CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Axial Capacity of Circular Jute-Fiber-Reinforced-Concrete Columns having GFRP Rebar's

by

Izhar Akram

A thesis submitted in partial fulfillment for the degree of Master of Science

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I want to dedicate this achievement to my parents, teachers and friends who always encourage and support me in every crucial time

CERTIFICATE OF APPROVAL

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Abstract

Fiber Reinforced Polymer (FRP) bars have seen a lot of coverage in the last few decades as a way to solve the issue of steel reinforcing bars corroding in reinforced concrete members. The action of concrete columns reinforced with FRP bars has been studied in numerous experiments. Due to its high durability, low self-weight, and low maintenance cost, fiber reinforced polymer (FRP) is becoming a viable alternative to steel as a structural material, especially in corrosive environments. Researchers are interested in using jute fiber with GFRP rebar because of its ductility, heat resistance, and light weight. Standard steel rebar's can be replaced with GFRP rebar.

- The aim of this study was to look into the structural behavior of circular concrete columns that were reinforced with GFRP bars with ties and spirals. The mix design ratio of PC and JFRC is 1:2:3:0.70. In the production of JFRC, 5% fiber content, having a 50mm length was added to concrete. A total of 12 circular concrete columns, including both with rings and spirals of 100 mm in diameter and 200 mm in height, were casted and tested under axial loading. Mechanical properties are tested as per ASTM standards.

The findings demonstrate that GFRP bars, a relatively new material with outstanding corrosion resistance and high strength, can be employed effectively as internal reinforcement in ductile concrete columns. Jute fibers increased the damping ratios of RC-columns and switched the failure mode from crushing to bridging. The bridging process of fibers, jute fibers also showed better crack restraining capability. Energy absorption, toughness index, and ductility were all improved by compressive properties. To improve the efficiency of jute fiber, concrete with different diameters of GFRP and different dosages of admixtures will be investigated.

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Abbreviations and Symbols

A	Aggregate
C	Cement
C.Em	Compressive Energy-Absorption Upto Maximum Load
CE	Total Compressive Energy Absorbed
Cr. E	Cracked Energy Absorption after Maximum Load
Cr. E	Compressive Cracked Energy-Absorption after Maximum Load
CS	Compressive Strength
CTI	Compressive Toughness Index
Em	Energy-Absorption upto Maximum Load
fl	Longitudinal Frequency
fr	Torsional Frequency
FRC	Fiber Reinforced Concrete
FS	Flexural Strength
ft	Transverse Frequency
GFRP	Glass Fiber Reinforced Polymer
Hz	Hertz
J	Joule
JF	Jute Fiber
JFC	Jute Fiber Concrete
JFRC	Jute Fiber Reinforced Concrete
kN	kilo newton
$\mathbf{m}^3$	Cubic meter
MJ	Million Joule
mm	Millimeter

MPa	Mega Pascal
NFRC	Natural Fiber Reinforced Concrete
PC	Plain Concrete
Pmax	Maximum Load
PRC	Plain Reinforced Concrete
S	Sand
s	second
STS	Splitting Tensile Strength
TE	Total Energy Absorbed
TTI	Total Toughness Index
T.I (-)	Toughness index
w/c	Water-Cement

Symbols

Δ	Compressive Strength
Δ(mm)	Displacement in Millimeter
$\xi\%$	Damping Ratio in Percentage
ϵ_o	Strain
Δ	Compressive Strength

Chapter 1

Introduction

1.1 Background

Concrete is the substance that is used the most in the construction sector worldwide. However, it was not used because of its sensitivity to low tension, poor resistance to crack opening, and lower tensile strain capacity effects. Fiber-reinforced concrete is frequently considered as a substitute to counteract the brittleness of ordinary concrete. Fiber has been used to reinforce weak matrixes. Numerous researchers discovered that adding fibres to concrete greatly enhances its properties. Both organic and inorganic fibres are used to strengthen various concrete components. The surface, length, elastic modulus, and material from which the fibres are made all play a role in determining the type of fibres used in concrete to increase tensile strength. In reinforced concrete (RC) structures, columns are key structural components. Columns are in charge of transmitting loads to the soil via the foundation. In civil engineering structures, reinforced concrete (RC) columns having a circular cross section are commonly utilized. Steel bars and stirrups are commonly used in such columns. During earthquakes, the load carrying capacity, energy dissipation and damping of RC-columns of columns play an important role. During earthquakes, the formation of cracks in columns as a result of seismic occurrences enabled water and moisture infiltration, resulting in corrosion of steel rebar's. Corrosion of steel reinforcement causes concrete structures to corrode and lose their serviceability. One of the most important issues in civil and infrastructural engineering is corrosion, particularly in buildings exposed to harsh environments, marine structures, and structures near coastlines.

[4] Suggested mortar-free structures (new building techniques) for earthquake-resistant houses in order to provide an accessible and cost-effective solution. Experimental research on compressive members reinforced with steel, GFRP, and GFRP rebars as transverse reinforcement under eccentric pressure was conducted by Tobbi et al. [5]. According to the investigation, using steel longitudinal bars and GFRP transverse reinforcement improved strength and ductility behaviour. GFRP rebar has high strength, high ductility, low weight, no corrosion while its price is cheap as compared to the steel reinforcement bars. It can be used as an alternative to steel reinforcement bars because steel bars cannot resist corrosion and it's expensive as compared to GFRP rebar. It is observed that improvement in load carrying capacity of FRP reinforced concrete was extensively expanded and the ductility factors were improved. Under pure axial loading, GFRP rebar contributed 35% to the load carrying capacity of the RC-column Afifi et al.Al-Oraimi and Seibi (1995) [8] confirmed that even a small percentage of natural fibres might improve the mechanical characteristics and impact resistance of concrete. It was found that brittle behaviour and environmental changes cause cracks to form in plain concrete. Jute fibres were examined by Razmi and Mirsayar for their potential use in enhancing the mechanical qualities of concrete. Natural fibre reinforced cement composites have been found to be an intriguing choice for low-cost building construction in poor nations. Natural fibres are now one of the most widely used reinforcing materials since they are sustainable, biodegradable, non-toxic, and environmentally beneficial A unique alternative strengthening method for concrete structures is GFRP rebar. In addition to being a concrete alternative, GFRP rebar also possesses other qualities like high tensile strength, weather resistance, low density, thermal expansion, stiffness, and damping capabilities. These advantages enhance equipment performance, life cycle, and safety measures [7].

The current study will examine and evaluate the behaviour of small prototype JFRC specimens reinforced with glass fibre reinforced polymer (GFRP) rebars and steel rebars under axial stress. Along with the specific failure mechanism, mechanical characteristics, axial load capabilities, and fracture pattern will be identified. A critical evaluation of the literature concluded that experimental research on circular GFRP with jute fibre reinforced concrete columns, particularly columns intended for axial loading, is limited. On the other hand, current design standards oppose the use of GFRP rebars as longitudinal reinforcement in columns. Therefore, thorough research must be done to understand how GFRP rebars acting as longitudinal reinforcement behave in jute fibre reinforced concrete. It is clear from a comprehensive study of the literature that the majority of investigations were restricted to observing the behaviour of columns reinforced with GFRP rebar without the inclusion of jute fibres. Jute fibre proved effective in improving compressive strength, flexural strength, and nearly-age fracture resistance and may be added to cement-based materials. Flexural strength may be greatly increased by including 30 mm length jute fibre into cement-based materials at a mixing level of 0.5-0.6 kg3 [6]. Jute fibre has the ability to improve from 8.8 MPa to a maximum of 44.44 MPa compressive strength. When used in various percentages (0.3%, 0.4%, 0.6%, 0.8%, 1%, 1.2%, 1.4%, 1.6%, and 1.8%) that may be cured for 3, 7 and 28 days [7].

As a result, the study's objective is to monitor the jute-fiber reinforced concrete circular column prototype's performance under axial loading in order to improve its tensile strength and ductility. According to the best knowledge of the author based on the literature review, no study has been performed on concentric circular columns having jute fibers with GFRP rebar's to enhance load carrying capacity and reduce corrosion and failure problems.

1.2 Research Motivation and Problem Statement

In RC constructions, columns play a crucial structural role in transmitting loads to the ground via the foundation. The stability of the column is crucial during seismic activity since a column failure in a key area could cause the building to completely collapse. Architectural bulky cross-sectional columns are usually used in front of houses having small corridors. This can experience cracks due to many reasons. These columns do not need normal strength concrete because of these large cross-sections due to the aesthetic view of the house. Corrosion is another factor that needs attention. To reduce the effect of corrosion and cracks JFRC and GFRP rebars are used. The mechanical characteristics of concrete columns can be enhanced by combining jute fibers and glass fiber-reinforced polymer rebars in the concrete. This procedure is also cost-saving as compared to the use of steel rebar in concrete as reinforcement. Thus, the problem statement is as follows.

