced from a crushing plant located in the Ferozabad area of Khuzdar, Balochistan.

Sieve analysis of coarse aggregate

Sieve size(mm)	Sample 1(g)	Sample 2(g)	Sample 3(g)	average	Retain %	C.Retain %	Passing %	Range %
25	0	0	0	0	0	0	**100**	**100**
19	320	210	340	290	9.6	9.6	**91.4**	**90-100**
12.5	1960	1990	2100	2016.6	67.22	76.82	**23.18**	**20-55**
9.5	620	680	480	593.3	19.77	96.59	**3.14**	**0-15**
4.75	100	120	80	100	3.3	99.89	**0.11**	**0-5**
pan	0	0	0	0	0	0	**0**	**0**

Table 3.5 Sieve analysis of coarse aggregate

3.3.7 Specific Gravity of Coarse Aggregate

According to ASTM standards, the specific gravity of coarse aggregates typically falls within the range of around 2.5 to 3.0. Our specific gravity value for coarse aggregates is 2.7.

Figure 3.11 Specific gravity test

3.3.8 Water Absorption of Coarse Aggregates:

According to the ASTM standards, the maximum allowable water absorption limit for coarse aggregates in any climatic situation should not exceed 2%. After conducting the water absorption test on our coarse aggregates, the obtained result indicates a water absorption rate of 0.938%.

3.4 Dimensions

The dimensions of the specimen were measured to be 6 inches by 6 inches by 20.5 inches. A clear cover of 1 inch was maintained for the longitudinal steel. The primary objective of creating short columns is to mitigate the emergence of secondary moments that arise due to the influence of slenderness. Furthermore, the selection of dimensions was made based on their compatibility with the condition and capabilities of the testing apparatus available in the laboratory.

3.5 Reinforcement details

- Main longitudinal reinforcement of all columns 4#12mm Bars.
- Ties of #6mm @ 6" center-to-center.

It is imperative to acknowledge that the main bars and spacing in the ties provided meet the minimum requirement outlined in the ACI code (ACI-318).

Figure 3.12 Steel

3.6 Casting

Prior to casting, it is imperative to thoroughly cleanse all materials and allow them to undergo a drying process. The process of casting the reinforced concrete specimen was completed 28 days prior to conducting the tests. A ratio of 1:2:4 was consistently upheld. The water-to-cement ratio was determined to be 0.55. The specimens were cast using steel moulds, which were lubricated with oil prior to casting to prevent adhesion between the moulds and the cured concrete. The figure depicts a concrete mixer machine that is utilized for the purpose of mixing materials, such as cement, fine aggregate, and coarse aggregate, in order to achieve the desired concrete composition. The machine operates by subjecting the materials to a rotational motion for a duration of 3 minutes, ensuring thorough mixing. Following this, the appropriate amount of water is added, and the mixture undergoes an additional 2 minutes of rotation to achieve a well-balanced ratio. The concrete mould was filled into three layers, each of which was compacted 25 times in succession using a tamping rod to ensure proper settling. Subsequently, the mould was left undisturbed for a duration of 24 hours. Subsequently, the specimens undergo the process of demoulding.

A total of 13 specimens were fabricated for the purpose of applying CFRP wrapping. Additionally, 8 cube specimens were casted in order to determine the compressive strength of concrete in a cubical form. Subsequently, the obtained cubical compressive strength values were converted into cylindrical compressive strength values for further analysis.

Figure 3.11 Washing aggregates

Figure 3.12 Drying process

Figure 3.13 Concrete mixing on mixer

Figure 3.14 Manual mixing of concrete

3.6.1 Slump test of fresh concrete:

According to ACI the range for slump test (Range is 75-150mm) for column.

Our value for after doing slump test is result 105-110mm.

Figure 3.15 Slump test

Figure 3.16 Tamping

Figure 3.17 Hardening of concrete

Figure 3.18 De-molding

3.7 Curing

The curing process of the RC Column specimens was conducted for a continuous duration of 28 days in a curing tank, after 24-hours casting period.

Figure 3.19 Curing tank

Figure 3.20 Specimen after curing

3.8 Compressive strength of cubes

Sample	Casting date	Curing days	Load carrying capacity (tonne)	Load carrying capacity (lb)	Area (in^2)	Strength (psi)	Strength (Mpa)
1	31-5-2023	28	72.17	159,107.61	36	4,419.65	30.47
2	31-5-2023	28	70.01	154,345.63	36	4,287.37	29.56
3	2-6-2023	28	73.92	162,965.7	36	4,526.825	31.21
4	2-6-2023	28	76.09	167,749.74	36	4,659.715	32.12
5	6-6-2023	28	71.28	157,145.5	36	4,365.15	30.09
6	6-6-2023	28	71.26	157,101.41	36	4,363.92	30.08
7	7-6-2023	28	78.75	173,614.03	36	4,822.61	33.25
8	7-6-2023	28	74.36	163,935.74	36	4,553.77	31.39
Average			**73.48**	**161,995.67**	**36**	**4,500**	**31.02**

Table 3.6 Compressive strength of cubes

The cubical strength of concrete is typically measured at 4,500 pounds per square inch (psi) or 31.02 megapascals (MPa). To convert this value to cylindrical strength, it is necessary to multiply it by a conversion factor of 0.8.

The compressive strength of concrete in cylindrical specimens is measured to be 3,600 pounds per square inch (24.82 megapascals).

Figure 3.21 Compressive test

3.9 Chamfering

In order to mitigate stress concentration and enhance the usability of Carbon Fiber Reinforced Polymer (CFRP), a radius of 1cm was chamfered to each corner by the utilization of a steel grinder.

Figure 3.22 Chamfering

Figure 3.23 surface finishing

Figure 3.24 After surface finishing

3.10 Application of CFRP on RC Column

The epoxy adhesive, namely Chemdur 300, was made in accordance with the manufacturer's instructions. The epoxy mixture consisted of two distinct components, Component A and Component B, which were combined at a ratio of 5:1 by weight (five parts of Component A for every one part of Component B). The mixer was agitated for a duration of four minutes until all visible streaks of colour had dissipated. Subsequently, the mixture was subjected to an additional stirring period of 1 minute, employing a low rotational speed in order to minimize the incorporation of air.
The epoxy resin that had been manufactured beforehand was placed on the previously prepared surface of the reinforced concrete column using a clean and dry brush. Previously resized The application of CFRP strips onto the surface coated with epoxy was carried out in the specified orientation. The strips were meticulously embedded into the epoxy with the application of manual pressure, resulting in the extrusion of epoxy material between the interlaced fibres. Additionally, it was crucial to remove any air bubbles that may have formed beneath the layers of sheets. An extra layer of 2 inches was applied as a covering over the previously laid strips. After a duration of 60 minutes, a subsequent layer of epoxy was administered to ensure the appropriate adhesion of the sheet to the columns.

3.11 CFRP Wrapping Pattern

For this research study, a set of 13 columns with equal dimensions and reinforcement was produced. The columns were categorized into six distinct categories according to the employed strengthening strategies, as visually depicted in Figure.

- Category A (Control): Control Specimen.
- Category B (Full Wrap): Wrapped fully.
- Category C (T6): Wrapped top 6 inches.
- Category D (B6): Wrapped bottom 6 inches.
- Category E (TMB-363): Wrapped top, middle & bottom with 3, 6, 3 inches.
- Category F (S3): Wrapped Spirally throughout the length with 3 inches CFRP strip.

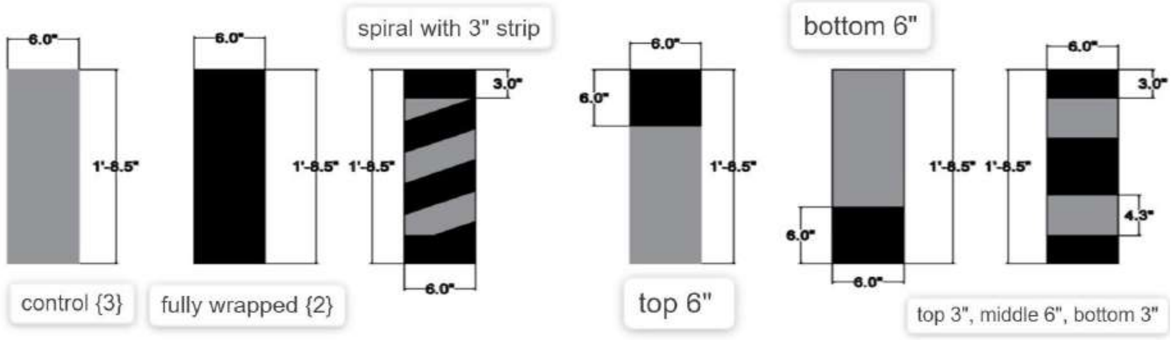


Figure 3.25 Patterns of wrapping

3.12 Preparations for Wrapping

Cutting of CFRP Sheet

Figure 3.26 Cutting of CFRP sheets

Epoxy Preparation

Figure 3.27 Mixing of Epoxy

Applying of Epoxy over Specimen

Figure 3.28 Applying of Epoxy

Wrapping of CFRP

Figure 3.29 Wrapping of CFRP sheets

Over-lap of 2 in

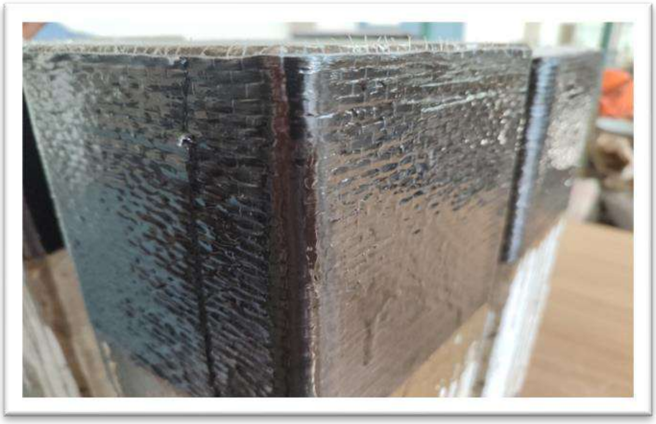


Figure 3.30 Overlap of CFRP sheets

Category A (Control): Control Specimen.

