NUMERICAL ANALYSIS OF RC CIRCULAR COLUMN TO ENHANCE THE COMPRESSIVE STRENGTH WITH CFRP

By

RIPON MIAH

NANDAN CHANDRA SUTRADHAR

MD. YOUSUF MIA

MD. ARIFUL ISLAM

KAMRUL HASAN SHARIF

A thesis submitted to the Department of Civil Engineering in partial fulfillment for the degree of Bachelor of Science in Civil Engineering

Department of Civil Engineering

Sonargaon University

147/I, Green Road, Dhaka-1215, Bangladesh

Section :17B

Fall-2022

NUMERICAL ANALYSIS OF RC CIRCULAR COLUMN TO ENHANCE THE COMPRESSIVE STRENGTH WITH CFRP

By

RIPON MIAH (ID: BCE1902017009)

NANDAN CHANDRA SUTRADHAR (ID: BCE1902017015)

MD. YOUSUF MIA (ID: BCE1902017038)

MD. ARIFUL ISLAM (ID: BCE1902017046)

KAMRUL HASAN SHARIF (ID: BCE1902017085)

Supervisor
MD.FAZLA RABBI ANIK
Lecturer & Coordinator

A thesis submitted to the Department of Civil Engineering in partial fulfillment for the degree of Bachelor of Science in Civil Engineering

Department of Civil Engineering

Sonargaon University

147/I, Green Road, Dhaka-1215, Bangladesh

Section: 17B

Semester Year: 2022

BOARD OF EXAMINERS

The thesis titled "NUMERICAL ANALYSIS OF RC CIRCULAR COLUMN TO ENHANCE THE COMPRESSIVE STRENGTH WITH CFRP" Submitted BY RIPON MIAH (ID:BCE1902017009),NANDAN CHANDRA SUTRADHAR (ID: BCE1902017015), MD. YOUSUF MIA (ID: BCE1902017038), MD. ARIFUL ISLAM (ID: BCE1902017046), KAMRUL HASAN SHARIF (ID: BCE1902017085) has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Civil Engineering on Date-of-Defense.

………………………………………

1. Md.Fazla Rabbi Anik — Chairman
   Lecturer & Coordinator

   Sonargaon University

………………………………………

2. Internal / External Member — Member

………………………………………

3. Internal / External Member — Member

DECLARATION

It is hereby declared that this thesis/project or any part of it has not been submitted elsewhere for the award of any degree or diploma.

STUDENT NAME	STUDENT ID.	SIGNATURE
RIPON MIAH	BCE1902017009	
NANDAN CHANDRA SUTRADHAR	BCE1902017015	
MD. YOUSUF MIA	BCE1902017038	
MD. ARIFUL ISLAM	BCE1902017046	
KAMRUL HASAN SHARIF	BCE1902017085	

Dedicated

to

"Our parents"

ACKNOWLEDGEMENTS

We are forever grateful to our Thesis Supervisor, Md.Fazla Rabbi Anik for his kind supervision and guidance throughout this important study and also with the continuous help from the beginning to the end of this study the work finally becomes positive to complete successfully.

We are grateful to our parents for their help & kind participation during preparing this Thesis book. This encouragement, helping hand, affection and sacrifice both directly and indirectly helped to reach on the today's position, without their love, appreciation, and encouragement it was impossible to reach here. Acknowledgement of their contribution is too small as a reward.

The satisfaction and euphoria that accompany the successful completion of the task would be great but incomplete without the mention of the people who made it possible with their constant guidance and encouragement crowns all the efforts with success. In this context, we would like to thank all the other staff members, both teaching and non-teaching, which have extended their timely help and eased our task.

ABSTRACT

This research numerically represents the technique of increasing compressive strength of reinforced concrete (RC) column using Carbon fiber reinforced polymer (CFRP) under pure compressive load. Many researchers worldwide have extensively used fiber-reinforced polymer (FRP) strengthening materials to enhance the shear and flexural strengths of reinforced concrete RC columns. However, studies on compressive strengthening are limited. FRP laminate can be used as external reinforcement for the reintegration of RC structures and due to their high tensile strength and corrosion resistance, they are preferable over steel plates. This study aims at demonstrating the behavior of RC columns under pure compressive loading with CFRP sheets with different configurations. Total 3 columns are modeled with the dimension of 250mm diameter and 1220mm length. One of them is performed as a control column and others are configured with different orientations of FRP sheets which are: fully wrapped, wrapped strips. Ultimate load, Displacement and cracking patterns has been measured from the numerical analysis. It is seen that CFRP performed better to increase the compressive strength compared to the control column. Fully CFRP wrapped column has increased the ultimate load-carrying capacity and ductility by about 179.08 % and 525.06 %. Finally, these results have been validated with the experimental result available in the literature. Numerical study has been carried out by using Finite Element Software, ABAQUS to bring into focus the versatility and powerful analytical capabilities of finite element techniques by objectively modeling the complete response of columns.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Concrete is a structural material consisting of hard, chemically inert particulate substances, known as aggregate (such as sand, gravel, etc.) that is bonded together by cement and water. Concrete is relatively brittle, and its tensile strength is typically only about one-tenth of its compressive strength.

To increase the tensile strength of concrete, Joseph Monier, a Parisian gardener invented reinforced concrete which has been hardened onto embedded metal (usually steel). Reinforced concrete is also known as ferroconcrete. Nowadays in some practices concrete is reinforced with a small number of different types of random fibers to increase the crack control parameter of concrete, toughness, and energy absorption capacity of the materials. Day by day this practice becomes popular.

Fibers are mixed with concrete as a percentage of the total volume of concrete and when concrete with fiber is hardened, this allows the concrete to resist a considerable amount of crack when bodies are subjected to different kinds of loading.

Figure 1 shows how the percentage of fibers affects the net deflection with the increasing load.

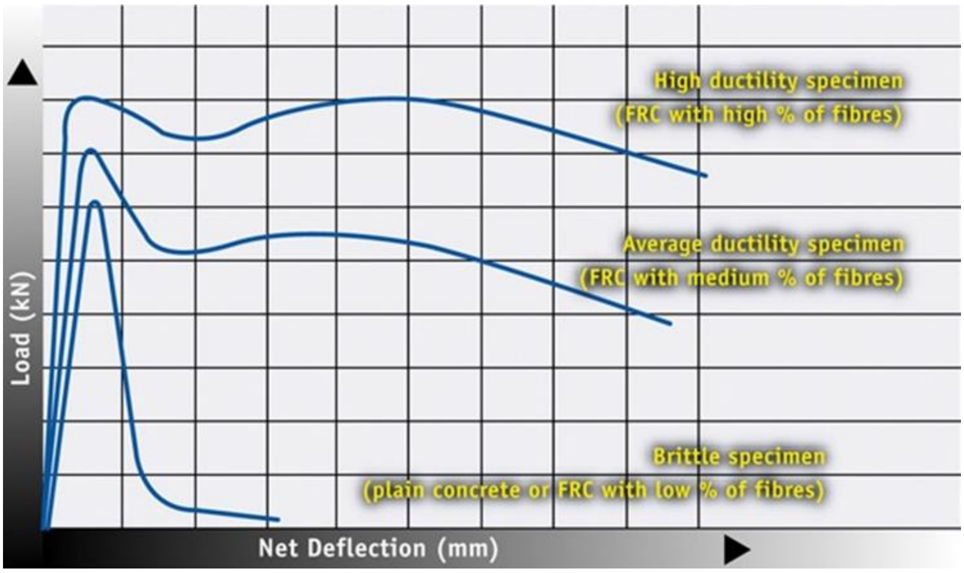
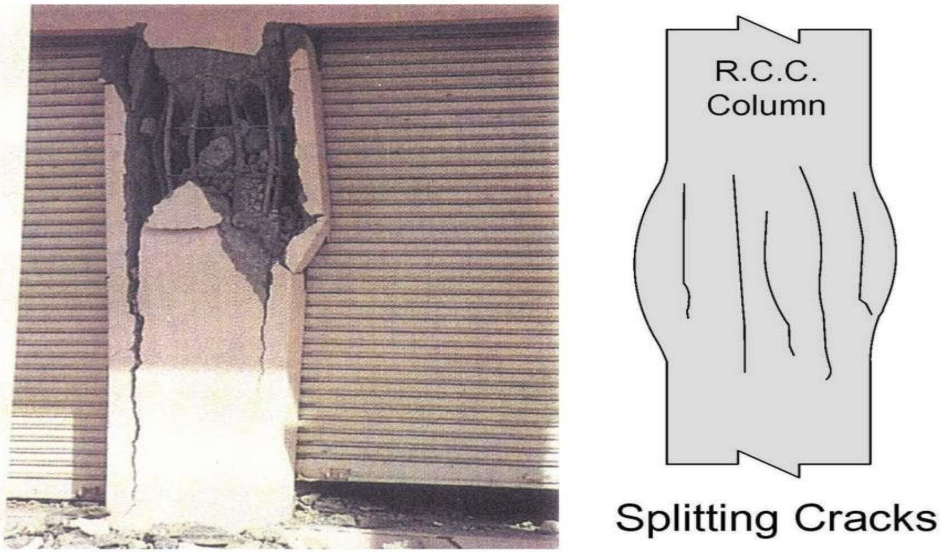
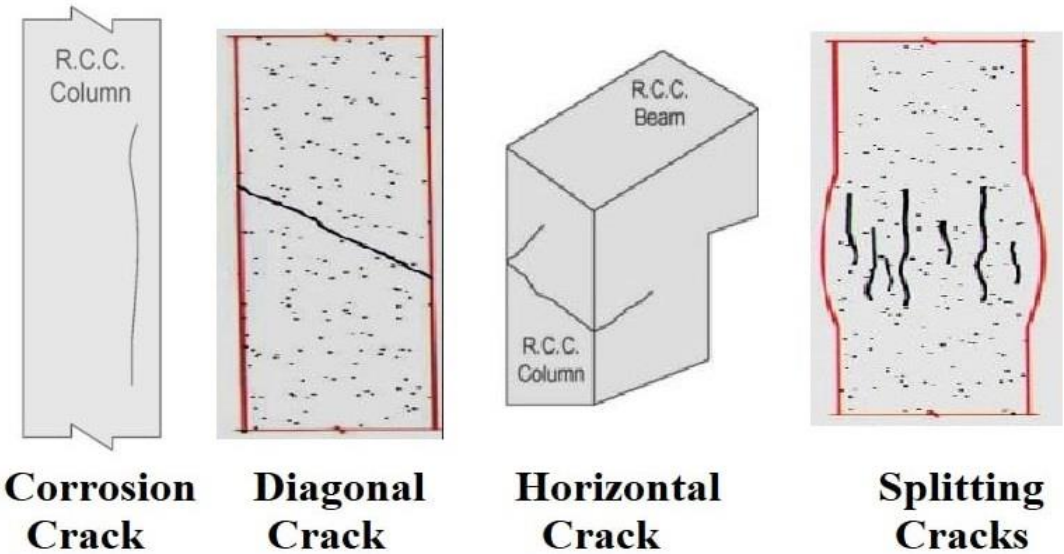


Figure 1:1 Load-Deflection Curves with different fiber percentage

Columns located at the perimeter of the building, when they subjected to the loads coming from the slab and columns, a compressional force is generated there which tends to twist the column with different angle of twist in either side (Yamao, et al., 2002). For the effect of a considerable amount of angle of twist between the material, cracking may happen there. To resist this kind of cracking effect, a Fiber Reinforce Polymer system is present nowadays. Using Fiber Reinforce Polymer (FRP), it can be possible to control the cracking behavior of the RC column at its post-cracking stage.



(1) Source: (https://images.app.goo.gl/UER1ge8Etx33GF5Q8)



(2) Source: (https://images.app.goo.gl/qTZf7FTxqZLuRYqV8)

Figure 1:2 (1), (2) Column cracks

Weight ratio, non-corrosiveness. These characteristics make FRP the most effective material for increasing crack control phenomena and compressional resistance, repair, and rehabilitation of deficient RC structures. Different Kinds of research potential on FRP have arisen since the '90s, but its applications are still unexplored. Strengthening and retrofitting of existing structures using externally bonded FRP is one of the first applications of FRP introduced in civil engineering. In the 1980s, several researchers initiated using FRP in civil engineering applications as a separate research domain to explore properties of FRP and highlighted typically two main fibrous materials like glass and carbon to strengthen structural members. Carbon fiber is usually manufactured in two categories i.e. high modulus and high strength. Glass fiber is produced in two forms i.e. E-glass and S-glass. However, E-glass fibers are comparatively not much stronger and stiffer than S-fibers.

Figure 1.3 shows the general behavior of FRP in comparison to steel under tensile stresses, from the stress-strain relationship figure it is clear that the stiffness of CFRP is higher than GFRP and steel. CFRP and GFRP are used in the high level of reinforced concrete strengthening applications. Some of the typical material properties of CFRP have been shown in Table 1.1

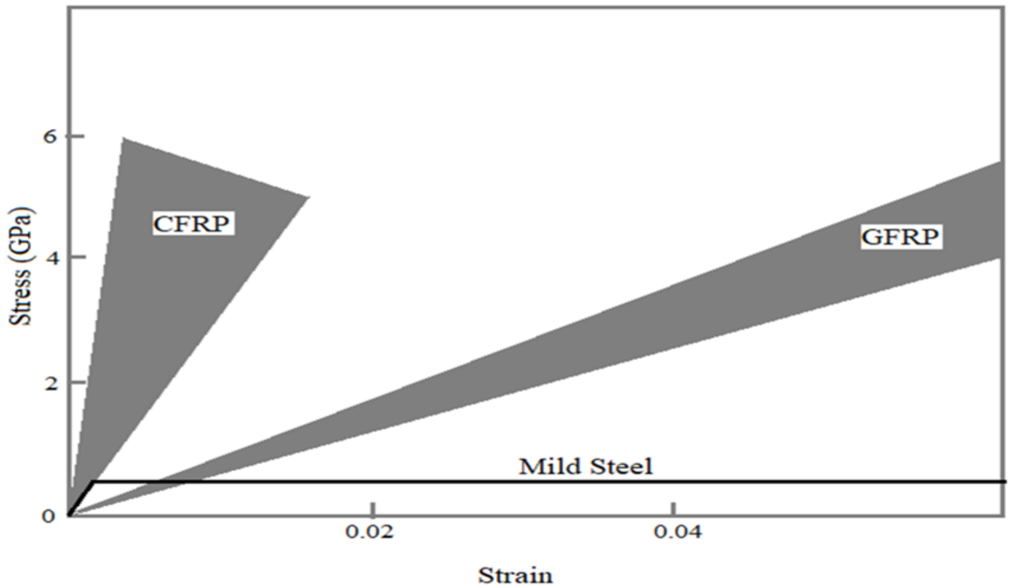


Figure 1:3 Typical stress-strain relation for different FRPs and normal steel

(Source : https://images.app.goo.gl/ZnfC8t9ekZmJUPRQ9)

In this study carbon fiber (CFRP) is used for strengthening of RC column to withstand the cracks develop for the twisting effect of RC columns, because CFRP of overhauled on other FRPs comparative to other FRP.