"Materials with improved mechanical properties, economical and environmentally friendly are required to be used as a construction material. Steel rebar has heavy weight and corrosion issues which lower the load-carrying capacity parameter under concentric loading, which causes the failure of bulky cross-sectional circular columns. This problem may be solved by using natural fibers such as jute fiber with glass fiber reinforced polymer rebar in concrete to increase the mechanical properties and load-carrying capacity to avoid the failure of the bulky cross-sectional circular columns. "

1.2.1 Research Questions

- What impact does jute fiber have on the dynamic properties of circular column?
- How much can jute fibre improve compressive, splitting tensile, and flexural strength?
- What impact does jute fibre have on the energy absorption following a crack?

1.3 Overall Objective of the Research Program and Specific Aim of this MS Research

The main goal of the research programme is to use more natural fibres in concrete structures in addition to replacing longitudinal steel rebars with GFRP rebars to increase performance and durability.

The specific aim of this MS research work is to investigate prototype concentric circular columns in the laboratory for the effect of jute fibers addition and steel bar replacement with GFRP rebar.

1.4 Scope of Work and Study Limitation

Experimental work has been done on PC and JFRC concrete to determine the concentric behavior of prototype circular columns, dynamic properties, and mechanical properties. To ascertain the mechanical characteristics of PC and JFC, three samples were employed. To describe the behavior of the prototype circular columns according to the ASTM C39 standard and earlier descriptions by Zia and Ali [7], separate samples were employed. Prototype testing and skewed boundary conditions are some of the study's weaknesses. Fiber length, content, and a single mix design ratio have all been tried

1.4.1 Rationale Behind the Variable Selection

Fibers are chosen based on their superior physical qualities in contrast to other fibres. Both fibres are accessible in the area. According to research by [10], fibres of various lengths may aid in bridging both small and large cracks and may have favorable physical characteristics. The rationale for the mix design and material selection is:

- Jute fibres are preferred due to their strong tensile strength, flexural strength, and toughness.
- To assess the positive results found by numerous types of research, the ratios 1(C):2(S):3(A) and 1%, 3%, and 5% of fiber content by mass of cement and 50mm of fiber are used [76].
- Due to their low maintenance requirements, excellent tensile strength, and corrosion resistance, GFRP rebars are employed [76].

1.5 Novelty of Work, Research Significance, and Practical Implementations

Concrete is a weak substance with poor stiffness and flexure strength. Due to its poor tensile properties, it is subject to fusion during micro-cracking [77]. Adding natural fibers made from agricultural waste to concrete greatly increased its resistance to impact loading, according to an experimental investigation [78]. It was found that adding small discrete fibers to concrete increased its mechanical properties [79]. To reduce the negative environmental effects of concrete and the damaging effects of these agricultural residues if not disposed of appropriately, these wastes should be used as sustainable building materials. The use of natural fibers in concrete may help this study also contribute to overcoming concrete's shortcomings.

To the best of the authors' knowledge, no similar research on circular columns made of GFRP rebars and jute fiber has been presented. As a result, it is necessary to investigate the effects of different JF and GFRP rebar lengths on the mechanical and dynamic properties of concrete. This could lead to the development of a better method for employing fiber and GFRP rebars in the civil engineering and building sectors.

JF and GFRP rebars are used in many applications in the earlier study. It is necessary to combine different lengths, and the long-term durability and bonding with concrete should be examined. The goal of the current study is to advance the use of JF and GFRP rebars in circular columns. These guidelines from the introduction apply to particular applications and properties in the construction sector. Additionally, this study might aid researchers by offering a way of thinking, recommendations, and an efficient technique to incorporate natural fibers into concrete.

1.6 Brief Methodology

A total of 18 specimens were cast to determine mechanical properties and 12 prototype circular columns were cast. Steel and GFRP rebar samples will also be tested. The prototypes will be tested at concentric loading till failure. To determine the efficacy of jute fibres in enhancing the load carrying capacity and general failure mechanism, prototype columns of PRC and JFRC will be compared. An axial strength test will be carried out in the CUST lab utilizing an UTM machine. The process of crack propagation would be visible with the naked eye.

Additionally, compressive, split-tensile, and flexural strength tests will be carried out experimentally to investigate mechanical properties. Uncracked dynamic properties like fundamental frequencies and damping ratio are determined experimentally, using resonant apparatus as per ASTM C-215. the mix design ratio is 1:2:3:0.70. (Cement: sand: aggregate: water). In contrast, 50mm-long fibres with a 5% cement mass content will be mixed to concrete to create JFRC. According to ASTM standards, the standard specimen will be cast and tested.

1.7 Thesis Outline

This MS thesis research work is divided into six chapters, which are mentioned below.

Chapter 1 exemplifies the introduction. It includes a backdrop, a purpose for the study and a definition of the problem, an overall goal, a specific goal, a description of the work to be done, a research technique, and an overview of the thesis.

Chapter 2 summarises the literature review in brief detail. Background, failure of RC columns under concentric load conditions, use of natural fibres in concrete, use of jute fibres in concrete, fibre reinforced polymers, use of GFRP rebars in concrete, testing procedures, and a summary are all included.

Chapter 3 elaborates experimental program. It involves background, raw material, mix design and casting procedure, mechanical and dynamic properties of PC and JFC, prepared specimens, testing procedure, and summary.

Chapter 4 explains experimental evaluation. It contains background, fundamental frequencies and damping ratios of prototypes, structural behavior of prototype circular columns for PRC and JFRC and summary.

Chapter 5 covers discussions. It encompasses background, nominal moment and design equation modification, relationship between material properties and prototypes performance and summary.

Chapter 6 covers conclusions and future work.

Chapter 2

Literature Review

2.1 Background

Fibers have been used to improve the properties of concrete, as well as its performance and serviceability. Jute fibers are natural fibers with improved tensile qualities that are inexpensive, easily available and environment friendly. Jute fibers are natural fibers that are used in concrete to improve its toughness, crack resistance, and durability. Rebar's made of GFRP are corrosion resistant and have a high tensile strength. By improving the mechanical properties of concrete columns, failure can be reduced. These properties can be improved by adding natural fibers. Under dynamic and static loads, fiber reinforced concrete (FRC) increases the characteristics of the concrete.

2.2 Failure in Circular Concrete Columns

Columns are essential structural members in reinforced concrete (RC) structures because they are necessary for the safe transmission of gravity and external dynamic loads to the ground through the base. Under axial load conditions, columns endured stresses. The cross sectional area of a short column determines its load carrying power. Load carrying capacities were significantly reduced when exposed to such significant lateral deformations.

FIGURE 2.1: Failure in Circular Columns

In a seismic event, the main longitudinal reinforcement buckled, resulting in poor column stability. Each year, huge resources are used for repairing RC columns. Earth quakes created cracks in compression members, which caused moisture and water to penetrate and rust the steel rebar's. To achieve improved performance and durability of RC columns under extreme earthquake loading, it is necessary to improve the confinement and thus load carrying capacity and flexural strength. In the past, the majority of research on damaged RC columns suggested that poor performance was due to insufficient reinforce properties. Furthermore, steel corrosion is a significant issue in RC structures, especially in areas where structures are subjected to harsh environments. Rusting caused a lot of damage to the contact between steel rebar and concrete, lowering bond strength and reducing column strength and reliability, possibly leading to shear failure. The researcher suggested in a research work that the using construction material with plastic development ability and enhancing the stiffness at columns might help against structural progressive failure [1]. For higher structural performance under intense load conditions, it is necessary to improve the ductility, strength, cracking, and resistance to corrosion of RC columns. **Figure 2.1** demonstrates how jute fibers and GFRP rebar's can reduce column failures.

2.3 Use of Natural Fibers in Concrete

ACI 544 [18] divides FRC into four categories based on the form of material used. Natural fibers help in the improvement of reinforced concrete's action and ability [8]. Natural fibers can help reinforced concrete behave better and perform better [8]. James et al. (2002) investigated that fiber reinforced concrete (FRC) would improve mechanical properties. [19]. The majority of studies concentrate on carbon, glass, propylene, and steel fibres. These fibres are extremely expensive, though. These fibres also can't be purchased easily. Additionally, these fibres are substantially more stiff, which has a negative impact on the flowability of concrete. The various research suggested using natural fibres rather than metallic ones. Natural fibers have caught the attention of researchers for use in polymeric materials due to their helpful qualities and ease of maintenance. The adhesive property between the polymer matrix and the fiber surface can be improved by chemically treating natural fiber. Khan and Ali [19] looked into the effects of fly ash, coconut fibers, and silica-fume on concrete properties. Resisting efficiency of concrete matrix improved against the sulfate and alkaline attack by addition of natural fibers in concrete [2].

Flexural strength was found to be increased by up to 7.5 percent when wheat straw was used in concrete [27]. The impact of hybrid sisal and nylon fibres on the mechanical and durability characteristics of self-compacting concrete were studied by Hari and Mini [23]. The compressive toughness of coir fibre reinforced concrete was increased by 910%. To improve the performance of asphalt roads and fracture resistance, bamboo fibre was employed. Bamboo fibre improved the dynamic modulus and stress tolerance [69]. hybrid fibre ratios of 0/100, 25/75, 50/50, 75/25, and 100/0 are among the many possible combinations. As a result of water absorption, it was concluded that fibre deterioration decreased and had an impact on durability. When combined with sisal in concrete, nylon fibre increases the material's strength and longevity.