Figure 3.313 Control specimen

Category B (Full Wrap): Wrapped fully.

Figure 3.32 Fully wrapped

Category C (T6): Wrapped top 6 inches.

Figure 3.33 Top 6"

Category D (B6): Wrapped bottom 6 inches.

Figure 14 Bottom 6"

Category E (TMB-363): Wrapped top, middle & bottom with 3, 6, 3 inches.

Figure 15 Top 3", Middle 6", Bottom 3"

Category F (S3): Wrapped Spirally throughout the length with 3 inches CFRP strip.

Figure 3.316 Spiral 3"

3.13 Prepared Specimen

The figures presented below depict specimens that have been created using different strengthening techniques.

Figure 3.37 Prepared specimen with FYP group

3.14 Testing Method

Compression tests were conducted on the reinforced concrete (RC) short columns. The testing procedures were conducted within the Material Testing lab of the Civil Engineering Department at Balochistan UET Khuzdar, utilising a Universal Testing Machine that possesses a maximum loading capability of 200 tonnes. The RC column specimens were subjected to testing using a Universal Testing Machine in order to ascertain their ultimate load carrying capability, fracture load, deformation, stress, and strain under compression. The data acquisition system, coupled to the software of the UTM placed on a computer, facilitated the collection and analysis of the relevant data.

Chapter-04 RESULTS AND DISCUSSION

The findings obtained from the experiments carried out within the scope of the study project are documented in this chapter. The primary subjects of discussion will be the method of failure, strain, force-deformation relations, and load-carrying capability of the results. This chapter will demonstrate the enhanced ductility of reinforced concrete (RC) short columns that have been changed using alternate techniques. The test results were obtained from a total of thirteen columns, consisting of three control columns, two full wrap columns, and four pairs of RC short columns wrapped with CRP in various configurations.

4.1 LOAD CARRYING CAPACITY

The Universal Testing Machine (UTM) with a capacity of 200 tonnes, available at the MT lab of the civil engineering department BUET Khuzdar, was used to apply load to all 13 columns. The results obtained are shown in Figure 4.1

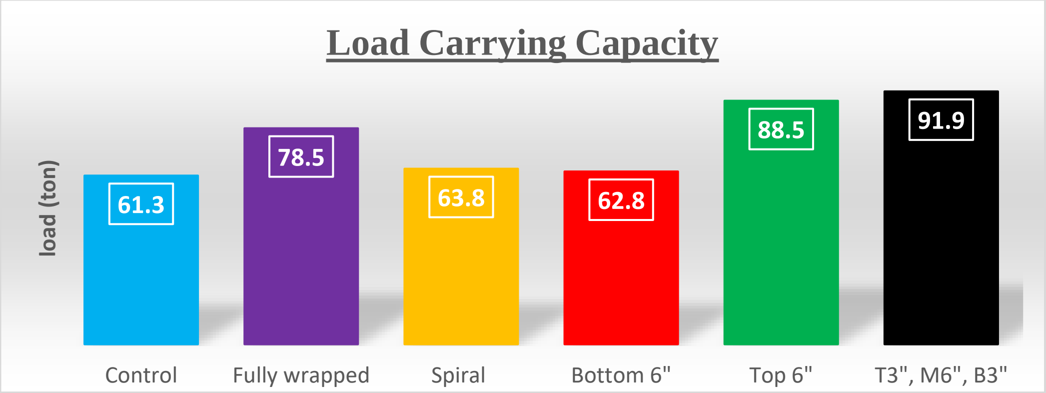


Figure 4.1 load carrying capacity

The control columns were capable of supporting a weight of 61.3 tons, whereas the fully wrapped columns were able to support a load of 78.5 tons. The Top 6" column exhibited a load-bearing capacity of 88.5 tons. The T3", M6", B6" column had a load-bearing capacity of 91.9 tons. The Bottom 6" column exhibited a load-bearing capacity of 62.8 tons. The Spiral 3" column exhibited a load-bearing capacity of 63.8 tons.

4.1.1 Comparison of Load Carrying Capacity w.r.t Control Column

Load Carrying Capacity of Control Column is 61.3 ton.

Specimen Name	Load Carrying Capacity (ton)	Percentage (%) Increase w.r.t Control
Fully Wrap	78.5	28.05
Spiral 3”	63.8	4.07
Bottom 6”	62.8	2.44
Top 6”	88.5	44.44
T3”, M6”, B”	**91.9**	**50.01**

Table 4.1 Load carrying capacity

4.2 Relationship between Force – Deformation of All Columns.

The graphs below explain the relationship between force and deformation of all columns.

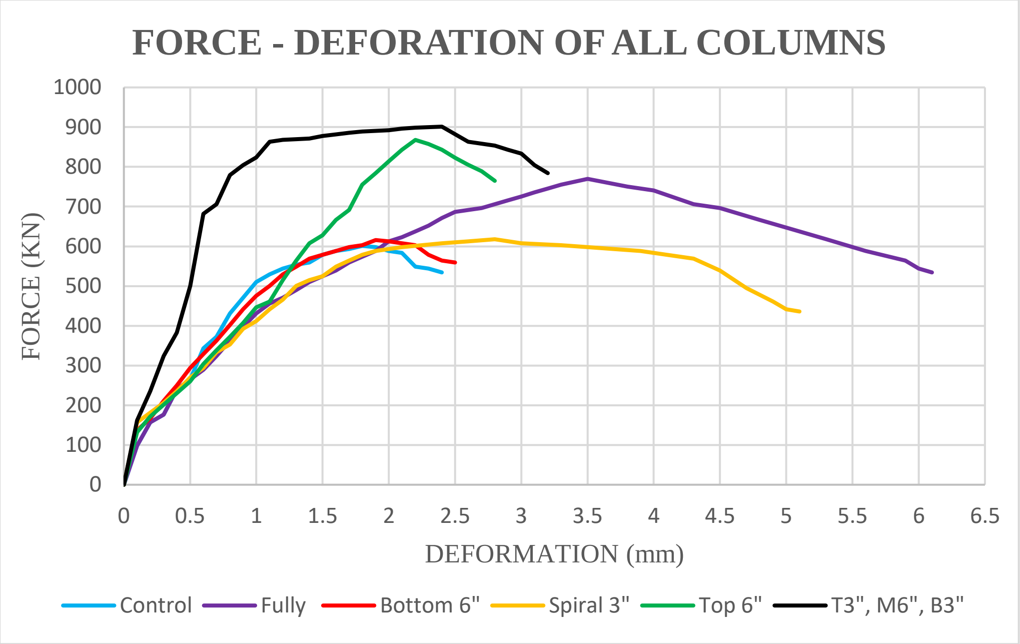


Figure 4.2 Force-Deformation curve of all columns

4.3 Relationship between Stress – Strain of All Columns.

The graphs below explain the relationship between stress and strain of all columns

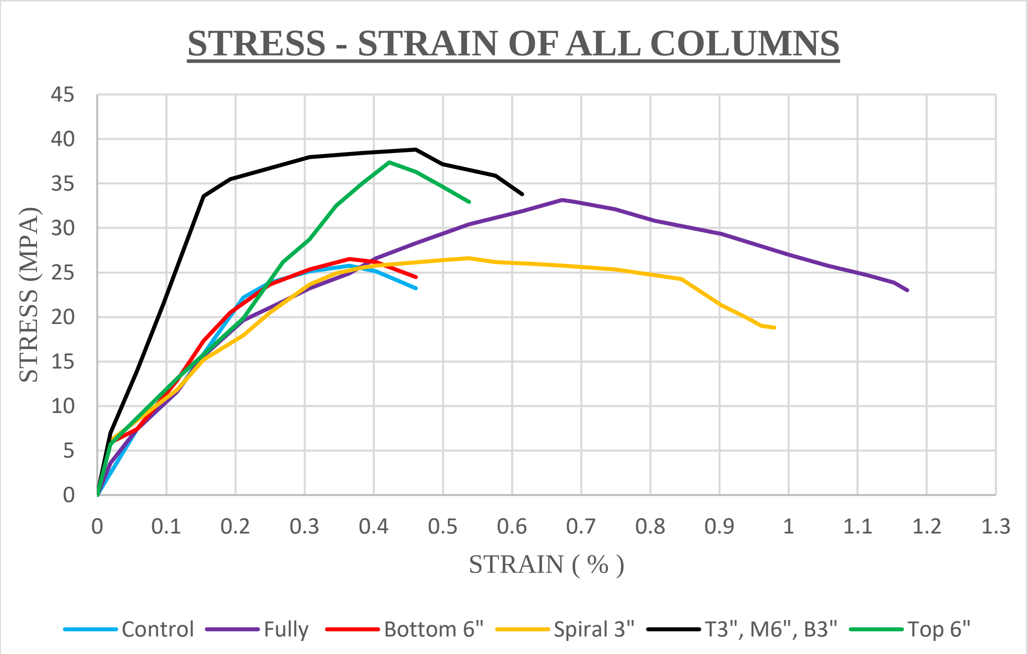


Figure 4.3 Stress-Strain curves of all columns

4.4 Stress At 0.1 % Strain of All Columns.

The figure below shows the stress produced at 0.1 % strain. And after comparing them, it found that the Control, fully wrap, top 6”, bottom “, spiral 3” had a slight difference with each other but T3”, M6”, B3” gives the highest value of stress at 0.1 %, nearly 100% more stress comparatively.