Table 1:1 Some Typical Properties of Carbon Fibers

Type of Fiber	Tensile Strength (psi)		Compressive Strength (psi)	Elongation Capability	Stiffness (modulus of elasticity-psi x 10^6)
Carbon Fiber	470,000		338,400	1.4%	33.0

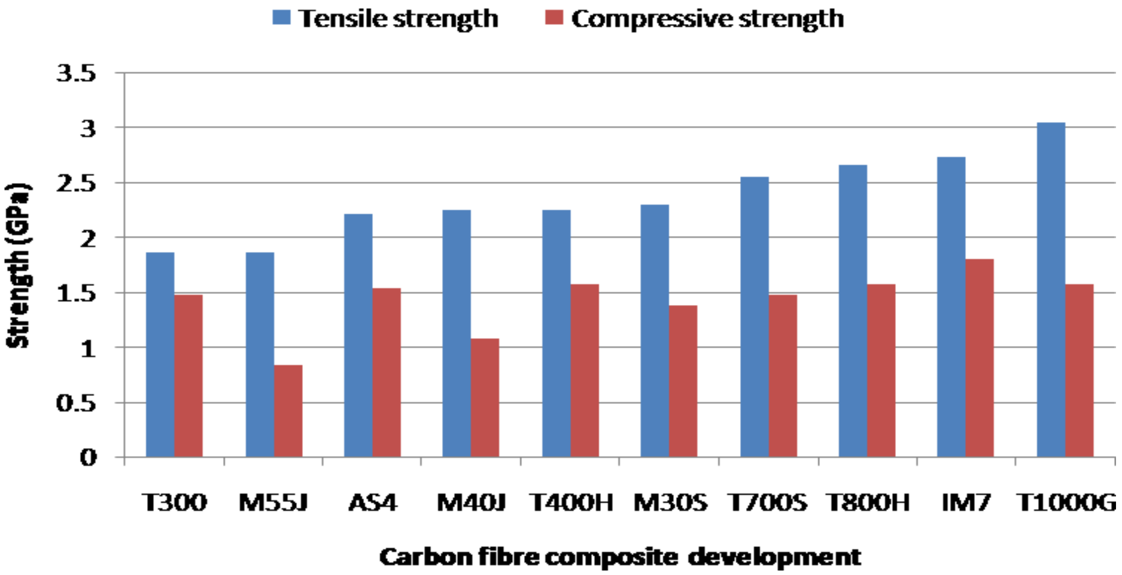


Figure 1:4 Tensile & compressive strength of unidirectional carbon fiber composites

(Source : https://images.app.goo.gl/9YwjLaWwHiQCdypf8)

Fiber Reinforced Polymer (FRP) as a reinforcement element is used extensively to address the strength requirements related to flexure and shear in structural members. But the strengthening of members subjected to compression is yet to be explored. In this Study, the behavior and performance of reinforced concrete column strengthened with bonded fibers especially with Carbon fibers (CFRP) subjected to pure compression is presented.

1.2 Historic Development of Fiber Reinforced Concrete

The concept of using fibers to increase the compressive strength is more than 4500 years old. Mesopotamian civilizations used straw fibers in sun-dried mud bricks in order to create a composite with increased toughness. This works as a matrix with better resistance to cracking and an improved post cracking response. When ordinary Portland cement concrete started to be used widely as a construction material many more attempts were made to use fibers for controlling cracks. Engineers had to overcome the major deficiencies of concrete, which were the low compressive strength and the high brittleness. A French engineer, named Joseph Monier, in 1847 came out with the idea of adding continuous fibers into the concrete, in the form of wires or wire meshes. This led to the development of ferrocement, and reinforced concrete as known today. The use of continuous steel reinforcing bars in the compressive zone of concrete undoubtfully helped to overcome the problem of the low compressive strength of concrete. However, the idea of using discontinuous fibers in the concrete was always a challenge.

1.3 Behavior of RC Column Subjected to Axial Load and Cyclic Lateral Load

Columns subjected to pure axial load rarely exist in practice. Reinforced concrete columns are usually subjected to combination of axial and lateral actions and deformations, caused by spatially complex loading patterns as during earthquakes causes lateral deflection that in turn affects the horizontal stiffness. In this study, a numerical model was developed in three-dimensional nonlinear finite element and then validated against experimental results reported in the literatures, to investigate the behavior of conventionally RC columns subjected to axial load and lateral reversal cyclic loading. To achieve this goal, numerical analysis was conducted by using finite element program ABAQUS. The variables considered in this study were axial load index, concrete compressive strength, column aspect ratio, longitudinal and transverse reinforcement ratios.

According to numerical case studies, the results revealed that axial load index and longitudinal reinforcement ratio have the most impact on the column response. Also, increasing concrete compressive strength and reducing column aspect ratio resulted in increasing strength capacity of the column. Moreover, increasing lateral confinement by transverse reinforcement at the column ends increases the flexural strength of a flexure-controlled RC columns.

1.4 Characteristics of Fiber Reinforced Polymer (FRP)

Fiber Reinforced Polymers (FRP) are unique composite materials in many respects. FRP can be formulated to be corrosion, abrasion, and UV resistant, as well as, smoke and fire retardant. FRP is often a cost-effective choice in many industrial applications; they have long life cycles and have demonstrated durability in extreme environments with reduced maintenance costs.

Here are some of the characteristics of Fiber Reinforced System.

- High strength with low unit weight- FRP materials are one of the strongest commercial materials available. Pound for pound, FRP is stronger in many ways than conventional construction materials. FRP's toughness allows thin sections to be used; stiffness can be acquired by using structural core materials, without substantially increasing weight.
- Corrosion resistance- Unlike metals, FRP materials do not suffer from corrosion/rusting. Materials fabricated from FRP have a longer service life in corrosive environments and perform extremely well in damp environments or even submerged in fresh and salt water. Durability FRP products have weathered climate extremes since their introduction during World War II. As a result, FRP architectural parts can often reduce long-term maintenance costs when compared to many traditional materials.
- High Strength to Weight Ratio– FRP is lightweight and strong; they possess a vast range of mechanical properties, including tensile, flexural, impact, and compressive strengths. Compared to other metals they have more strength per unit of weight than most metals. Their lightweight also helps in easy shipment and installation.
- Customizable- Every industry has unique problems to solve. With FRP engineers have the ability to tailor or modify the design of their FRP to meet their specific requirements.

- Anisotropic- Engineers can maximize the performance and efficiency of the structure when they take advantage of the inherent anisotropic properties of FRP. Because the maximum strength is in the direction of the fiber reinforcement's engineers can optimize the design to optimize the materials and the overall performance of the structure.

- Parts consolidation- A single FRP structure can replace an assembly of many parts and fasteners. This feature saves time, reduces assembly costs, and has given rise to the "cascade effect" of benefits for the user: For example, lighter equipment, smaller work crews, and lighter supporting structures can be used during installation. Light transmission FRP panels can be made translucent. This is a unique property among structural materials. FRP components can simultaneously provide structure and enclosure, while providing natural or artificial light.

  Low thermal conductivity FRP performs extremely well in harsh environments including subzero to high ambient temperatures. Composite materials do not easily thermally conduct; thus they provide excellent insulation. FRP composite products can be found in building doors, panels, and windows for extra protection from severe weather. They perform well in tropical as well as arctic regions.

- High Tensile Strength with Low Modulus of Elasticity- FRP has high tensile strength due to its composite properties. Engineers can specify unique resin, fiber-reinforcement compositions when working with FRP manufacturers. The design control inherent to FRP will enhance performance and can only be realized when working with composites, not metals.
- Radar transparency- Most glass-fiber-based FRP composites are transparent to radar and radio frequencies. This attribute enables composite products to be used as decorative canopies or enclosures, designed to hide communications equipment on top or within building structures.
- Fire characteristics- FRP systems can be designed to meet all the reaction-to-fire requirements mandated in the International Building Code sections related to interior finish, light-transmitting materials, and external assemblies.

- Dimensional stability- FRP composites behave similarly to most materials in that they expand and contract due to changes in temperature. The coefficient of thermal expansion (CTE) varies with the content and type of resin and reinforcement used, as well as with the direction of the fiber. Typically, the CTE of glass-fiber-reinforced unsaturated polyester resin is 14–22 x 10–6 in/in/o F (25–40 x 10–6 mm/mm/o C). Most carbon fibers have a negative CTE and the result is a contraction in the fiber when temperature is increased. However, a properly designed carbon/epoxy laminate can be manufactured with a zero CTE.
- Nonconductive- Typically FRP composites are insulators. They are used for utility poles, stand-off insulators, and other applications where electrical conductivity is disadvantageous. An exception is carbon fiber, which alone is conductive. Although thermoset resins are non-conductive, fillers can be utilized to induce conductive or semi-conductive behavior if desired. Nonmagnetic FRP composite parts manufactured with glass fiber and traditional thermoset resins are non-magnetic. Magnetism can be engineered into FRP composite laminates through the incorporation of magnetically responsive fillers or fibers.
- Appearance flexibility- An extremely wide range of textures, shapes, and colours is achievable when manufacturing parts or building components with FRP materials. Various combinations of pigments, fine aggregates, and durable metallic powders can be added to the actual laminate in order to reduce or eliminate the need to paint the FRP composite products.
- Design flexibility- An FRP design begins by considering liquid polymer resins and formable reinforcing fibers. The finished component, or part, can be curved, corrugated, ribbed, or contoured into a variety of shapes. Unlike homogeneous materials, the design of an FRP laminate, component, or system can be tailored at the material level to increase the strength and stiffness of the finished product.
- Reproducibility and matching- As architectural components are moulded from a durable mold, FRP replicates are identical to each other. When moulds are taken from existing shapes, FRP materials faithfully reproduce the original shape, feature, and texture. This attribute has made the material a dependable source for making replications of countless historic building ornamentations

and parts for historic preservation projects. HOME > Why Composites > Characteristics of FRP composites 1 Responsive page to work across mobile, tablet and 1 desktop platforms. Notes First-tier index and sub sections Topic body with images. 2 3 4 Call for action 5 Links to related topics 6 Footer with Terms of use, Privacy policy, Site map, BFG Locations.

- ❑ Ability to Form Complex Shapes- Engineers can harness ultimate design flexibility when using FRP—an advantage over traditional materials such as metal, concrete, and wood.

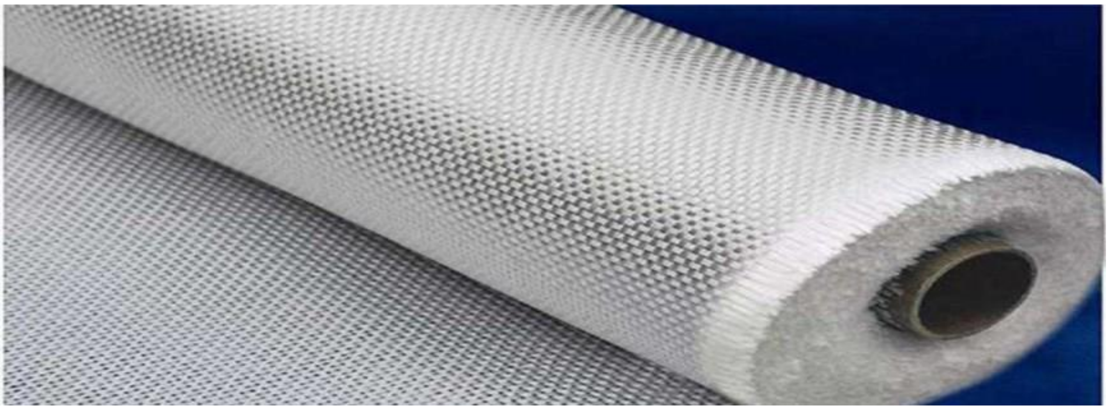
1.5 Types of FRP Composites

There are many types of FRP composites are used now a days for strengthening the normal RC column. Among of them these FRP composites are very common.

Which are:-

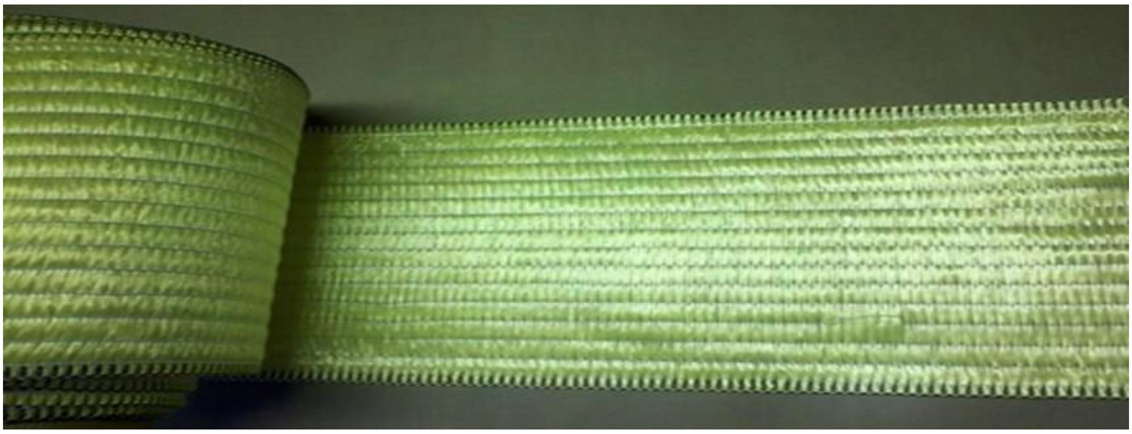
- ❑ Carbon Fiber Reinforced Polymer (CFRP)
- ❑ Glass Fiber Reinforced Polymer (GFRP)
- ❑ Basalt Fiber Reinforced Polymer (BFRP)
- ❑ Aramid Fiber Reinforced Polymer (AFRP)

Carbon Fiber (Source: https://images.app.goo.gl/BoERkV5kvoKbhm4AA)



Glass Fiber (Source: https://images.app.goo.gl/uDFHscKD9wSn2uBk8)

Basalt Fiber (Source: https://images.app.goo.gl/AsomFrnXyCXgSE2d9)



Aramid Fiber (Source: https://images.app.goo.gl/4s9jbSCdYBx9r44g7)

Figure 1:5 Different Fiber Polymer Composites

1.6 CFRP (Carbon Fiber Reinforced Polymer)

Carbon fiber reinforced polymers are composite materials that rely on carbon fiber to provide strength and stiffness while the polymer provides a cohesive matrix to protect and hold the fibers together and provides some toughness. Carbon fibers provide highly directional properties much different than the metals most commonly used for these automotive applications. They can be engineered to achieve mass reductions not achievable by the metals. Since these are artificially composited materials their properties and performance can be tailored to the application through varying strength, length, directionality, and amount of the reinforcing fibers and in the selection of the polymer matrix. The largest drawbacks are the high cost of producing the fibers and the low throughput rates at which components can be manufactured. The cumulative time to place the fibers in a mold, inject the polymer, and allow the part to set is in the order of a few minutes.

Carbon Fiber Reinforced Polymer (CFRP) is composed of carbon fibers embedded in a polymer resin in which the carbon fibers function as the reinforcement material and the polymer resin functions as the matrix to hold the fibers. The typical structure of CFRP can be illustrated in Figure 1.6.

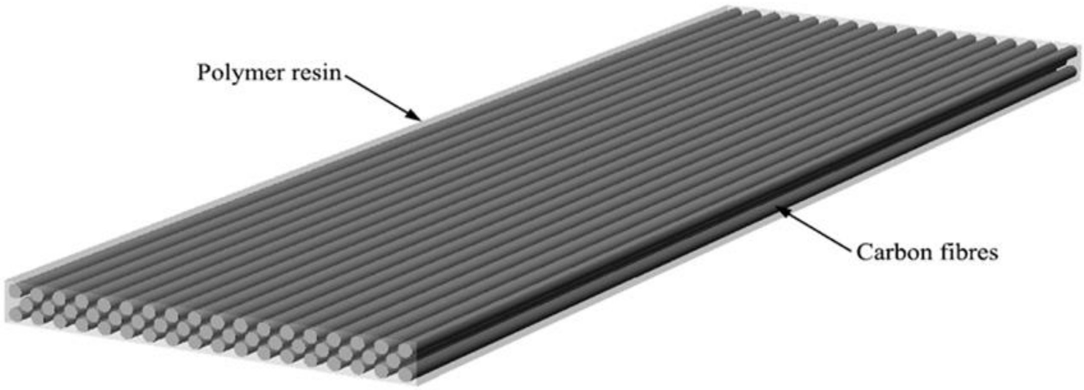


Figure 1:6 Typical structure of Carbon Fiber Reinforced Polymer (CFRP)

(Source: https://images.app.goo.gl/MbyenB38dUUjt1jh6)

Some properties of CFRP composite materials, which are advanced composite materials, like high load-bearing capacity, low density, high toughness, low damage tolerance, high strength, high hardness, lightness, low frictional coefficient, good wear resistance, chemical and dimensional stability, corrosion resistance, low electric resistance and vibration damping properties make them preferable.