Wahyuni et al. [28] examined the splitting-tensile strength of concrete with % bamboo fiber by weight of cement and a bamboo fiber length of 2cm. The cylinder's splitting tensile strength was also checked after 28 and 90 days. The tensile strength of the BFRC was found to be 26 percent higher than that of the PC. In order to assess the qualities of concrete, Ahamed et al. [35] investigated coir, which includes sisal, jute, hemp, banana, and pineapple fibres. They discovered that because each organic fibre has distinct characteristics, the natural fibre can alter specific concrete properties. Wang et al studied that the Yunnan Province of China has an abundance of coir, sisal, and other natural fibres (such as pine and wheat fibres), which are commonly used in the construction of walls and dwellings due to their affordable and ecologically beneficial qualities as well as totally fulfilled. Park et al. [13] used a micromechanical test and non-destructive acoustic emission to investigate the resilience of jute fibers. During a boiling water test, it was discovered that the tensile strength of jute fibers decreased significantly as the bars expanded and weakened. Sen et al. [14] investigated the mechanical and toughness properties of jute fiber composites under a variety of factors. When compared to pure water and salt water, salt water media consumption results in more negative effects on longevity and mechanical properties.

Toledo and Filho et al. [22] tested concrete specimens reinforced with coconut fibers in three pH samples, namely tap water, calcium hydroxide, and sodium hydroxide. Coconut fiber reinforced concrete maintained 60.9 percent of its initial strength after 420 days in sodium hydroxide. They have looked at the impact of various test conditions. In order to assess flexure and shear reinforcement, the relevance of plant fibres, such as wheat straw, was examined. With a mix design ratio of (1:2:4) for PC, 25 mm long wheat straw was used as the primary filler for the mass of concrete. A number of characteristics, including energy absorption, flexure strength, and toughness index, were enhanced by 7.5%, 30.4%, and 11.1%, respectively. With the use of wheat straw, crack propagation was slowed down to some level. Wheat straw fibres displayed improved behaviour in hard pavements and can produce designs that are similar [5]. The sisal and coir fibres on asbestos were substituted, and the three-point bending test was used, by Agopyan et al. [45].

According to the testing findings, sisal and coir both withstood the greatest load, however when coir tile was put up against sisal tile, the coir shown the greatest strength. It was investigated experimentally whether date palm agricultural wastes could be used to build sound-absorbing structures. Samples in the following sizes were created: 25, 35, 45, and 55 mm. It was discovered that samples with a thickness of 55 mm exhibited the greatest sound absorption [74. Researchers have extensively studied sisal and coir fibre reinforced concrete, and it is well acknowledged that as the source of the fibre changes, so does the optimal fibre content.

Ramakarishan and Sundarararajan [10] examined the resilience of coconut, sisal, jute, and hibicius and cannabinus fibers. They submerged the specimens in water saturated with lime and sodium hydroxide for 60 days, performing alternate wetting and drying cycles. They noticed that the chemical composition of the fiber had changed. In terms of tensile properties, coconut fiber was found to be the strongest of the batch. Natural fibers' long-term durability is assessed in this way.

Table 2.1: Natural Fibers and their Properties

Sr No.	**Refrence**	**Fiber**	**Conclusion**
1	Al et al. [67]	Coconut	Particularly after specimen breaking, an increase in fibre content lowers the fundamental frequency and raises the damping ratio. The best dynamic qualities are found in fibres with a 5 cm length and a 5% fibre content.
2	Hussain and Ali [67]	Jute	Jute fibre addition to concrete results in 100% and 68% increases in the damping ratio and dynamic elastic modulus, respectively.
3	Yan and Chouw [67]	Coir	The fundamental frequency, dynamic Poisson's ratio, and elastic modulus are all reduced by fibre, while the damping ratio is dramatically raised. Jute fibre reinforced composite was shown to have improved dynamic behaviour.
4	Omer et al. [68]	Jute and kenaf	When subjected to dynamic loading, jute fiber's compressive modulus, flow stress, and compressive strength all rose higher than those of kenaf fibre.
5	[70]	Wheat Straw	High energy absorption, high toughness index, strong, high water absorption capacity, easily available.
6	[75]	Flax fiber	High tensile strength, elongation property up to 2.7-3.2%, biodegradable, cost effective

Along with recycled aggregates, a bamboo sheet twinning tube was produced and employed as a column. Results showed that ductility, compressive strength, and residual bearing capacity had been significantly improved [73]. To evaluate hemp concrete's hydrothermal performance to that of conventional concrete, hemp concrete was created. Hemp concrete has been shown to increase a building's energy efficiency and lessen its environmental effect [71]. By mixing agricultural wastes with other composites, agricultural wastes can be utilized as insulation [72].

2.3.1 Use of Jute Fiber in Concrete

Jute fiber is abundant and has low cost and maintenance needs. The length and volume of fibers have a positive effect on the toughness of concrete during early and prolonged treatment times, according to the results [15]. Natural fibers like jute, kenaf, and jute rope polymer lamination increased shear strength by 35%, 34%, and 36%, respectively. Zakaria et al. [17] looked at the effectiveness of jute fibres in reinforcing concrete. With the volumetric fraction of jute fibres having a range of lengths from 10 to 25mm, two distinct mix design proportions of 1:2:4 and 1:1.5:3 were applied. It was determined that there had been a significant improvement in the compressive strength, splitting tensile strength, and flexural strength. Studies on concrete behaviour using jute fibres were undertaken by Islam and Ahmed [16]. It was discovered that adding just 0.25 percent of jute fibres improved compressive strength and inhibited crack growth.Jute fibres have a tensile strength of 250–300 MPa, which is sufficient for the majority of applications, and are roughly seven times lighter than steel fibres, according to research by Kundu SP, Chakraborty S, Roy A, et al.

A study also examines the effects of long continuous jute fibres and short discrete jute fibres on the failure and impact parameters of cementitious composites .In a experimental research work, it was explored that concrete having jute fiber can withstand against freeze and thaw effects and, also, can help in reducing the thickness of pavement with showing the same results [3]. According to research, the duration and volume of jute fibers have a significant impact on bond strength [24]. Jute, nylon, and polypropylene fibre reinforced concrete (JFRC), as well as nylon and polypropylene fibre reinforced concrete (NFRC), were studied experimentally on natural fibre reinforced concrete by Zia and Ali [30]. (PPFRC). Plain concrete and fibre reinforced concrete are both made with a mix design ratio of 1:3:1.5:0.7 (cement, sand, aggregate, water). A 5% fibre content with a 50 mm fibre length was used. It was shown that PPFRC's compressive strength increased by 1% compared to PC, whereas JFRC and NFRC's compressive strength was decreased by 36%. The splitting tensile strength of JFRC and NFRC decreased by 21% and 11%, respectively, while PPFRC had a 5% improvement. To find out how well jute, coconut, and kelp fibre worked in cement and mortars, Kesikidou and Stefanidou [18] conducted trials on each material. The use of natural fibres improved the mechanical qualities in terms of strength and durability, it was found.

Sen et al[33] .'s tests on the variation in the mechanical characteristics of jute fibres across various time periods. Jute composites spent up to 2736 hours submerged in water. It was determined that the tensile strength and flexure strength of jute composites were decreased based on the length of time the fibres were submerged. Different percentages of jute fibres (0.3%, 0.4%, 0.6%, 0.8%, 1%, 1.2%, 1.4%, 1.6%, and 1.8%) that can be cured for 3, 7, and 28 days can be utilised to increase compressive strength from 8.8 MPa to a maximum of 44.44 MPa [7]. The quantity of jute fibre in the cement matrix enhanced the initial and ultimate setting times [9]. In the hydration test, it took around 860 minutes for the cement sample to reach the maximum temperature, but it took 1020 minutes for the jute-reinforced cement sample [10]. Ananad et al[22] discovered that adding jute fibre and metakaolin to concrete increases its strength. In this study, concrete is tested using Metakaolin cement substitution and jute fibre addition. The percentages of jute fibre added are 0%, 1%, 2%, 3%, 4%, 5%, and 6%. Metakaolin replacement percentages are 0%, 3%, 6%, 9%, 12%, 15%, and 18%. Prepare a fresh mix with 5% metakaolin and different percentages of Jute Fiber after the analysis.