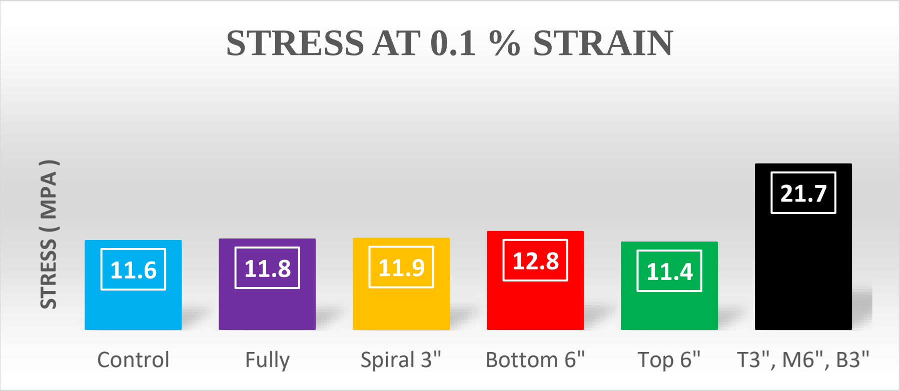


Figure 4.4 Stress at 0.1 % strain

4.5 Stress at 0.2 % Strain of All Columns.

The figure below shows the stress produced at 0.2 % strain. And after comparing them, it founds that the Control, fully wrap, top 6”, bottom “, spiral 3” had a slight difference with each other but T3”, M6”, B3”gives the highest value of stress at 0.2 % strains, nearly 100% more stress comparatively.

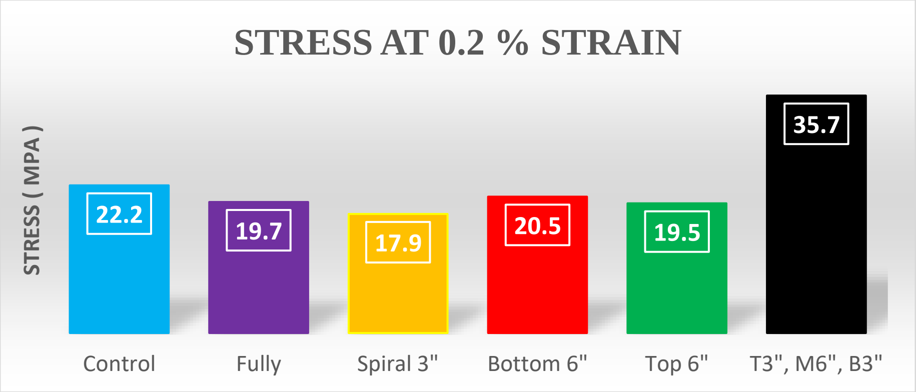


Figure 4.5 Stress at 0.2 % strain

4.6 Strain At Maximum Stress

The figure below shows the Strain produced at Maximum Stress. The fully wrap column showed a strain of 0.67 percent, while the control column showed a minimum strain of 0.36 percent. Comparing the other retrofitting methods to the control column, the strain increased. And stain at maximum stress of top 6”, bottom “, spiral 3”, T3”, M6”, B3” lies between control and fully wrap.

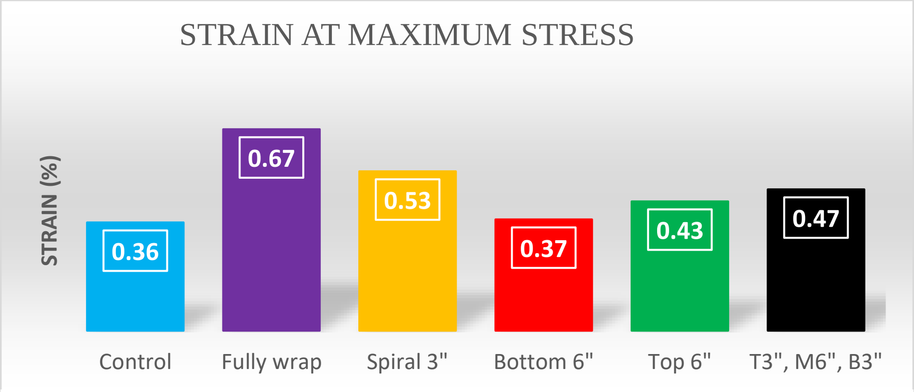


Figure 4.6 Strain at Maximum stress

4.7 Maximum Deformation (mm)

The figure below shows the Maximum Deformation (mm) occurred in columns at fracture point. The fully wrap column showed a Max Deformation of 6.1 mm, while the control column showed a Max Deformation of 2.4 mm. And max deformation of top 6”, bottom “, spiral 3”, T3”, M6”, B3” lies between control and fully wrap. Fully wrap and spiral 3” shows more deformation and ductile behavior.

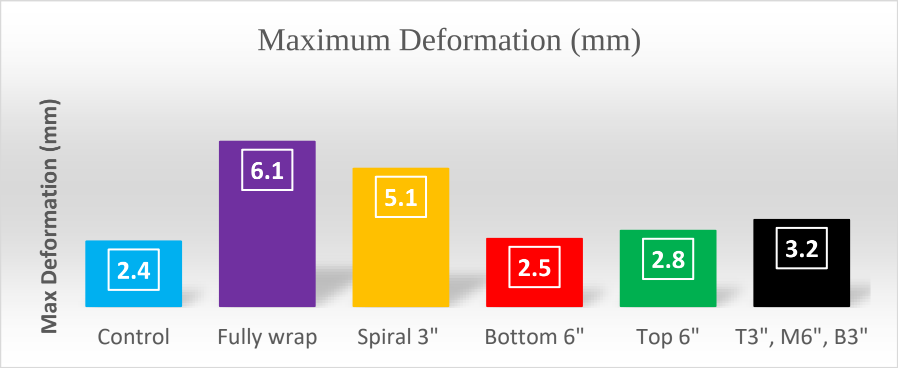


Figure 4.7 Maximum deformation(mm) at Fracture

4.8 Maximum Strain (%)

The figure below shows the Maximum Strain (%) occurred in columns at fracture point. The fully wrap column showed a Max Strain of 1.17 %, while the control column showed a Max Strain of 0.46 %. And max strain of top 6”, bottom “, spiral 3”, T3”, M6”, B3” lies between control and fully wrap. Fully wrap and spiral 3” shows more strain and ductile behavior.

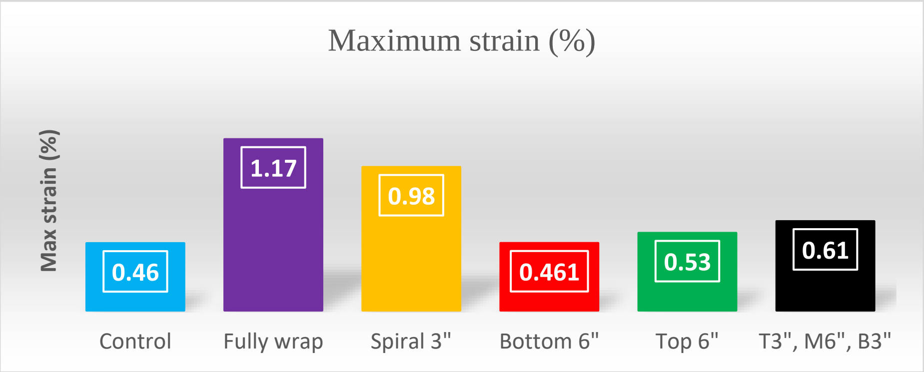


Figure 4.8 Maximum strain (%) at Fracture

4.9 Behaviors and Failure modes of Short RC Columns Under Axial Load

In this section we will discuss the behavior, failure modes, relationship between force – deformation, relationship between stress – strain, and comparison of strain and Deformation with respect to control column of different columns.

4.9.1 Control Short RC Column

4.9.1.1 Behavior of Control Column

No cracks were produced for the first 40 tons of load. After crossing the 42.5-ton load, we could see a slight crack starting to develop from the middle of the column. And as the load crossed 51.8, it was seen that the cracks which were started from the middle were propagate toward upward as well as downward, and at the same time, cracks started to be produced from the upper portion of the column and propagate towards middle of the column, and finally this caused the crack failure which failed at peak value 61.3.