1.7 The Objective of the Research

The objectives of the investigation are:

- To model an RC column using ABAQUS software and make a Finite Element (FE) analysis.
- To investigate the performance of CFRP to increase the compressive strength using the FE analysis.
- To investigate the effective orientation of FRP composites using the FE analysis.
- To examine the failure patterns of RC columns made configured with CFRP using the FE analysis.
- To Compare the FE analysis result with available literature results and analytical calculations.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Most of the research projects investigating the use of FRP focused on enhancing the flexural and shear behavior, ductility, and confinement of concrete structural members. A limited number of mostly experimental studies were conducted to investigate the compression strengthening of RC members. There is some research conducted over two decades on the compressional strengthening of RC columns using Fiber Reinforced Polymer (FRP), they are discussed below.

2.2 Previous Background of the Study

(Lewangamage, et al., 2017) found that the use of carbon fiber reinforced polymer (CFRP) materials is considered as a very effective retrofitting technique for reinforced concrete columns, still it is the identification of cost reduction strategies that draws most of the attention since the use of CFRP materials is considered as more expensive than any other retrofitting method. Providing partial confinement in place of full confinement which is the current practice may be a viable option that allows for considerable cost savings while maintaining the required structural capacity. Although CFRP technology has been in use for several decades, some countries still do not have adequate technical know-how to use this technique effectively. As there are several design guidelines available globally, it is quite unclear which design guideline will provide an economical design while maintaining the required factor of safety. This paper presents an experimental study conducted using 17 specimens to investigate the strength increments due to external CFRP confinement of reinforced and unreinforced concrete columns. Reinforced concrete columns were provided with both full and partial confinement to study their strength and ductility increments. The volumetric ratio of CFRP was kept constant for partially confined columns to study the effect of the jacket arrangement pattern. The experimental failure loads obtained were reviewed against the theoretical values calculated using ACI and fib guidelines, to investigate the overall safety factors available when using each design guideline. The experimental results showed considerable strength and ductility increments in all of the fully and partially confined specimens.

Although the volumetric ratio of CFRP was kept same for all partially confined columns, it was observed that depending on the jacket location, the strength and ductility increments would vary. It was also observed that both design guidelines give for fully confined reinforced concrete columns, a factor of safety exceeding 1.5.

(Saeed, 2020) said that the use of FRP materials in strengthening and repairing of reinforced concrete (RC) structures has increased in the past two decades. Recently, FRP materials have become one of the most used materials in rehabilitation engineering. For seismic retrofitting of RC structures, usually the process involves strengthening or repairing the vertical support elements of the buildings or bridges. Several studies focused on the use of FRP materials in strengthening and repairing RC columns. Externally bonded (EB) FRP sheets or laminates and near-surface-mounted (NSM) FRP rods have been used for enhancing the strength and ductility of RC columns. Although glass FRP (GFRP) and basalt FRP (BFRP) rods have been used in flexural strengthening of RC columns, NSM-CFRP rods have not been used yet. In addition, studies in the use of CFRP ropes in flexural strengthening or repairing of RC columns are not available.

To address these gaps, an experimental investigation was conducted on the use of CFRP materials in strengthening and repairing RC columns. The investigation consisted of three main parts. The three parts focused on strengthening and repairing slender RC columns using CFRP materials. The first part of the investigation focused on the use of CFRP sheets, rods, and ropes in flexural strengthening of RC columns. Half scale square (150 x 150 mm) RC columns were fabricated and tested. Each specimen consisted of two 1.065-meter long columns connected in the middle by a stiff element (concrete stub). All columns were designed based on older codes (pre 1970s). The specimens were (1) as built specimen, (2) strengthened with CFRP confinement only, (3) strengthened with CFRP confinement and NSM-CFRP rods, and (4) strengthened with CFRP confinement and NSM-CFRP ropes (two specimens). Another specimen was strengthened with EB-CFRP sheets. The results showed that both EB and NSM techniques can effectively be used in strengthening slender RC columns. In addition, CFRP ropes are very effective in strengthening RC columns. The strength enhancement ranged from 35% to 60%. Finally, a theoretical model was created to predict the load-displacement response of RC columns strengthened with EB-CFRP sheets and NSM-CFRP rods and ropes. The theoretical results showed good agreement with the experimental results. The second part of the investigation focused on the use of CFRP sheets and ropes in repairing damaged RC columns. Recently, RC columns have been upgraded and strengthened with FRP confinement all around the globe. Future cases of repair will likely encounter RC columns that were strengthened previously with FRP confinement. However, studies on repairing damaged columns that were enhanced by confinement before damage are not currently available. Moreover, there is a vital need for an emergency repair technique that can be used to rapidly repair damaged columns of essential structures after a seismic event. In this study, the time required to complete the repair was a key factor to propose a rapid CFRP-based repair technique. A total of four specimens, each one representing two columns, were fabricated and tested. The technique was applied to square RC columns (150 mm x 150 mm x 1,065 mm) subjected to combined axial and cyclic lateral loads. The process of applying the repair technique was completed in three days. Test results showed that the proposed repair technique was effective not only by restoring the original strength, but also by improving the strength significantly. Moreover, the measured and idealized load-displacement response showed that the ductility of the repaired column was reasonably sufficient. The proposed technique appears promising and may be considered as a permanent repair technique.

The third part of the investigation focused on the tensile strength of CFRP ropes anchored to concrete using chemical epoxy. One of the major problems with using fiber reinforced polymer (FRP) in strengthening reinforced concrete (RC) structures is premature debonding of FRP. Anchoring FRP materials to concrete has become associated with most of the strengthening techniques. One of the anchoring techniques is using handmade anchors made from FRP materials. In previous studies, most FRP anchors were made from rolling pre-cut FRP sheets with short embedment (mm) as they were used for flexural or shear strengthening of RC columns. In the present study, FRP anchors were made from carbon fiber reinforced polymer (CFRP) ropes and had long embedment to be used for flexural strengthening of RC columns. A total of twenty-one pullout tests were conducted on CFRP rope anchors bonded to concrete using chemical epoxy. The test parameters included embedment lengths of 45 mm, 90 mm, 135 mm, 180 mm, 270 mm, and 315 mm; anchor hole diameters of 12.7 mm, 19.1 mm, and 25.4 mm; and two epoxy types, Hilti 500 and Master Brace SAT 4500. Test results showed that the pullout strength of CFRP anchors increased with the increase in embedment length, and no significant effect of the hole diameter on the pullout strength was observed. However, the bond strength increased with decreasing embedment length and hole diameter. For shorter embedment lengths, the distribution of the bond stress along the length of the anchor is expected to be more uniform than that of anchors with longer embedment lengths. The average bond stress (strength) is calculated by dividing the maximum pullout force by the embedment length. Therefore, increasing the embedment length without significant improvement in the pullout load results in lower bond strength. The observed pullout results and failure modes were compared to the predictions using available models. Finally, a modified model was proposed to predict the pullout strength of CFRP rope anchors.

(Wang, et al., 2016) used Fiber-reinforced polymer (FRP) as external reinforcement. The behavior of fiber-reinforced polymer (FRP) tube reinforced concrete (FTRC) columns under different loading conditions was investigated in this study. Four groups of 16 specimens were cast and tested. Specimens in the first group (the reference group) were reinforced with longitudinal steel bars and steel helices (Group REF). Specimens in the second group were reinforced with intact glass FRP tubes (Group IT). Specimens in the third group were also reinforced with intact glass FRP tubes. In addition, polymer grid was embedded into the concrete cover to reduce the cover spalling (Group ITG). Specimens in the fourth group were reinforced with perforated glass FRP tubes (Group PT). One specimen from each group was tested under concentric loading, one under 25-mm eccentric loading, one under 50-mm eccentric loading, and one under four-point loading. Results from the experimental study show that FRP tubes significantly increase the load-carrying capacity and ductility of FTRC specimens. Group ITG specimens performed better than the other groups of specimens. Experimental and analytical interaction (P−M) diagrams also show the enhanced performance of FTRC specimens.

(Haji, et al., 2019) said that the most important phenomenon that threatens the stability and health of structures in different parts of the world is the occurrence of an earthquake with varying intensity and magnitude.

The most dangerous type of failure in structures is shear failure, which could occur in short columns. Consequently, such columns, with the potential of failure in shear, must be retrofitted. This paper explores three new methods for strengthening RC circular short columns, including the Near Surface Mounted (NSM), externally bonded with new pattern and an innovative hybrid strengthening technique (using near-surface mounted method in the form of spiral grooves filled with CFRP hand-made bar in composition with externally bonded CFRP sheet) and compare them with two common methods of strengthening (full and partial wrapping). Six circular short columns were constructed, strengthened and tested under constant axial load and cyclic lateral loading. An analytical procedure was used to predict the behavior of the columns. A good correlation was observed between analytical values and experimental results. An innovative hybrid strengthening method and externally bonded method with new pattern showed higher values in strength, energy absorption, ductility and stiffness compared to existing methods.

(Choo, 2005) Fiber reinforced polymer (FRP) composites have been increasingly used in concrete construction. This research focused on the behavior of concrete columns reinforced with FRP bars, or pre-stressed with FRP tendons. The methodology was based the ultimate strength approach where stress and strain compatibility conditions and material constitutive laws were applied. Axial strength-moment (P-M) interaction relations of reinforced or pre-stressed concrete columns with FRP, a linearly-elastic material, were examined. The analytical results identified the possibility of premature compression and/or brittle-tension failure occurring in FRP reinforced and pre-stressed concrete columns where sudden and explosive type failures were expected. These failures were related to the rupture of FRP rebars or tendons in compression and/or in tension prior to concrete reaching its ultimate strain and strength. The study also concluded that brittle-tension failure was more likely to occur due to the low ultimate tensile strain of FRP bars or tendons as compared to steel. In addition, the failures were more prevalent when long term effects such as creep and shrinkage of concrete, and creep rupture of FRP were considered. Barring FRP failure, concrete columns reinforced with FRP, in some instances, gained significant moment resistance. As expected the strength interaction of slender steel or FRP reinforced concrete columns were dependent more on column length rather than material differences between steel and FRP. Current ACI minimum reinforcement ratio for steel (p min) reinforced concrete columns may not be adequate for use in FRP reinforced concrete columns. Design aids were developed in this study to determine the minimum reinforcement ratio (pf, min) required for rectangular reinforced concrete columns by averting brittle-tension failure to a failure controlled by concrete crushing which in nature was a less catastrophic and more gradual type failure. The proposed method using pf, min enabled the analysis of FRP reinforced concrete columns to be carried out in a manner similar to steel reinforced concrete columns since similar provisions in ACI 318 were consistently used in developing these aids. The design aids produced accurate estimates of pf, min. When creep and shrinkage effects of concrete were considered, conservative pf, min values were obtained in order to preserve an adequate margin of safety due to their unpredictability.

(Ghanem, 2016) Wrapping reinforced concrete (RC) columns with Fiber Reinforced Polymer (FRP) composites is effective in increasing their capacity. The current state of art concentrates primarily on fully wrapped RC columns and few studies dealt with partially wrapped columns. The majority of the studies did not account for the influence of the existing steel reinforcement on the column's behavior. Other studies estimated the total confinement pressure as the sum of the confinement pressure due to the external FRP jacketing and due to the internal transverse steel reinforcement. Few models dealt with the coupled effect of the confinement from steel and partial FRP wrapping of RC columns. The objective herein is to evaluate the effectiveness of partial wraps (or strips) and to develop a confined concrete compressive stress-strain ($f_c – \varepsilon_c$) model that accounts for partial wrapping. Three dimensional finite element (FE) models are generated to evaluate the influence of different parameters on the behavior of concentrically loaded RC circular columns that are partially and fully wrapped with FRP. The influence of FRP volumetric ratio, concrete compressive strength, transverse steel reinforcement ratio, longitudinal steel reinforcement ratio, and strip arrangement, are evaluated. The results indicated an increase in ductility as the number of FRP strips was increased, and showed that longitudinal steel had little influence on the confined $f_c – \varepsilon_c$ relationship. The proposed $f_c – \varepsilon_c$ model, derived from the parametric study, accounts for the effect of partial and full confinement, the unconfined concrete strength f_c', and yielding of transverse steel. Comparison of the results generated using the proposed model with FE and experimental results are in good agreement. The finite element method (FEM) is also used to evaluate the effectiveness of RC columns, wrapped with carbon FRP, subjected to an eccentric load, with a case study of a bridge column wrapped with FRP.

2.3 Application Range of CFRP Strengthening

- Load increases
- Seismic reinforcement
- Improve structural state
- Damage of structural parts
- Change the structural function
- Remit mistakes in design and construction

2.4 Structural Elements of CFRP Strengthening

- Columns strengthening
- Columns strengthening
- Slabs strengthening
- Walls strengthening
- Pipes strengthening
- Pier caps strengthening

2.5 Construction Field of CFRP Structural Strengthening

- Civil buildings
- Bridges
- Tunnels
- Piers/wharfs
- Airports
- Highways, railways

2.6 Advantages and Disadvantages of Using CFRP

CFRP is the most common FRP material due to its good tensile strength and availability.

Advantages of CFRP composite are:

- **Lightweight**: carbon fiber reinforced polymer is a low-density material with a very high strength to weight ratio. Its weight is ¼th if the steel; which means it does not increase the weight and section of the structure.

- **High tensile strength**: one of the strongest of all commercial reinforcing fibers when it comes to tension, carbon fiber is very difficult to stretch or bend.
- **Corrosion resistance:** Carbon fiber is one of the most corrosion-resistant materials available for construction**.**
- **Very low thermal expansion:** With respect to steel or aluminum, carbon fiber has less expansion or contraction in hot or cold weather.
- **Radiolucence** – carbon fiber is transparent to radiation and invisible in x-rays, making it valuable for usage in medical equipment and facilities.
- **High electric conductivity:** CFRP composites are excellent when it comes to conducting electricity.
- **Exceptional durability**: Compared to other metals, carbon fiber has enormous fatigue properties which means it won't wear out under the stress of constant use.
- **Ultra-violet resistant** – carbon fiber can be UV resistant with use of the proper resins.

Disadvantages of CFRP composite are:

- **Carbon fiber will break or shatter** when it's compressed, pushed beyond its strength capabilities or exposed to high impact. It will crack if hit by a hammer. Machining and holes can also create weak areas that may increase its likelihood of breaking.
- **Cost:** The price of carbon fiber reinforced polymer is too high.
- **High repair cost:** The repairing cost for CFRP is huge.
- **Manufacturing Time:** To manufacture CFRP it requires a lot of time.

(1) (Source: https://images.app.goo.gl/1cfJvr5CMzBQ82V87)

(2) (Source: https://images.app.goo.gl/Wf8mpdRPDc6P2CDp9)

(3) (Source: https://images.app.goo.gl/VBSfFG4KUhd77Khq9)

Figure 2:1 (1), (2), (3) Strengthening process of RC column using CFRP composites

2.7 Background and Present State of The Problem

From the background work, it is seen that increasing compressive strength with CFRP isn’t done many before. Every researcher worked with one orientation of FRP composites but in this present study, CFRP is used to increase the compressive strength with different orientations, and comparison has been made to find which orientation is better. Crack patterns are also discussed in this study.

CHAPTER 3
METHODOLOGY

3.1 Introduction

Usually, software packages for structural analysis have been developed on the basis of the finite element method (FEM). Utilization of the software packages has been increased due to advantageous provision for rapid and nearly exact analysis and for the other post-processing utilities. Complex geometrical structures can be modeled through finite element analyzing software with higher accuracy. Using these software's are timesaving and provides a complete framework of the work before field experimental work. There are many finite elements analyzing software are available. Among them the available software for structural analysis is mentioned as follow:

- ABAQUS
- ANSYS
- ETABS
- SAP 2000
- GRASP
- STAAD-PRO
- ALGOR
- COSMOS
- MATLAB
- PATRAN

Among these, we used ABAQUS for the project because of its availability and popularity. It is easy to use and almost gives an accurate result.