The concrete grade employed in the analysis is M35. Affan & Ali investigated that by addition of jute fiber total compressive and flexural energy absorption enhanced up to 87% and 53%. Enhancement of 124%, 2% and 86% in compressive, flexural and splitting toughness index. Hussain and Ali [32] investigated the use of jute fibers to improve the impact resistance of RC slabs when subjected to an impact load. Fifty-two RC steel slab panels with and without jute fibers, measuring 430 x 280 x 75mm, were made with a 50cm fiber length and a 5% fiber content by mass of cement. Drop weights were dropped from various heights of 60 and 90cm for impact resistance, as well as dynamic and mechanical material measurements. At 90 and 60 cm drop heights, impact resistance of slabs with jute fibers increased by 6 and 6.5 times, respectively. Despite this, the dynamic elastic modulus of JFRC slabs increased by 68 percent as compared to steel RC slabs. [18, 19] studied the mechanical properties of jute fibers, as shown in **Table 2.1.**

Table 2.2: Mechanical Properties of Jute Fiber [80]

Properties	**Values**
Length	50 mm
Diameter	0.40 mm
Aspect Ratio	125 -
Density	1460 kg/m^3
Specific Gravity	1.5
Water Absorption	13%
Tensile Strength	393-773 MPa
Elongation	1.5-1.8 %
Stiffness	10-30 kN/mm^2

Tan et al. [31] tested the effectiveness of sisal fibers in concrete that had been externally wrapped with jute fibers. A total of 24 specimens were cast and examined until they failed. The use of jute fiber as a confinement improved the compressive strength of both plain concrete and sisal fiber reinforced concrete, according to the findings. The mechanical behaviour of jute fiber reinforced concrete materials was investigated by Liu et al. [4].

Naik N, Shivamurthy B, Thimappa BH, et al investigated that, jute fibres can be used in place of typical fibres in concrete materials. The action of jute fiber was identified using two classes. The percentage of fiber was fixed in the first group while the length of the fiber was gradually changed from 10 to 50mm, and the length of the fiber was fixed in the second group while the percentage of fiber was gradually changed from 0.5 to 0.6 kg-m-3. The percentage increase in compressive strength of different grades of jute fiber concrete was found to be 20.44 percent, and the percentage increase in flexural strength was found to be 53.47%. Even with good strength properties, the use of jute fiber can be seen to have adequate advantages stated by different researchers. Jute fibers have a higher tensile strength, a lighter mass, a lower price, and are easier to obtain than other natural fibers. Khan and Ali [21] provided the main principle for preparing the PC and FRC.

Table 2.3: Different Mix Design Proportion, Jute Fiber Content, and Length Tested Results from Earlier Studies

Fiber Content	**Mix Design Proportions**	**Length of Fibers (mm)**	**CS**	**STS**	**FS**	**Refrences**
PC	-	-	100	100	100	
JFC	-	-	-	-	-	
0.6Kg/m^3	1:1.74:3.24	30	119	-	154	[4]
0.25%*	1:’1.5:’3	15	105	105	119	[20]
0.50%*	1:’1.5:’3	15	98	78	90	
0.25%*	1:02:04	15	102	101	111	
0.50%*	1:02:04	15	88	113	101	

2.4 Fiber Reinforced Polymer Rebar

Filaments or fibers are encased in a polymeric resin matrix binder to create FRP reinforcing bars. Steel used for reinforcement can cause major corrosion concerns due mainly to the environment and exposure to chlorides, resulting in significant deterioration. FRP reinforcing may be manufactured from several types of fibers such as glass (GFRP), basalt (BFRP), or carbon (CFRP). The FRP offers several advantages over traditional steel bars, including a density of one-quarter to one-fifth that of steel, higher tensile strength, and minimal erosion even in harsh environments [3].

GRFP reinforced circular columns were tested and compared with steel reinforced circular columns. It was observed that GFRP reinforced circular had 16% ductility better than that of steel reinforced circular columns [4]. The interfacial bond behaviour of GFRP bars in regular or high-strength concrete was studied by Lee et al [25].

The findings reveal as the compressive strength of concrete rose, the bond strength of GFRP bars tended to rise steadily. However, the bond strength of the GFRP bars increased at a slower pace than the steel bars. Because GFRP has a lower density than standard reinforced concrete, it is predicted to cost 20% less to construct as compared to steel reinforced concrete [27]. Liu et al. developed a procedure [24]. by encircling the longitudinal fibres with additional GFRP layers. With a thickness of 1.5 mm and a winding angle of 83.3°, 1, 2, and 3 winding layers have all been used. The improvement in compressive strength, ductility, and failure behaviour was then evaluated using compressive strength tests on GFRP bars with a 20 mm core diameter that were 20 mm and 30 mm high.

According to test results, adding more winding layers to GFRP bars with a 20 mm core diameter has improved their ductility and compressive strength in promising ways. For instance, the compressive strength of 20 mm and 30 mm high bars rose by 74% and 63%, respectively, for bars having three winding layers. A comparison of the mechanical characteristics in compression and tension revealed that two winding layers are necessary to boost strength and ductility to their fullest potential. Because FRP rods are non-corrosive and lightweight, they can be used in combination with high concrete to overcome some challenges, especially in extremely corrosive environments [24]. The deformed surface augmentation of the FRP bars can improve its durability performance in the marine and coastal settings, according to research by Ahmed et al [23].

The comparative test revealed that GFRP bars outperformed BFRP bars in terms of endurance when exposed to a salty environment. Morover The FRP-SWSSC will degrade more severely as a result of the longer exposure duration and higher temperature, which will also result in decreased flexural and shear performance. The durability of the FRP bars may be more seriously threatened by the simulated standard SWSSC pore solution compared to the simulated high-performance SWSSC pore solution. According to Afifi et al. [44], GFRP transverse reinforcement had a greater influence on ductile behaviour and confinement efficacy than GFRP RC columns' load bearing abilities. A 3% to 7% increase in axial compressive strength was reported, while ductility and confinement efficiency improved by 57 percent to 208 percent and 21 percent to 43 percent, respectively.

Table 2.4: Summary of the Mechanical Properties of GFRP Rebars as Stated in Previous Literature

Reference	**Diameter** (mm)	**Length** (mm)	f_{uT} (MPa)	E_{ft} (GPa)	F_{uC}/f_{uT}	E_{fc}/E_{ft}
Muhammad et al. [8]	19.1	-	729	44	0.38	0.91
Khuramian et al. [6]	16	32	629	38.7	1.24	1.06
Hadi and Yousif [19]	10	6.25	1103	92.4	0.62	0.65
Xue et al.[38]	15.9	-	654	39	0.36	0.92

2.4.1 Use of GFRP Rebar's in Concrete Columns

According to Afifi et al. [44], GFRP transverse reinforcement had a greater influence on ductile behavior and confinement efficiency than GFRP RC columns' load bearing abilities. A 3% to 7% increase in axial compressive strength was reported, while ductility and confinement efficiency improved by 57 percent to 208 percent and 21 percent to 43 percent, respectively.

Rizkalla et al. [39] investigated the design of FRP for concrete structure strengthening. In concrete, various FRP bars such as aramid and glass fiber polymer rebar's were used. The bonding strength of FRP bars in concrete was reduced by 80% to 90% when exposed to high temperatures of 20 to 250 C, while steel bars showed a 38% reduction in bonding strength. Hadi et al. [19] looked at the use of GFRP rebars to strengthen circular columns.

Twelve specimens having a diameter of 205mm and a height of 800mm were cast and tested until failure. In comparison to steel reinforced specimens, the results showed that an increase in transverse reinforcement spacing resulted in a loss in axial load bearing capabilities. The reduction in spiral spacing enhanced the ductility of concrete column specimens. The flexural strength and serviceability of a geopolymer concrete beam with GFRP rebars were investigated by Maranan et al.

[44] using a four-point bending test. Based on the findings of the experiments, it was found that as the glass fibre reinforcement ratio grew, a beam's efficiency likewise increased. Geo-polymer concrete beams respond better than Based composites concrete beams that were strengthened by the bending resistance of the GFRP. The mechanical qualities of geo-polymer originally made the geo-polymer concrete superior than the conventional concrete in the same assessment. The addition of more GFRP rebars to the reinforcement ratio improved efficiency in terms of post crack, stiffness, load capacity, and deformation. Pantelides et al. [49] investigated the load-bearing ability of GFRP-reinforced concrete columns. In comparison to steel RC columns, columns with GFRP longitudinal bars and GFRP spirals demonstrated an 84 percent load bearing capability. Mohamed et

al. [46] investigated the behaviour of concrete columns with GFRP and CFRP rebar's and found that GFRP specimens had a significant decrease in compressive strain.

Hasan et al. [54] examined concentric loads on high strength concrete (HSC) columns using steel and GFRP rebar's. When GFRP rebar's were used in place of conventional steel bars, the load capacity of the HSC columns was reduced by 30% when compared to steel reinforced HSC columns. Alsayed et al. [48] investigated rectangular RC columns with measurements of 450 x 250 x 1200 mm and a 1.07% reinforcement ratio. In the absence of lateral reinforcement, it was discovered that replacing longitudinal steel rebars with an equal amount of GFRP rebar's reduced load carrying capacities by 13%. (Whether steel or GFRP). The installation of GFRP ties as a substitute for steel ties resulted in a 10% reduction in load capacity, according to the findings. Until 80 percent ultimate capacity, the load-deformation behavior remained unaltered. The load and moment interaction diagrams of circular concrete columns with GFRP rebar's were explored by Karim et al. [42].