4.9.1.2 Failure of control column

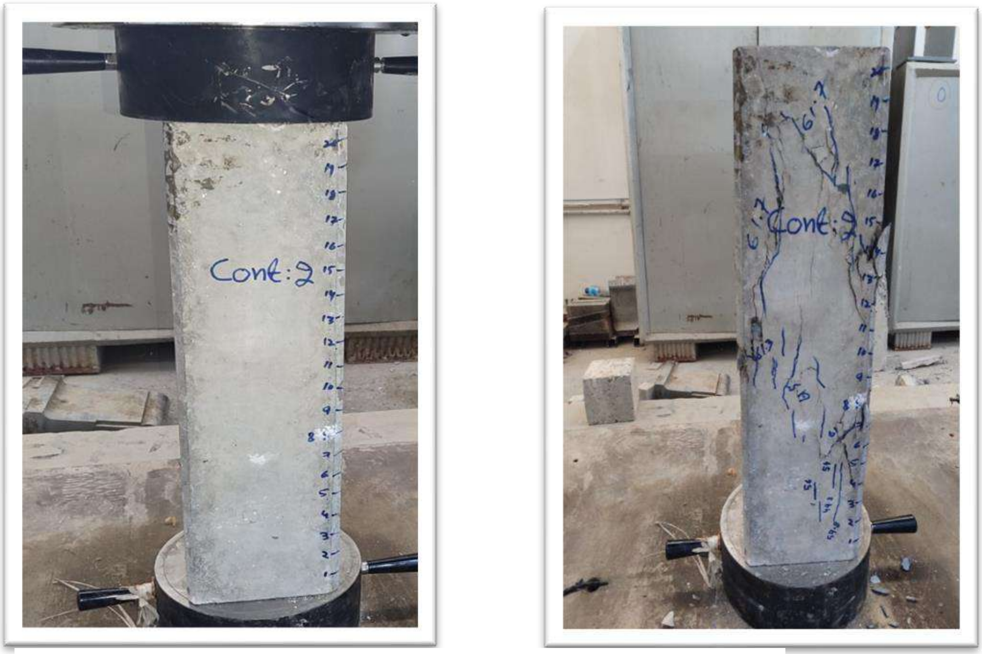
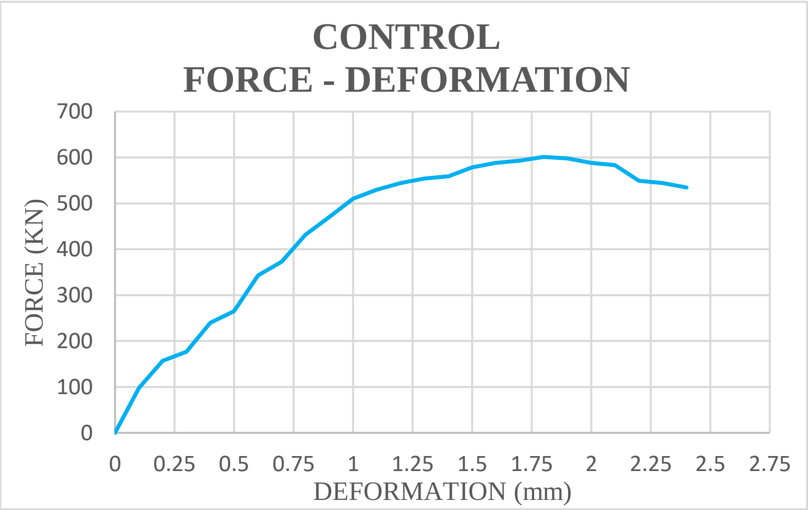
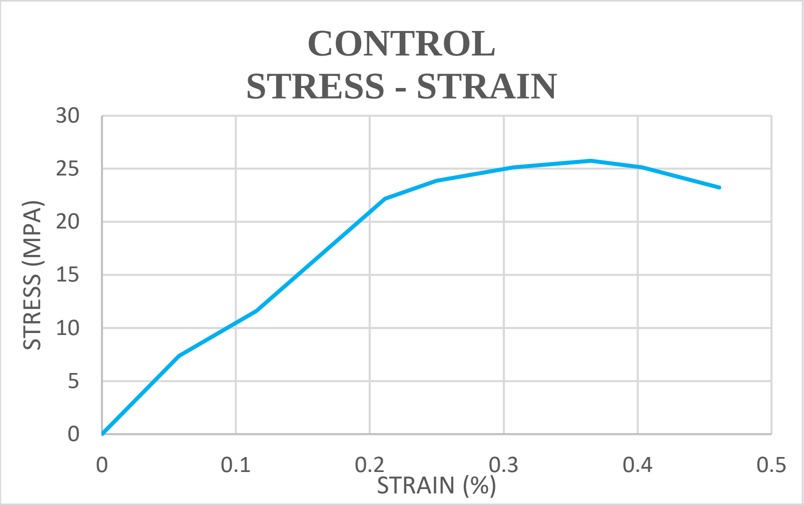


Figure 4.9 Before and After testing of control column

4.9.1.3 Relationship between force and deformation.



4.9.1.4 Relationship between stress and Strain.



4.9.2 Fully Wrapped Short RC Column

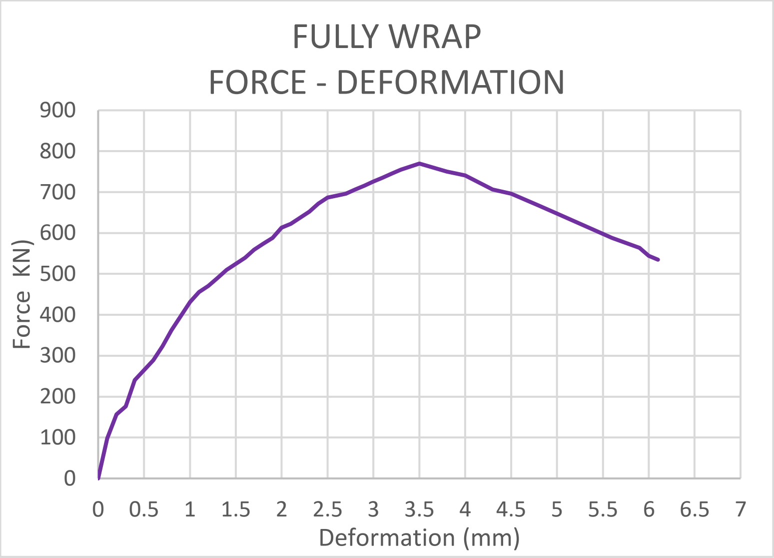
4.9.2.1 Behavior of Fully Wrapped

After applying the load, it was observed that no cracks were generated for the first 65-ton loads, after crossing the 65-ton load, slight cracks were observed by hand sensation and the concrete inside the sheet was disturbed. And finally, the column failed at 78.5-ton load.

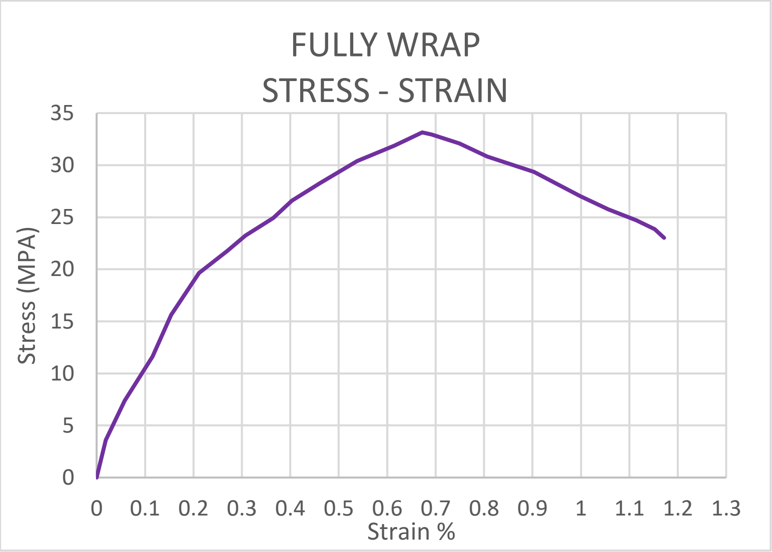
4.9.2.2 Failure of Fully Wrapped

Figure 4.10 Before and After testing of fully wrapped

4.9.2.3 Relationship between force and deformation.

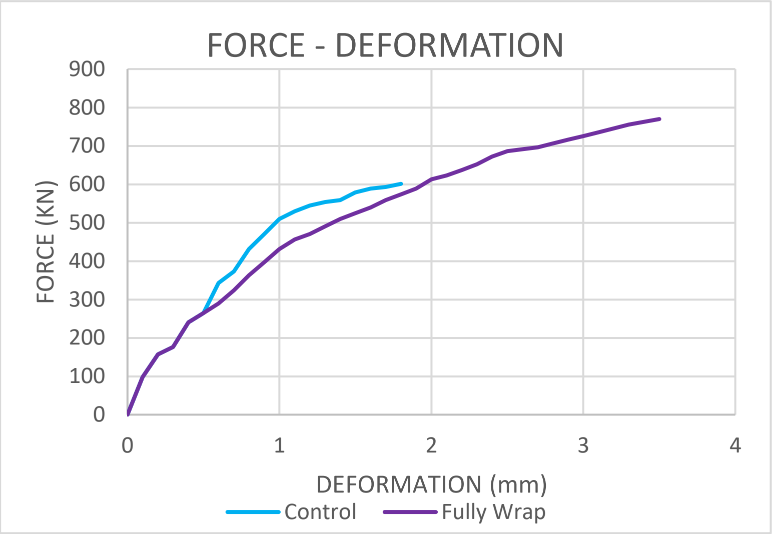


4.9.2.4 Relationship between stress and Strain.



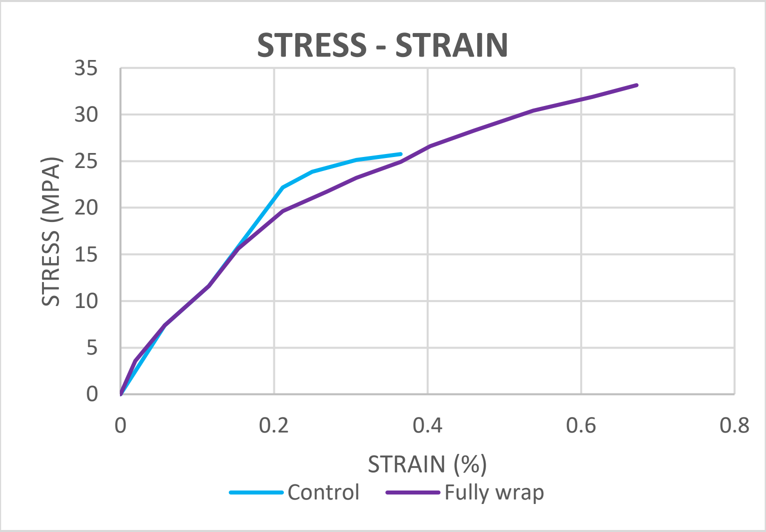
4.9.2.5 Comparison of Deformation w.r.t control

The force-deformation curve of the fully wrapped column indicates that the deformation of this column exceeds that of the control column at its maximum load carrying capability. The fully wrapped column experienced a deformation of 3.5 mm, while the control column had a deformation of 1.8 mm. The data indicates that the deformation capacity of the fully wrapped column was enhanced by 94.4%.