3.2 Finite Element Analysis

The finite element method (FEM) is a used method for solving problems of engineering and mathematical models. It conducts with a particular numerical method for solving partial differential equations. It solves the deferential equations by two or three space variables. Engineers and especially in civil discipline can convert any topic related to physics problems to FEA. It can verify the mathematical model includes structural analysis, fluid dynamics, and heat transfer. Mainly FEM conducts by dividing a large system into smaller, make the large system into more simple parts that are called finite elements. System of algebraic equations results in by the finite element method formulation of a confined value problem. Simple equations that model these finite elements are assembled into a larger system of equations. Various methods from calculus are uses which conduct various methods to get the approximate solution by minimizing an associated error function. Engineers can identify the prediction accuracy of a complicated model. By conducting this, they find out the core problem.

Reinforced concrete is one of the most complex materials in finite element modeling due to complicated nonlinear behavior in tension and compression. The correct definition of materials in finite element method modeling, inelastic, and plastic behaviors as well as in compression and tension domains can have a great impact on the responses and outputs.

In this study, the damage plasticity model is used for concrete. The model is a plasticity-based, Continuation based damage model. The model assumes tensile cracking and compressive crushing of the concrete material are the main two failure mechanisms. Damaged plasticity characterized the uniaxial tensile and compressive response of concrete.

3.3 ABAQUS Software

Abaqus is a software application used for both the modeling and analysis of mechanical components and assemblies (pre-processing) and visualizing the finite element analysis result. Abaqus/Standard, a general-purpose Finite-Element analyzer that employs an implicit integration scheme (traditional) besides Abaqus/Explicit, a special-purpose Finite-Element analyzer that employs an explicit integration scheme to solve highly nonlinear systems with many complex contacts under transient loads. Abaqus is used in the automotive, aerospace, and industrial products industries and structural engineering. Users can define their own material models so that new materials could also be simulated in Abaqus. Abaqus also provides a good collection of Multiphasic capabilities, such as coupled acoustic-structural, piezoelectric, and structural-pore capabilities, making it attractive for production-level simulations where multiple fields need to be coupled. Abaqus was initially designed to address non-linear physical behavior; as a result, the package has an extensive range of material models such as elastomeric (rubberlike) and hyperplastic (soft tissue) material capabilities. Every complete finite-element analysis consists of 3 separate stages:

- ❑ Pre-processing or modeling: This stage involves creating an input file which contains an engineer's design for a finite-element analyzer (also called "solver").
- ❑ Processing or finite element analysis: This stage produces an output visual file.
- ❑ Post-processing or generating report, image, animation, etc. from the output file: This stage is a visual rendering stage.

Figure 3:1 Finite element model solving steps

Abaqus/CAE is capable of preprocessing, post-processing, and monitoring the processing stage of the solver; however, the first stage can also be done by other compatible CAD software or even a text editor. Abaqus/Standard, Abaqus/Explicit or Abaqus/CFD can accomplish the processing stage.

3.4 Finite Element Model Development

In this research, a 3D finite model is developed to simulate the enhancement of axial compressive strength of RC Circular Column using CFRP. Total 3 column has been analyzed to determine the compressive strength which are:

- ❑ Normal RC column
- ❑ RC column with fully CFRP wrapped
- ❑ RC column with CFRP wrapped strip

All the column dimensions are the same (250mm diameter and 1220mm length) and the same amount of reinforcement are used. The load cell is placed on the top part which creates an axial compression on the column. The diameter of the load cell is 300mm.

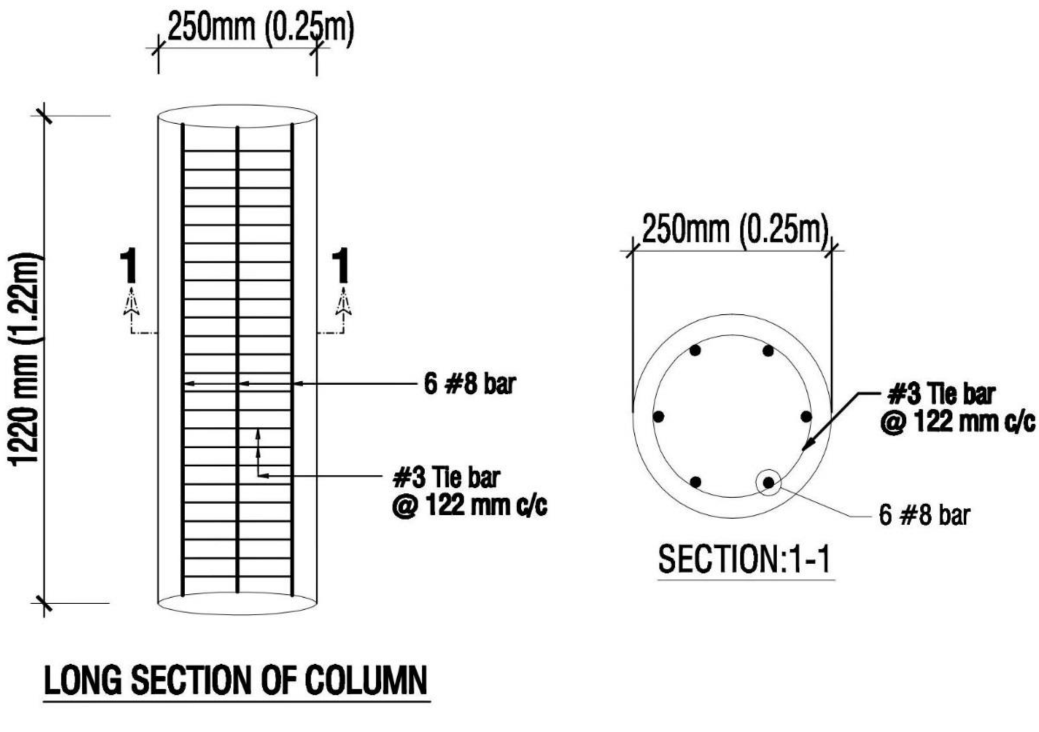


Figure 3:2 Designed circular column longitudinal profile & cross section

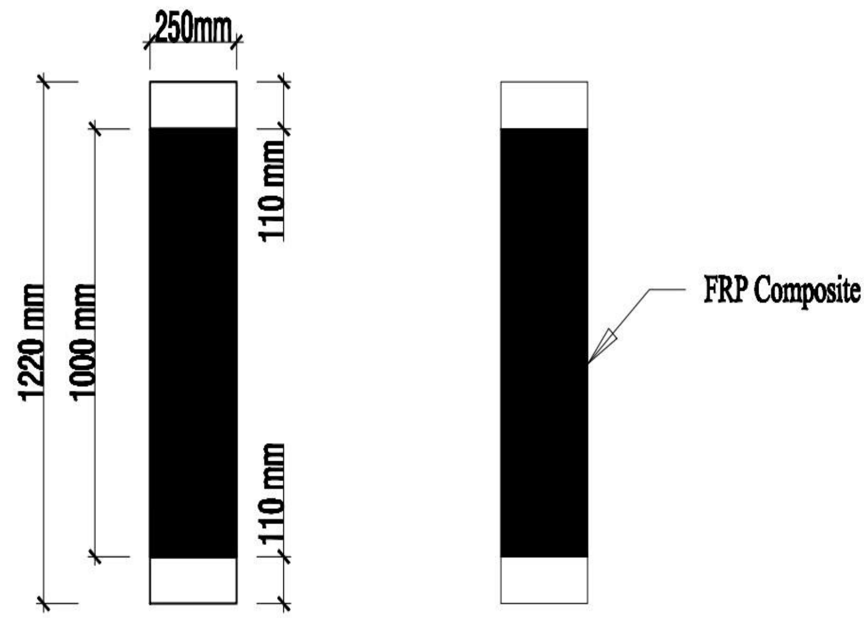


Figure 3:3 Designed RC column with fully FRP wrapped

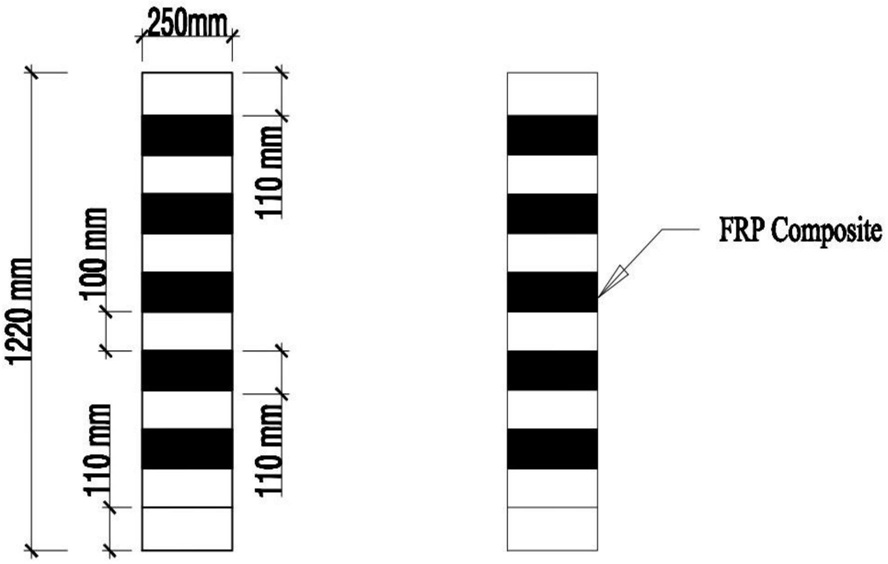


Figure 3:4 Designed RC Column partially·wrapped with FRP strips

3.5 Material Properties of Modeling

For modeling in ABAQUS anyone must define the material properties of the column. The material used for modeling are:

- Concrete
- Reinforcement
- CFRP

3.5.1 Concrete

In compression, the stress-strain curve for concrete is linearly elastic up to about 30 percent of the maximum compressive strength. Above this point, the stress increases gradually up to the maximum compressive strength. After it reaches the maximum compressive strength σ_{cu} , the curve descends into a softening region, and eventually crushing failure occurs at an ultimate strain ε_{cu} . In tension, the stress-strain curve for concrete is approximately linearly elastic up to the maximum tensile strength. After this point, the concrete cracks and the strength decreases gradually to zero. Figure (3.5) shows typical uniaxial compressive and tensile stress-strain curve for concrete.

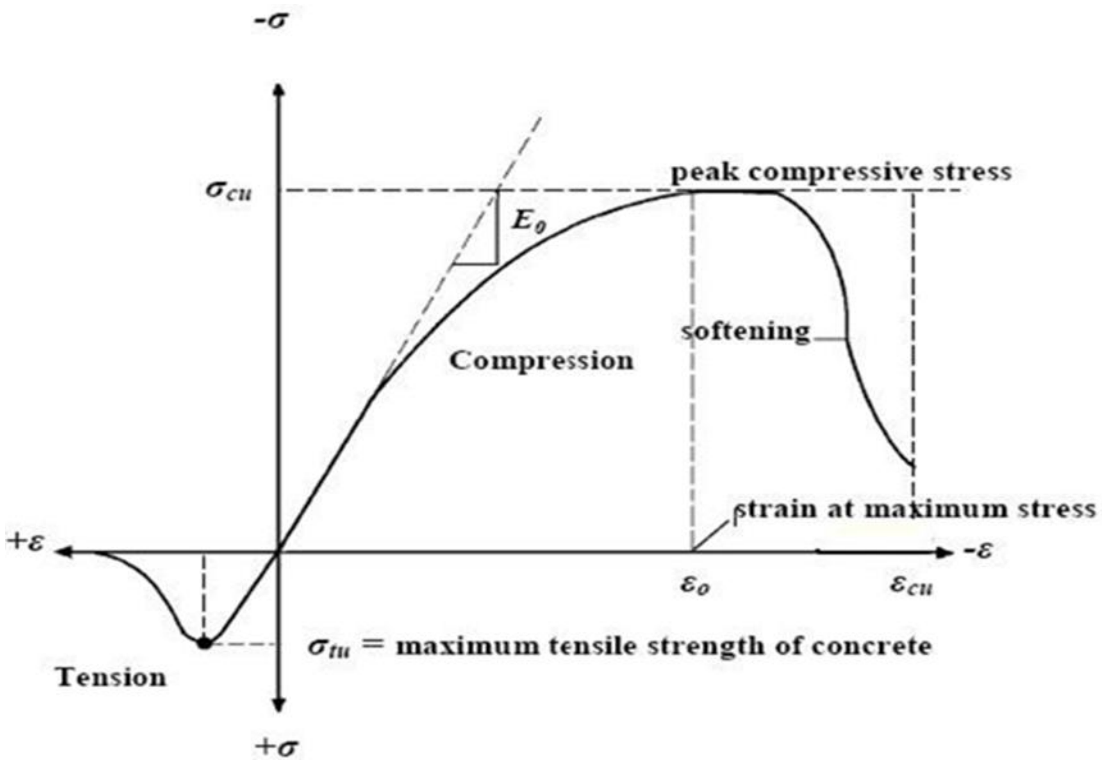


Figure 3:5 Typical uniaxial compressive and tensile stress-strain curve for concrete

(Source: https://images.app.goo.gl/pnkxe5skBiNVnDfF7)

The present study assumed that the concrete is homogeneous and initially isotropic. The two main concrete failure mechanisms are cracking under tension and crushing under compression. The stress-strain relationship in compression for concrete used in ABAQUS is represented in Fig 3.6. A Poisson's ratio of 0.18 was used for concrete. The stress-strain follows a linear elastic relationship until the value of the failure stress is reached under Uni-axial tension. Stress-Strain curve used in ABAQUS as shown in material. Concrete damage plasticity (CDP) data are used in ABAQUS modeling.