In concrete, twelve samples were made with # 4 GFRP rebar's and # 3 helices. The load carrying ability of GFRP reinforced specimens was found to be lower than that of steel reinforced specimens. In addition, insufficient longitudinal reinforcement resulted in brittle failure of GFRP reinforced specimens before the moment interaction diagram approach reached pure flexure strength. Luca et al. [39] carried out laboratory tests on concentric concrete columns reinforced with GFRP and steel rebar's. Under pure axial load, five full-scale square cross-section columns measuring 610 x 3000mm were tested. The findings showed that GFRP longitudinal reinforcement had higher strains than conventional steel reinforced concrete columns due to their lower load carrying capacity. The confinement of lateral connections had the greatest impact on longitudinal rebar buckling. At a 1% reinforcement ratio, the axial deformation activity of GFRP RC columns is identical to steel RC columns. Since GFRP longitudinal rebars contributed less than 5% of load carrying capacities compared to 15% of longitudinal steel rebars, they can be overlooked when determining load ability. Many studies have found that GFRP bars have a low elastic modulus, making them more prone to buckling failure than steel rebars. As a result, longitudinal GFRP rebars needed to be restrained by transverse reinforcement. The effectiveness of partially steel fiber-reinforced high strength concrete and fiber-reinforced polymer rebars was examined by Zhu et al. [45], as well as the flexural behaviours. Twelve beam specimens were examined under a four-point bending force. the tension zone of the beam reinforced with varying percentages of steel fibres. The steel fibres successfully increased the tension zone and produced significant bending moments. As layer thickness increased, FRP rebars' ductility reduced, resulting in fiber-reinforced, high-strength concrete (FRHSC). division of the FRHSC steel fibre volume. High ductility over the entire depth of the structure is necessary to be outfitted with steel fibres.

Corrosion of steel rebars is one of the most important factors in the reduction of axial load carrying capacity, which reduces column strength and eventually leads to failure. To investigate the action of concentric circular columns, GFRP rebars are used in jute fiber reinforced concrete (JFRC) column prototypes in this research. Under axial loading, the action of prototype PRC and JFRC columns with GFRP rebars will be investigated and compared. To the best of the author's knowledge, no research on circular concrete columns reinforced with jute bres and GFRP rebars has been conducted. One of the most significant contributors in the decline in axial load carrying capacity, which lowers column strength and eventually results in failure, is corrosion of steel rebars. In this research, GFRP rebars are employed in prototype jute fibre reinforced concrete (JFRC) columns to study the behaviour of concentric circular columns. The behaviour of prototype PRC and JFRC columns with GFRP rebars will be examined and compared under axial loading. To the best of the author's knowledge, no studies on GFRP rebars and jute fiber-reinforced concrete columns have been done.

2.5 Testing Practice

The behavior of any structure can be anticipated in four stages. consists of (i) a full-scale structure under realistic conditions [35], (ii) full-scale structural elements with specific constraints [36], (iii) scaling the prototype structure or typical structural elements with the necessary gradient for raw material, size, loading conditions, and end-limits [37], and (iv) small prototype structural elements for comparative comparison to verify efficiency, only one variable if all other conditions are the same [38, 39]. This criterion's fourth (iv) requirement is being applied. Under axial load circumstances, the performance of tiny prototype circular columns reinforced with steel and GFRP rebars is assessed.

2.6 Summary

Fiber can be used to improve the mechanical properties of concrete, according to an analysis of the literature. Jute strands have enhanced qualities and significantly influenced the concrete's toughened properties. GFRP rebars have superior mechanical qualities and can be utilised as a substitute for steel rebars in harsh environments for increased structural effectiveness and corrosion resistance. To the best of the author's knowledge, based on a thorough review of the literature, no research has been done on JFRC's suitability with GFRP rebars for circular column applications. Twelve prototype circular columns with GFRP rebars as steel rebar replacements in jute fiber reinforced concrete were experimentally tested in this study. On top and bottom, a 12.5 mm clear cover is given, with 12.5 mm on each side. For PC, PRC, JC, and JFC specimens, various properties such as fundamental frequencies, damping ratios, and mechanical properties were evaluated.

Chapter 3

Experimental Program

3.1 Background

Jute fibre reinforced concrete reinforced with glass fibre reinforced polymer rebars uses fibres to enhance its mechanical qualities. The key benefits of fiber reinforced concrete are enhanced mechanical properties, hardness, and energy absorption. Experimentation is used to study the behaviour of GFRP rebars in jute fiber reinforced concrete.Fiber has been used to reinforce weak matrixes. Numerous researchers discovered that adding fibres to concrete greatly enhances its properties. Both organic and inorganic fibres are used to strengthen various concrete components. This chapter goes into raw material collection, mix design ratios, casting, mechanical and dynamic properties of PC and JFC, testing procedure, sample detailing, and the efficacy of jute fibers in concrete.

3.2 Raw Materials

For the PC and JFRC mixtures in this analysis, coarse aggregate, lawrencepur sand, ordinary portland cement, fresh water, jute fibers, and GFRP rebars were used. The coarse aggregates have a maximum scale of 10 mm. Jute fibers are available in their natural state, where they are prepared by hand at a cost of 50 mm long

FIGURE 3.1: Jute Fibers: a) Raw Fibers, b) Prepared Fibers

TABLE 3.1: Mechanical Properties of GFRP Rebar [80]

Properties	**Values**
Length	50 mm
Diameter	0.40 mm
Aspect Ratio	125
Density	1460 kg/$m^2$3
Specific Gravity	1
Water Absorption	13%
Tensile Strength	393-773 MPa
Elongation	1.5-1.8%

Park et al. [23] Uses experiments to determine the physical properties of jute fibers. Tensile strength varies between 390 and 770 MPa. It has a density of 1458 kg/m^3 and can absorb up to 13% of water. Cellulose, lignin, fat, wax, and water-soluble materials are chemical constituents of jute fiber. These chemicals (cellulose, wax, and lignin) may be the cause of the jute fiber's poor bond with the concrete mix. A basic pre-treatment is used, in which jute bers are immersed in water for around half an hour to clear dust and wax from the water tank. The jute fiber is then removed from the bath and air dried.

TABLE 3.2: Mechanical Properties of GFRP Rebar [81]

Properties	**GFRP**	**Steel**
Diameter	6 mm	6mm
Cross Sectional Area	28.27 mm2	28.27 mm2
Density	2200 kg/m3	7850 kg/m3
Weight	0.051 kg/m3	0.22 kg/m3
Tensile Strength	729.74 MPa	505.5 MPa
Elastic Modulus	44 GPa	200 Gpa
Ultimate Shear Strain	1.82%	6.12%

Steel and GFRP rebars have the same size, with a diameter of 6 mm and a longitudinal length of 430 mm. For all prototype columns, 6 mm steel rebars were used as transverse shear reinforcement. Figure 3.2 shows the length, diameter, and tensile stress-strain curve of GFRP rebars. As shown in Table 3.1, the mechanical characteristics of GFRP rebars were measured experimentally. ASTM D7205 [52] was used to determine the tensile characteristics of GFRP rebars. When compared to steel rebars, GFRP rebars had a higher tensile strength, lower density, and lower modulus of elasticity.

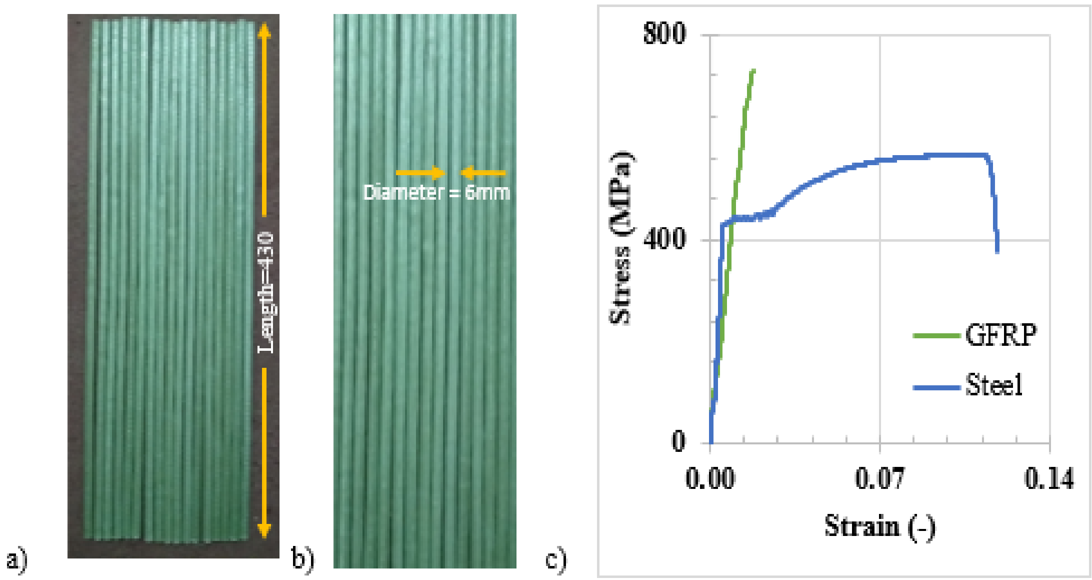

FIGURE 3.2: GFRP Rebars: a) Cut Length of Rebars, b) Diameter of Rebars and c) Relative Strength of Steel and GFRP Rebar[81]

3.3 Mix Design, Casting Procedure and Mechanical Properties

For the preparation of Plain concrete (PC) specimens in this study, a single mix design ratio of 1: 2: 3: 0.7 (cement: sand: aggregate: water) was used, as shown in **Table 3.2**. Jute fiber concrete (JFC) specimens had a similar mix design percentage, with the addition of 5% jute fiber content by mass of cement and a consistent fiber length of 50 mm. The primary motivation for using this mix design proportion was to attain the desired compressive strength of 20 MPa so that FRC could be used in practical building. A non-tilting rotary-type drum concrete mixer was used to create the PC and JFC specimens. To make PC specimens, all ingredients were combined with water in a concrete mixer, which was then swirled for three minutes for a more homogeneous mix. A new approach was included in the manufacture of JFRC specimens to eliminate the balling effect, as reported by [53]. For better mixing, all elements (cement, sand, aggregate) were poured in layer by layer form.