4.9.2.6 Comparison of Strain w.r.t control

The stress-strain curve demonstrates that the strain of this column, when fully wrapped, exceeds that of the control column at its maximum stress. The magnitude of the fully enveloped column's strain was 0.67. The magnitude of the strain on the control column was 0.36. The data indicates that the tensile strength of the fully wrapped column was enhanced by 86.11%.



4.9.3 Spiral 3” Short RC Column

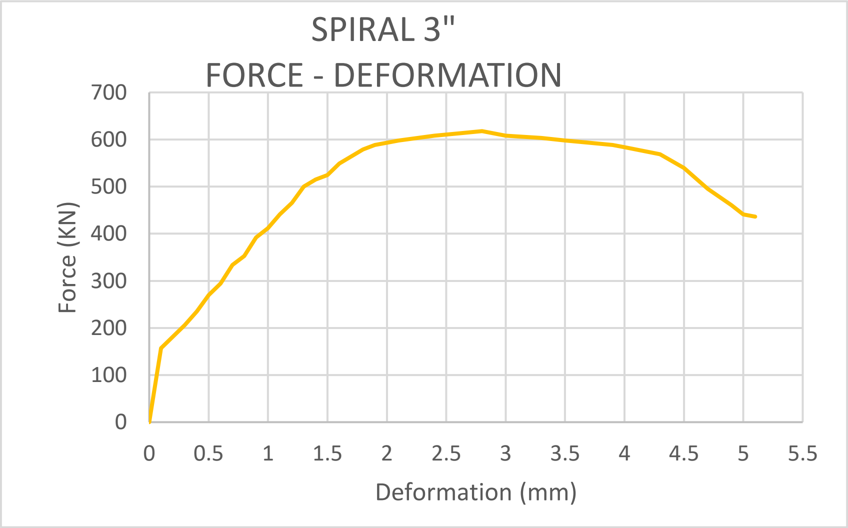
4.9.3.1 Behavior of Spiral 3”

No significant load increment was observed in the spiral, it remained almost the same as the control column, Because the fiber was unidirectional and we wrapped it at a certain angle on the column, that’s why fiber doesn’t absorb tensile forces. In his failure behavior we could see that the portion that was unwrapped started producing cracks and that was the reason for the failure at the load of 63.8 ton.

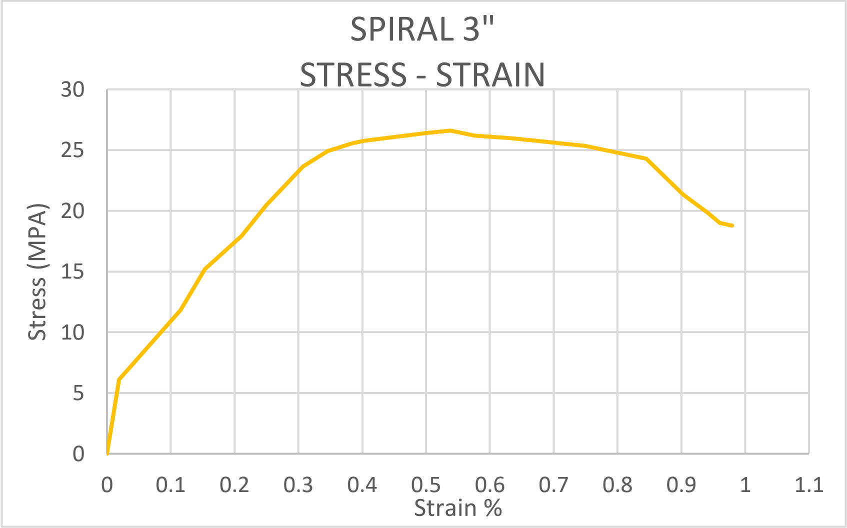
4.9.3.2 Failure of spiral 3”

Figure 4.11 Before and After testing of spiral 3”

4.9.3.3 Relationship between force and deformation.

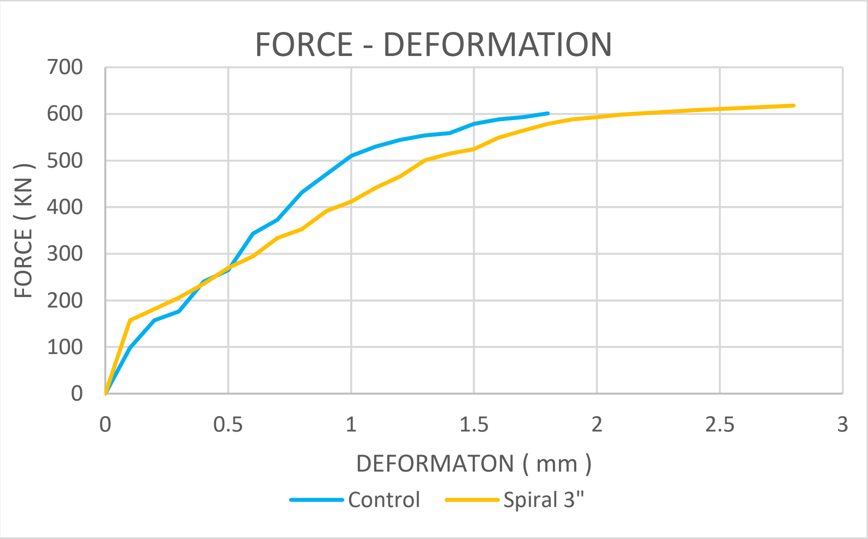


4.9.3.4 Relationship between stress and Strain.



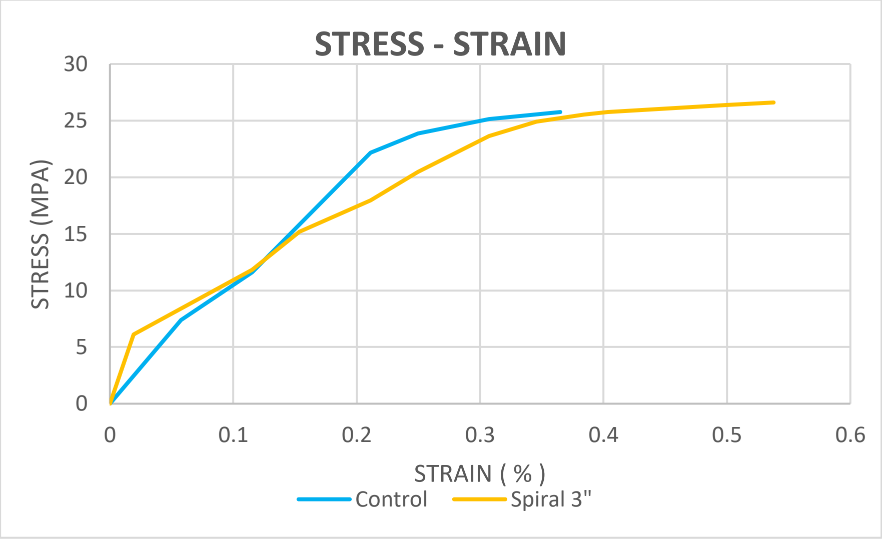
4.9.3.5 Comparison of Deformation w.r.t control

The force-deformation curve of the spiral 3” column, indicates that the deformation of this column exceeds that of the control column at its maximum load capacity. The spiral 3" experienced a displacement of 2.8 mm, while the control column had a deformation of 1.8 mm. The data indicates that the spiral 3" experienced a 55.55% increase in its ability to withstand deformation.



4.9.3.6 Comparison of Strain w.r.t control

The stress-strain curve reveals that the strain exhibited by the spiral 3" column exceeds that of the control column at its highest stress level. The magnitude of the spiral's strain was 0.53, The magnitude of the strain on the control column was 0.36. The data demonstrates that the straining capacity of the fully wrapped column was enhanced by 47.22%.



4.9.4 Bottom 6” Short RC Column

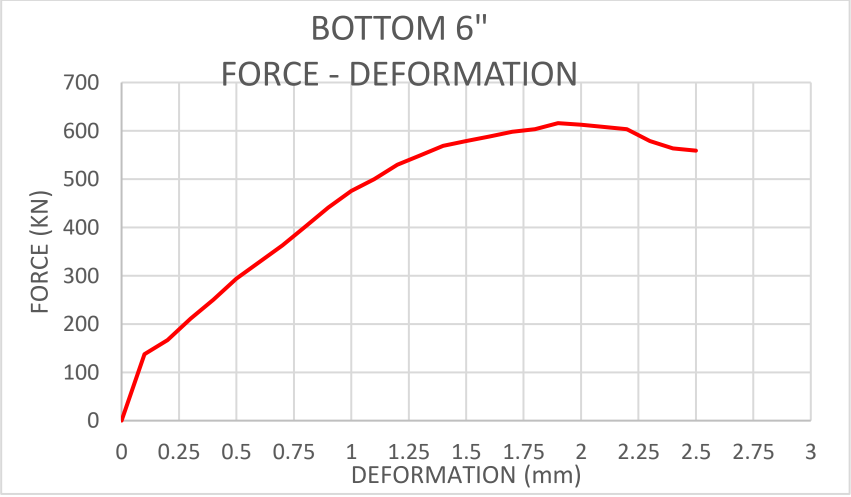
4.9.4.1 Behavior of Bottom 6”

No cracks were produced for the first 45 tons of load. After crossing the 47-ton load, we could see a slight crack starting to develop from the middle of the column. And as the load crossed 55.8, it was seen that the cracks which were started from the middle were propagate toward upward, and at the same time, cracks started to be produced from the upper portion of the column and propagate towards middle of the column, and finally this caused the crack failure which failed at peak value 62.8.