Table 3:1 Material property of concrete

Modulus of elasticity, E (MPa)	15427.30
Poisson's ratio	0.18
Characteristic compressive strength, f'_c (MPa)	20
Characteristic tensile strength(f_t), MPa	3

Table 3:2 Concrete damage plasticity parameter

Dilation Angle	31
Eccentricity	0.1
Fb0/fc0	1.16
k	0.67
Viscosity parameter	0.001

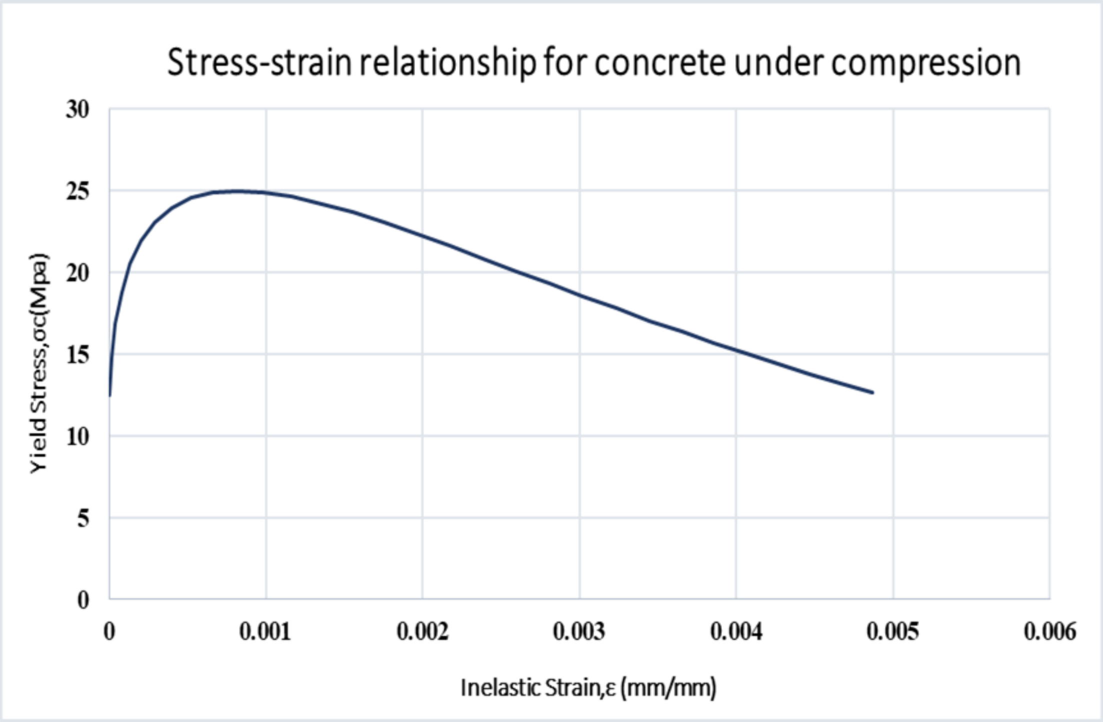


Figure 3:6 Stress-strain relationship for concrete under uniaxial compression

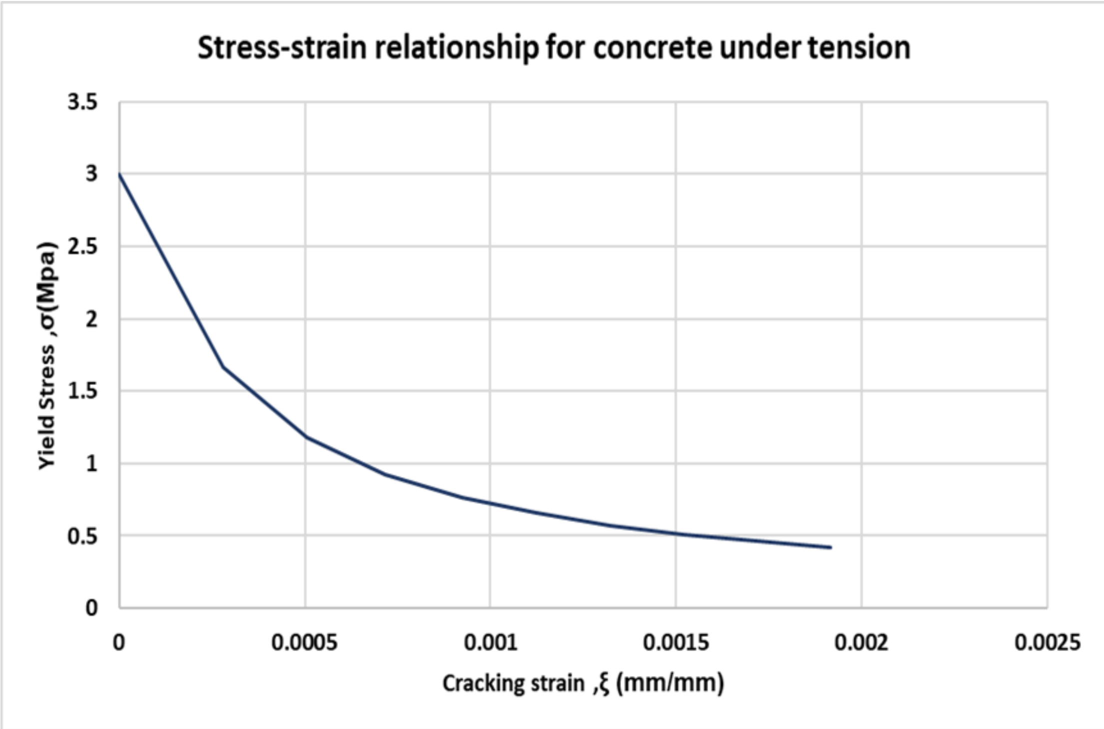


Figure 3:7 Stress–strain relationship for concrete under uni-axial Steel

Steel is assumed to be an elastic-perfectly plastic material and identical in tension and compression. Poisson's ratio of 0.3 was used for the steel reinforcement in this research.

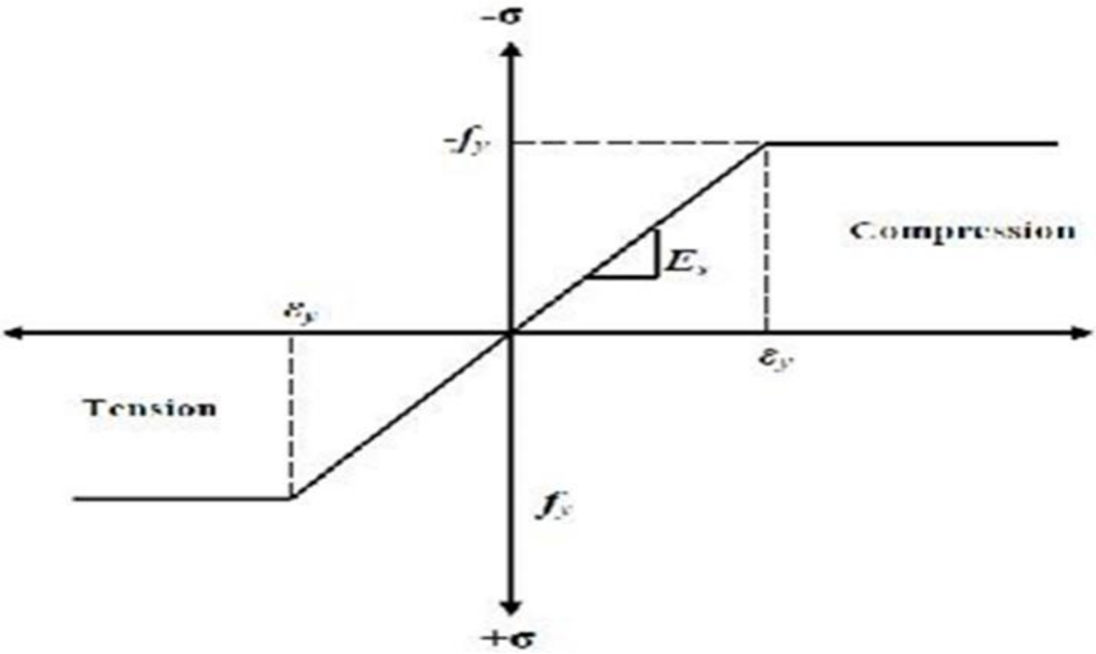


Figure 3:8 Stress-strain curve for steel reinforcement

Table 3:3 Properties of reinforcing steel bars for column

Elastic modulus E (GPa)	200
Nominal Diameter (mm)	12&10
Yield Stress (N/mm2)	420
Poisson's ratio	0.3
Tensile Strength (N/mm2)	655
Density tonne/mm^3	7.8e-8

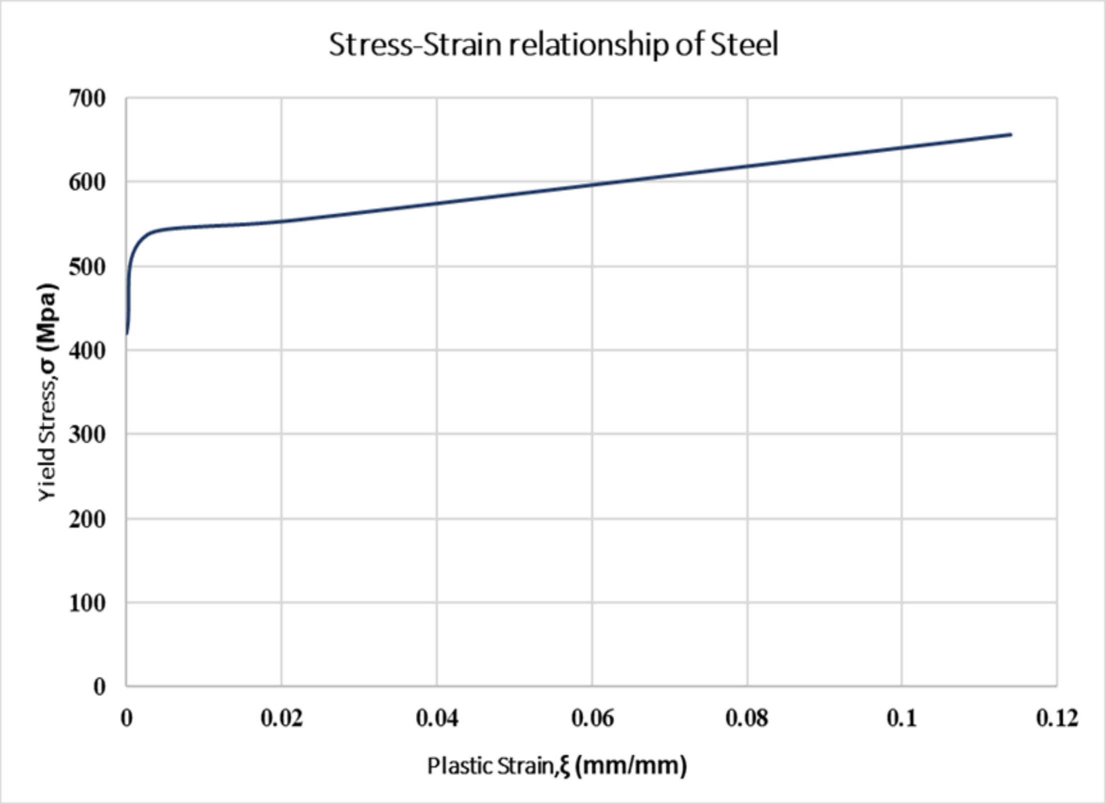


Figure 3:9 Stress-strain relationship for steel used in ABAQUS

3.5.2 Carbon Fiber Reinforced Polymer (CFRP)

FRP composites are materials that consist of two constituents. The constituents are combined at a macroscopic level and are not soluble in each other. One constituent is the reinforcement, in the form of fibers, i.e., carbon and glass, which is embedded in the second constituent, a continuous polymer called the matrix. Carbon and glass are typically stiffer and stronger than the matrix. The FRP composites are anisotropic materials, which means their properties are not the same in all directions. The material of CFRP is very light and strong as the tightly packed material is resistant to breaking due to its bonded structure. Deflections are reduced by using CFRP laminates to strengthen the RC slab with a large opening and thus the load-carrying capacity increases.

Table 3:4 Elastic and hasin damage properties of CFRP used in ABAQUS

Parameter	**Quantity**
Elastic modulus of fabric, E1, E2, respectively	130 and 8 GPa
Longitudinal and transverse Poisson’s ratio	0.28
Shear modulus G12, G13, G23, respectively	4500, 4500, and 3600 Mpa
Longitudinal tensile and compressive strength, respectively	2200 and 2200 MPa
Transverse tensile and compressive strength, respectively	61 and 130 MPa
Longitudinal and transverse shear strength, respectively	85 and 40 MPa
Longitudinal tensile fracture energy	70 MJ/mm^2
Longitudinal compressive fracture energy	70 MJ/mm^2
Transverse tensile fracture energy	0.25 MJ/mm^2
Transverse Compressive fracture energy	0.25 MJ/mm^2

3.6 Model Development with ABAQUS

Based on the central objectives of this research, three-dimensional Finite Element models of reinforced concrete column is developed. For developing a 3D finite element model in ABAQUS some modules have been followed. Which are:

- Element's type
- Material property
- Assigning sections
- Defining step
- Interaction between elements
- Specify boundary conditions and load
- Meshing
- Assigning job
- Evaluating the results
-

3.6.1 Creating and Assembling Parts

At first, in the Part module, Concrete was modeled using a 3D eight-node linear brick element (C3D8) with reduced integration and hourglass control. The C3D8 element is a general-purpose linear brick element, fully integrated (2x2x2 integration points). The shape functions can be found in. The node numbering follows the convention of Figure 3.10 and the integration points are numbered according to Figure 3.11. The solid element (C3D8) has eight nodes with three degrees of freedom at each node – translations in the nodal x, y, and z directions. The element is capable of plastic deformation, cracking in three orthogonal directions, and crushing.

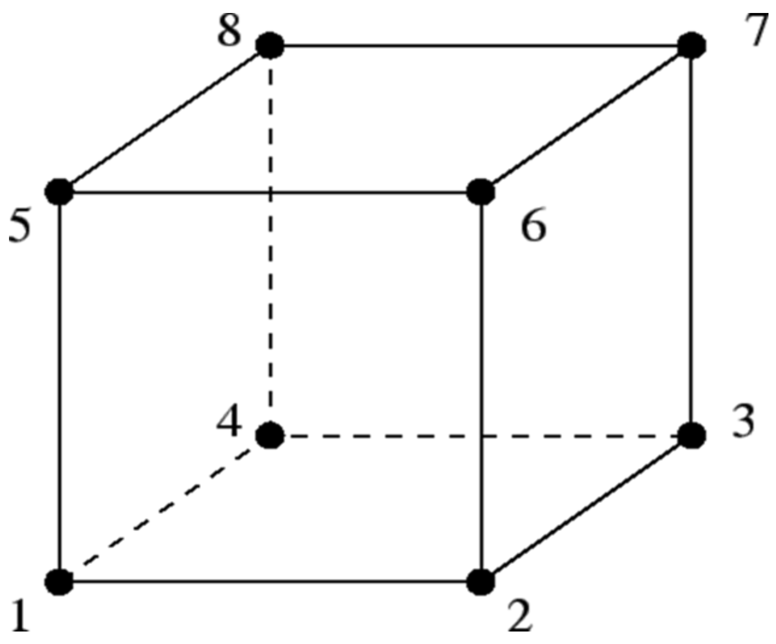


Figure 3:10 Node brick element

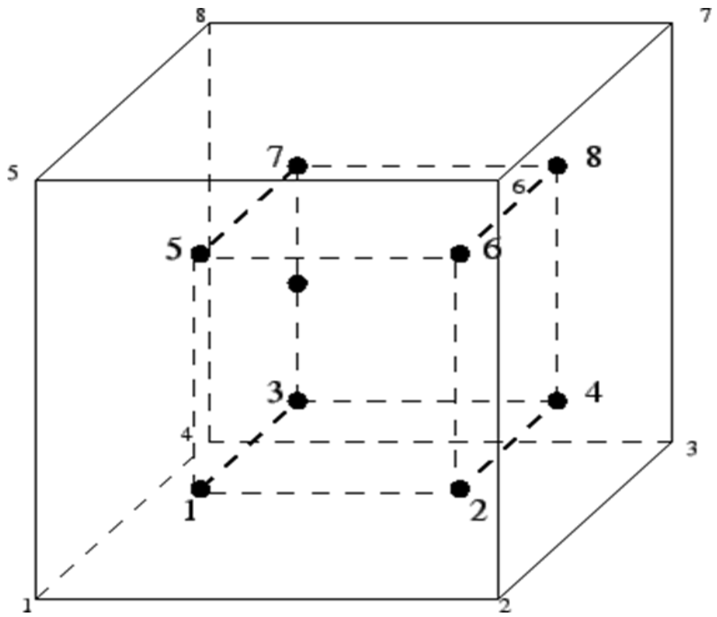


Figure 3:11 2x2x2 integration point scheme in hexahedral elements

The embedded reinforcing steel bars were modeled using linear two-node truss elements (T2D3) with three degrees of freedom at each node. Truss element(T2D3) are used in two and three dimensions to model slender, line-like structures that support loading only along the axis or the centerline of the element. No moments or forces perpendicular to the centerline are supported.

Necessary partitions of the concrete column are made to facilitate load application and meshing. The steel reinforcement of size 1220 mm is modeled as two-node truss elements connected to the nodes of adjacent solid elements. Stirrup’s diameter is 225 mm are also designed with a two-node truss element. Linear 3D three-node triangular facet thin shell elements are used to model the composites.