FIGURE 3.3: Slump (a) PC and (b) JFC

Layer by layer, a third of the whole material was poured into the mixer (cement. After that, 1/3rd of the water was dispersed across the entire material (sand, aggregate, and jute fibers). The remaining two parts were made with the remaining 2/3rd of the water.

TABLE 3.3: Mix Design Ratios for PC and JFC

Property	**Fibre (%)**	**Cement (kg/m3)**	**Fibre (kg/m3)**	**Fine Aggregate (kg/m3)**	**Coarse Aggregate (kg/m3)**	**Water (liter/m3)**
PC	0\%	333.33	0	666.66	1000	233.33
JFC	5\%	330.81	16.67	661.61	992.42	231.56

To determine the mechanical properties of PC and JFC, a total of 18 specimens were cast and tested. Six cylinders were cast and tested for compressive properties, six cylinders for split-tensile qualities, and six beams for flexural values. The cylinders and beams that were examined have diameters of 100 x 200 mm and 100 x 100 x 450 mm, respectively. According to ASTM standards C39/C39M-18 [14], C496/C496M-17 [56], and C78/C78M-15b [57], the loading rate for compression, spit-tensile, and flexure testing was 0.15 MPa/s, 0.78 MPa/min, and 0.86 MPa/min, respectively. ASTM standard C215-02 [58] was used to conduct pre-destructive and non-destructive dynamic testing. Cracking behavior, strength (S), energy absorption (E), matching curves, and toughness index were all determined and compared. Table 3.3 shows the fundamental frequencies and damping ratios calculated for cylinder and beam specimens of PC and JFC. For beam and cylinder specimens, an average of three and six readings were collected, respectively. It was observed that fundamental frequencies for PC specimens were higher than those found when jute fibers were used in concrete. The addition of jute fibers improved the damping and energy dissipation of JFC specimens.

For a total of 6 minutes, the mixer was rotated (2 minute each layer). The ASTM standard C143/C143M -15a [54] was used to determine the workability of PC and JFC specimens using a slump cone test. PC specimens had a higher slump than JFC specimens. The water absorption property of jute fibers may be responsible for the reduced slump of JFC. Moulds were filled in three layers and the concrete was compressed with twenty-five rod blows to avoid air spaces. All of the specimens were prepared using the same method. The specimens were taken from the moulds after 48 hours of air drying, and all of the specimens were labelled. Following labelling, specimens were kept in the water tank for a 28-day curing period in accordance with ASTM C192/C192M [55].

The following are the results for fundamental frequencies and damping ratios of cylinders and beams for PC and JFC:

For the purpose of determining the mechanical properties of PC and JFC, a total of 18 specimens were casted and tested. Six cylinders were casted and tested for compressive properties, six cylinders for split-tensile qualities, and six beams for flexural values. The cylinders and beams that were examined have diameters of 100 x 200 mm and 100 x 100 x 450 mm, respectively. According to ASTM standards C39/C39M-18 [14], C496/C496M-17 [56], and C78/C78M-15b [57], the loading rate for compression, spit-tensile, and flexure testing was 0.15 MPa/s, 0.78 MPa/min, and 0.86 MPa/min, respectively. ASTM standard C215-02 [58] was used to conduct pre-destructive and non-destructive dynamic testing. Cracking behavior, strength (S), energy absorption (E), matching curves, and toughness index were all determined and compared. With the naked eye, crack propagation characteristics and failure modes were seen. ilure behaviour of the material under compression, splitting, and flexural loads. Table 3.3 shows the fundamental frequencies and damping ratios calculated for cylinder and beam specimens of PC and JFC. For beam and cylinder specimens, an average of three and six readings were collected, respectively. It was observed that fundamental frequencies for PC specimens were higher than those found when jute fibers were used in concrete. The addition of jute fibers improved the damping and energy dissipation of JFC specimens. The following are the results for fundamental frequencies and damping ratios of cylinders and beams for PC and JFC:

Table 3.4: Fundamental Frequencies and Damping Ratios for Beam and Cylinder Specimens.

Property	Compressive		Splitting-tensile		Flexural	
	PC	JFC	PC	JFC	PC	JFC
P.max (kN)	145.13±14.24	73.10±3.14	79.12±11.15	54.10±1.04	11.38±1.70	9.32±1.80
Strength (MPa)	18.40±1.81	9.3±0.59	2.51±0.38	1.71±0.03	5.12±0.85	4.19±0.96
E1	0.12±0.03 MJ/m3	0.10±0.01 MJ/m3	21.10±2.91 J	23.25±1.97 J	7.27±1 J	5.84±1.76 J
Ecr.	0.21±0.01 MJ/m3	0.29±0.01 MJ/m3	0 J	69.25±7.34 J	0 J	11.52±0.41 J
T.E	0.33±0.04 MJ/m3	0.39±0.02 MJ/m3	21.10±2.91 J	92.5±9.31J	7.27±1 J	17.36±2.17 J
T.T.I	2.75±0.11	6.9±0.44	1	3.97±0.06	1	2.97±0.31

Under various loading circumstances, corresponding curves of mechanical characteristics, crack propagation appearance, and failure modes are shown in **Figure: 3.3**. **Figure: 3.3 (a)** shows that under compressive load, cracks in the PC specimen are longer, wider, and more numerous than small cracks in the JFC specimen.

As a result of spalling and crushing, several concrete particles in PC have shattered and fallen down. PC specimens show brittle behaviour, whereas JFC specimens show bridging effect. However, as the load was increased in the JFC specimen, the crack size grew larger, which was restricted by jute fibers to prevent further spread. Under split-tensile loading, failure mode is seen in **Fig. 3.3(b)**.

The PC specimen fractured into two sections unexpectedly and without warning, but the JFC specimen showed bridging effect. The failure mode under flexure loading is depicted in **Figure. 3.3(c)**. The actual and schematic diagrams show that the PC beam splits into two halves abruptly, with the bridging effect obvious for the JFC beam specimen. The use of jute fibers controlled the cracks and switched the failure mechanism from crushing to bridging. The actual and schematic diagrams show that the PC beam splits into two halves abruptly. **Table 3.4** lists all of the computed mechanical parameters such as peak load (P.m), strength (S), energy absorption at peak load (E1), energy absorption from peak to ultimate load (Ecr), total energy absorption (T.E), and toughness index (T.I).

The compressive strength of the JFC specimen was reduced by up to MPa, whereas E1, Ecr, E, and T.I were all enhanced. **Table 3.4** illustrates PC specimens. The comparison of mechanical properties under mechanical loading is shown in **Figure 3.3(a, b, and c)**. The experimental calculations revealed a significant improvement in total energy in compression (T.E.C), total energy in splitting (T.E.S), and total energy in flexure (T.E.F), as well as their respective toughness (T.I). Under compressive, splitting, and tensile stress, the (E1), (T.E), and (T.I) of JFC specimens have risen by 8.69%, 63 percent, 276 percent, 304 percent, 124 percent, and 200 percent, respectively, compared to PC specimens. Although the load carrying capacity and compressive strengths of the JFC specimen are lower than those of the PC specimen, characteristics like as energy and toughness index have increased dramatically.