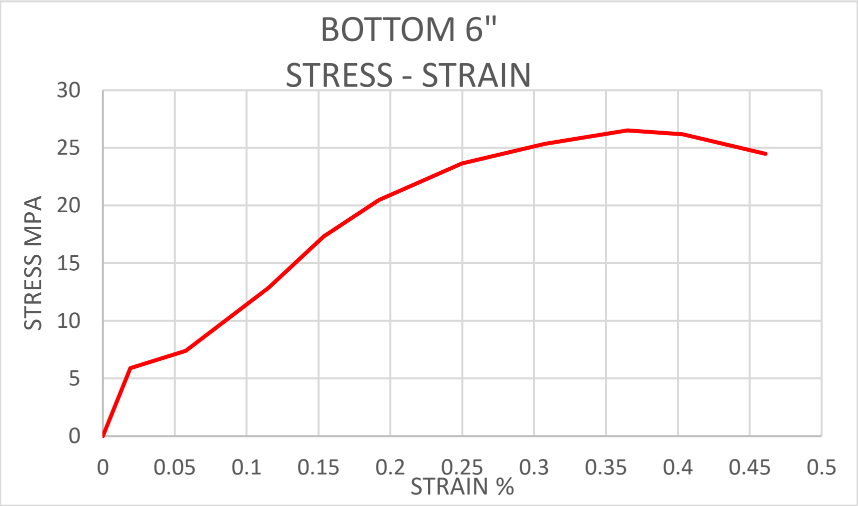
4.9.4.2 Failure of Bottom 6”

Figure 4.12 Before and After testing of bottom 6”

4.9.4.3 Relationship between force and deformation

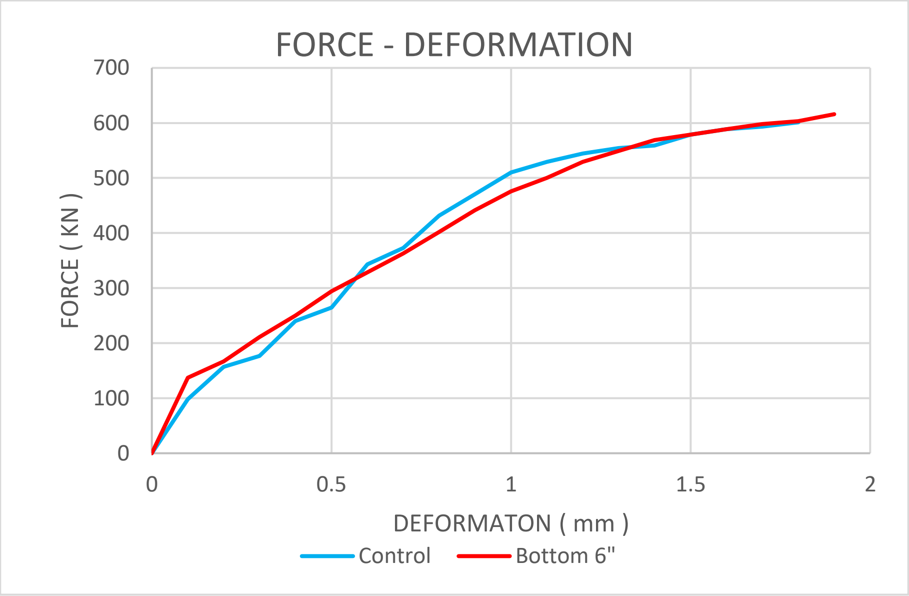


4.9.4.4 Relationship between stress and Strain.



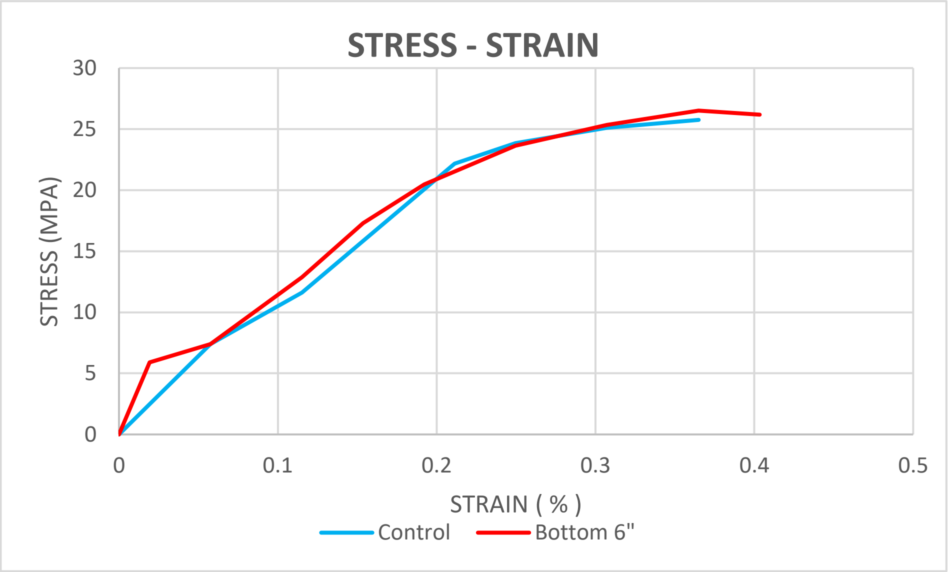
4.9.4.5 Comparison of Deformation w.r.t control

Curve illustrates the force-deformation relationship of the Bottom 6" column. It indicates that the column's deformation significantly increases from the control condition when it reaches its maximum load-carrying capability. The bottom 6" experienced a deformity of 1.9 mm, while the control column experienced a deformation of 1.8 mm. This indicates that the structural integrity of the column was enhanced by a 5% increase in its deformation capacity.



4.9.4.6 Comparison of Strain w.r.t control

According to curve, the stress-strain curve of the bottom 6" column indicates that the strain of this column significantly increases from the control at its maximum stress. The stress exerted on the bottom 6" was 0.4. The magnitude of the strain in the control column was 0.36. This indicates that the straing capacity of this column was enhanced by 11.11%.



4.9.5 Top 6” Short RC Column

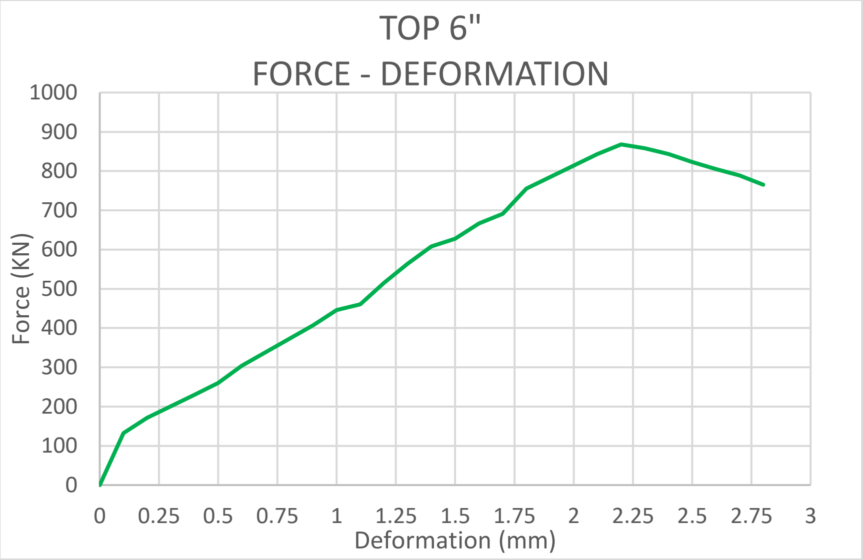
4.9.5.1 Behavior of Top 6”

No cracks were produced until the first 55 ton load, After that, as the load increased, the cracks started from the middle and propagate upward as well as downward, After crossing the load 75 ton, cracks started coming down from the upper six inch wrapped portion, And these cracks continue to increase until they reach their peak value and fail at a load of 88.5 tons.

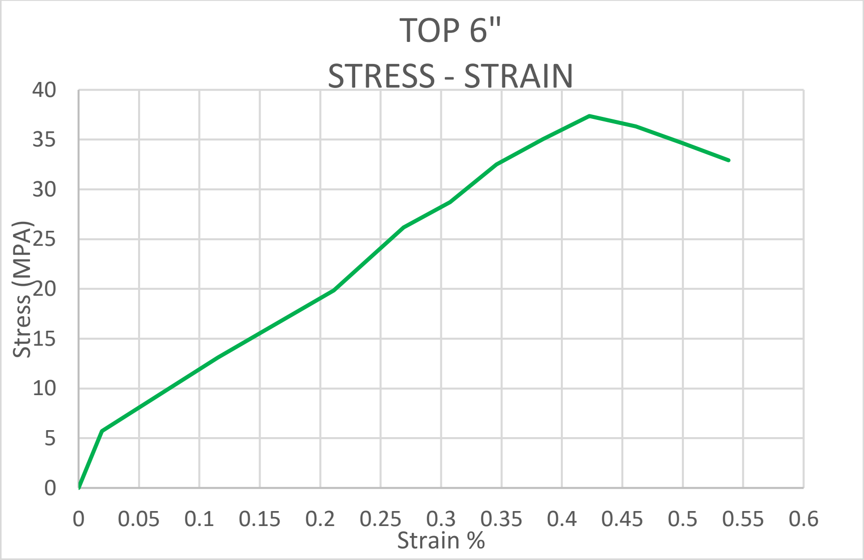
4.9.5.2 Failure of Top 6”

Figure 4.13 Before and After testing of top 6"