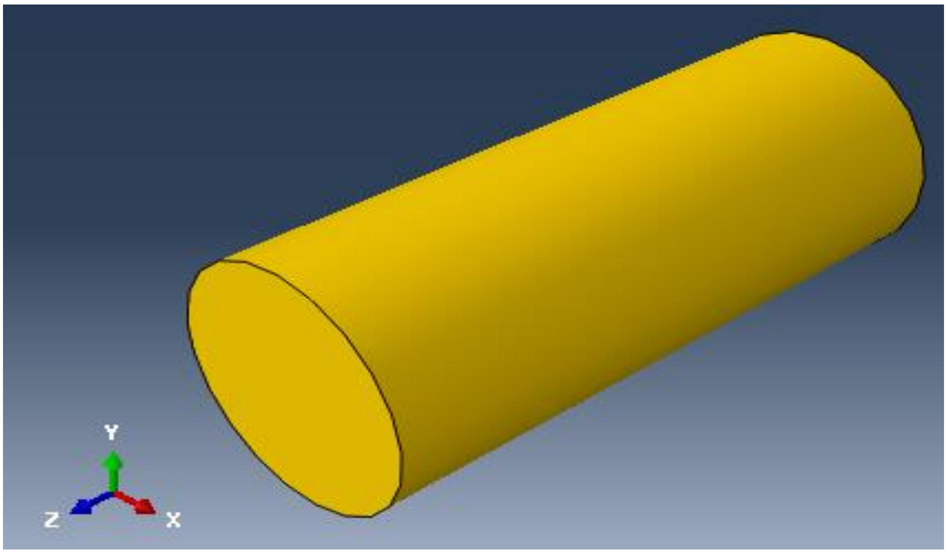


Figure 3:12 3D-Solid column designed in ABAQUS

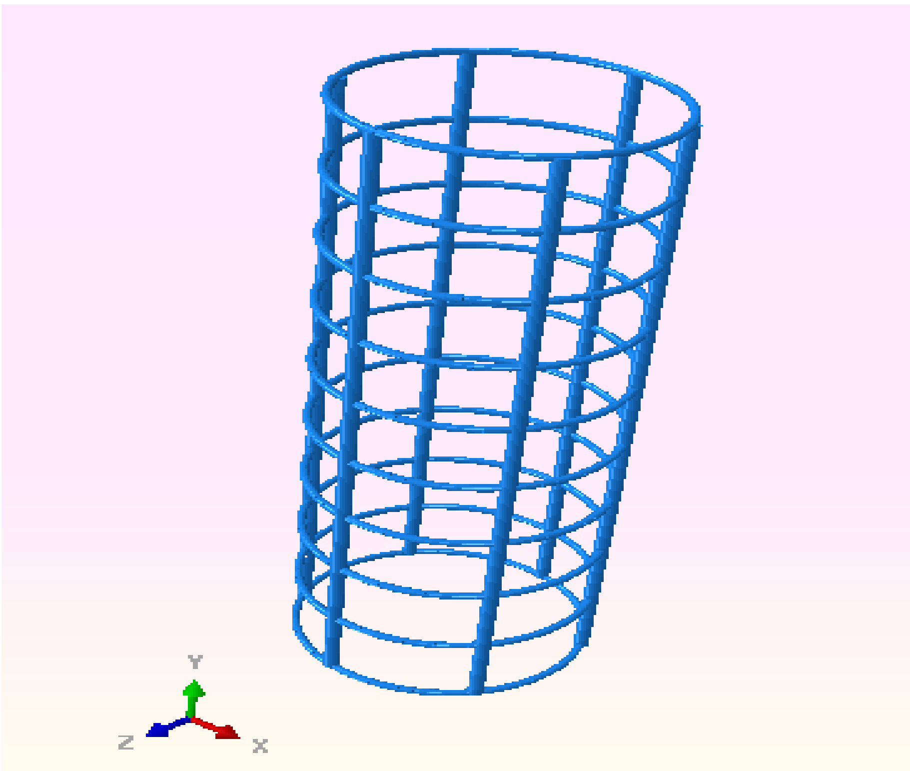


Figure 3:13 Reinforcement and Stirrups modelling

Eight initial plys are used to make a composite layer. For CFRP each layer is 0.145mm thick. For loading and Support 3D-Analytical rigid element is selected. Main facility of this rigid element is we don't have to mash it.

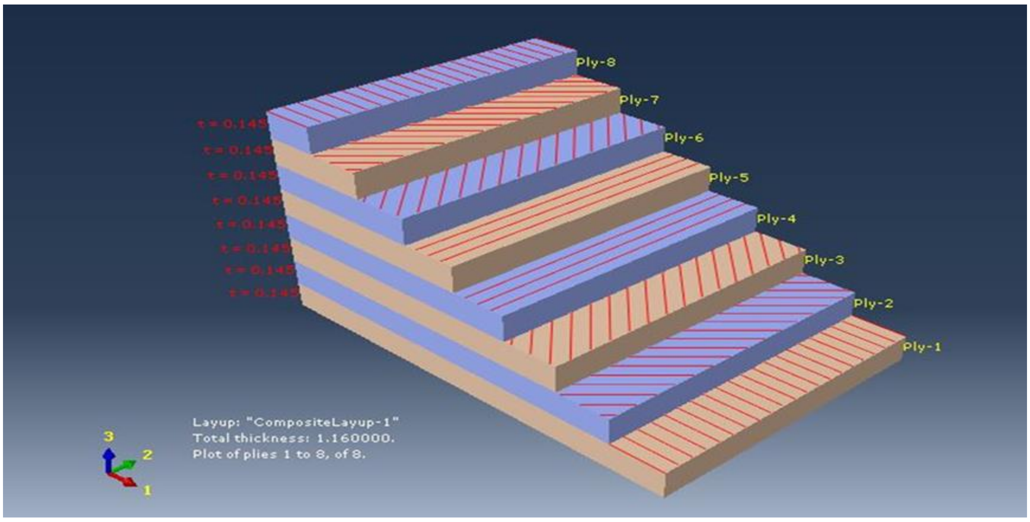


Figure 3:14 Composite ply layers orientation

In the property module, all the material properties are inputted and in the assembly module, all the parts are joined together. Embedded region constraint is used to make the bonding between the column and reinforcement. Rigid body constraint is used to make a surface-surface contact between the column and load-cells and supports. CFRP is assembled with a column with Lamina type bonding. Some reference points are created to place the load for collecting output data.

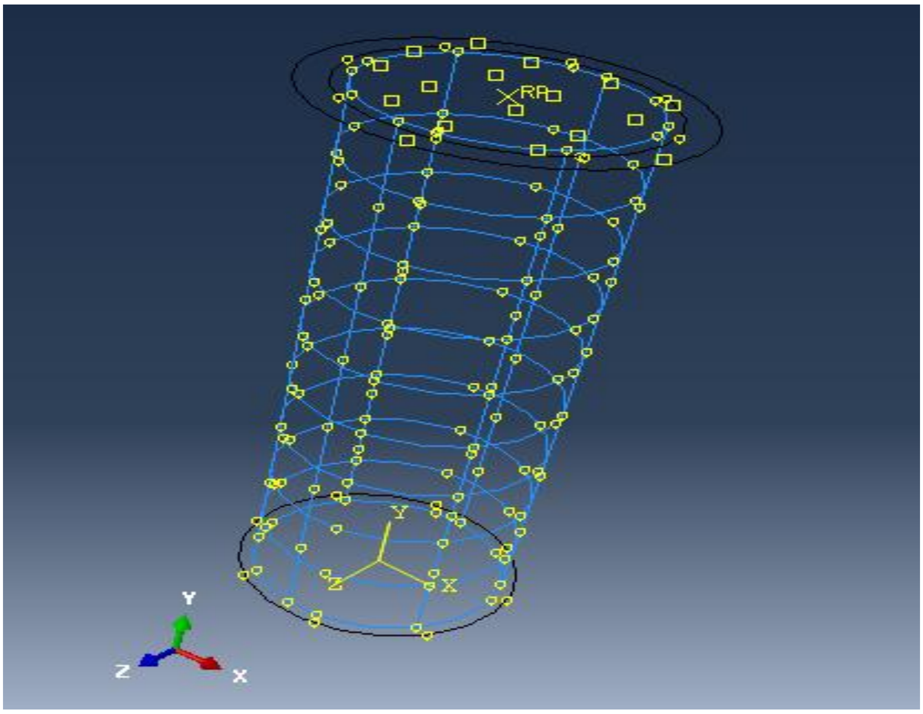


Figure 3:15 Constraint's profile used in ABAQUS modeling

3.6.2 Mesh Sensitivity Test

Meshing is the process of generating nodes and elements. A mesh is generated by defining nodes and connecting them to define the elements. Meshing is one of the key components to obtaining accurate results from an FEA model. The elements in the mesh must take many aspects into account to be able to discretize stress gradients accurately. Typically, the smaller the mesh size, the more accurate the solution. After assembling and assigning the properties, a mesh sensitivity test has been done for finding the optimum mesh.

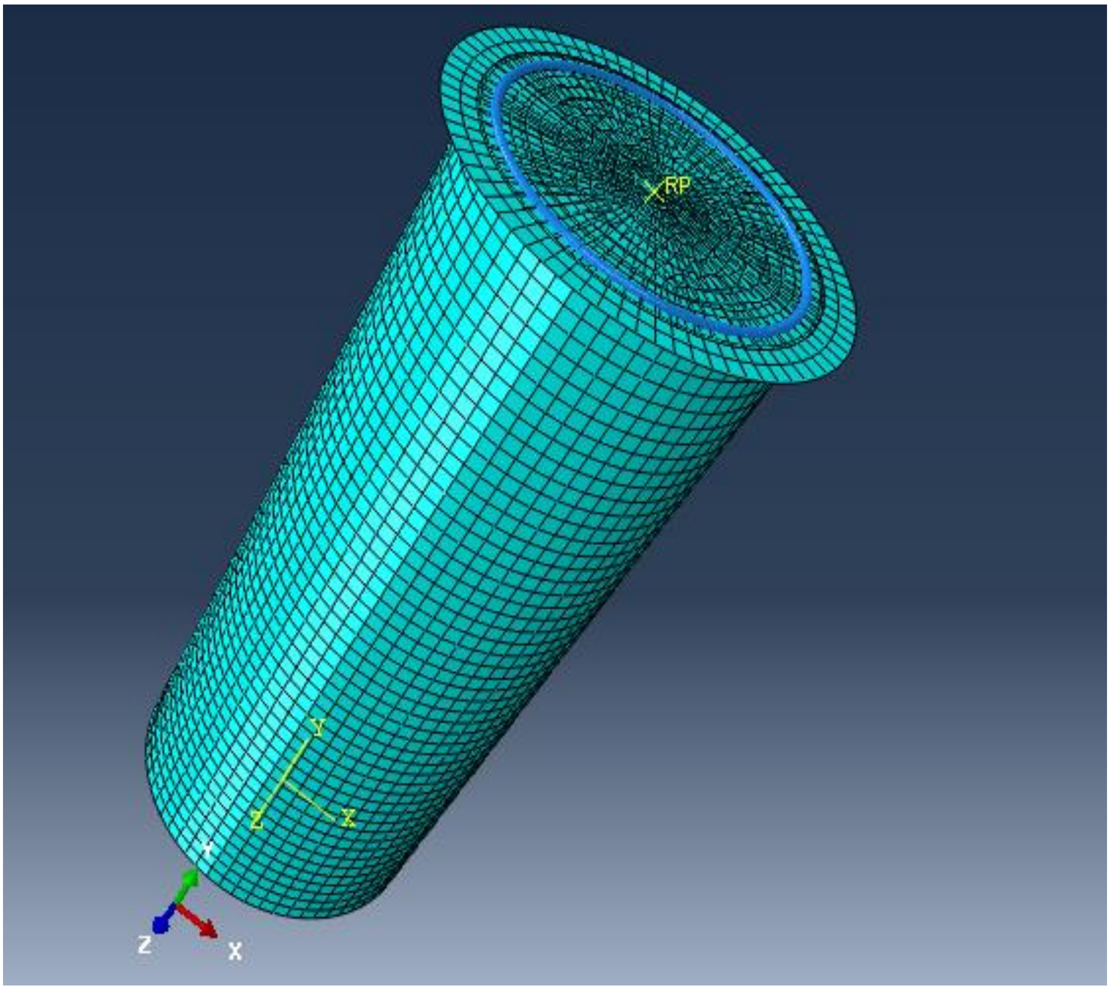


Figure 3:16 Meshed Column

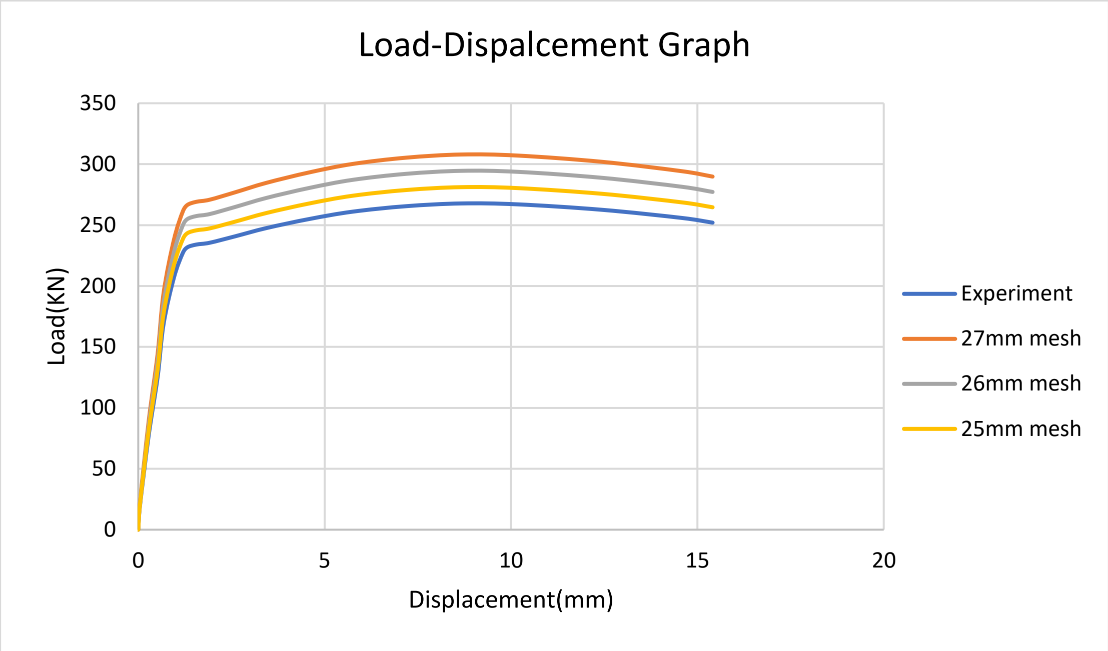


Figure 3:17 Load vs Displacement graph for finding optimum mesh

From the Load vs Displacement Graph, it is clear that 26mm and 27mm mesh gives a constant result, optimum mesh, 25 mm is selected for further analysis. CFRP is also modeled with optimum mesh Size. After meshing a job is created to perform the analysis.

3.6.3 Analytical Progress and Data Reading

The analysis has been carried out under displacement control. A load-cell has been placed on the top of the column and a constant displacement of 15mm has been applied at a rate of 1mm/min. This will create an axial compressive force at both ends of the column and a compression will be produced due to the load-cell. A fixed support has been placed at the bottom of the column. A full Newton nonlinear analysis method has been conducted for each of the models. From the analysis total applied force is collected with respect to time.