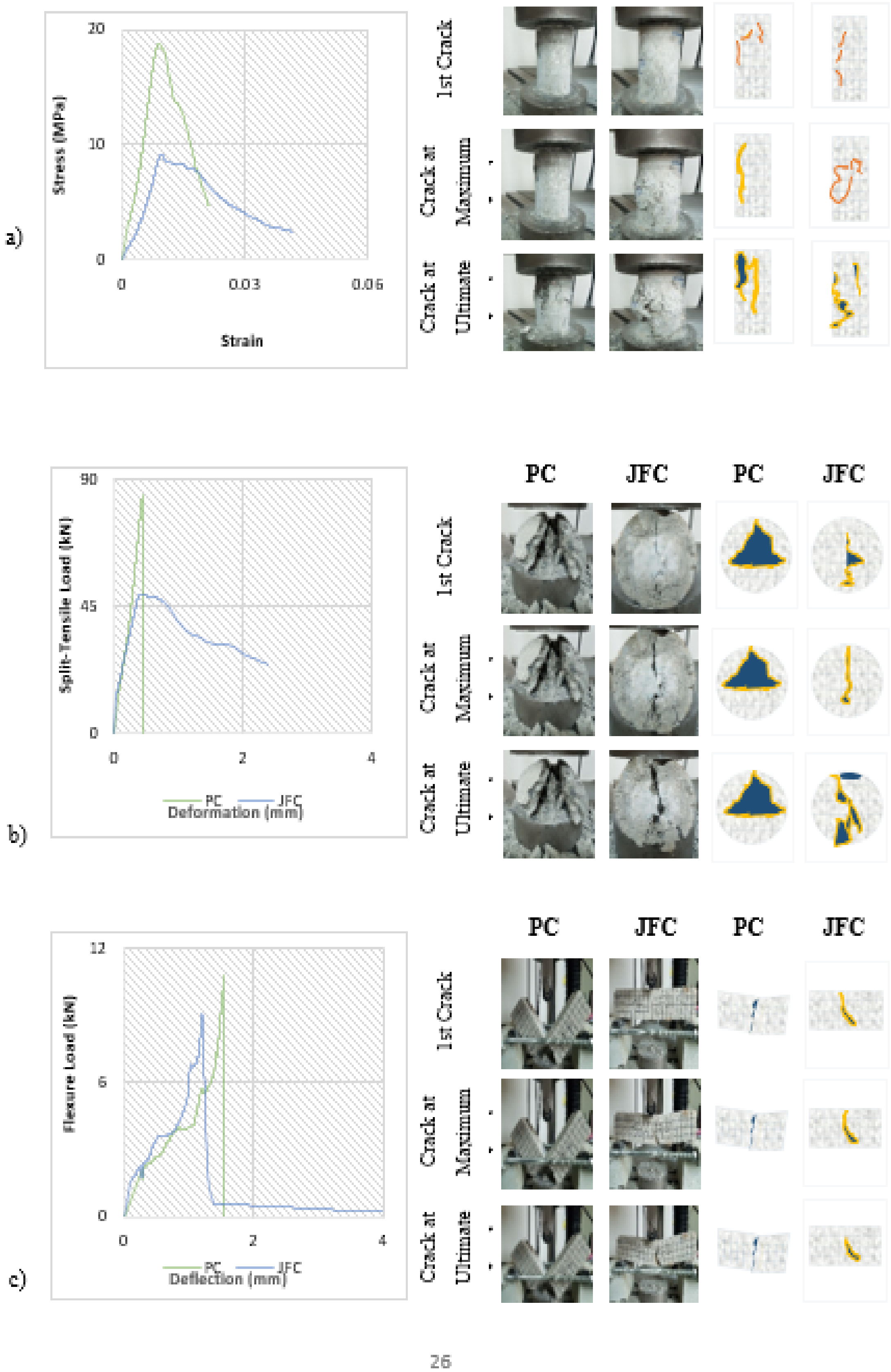

FIGURE 3.4: Mechanical Properties Under: a) Compression Loading, b) Splitting Loading and c) Flexural Loading

TABLE 3.5: Mechanical Properties of PC and JFC

Property	**Compressive**		**Splitting-Tensile**		**Flexural**	
	PC	**JFC**	**PC**	**JFC**	**PC**	**JFC**
P.max (kN)	145.13±14.24	73.10±3.14	79.12±11.15	54.10±1.04	11.38±1.70	9.32±1.80
Strength (MPa)	18.40±1.81	9.3±0.59	2.51±0.38	1.71±0.03	5.12±0.85	4.19±0.96
E1	0.12±0.03	0.10±0.01	21.10±2.91	23.25±1.97	7.27±1	5.84±1.76
	MJ/m^3	MJ/m^3	J	J	J	J
Ecr.	0.21±0.01	0.29±0.01	0	69.25±7.34	0	11.52±0.41
	MJ/m^3	MJ/m^3	J	J	J	J
T.E	0.33±0.04 MJ/m^3	0.39±0.02 MJ/m^3	21.10±2.91	92.5±9.31J	7.27±1	17.36±2.17
			J		J	J
T.T.I	2.75±0.11	6.9±0.44	1	3.97±0.06	1	2.97±0.31

3.4 Specimens

A total of 36 prototype circular columns of 100 mm diameter and height of 200 mm (Diameter x height) was prepared for investigation of structural behavior and performance under pure axial load condition. 36 prototype circular columns of 100 mm and height 200 mm (Diameter x height) was prepared for investigation of structural behavior and performance under pure axial load condition. A total of 36 prototype specimens were divided in two groups in order of 18 prototypes for plain reinforced concrete (PRC) and 18 prototypes for jute fiber reinforced concrete (JFRC) columns as presented in **Table 3.6**. The current study will examine and evaluate the behaviour of small prototype JFRC specimens reinforced with glass fibre reinforced polymer (GFRP) rebars and steel rebars under axial stress. Along with the specific failure mechanism, mechanical characteristics, axial load capabilities, and fracture pattern will be identified. A critical evaluation of the literature concluded that experimental research on circular GFRP with jute fibre reinforced concrete columns.

Furthermore out of 18 PRC prototype columns 9 columns were reinforced with longitudinal steel rebars and 9 columns with longitudinal GFRP rebars. Similarly out of 18 JFRC prototype columns 9 columns were reinforced with longitudinal steel rebars and 9 columns were reinforced with longitudinal GFRP rebars. Selection of dimensions for prototype circular columns were based on the favorable condition and capacity of the servo-hydro testing machine (STM) apparatus in the laboratory. All prototype circular columns were prepared as beams and tested as columns. The prototype specimens were identified by variation in the longitudinal reinforcement type i.e. GFRP rebars and steel rebars. For longitudinal reinforcement was provided by steel and GFRP rebars of 6 mm diameter in PRC and JFRC specimens respectively. Steel rebars of 6 mm diameter was utilized for shear reinforcement in both PRC and JFRC prototypes. Reinforcement detailing of all the prototype columns are demonstrated in Fig. 3.4 Two different loading rates of 0.19 and 0.27 MPa/s were used according to ASTM C39M-18 [14] and average of two prototype were taken. Non-destructive dynamic testing was performed before destructive testing for prototype columns under axial load condition.

TABLE 3.6: Test Matrix with Labelling for Prototype Specimens

S. No	**Longitudinal Rebars**	**Steel Ties**	**Steel Spirals**	**GFRP ratio (ρ)**	**Labels PRC**	**JFRC**
1	5-Ø6	Ø6-75mm		0.018	5SPC	
2	5-Ø6	Ø6-75mm		0.018		5SJC
3	5-Ø6	Ø6-75mm		0.018	5GPC	
4	5-Ø6	Ø6-75mm		0.018		5GJC
5	7-Ø6	Ø6-75mm		0.018	7SPC	
6	7-Ø6	Ø6-75mm		0.018		7SJC
7	7-Ø6	Ø6-75mm		0.018	7GPC	
8	7-Ø6	Ø6-75mm		0.018		7GJC
9	5-Ø6		Ø6-75mm	0.018	5SPC	
10	5-Ø6		Ø6-75mm	0.018		5SJC
11	5-Ø6		Ø6-75mm	0.018	5GPC	
12	5-Ø6		Ø6-75mm	0.018		5GJC

*Note: A and B represents different load rates (0.19 MPa/sec and 0.27 MPa/sec) applied on prototype specimen A and B respectively.

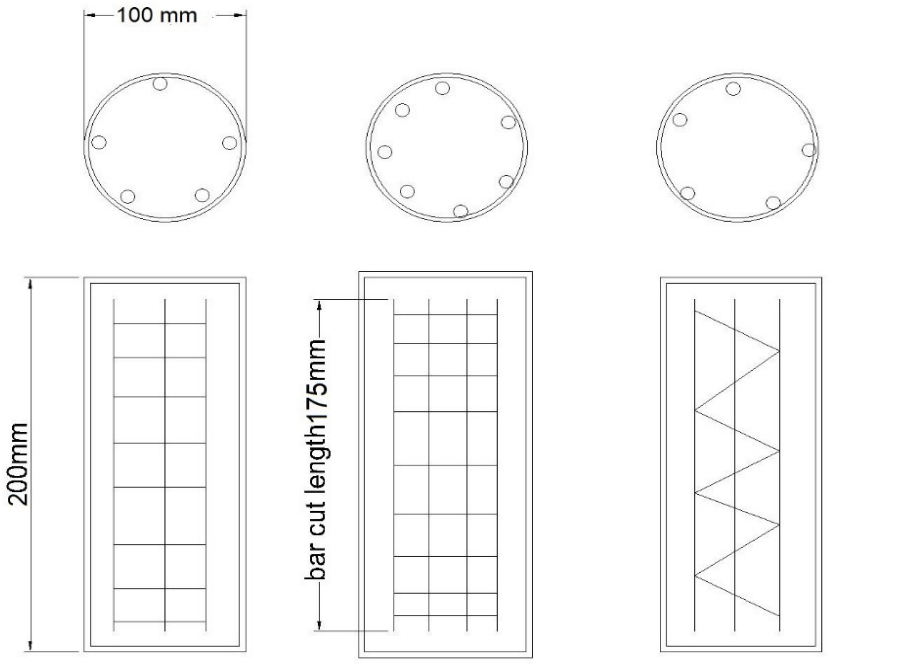

FIGURE 3.5: Reinforcement Detailing and Dimensions

3.5 Testing Procedure for Prototype Circular Columns

3.5.1 Dynamic Testing

According to ASTM 215-14 Table 3.3, a dynamic test is conducted on the specimens before the destructive (mechanical) test. With the use of a hammer and an accelerometer, the response frequencies lateral (RFL), response frequencies transverse (RFT), and response frequencies rotational (RFR) are identified. Both cylinders and beamlets are used in the test. An accelerometer is mounted to one side of the cross section of cylinders and beamlets to measure the RFL, and the other side of the cross section of the specimens is struck with a hammer.