4.9.5.3 Relationship between force and deformation

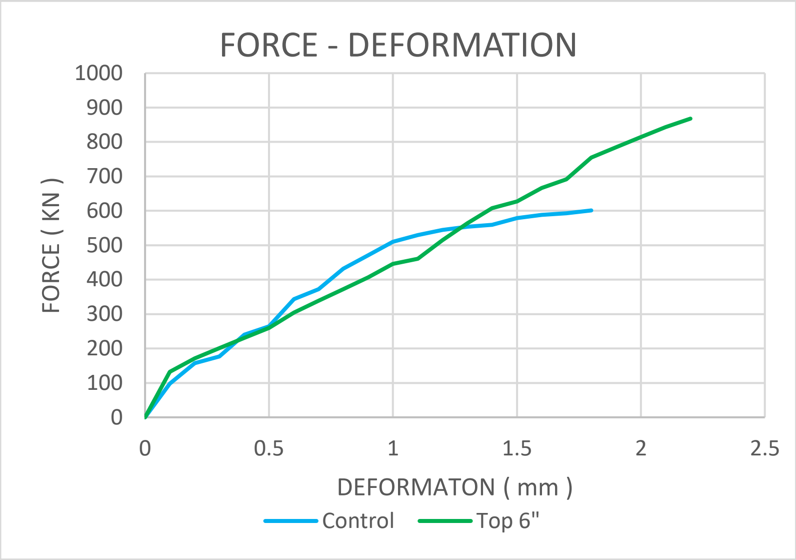


4.9.5.4 Relationship between stress and Strain.



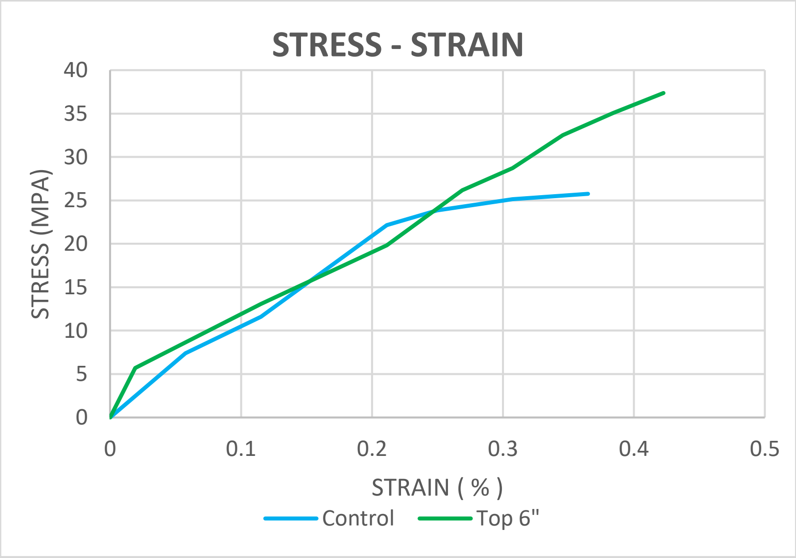
4.9.5.5 Comparison of Deformation w.r.t control

The force-deformation curve of the top 6" column, indicates that the deformation of this column exceeds that of the control column at its maximum load capacity. The top 6" experienced a deformation of 2.2 mm, while the control column experienced a displacement of 1.8 mm. The data indicates that the column's ability to withstand deformation was enhanced by 22.22%.



4.9.5.6 Comparison of Strain w.r.t control

The stress-strain curve reveals that the strain of the top 6" column exceeds that of the control column at its peak stress. The stress on the top 6" column was 0.42. The magnitude of the strain on the control column was 0.36. This indicates that the straining capacity of this column was enhanced by 16.67%.



4.9.6 Top3", Middle 6", Bottom 3" Short RC Column

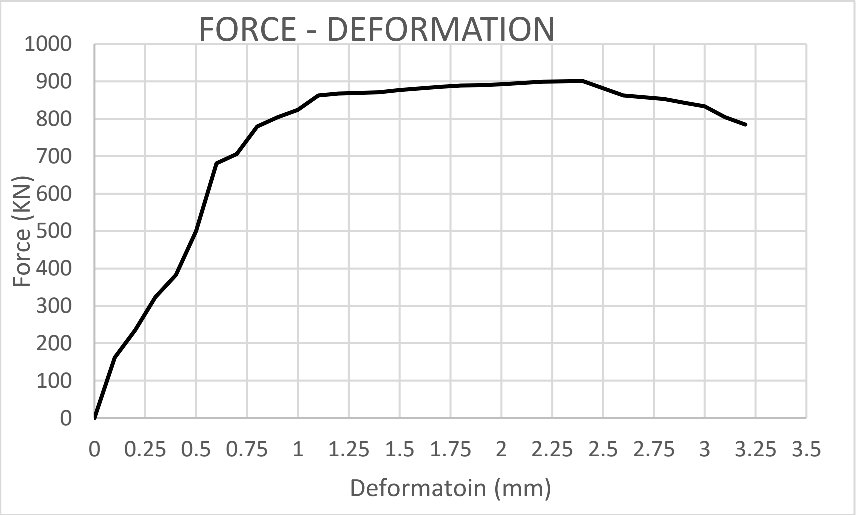
4.9.6.1 Behavior of Top3", Middle 6", Bottom 3"

No cracks were produced in this spaceman until the first 70 tons loads, As the load increased from 70 tons Cracks started to be produced in unwrapped portion of column, after crossing 80 ton load the cracks continued to increase and as soon as it reached 91.9 ton the specimen failed.

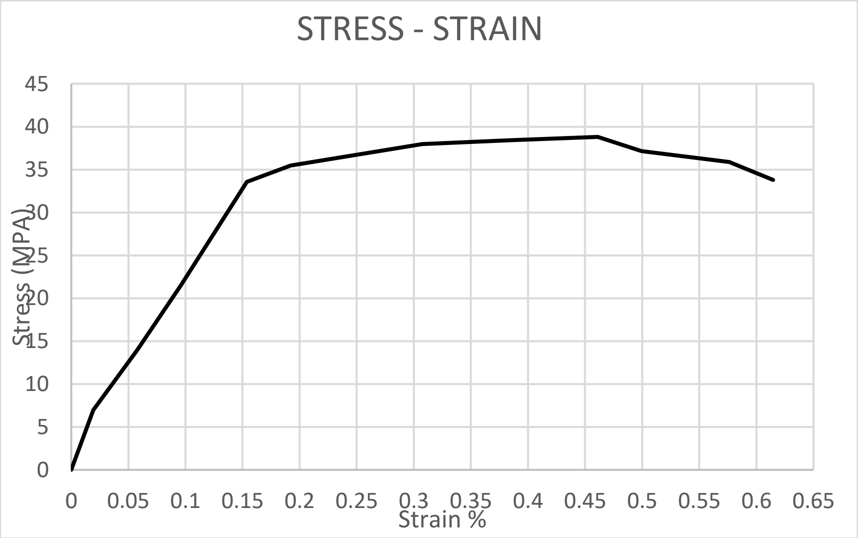
4.9.6.2 Failure of Top3”, Middle 6”, Bottom 3”

Figure 4.14 Before and After testing of T3", M6", B3"

4.9.6.3 Relationship between force and deformation

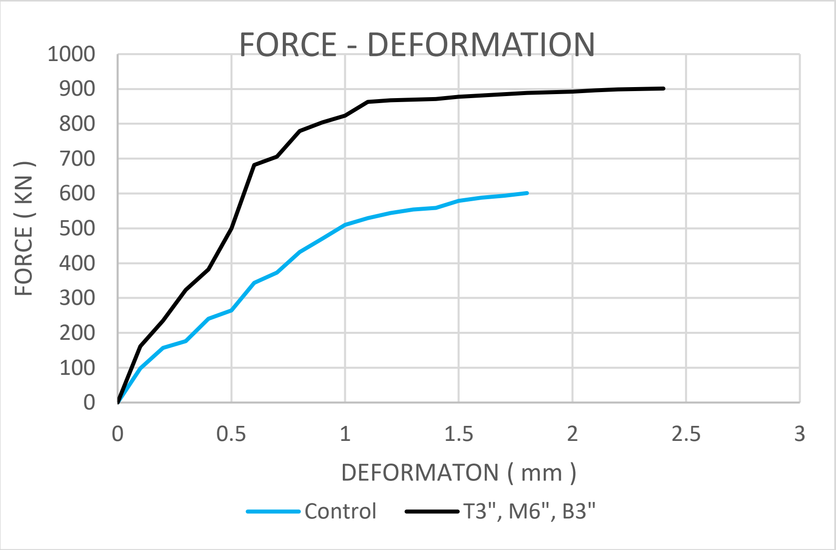


4.9.6.4 Relationship between stress and Strain.



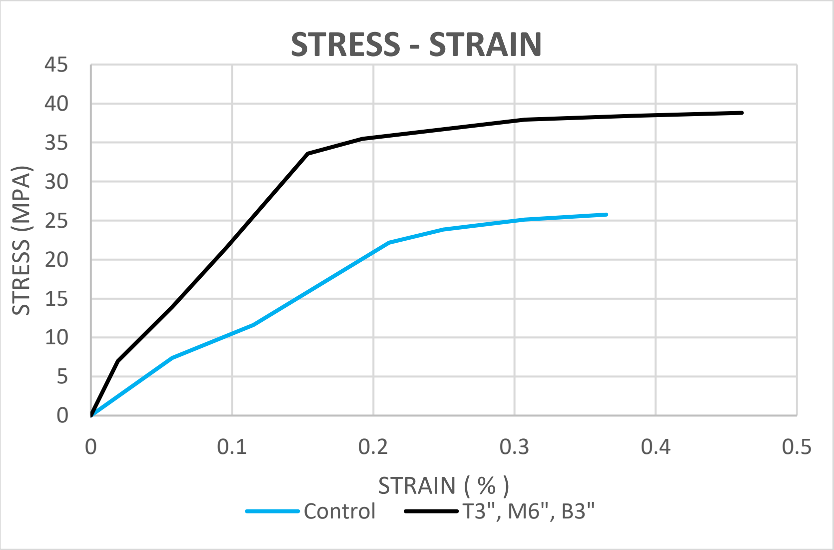
4.9.6.5 Comparison of Deformation w.r.t control

The force-deformation curve demonstrates that the deformation of the Top3", Middle 6", and Bottom 3" columns exceeds that of the control column at its maximum load capacity. The displacement of the Top3", Middle 6", and Bottom 3" columns was measured to be 2.4 mm, whereas the displacement of the control column was 1.8 mm. This indicates that the ability of the fully wrapped column to withstand deformation was enhanced by 33.33%.