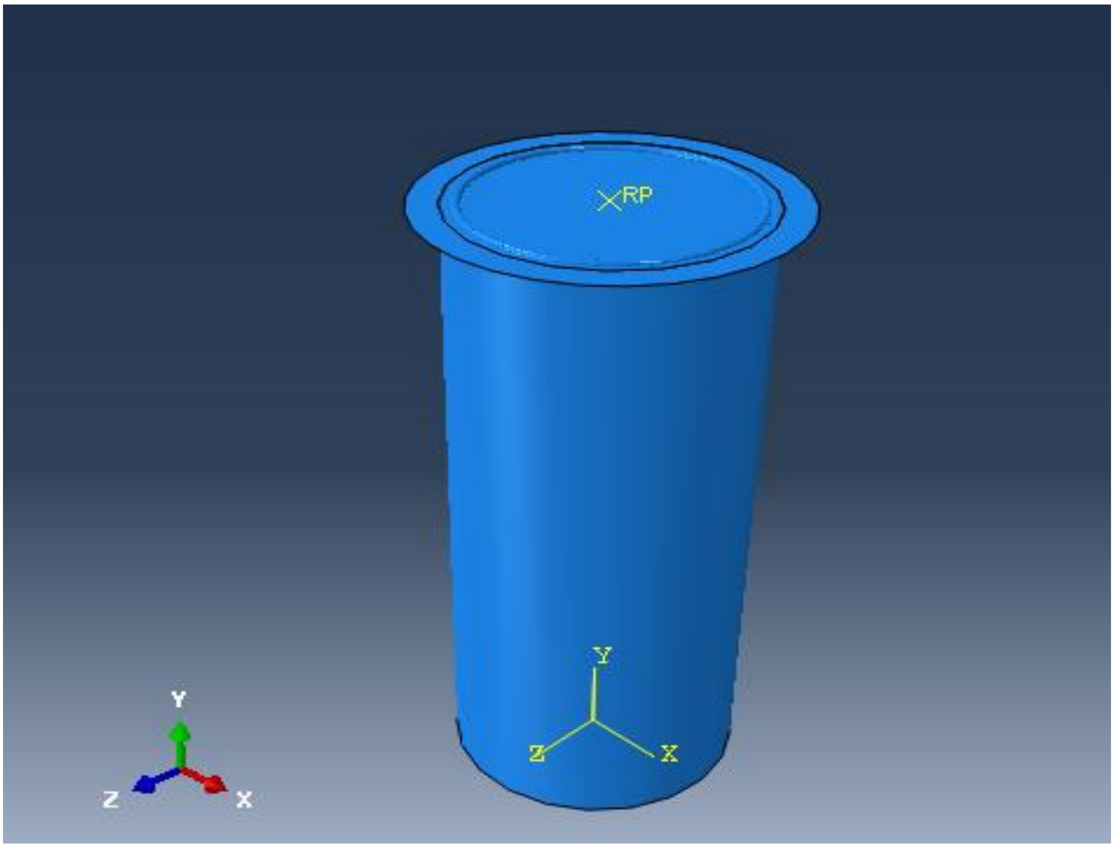


Figure 3:18 Final designed column model in ABAQUS

3.7 Modeled Column Codes and Legends

The following column codes and legends are used in this research paper:

Column Code	**Legends**
Control Specimen	CS
Fully CFRP wrapped Column	FCWC
CFRP wrapped strip Column	CWSC

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter includes numerical results of all columns with different types of configurations and orientation of CFRP. Their behavior throughout the test is described using recorded data on compressive behavior and the ultimate load-carrying capacity. The crack patterns and the mode of failure simulated by ABAQUS for each column are also described in this chapter. All the columns are tested till complete failure. It is observed that the control column had less load resistance compared to that of the FRP strengthened columns.

Finally, the numerical result is verified with an experimental study.

4.2 Effect of CFRP on Increasing Compressive Strength

It is observed that introducing CFRP has increased the compression carrying capacity of the column compared to the control column. The displacement decreased compared to the control column and load-carrying capacity also increased.

4.2.1 Control Column Vs Fully CFRP Wrapped Column

Table 4:1 Displacement and Ultimate load data for control and Fully CFRP wrapped column

Specimen	**Ultimate load (KN)**	**Increase in Load %**	**Displacement(mm)**	**Increase in Ductility (mm) %**
CS	282		8.66	
FCWC	787	179.08	54.13	525.06

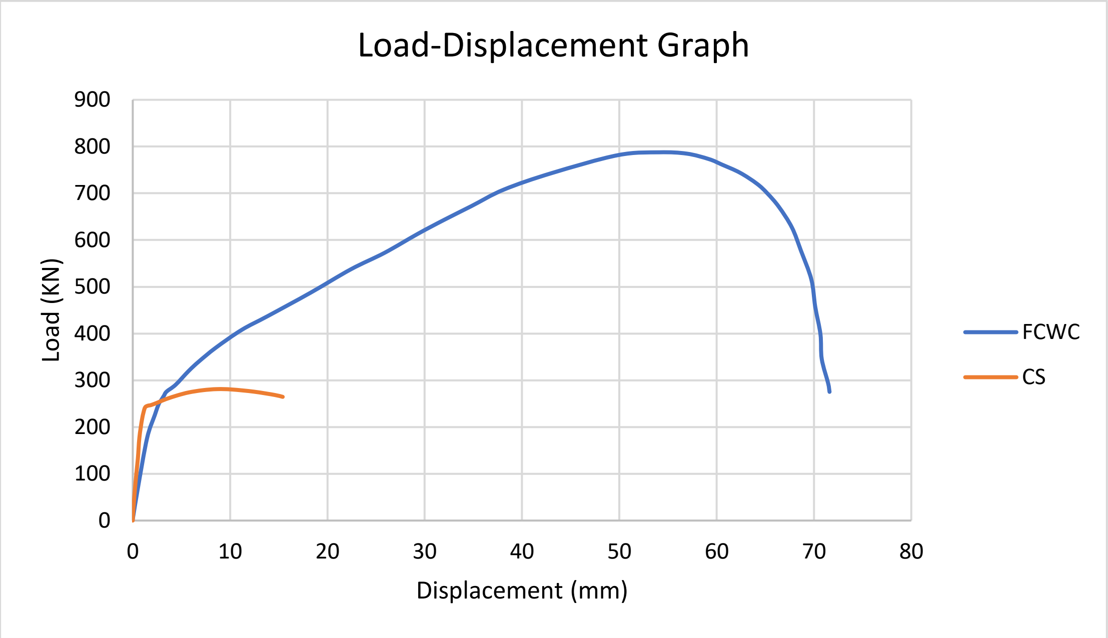


Figure 4:1 Load vs Displacement graph between Control column and Fully CFRP

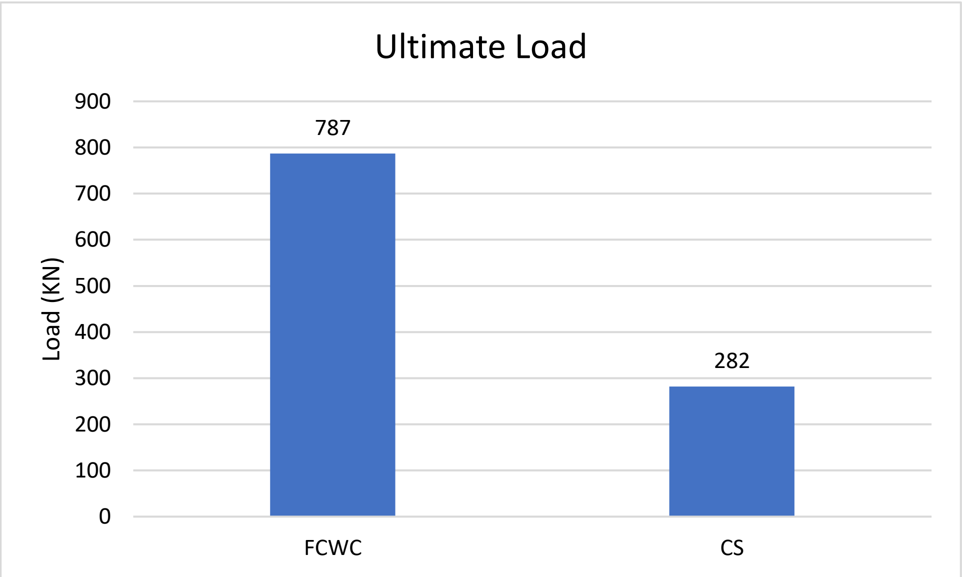


Figure 4:2 Ultimate load-carrying capacities of control and fully CFRP wrapped column

4.2.2 Discussion

From the result, it is clear that FCWC has more load resistance than CS. Load resistance of FCWC has increased up-to 193% than CS and Ductility increased up-to 525%. For CS, after the yielding of the reinforcement an ultimate peak value of load is noticed and after that ultimate failure of the column occurs. But for FCWC after the linear increase of load instead of yielding reinforcement CFRP start carrying load and a high increase of graph is seen. CFRP also increases the stiffness of the column.

4.2.3 Control Column Vs CFRP Wrapped Strip Column

Table 4:2 Displacement and Ultimate load data for control and CFRP wrapped strip column

Specimen	Ultimate load (KN)	Increase in Load %	Displacement(mm)	Increase in Ductility (mm) %
CS	282		8.66	
CWSC	507	79.78	43.66	404.15

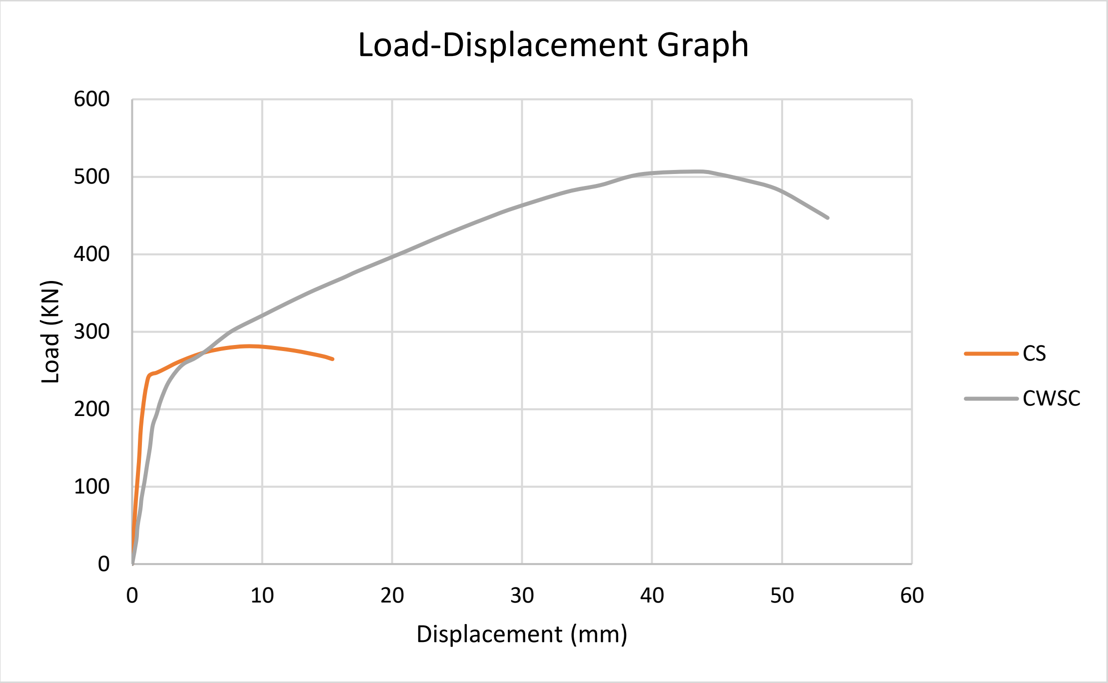


Figure 4:3 Load vs Displacement graph between Control column and CFRP wrapped Strip column

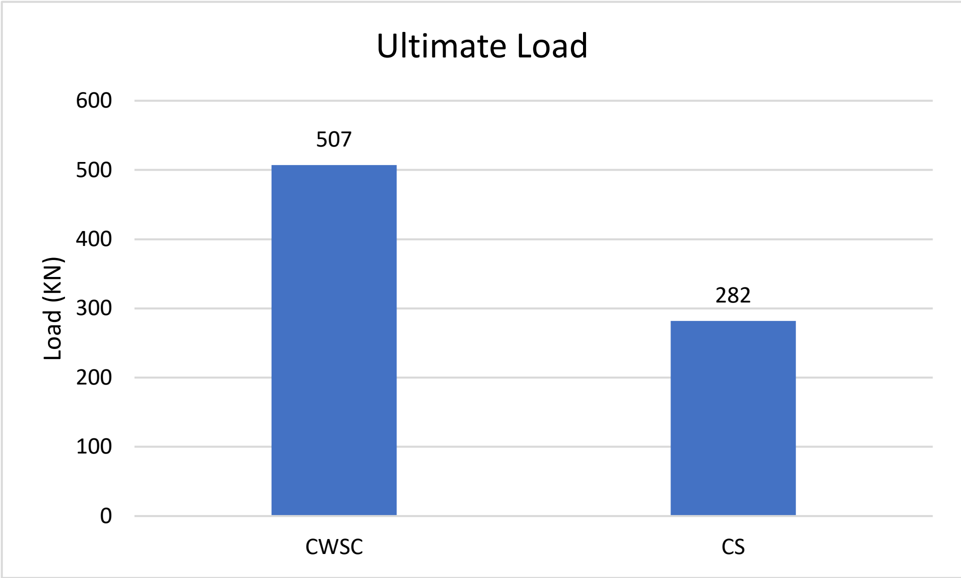


Figure 4:4 Ultimate load carrying capacities of control and CFRP wrapped strip column

4.2.4 Discussion

From the result, it is clear that CWSC has more load resistance than CS. Load resistance of CWSC has increased up-to 79% than CS and displacement increased up-to 404%.. For CS, after the yielding of the reinforcement an ultimate peak value of load is noticed and after that ultimate failure of the column occurs. But for CWSC after the linear increase of load instead of yielding reinforcement CFRP start carrying load and an increase of graph is seen. CFRP also increases the stiffness of the column.

4.2.5 Summary

Table 4:3 Summary table of Displacement and Ultimate load data for control , fully CFRP wrapped and CFRP wrapped strip column

Specimen	**Ultimate load (KN)**	**Increase in Load %**	**Displacement(mm)**	**Increase in Ductility (mm) %**
CS	282		8.66	
FCWC	787	179.08	54.13	525.06
CWSC	507	79.78	43.66	404.15