4.9.6.6 Comparison of Strain w.r.t control

The stress-strain curve indicates that the strain of the Top 3", Middle 6", Bottom 3" column exceeds that of the control column at its maximum stress. The strain in the Top 3", Middle 6", Bottom 3" column was measured to be 0.46. The magnitude of the strain on the control column was 0.36. The data demonstrates that the straining capacity of the fully wrapped column was enhanced by 27.77%.



4.10 COST ANALYSIS

Figure 4.15 displays the price value, measured in rupees, of CFRP wrapping on individual columns. The cost is anticipated at a rate of Rs 800 per square foot. The analysis doesn't includes the cost of epoxy. The quantity of epoxy employed exhibits a direct correlation with the surface area and expense of CFRP. Consequently, the outcomes and conclusions will remain unaffected by this factor.

Special thanks to Imporient Chemical, PVT, Limited, Pakistan, for student discount, technical guidance and other cooperation.

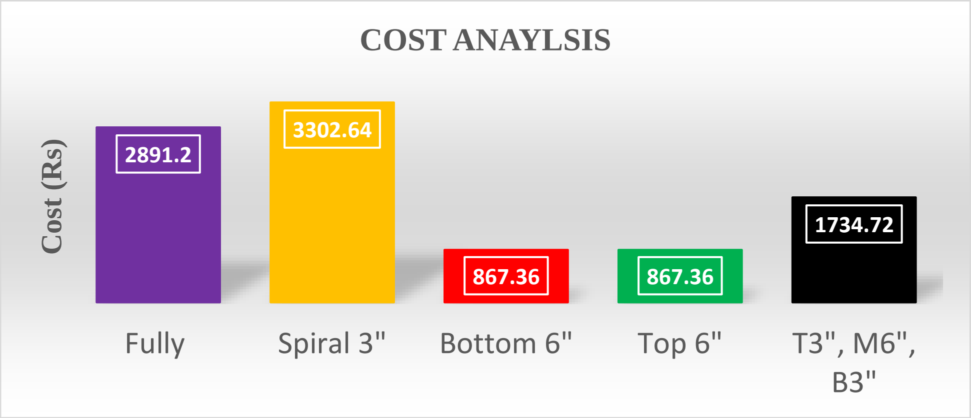


Figure 4.15 Cost analysis

Figure 4.15 and table 4.2 illustrates the cost analysis of the amount of strength acquired through various designs. The highest level of strength achieved was in the top 6" wrapped column.

Specimen	CFRP Wrap Area (sq in)	Strength (ton)	Cost (Rs)	Strength(ton)/Rs	Strength(ton)/Rs 1K
Fully	520	78.5	2891.2	0.0271	27.15
Spiral 3"	594	63.8	3302.64	0.0193	19.31
Bottom 6"	156	62.8	867.36	0.0724	72.4
Top 6"	**156**	**88.5**	**867.36**	**0.102**	**102**
T3",M6", B3"	312	91.9	1734.72	0.0528	52.9

Table 4.2 Cost analysis and Strength(ton)/Rs

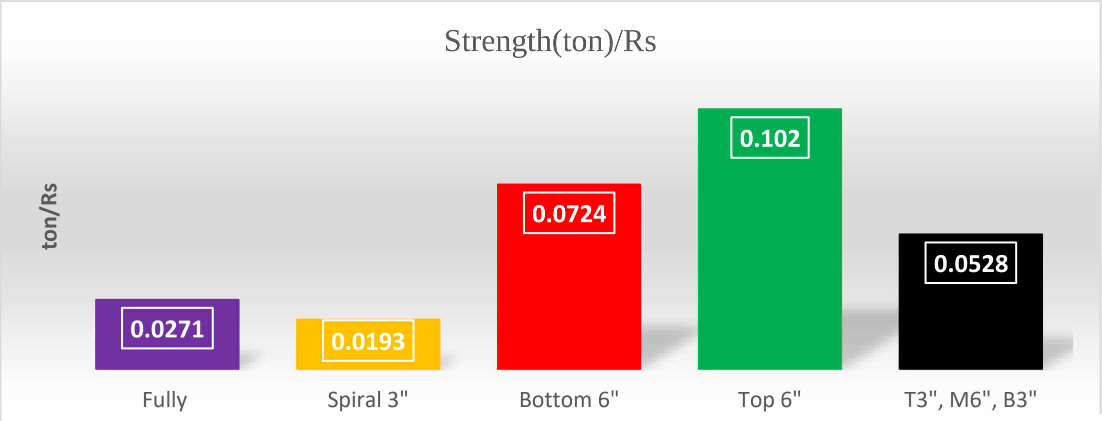


Figure 4.16 Strength(ton)/Rs

Chapter-05 CONCLUSIONS & RECOMMANDATIONS

The results obtained from the experiments conducted within the framework of this research study have enabled us to formulate the following conclusions and recommendations.

5.1 Conclusions

1. Every Strengthening approach shown an enhancement in the load carrying capability of columns.
2. The column covered with CFRP at the top 3", middle 6", and bottom 3" demonstrated the most significant increase in strength.
3. Fully wrap and spiral 3" wrap exhibits superior ductility in comparison to alternative strengthening techniques.
4. All Strengthening approaches exhibited enhanced performance in terms of deformation and straining values of columns, when compared to the control.
5. The utilization of CFRP to wrap the Top 6" section proved to be the most economically efficient method.

5.2 Future Recommendations

1. Future research can involve the application of these techniques to numerically model RC short columns.
2. Further investigation should be conducted on RC intermediate and RC long columns to address practical concerns.
3. An investigation should be conducted to explore the feasibility of substituting carbon fibre reinforced polymers with glass fibre reinforced polymers.
4. The testing procedure for eccentrically loaded columns should be conducted in a similar manner to the study, rather than using co-centrically loaded columns. Columns can vary in length, ranging from short to middle to long.
5. It is imperative to subject circular and rectangular columns to the same testing criteria as square columns in this study.

Chapter-06 SUSTAINABLE DEVELOPMENT GOALS (SDG’s)

The Sustainable Development Goals (SDGs) encompass fundamental objectives aimed at effecting global transformation. These objectives serve as a compelling impetus to save the environment, eradicate poverty and inequality, and guarantee universal well-being, good health, and equitable justice for all individuals around the globe. These objectives ensure the equitable provision of a healthy and fulfilling existence for all inhabitants of our planet, encompassing both animal and human populations. The Sustainable Development Goals (SDGs) are a set of 17 global objectives that were unanimously adopted by all Member States of the United Nations in 2015. They are a crucial part of the 2030 Agenda for Sustainable Development.

SUSTAINABE DEVELOPMENT GOALS (SDG’s) USED IN THIS STUDY

Our final year project in the field of civil engineering was centered around the enhancement of short reinforced concrete (RC) columns through the utilization of CFRP materials. Additionally, our project aimed to provide a cost-effective solution while also aligning with various Sustainable Development Goals (SDGs). Our project makes a significant contribution to certain Sustainable Development Goals (SDGs) in the following ways:

SDG 9: INDUSTRY, INNOVATION AND INFRASTRUCTURE.

The focus of our civil engineering final year project was to improve short reinforced concrete (RC) columns by incorporating Carbon Fibre Reinforced Polymer (CFRP) materials. In addition, our initiative sought to offer a financially efficient solution while also being in line with multiple Sustainable Development Goals (SDGs). Our project significantly contributes to certain Sustainable Development Goals (SDGs) through the following means:

SDG 11: SUSTAINABLE CITIES AND COMMUNITIES.

Enhancing the structural integrity of existing reinforced concrete (RC) columns is crucial for guaranteeing the safety and longevity of urban buildings. This practice is in accordance with Goal 11, The objective is to create cities and human settlements that are inclusive, secure, resilient, and sustainable.

SDG 12: RESPONSIBLE CONSUMPTION AND PRODUCTION.

The project's focus on strengthening existing columns rather than creating completely new structures is in line with the concepts of responsible consumerism. Implementing this technique results in a decline in the demand for raw materials and a decrease in the production of construction waste, so making a substantial contribution to the attainment of Goal 12.

SDG 13: CLIMATE ACTION.

The implementation of retrofitting and strengthening measures for existing structures serves to advance sustainable construction standards, contributing to the mitigation of climate change effects. Carbon fiber materials have the advantageous characteristic of being lightweight, which consequently contributes to the reduction of the overall carbon footprint associated with shipping and installation. This aligns with the objectives outlined in Goal 13.

SDG 17: PARTNERSHIP FOR THE GOALS.

Engaging in collaborations with engineering businesses, research institutes, or local communities for the implementation of a project exemplifies the significance of collaborative efforts in attaining sustainable development goals, aligning with the principles outlined in Goal 17.

IMPORTANCE

The primary focus of our project is to highlight the effective utilization of CFRP materials, with the aim of achieving cost-efficiency in the reinforcement process. This endeavor serves as a demonstration of the practical implementation of sustainable development concepts within the field of civil engineering. The aforementioned attributes, namely efficiency, affordability, and environmental consciousness, play a pivotal role in making a substantial contribution towards the achievement of the Sustainable Development Goals (SDG’s).

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