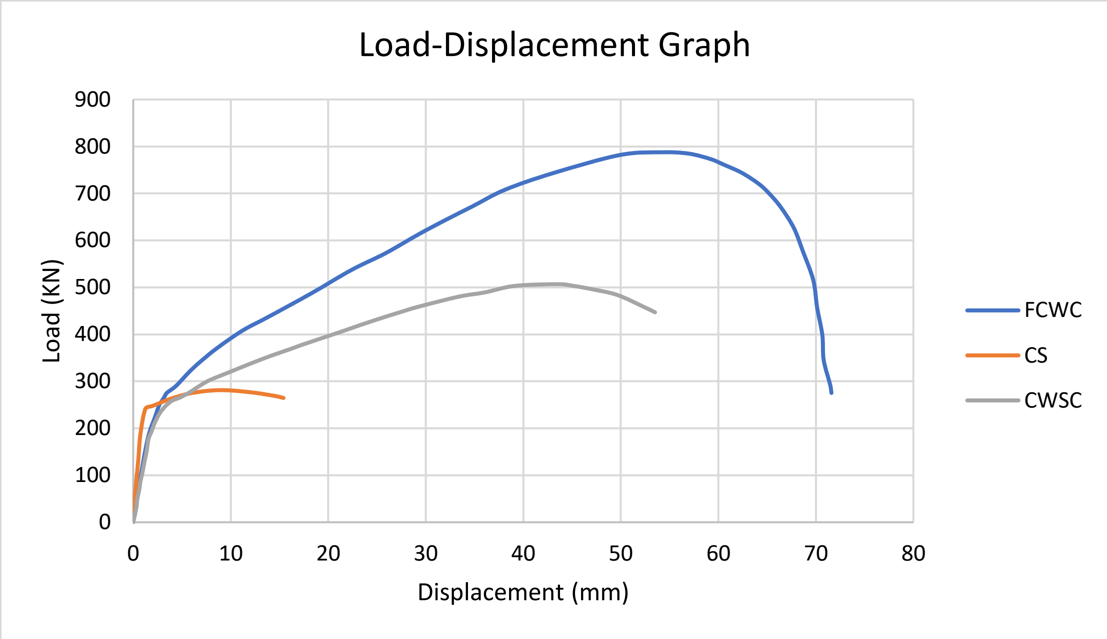


Figure 4:5 Load vs Displacement graph of all types of columns

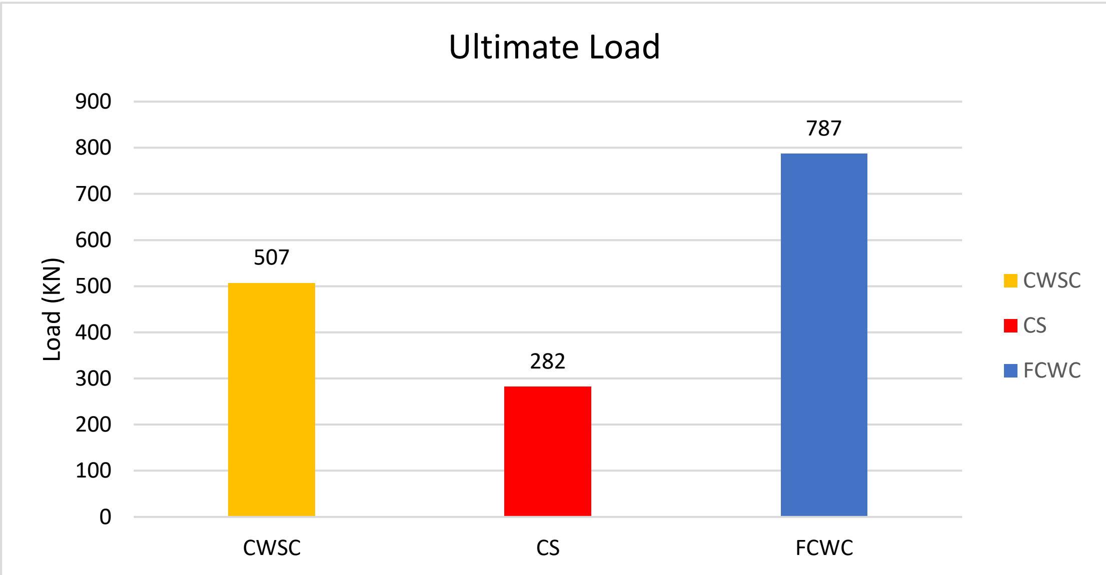


Figure 4:6 Ultimate load of all columns

4.2.6 Discussion

From the summary table, it is clear that FCWC has more load resistance than CS. Load resistance of FCWC has increased up-to 193% than CS and Ductility increased up-to 525%. For CS, after the yielding of the reinforcement an ultimate peak value of load is noticed and after that ultimate failure of the column occurs. But for FCWC after the linear increase of load instead of yielding reinforcement CFRP start carrying load and a high increase of graph is seen. CFRP also increases the stiffness of the column.

It is clear that CWSC has more load resistance than CS. Load resistance of CWSC has increased up-to 79% than CS and displacement increased up-to 404%.. For CS, after the yielding of the reinforcement an ultimate peak value of load is noticed and after that ultimate failure of the column occurs. But for CWSC after the linear increase of load instead of yielding reinforcement CFRP start carrying load and an increase of graph is seen. CFRP also increases the stiffness of the column.

4.3 Crack and Failure Pattern

The ABAQUS program records a crack pattern at each applied load step. A cracking sign represented by a block appears when principal tensile stress exceeds the ultimate tensile strength of the concrete. The cracking sign appears perpendicular to the direction of the principal stress. ABAQUS program displays blocks at locations of cracking or crushing in concrete elements. It shows the appearance of flexural cracks, diagonal Load cracks, and compression cracks.

If only an isolated portion of the column is accessible, a compression crack may appear similar to a tensile crack.

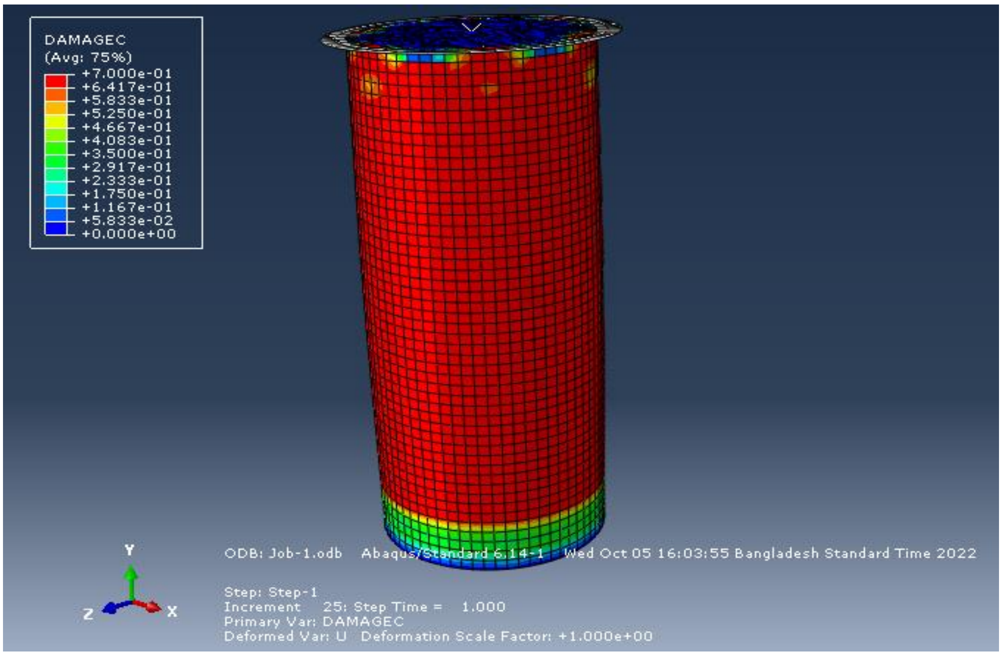


Figure 4:7 Compressive cracks of the column

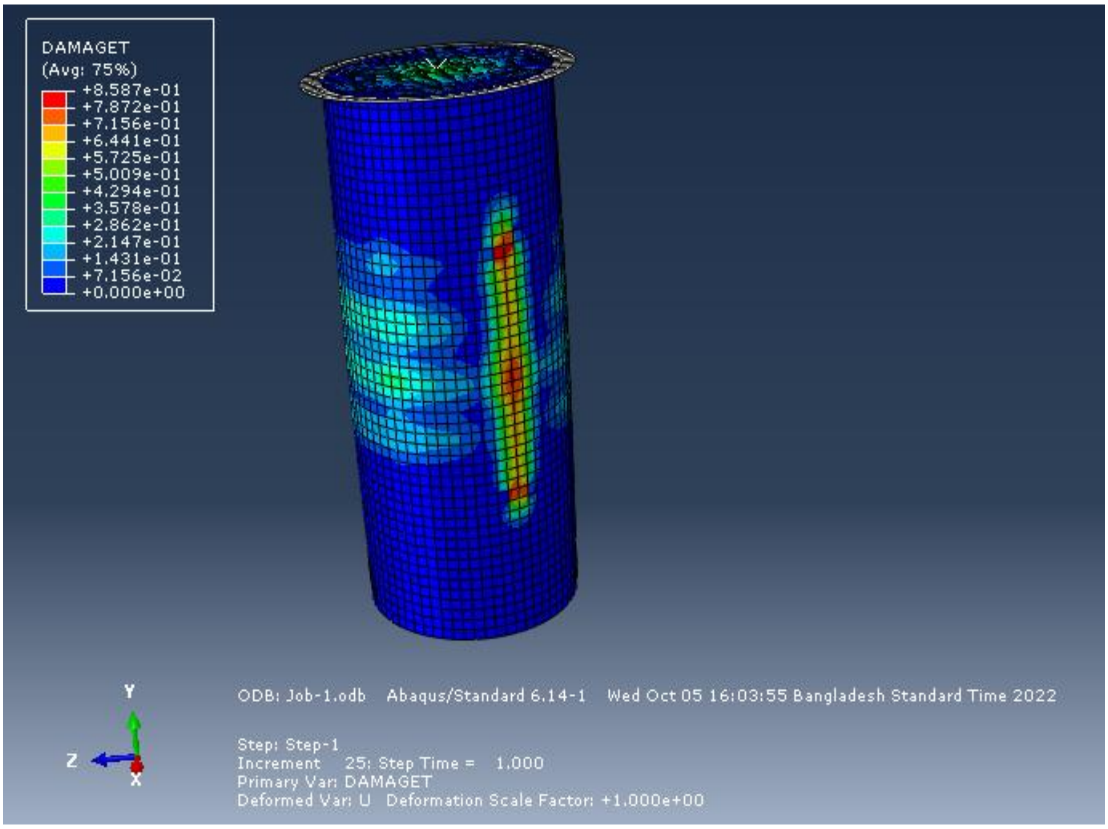


Figure 4:8 Tensile cracks of the column

4.4 Discussion

After inspecting all the cracks, it is seen that all the cracks create with respect to principal stress direction. This clearly indicated that these cracks are compression cracks. This also helped to validate the finite element model.

4.5 Validation of FEM

Many parameters in a finite element analysis are uncertain. This will inevitably account for some differences in the behavior of the real structure and results of the analysis. Validation of finite element model is an important criterion to make to model more acceptable.

(Nishikawa, et al., 1996) experimented this same setup which is analyzed in this Study. From the experiment they have found out that normal reinforced concrete column can resist up-to 268 KN compressive load and from the FE analysis it is seen that CS take up-to 287 kN load.

Table 4:4 Error percentage between Experimental and FE analyzed column

Program	**Ultimate Load(kN)**	**Error (%)**
Experiment column	268	
FE analyzed column	282	7.09

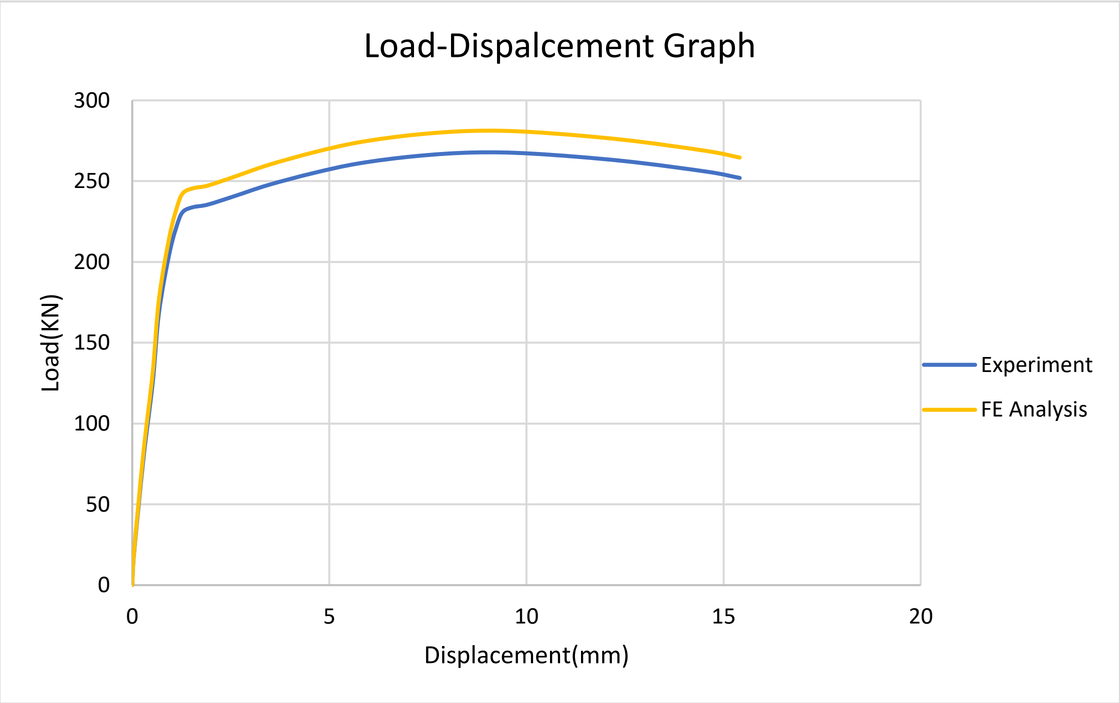


Figure 4:9 Load vs Displacement graph of Experiment and FE analysis

CHAPTER 5
CONCLUSIONS AND FUTURE WORKS

5.1 Conclusions

After completing all the Finite element analysis result has been extracted from the software. All the load vs Displacement graph has been plotted. All the FRP wrapped column graphs are compared with the Control specimen graph and significant improvement has been noticed. The ultimate load-carrying capacities of all the columns are also determined. Based on the finite element result and experimental work following conclusion are drawn:

- ❑ The ultimate load of all strengthen columns were greater than the control column.
- ❑ The increase in magnitude depends on the FRP strengthening configurations.
- ❑ The maximum increase in load is obtained for fully CFRP wrapped configurations.
- ❑ Fully CFRP wrapped column increased load resistance up-to 179 % than control column.
- ❑ CFRP wrapped strip column increased the displacement which is 404.06% .
- ❑ The maximum increase in displacement was observed by Fully CFRP wrapped column with is up-to 525.14%
- ❑ Compared to the Experimental work and FE analyzed result, the error is only 7.09%.

5.2 Limitations and Recommendations for Future Works

In this study, only the Abaqus 6.14 software is used for the analysis. The software was a trial version; original software will be gives the more accurate results.

The following working scopes can be researched in the future:

- ❑ To Increase the compressive strength of RC column using Steel fiber reinforced concrete (SFRP).
- ❑ To increase the flexural strength of RC column using CFRP and GFRP.
- ❑ To Increase the compressive strength of RC column using Jute fiber.
- ❑ To Increase the load strength of RC column Recycled material.

REFERENCE

Brencich, A. & Gnecco, M., 2012. Failure Case Studies in Structural Engineering Courses and Professional Practice. *Arab. J. Sci. Eng.,* p. 2113–2126.

Choo, C. C., 2005. Investigation of rectangular concrete columns reinforced or prestressed with fiber reinforced polymer (FRP) bars or tendons.

Ghanem, S. Y., 2016. CIRCULAR RC COLUMNS PARTIALLY CONFINED WITH FRP.

Haji, M., Naderpour, H. & Kheyroddin, A., 2019. Experimental study on infl uence of proposed FRP-strengthening techniques on RC circular short columns considering diff erent types of damage index. Volume 209, pp. 112-128.

Hsu HL, C. D., 2001. Upgrading the Performance of Steel Box Piers Subjected to Earthquakes. *Journal of Constructional Steel Research,* pp. 945-58.

Lakshmi, B. & Risal, E. M., 2019. STRENGTHENING OF COLUMN USING CFRP. *International Research Journal of Engineering and Technology (IRJET),* 6(5), pp. 7598-7608.

Lewangamage, C. S., Rankoth, C. K. & Jayasinghe, M. T. R., 2017. A Study on Reinforced Concrete Columns Partially Confined with Carbon Fibre Reinforced Polymer (CFRP). *Journal of the Institution of Engineers, Sri Lanka,* Volume 04, pp. 41-50.

MacRae G, K. K., 2001. Seismic Behavior of Hollow Stiffened Steel Bridge Columns. *Journal of Bridge Engineering.*

Nishikawa, K. et al., 1996. An Experimental Study on Improvement of Seismic Performance of Existing Steel Bridge Piers.. *Journal of Structural Engineering,* pp. 975-86.

Saeed, Y. M., 2020. Use of Carbon Fiber Reinforced Polymer (CFRP) including Sheets, Rods, and Ropes in Strengthening and Repairing Long Reinforced Concrete Columns.

Tremblay, R., Wilson, J. & Bruneau, M., 1996. Performance of Steel Bridges During the 1995 Hyogoken-Nanbu (Kobe, Japan) Earthquake. *Canadian Journal of Civil Engineering*.

Wang, W., Sheikh, M. N. & Hadi, M. N. S., 2016. Experimental study on FRP tube reinforced concrete columns under different loading conditions.

Yamao, T. et al., 2002. Steel Bridge Piers with Inner Cruciform Plates under Cyclic Loading. *Thin-Walled Structures*, pp. 183-97.