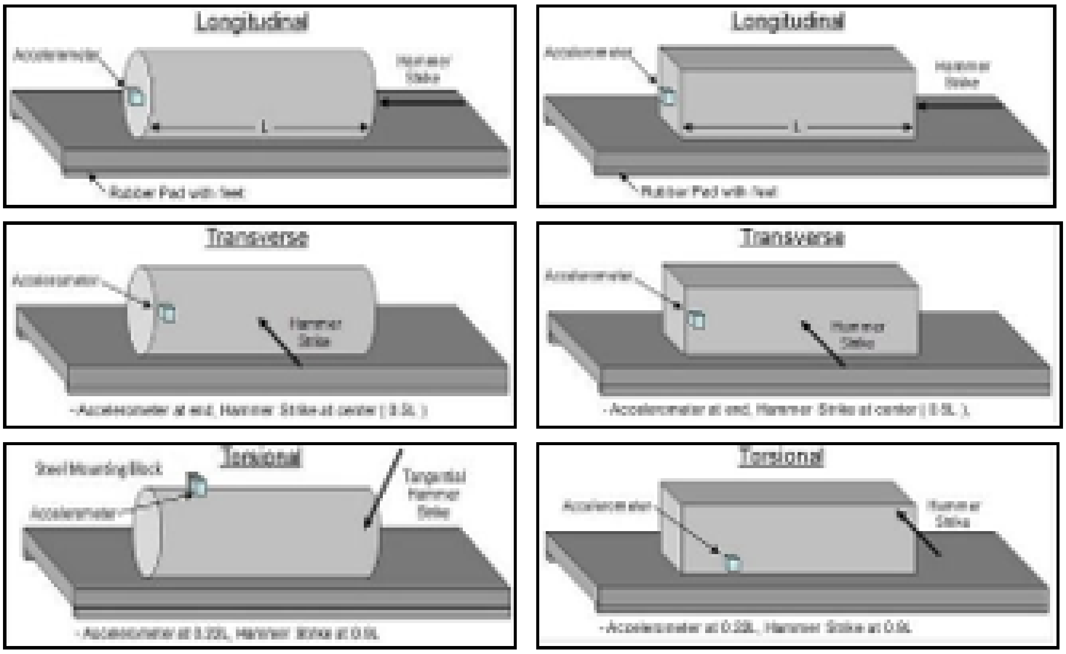

FIGURE 3.6: Fundamental apparatus for dynamic testing as per ASTM C215 [58] for; a) Longitudinal frequency, b) Transverse frequency, and c) Torsional frequency.

The accelerometer records the frequencies it sees and sends them to the computer that is connected to it. For cylinders and beamlets, the RFT and RFR processes used to attach the accelerometer and determine the hammer hit site are different. For RFT, the accelerometer is mounted to the side of the cylinder indicating the length of the cylinder at least 25 cm before the edge. Then a hammer blow is delivered at the same side that is facing the middle of the cylinder's length. The accelerometer for RFR is mounted at the top and displays the length of the cylinder with the same distance from the edge as RFT. The strike is delivered at an accelerometer that is perpendicular to the opposite cylinder length edge. For the purpose of determining RFT, an accelerometer that is attached to one side of the length at the same margin as used for cylinders is placed on the length of the beamlets from the edge. Hammer blows are delivered at the length's centre on the same side that the accelerometer is mounted. The accelerometer for RFR is mounted to the upper corner of the rectangle (side face of the beamlet). A strike is made at the opposite side's bottom corner of the same side of the rectangle in such a manner that the diagonal of the rectangle is formed by the line connecting the hammer's striking point and the accelerometer.

Table 3.7: Testing Standards and Studied Parameters

Test	**Followed Standards**	**Focused Parameters**	**Additional Parameters Considered for Study**
Compressive properties	ASTM C39	compressive strength (C-S)	- Stress–strain curves - Compressive Pre-crack energy absorption - Compressive post crack energy absorption - Compressive total energy absorption - Compressive toughness indexes - Modulus of elasticity
Splitting tensile properties	ASTM C496	Splitting- tensile strength (STS)	Load deformation curves, splitting-tensile pre-crack energy absorption (SE1), splitting- tensile post-crack energy ab energy absorption (STE)
Flexural properties	ASTMC78, ASTM C1609	Flexural Strength (F-S)	Load-deflection curves, flexural pre-crack energy absorption, flexural post-crack energy absorption, flexural total energy absorption (FTE) and flexural toughness indexes (FTI).

Continued Table 3.6 Testing Standards and Studied Parameters

Test	**Followed Standards**	**Focused Parameters**	**Additional Parameters Considered for Study**
Dynamic properties	ASTM C215-14	fundamental frequency longitudinal(RFL), fundamental frequency trans- verse (RFT), fundamental frequency torsional (RFR), damping ratio	No other variables were examined.
	ASTM C1548	Dynamic modulus of elasticity	
		(DME), Dynamic modulus of rigidity (DMR), Poisson ratio	
			No other variables were examined.
Role of fibers in concrete	(Affan & Ali, 2022)	Broken surfaces of specimen, failure	Fiber breakage and fiber pull out in case of hybrid fibers.
		Mechanism of fibers, and bonding of fiber with the surrounding matrix	

The damping ratio, dynamic elasticity modulus, dynamic modulus of rigidity, and poisson's ratios are computed from these measured harmonics. These estimated parameters aid in understanding PC performance and resistance to lateral loads, as well as those of all varieties of JWS-FRCs.

3.5.2 Concentric Load Testing

The compressive strength, energy absorption, and compressive toughness index of PRC and JFRC prototype columns were determined according to ASTM standard C39/C39M-18 [14]. The Prototype circular columns were capped with plaster of Paris to evenly distribute the load across the cross sectional area. For concentric load testing, the CUST civil engineering laboratory's servo-hydro testing machine (STM) was used. The load mechanism for concentric testing is depicted in Fig. 3.5.

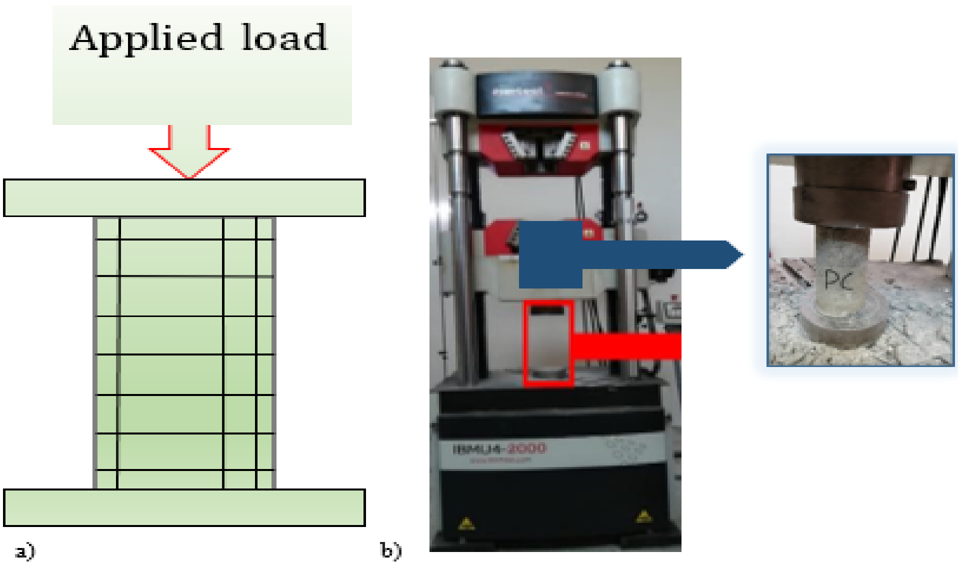

FIGURE 3.7: Concentric Load Mechanism: a) Schematic Diagram and b) Experimental Test Set Up with Actual Prototype to be Placed

3.6 Summary

The non-destructive dynamic properties of PC and JFC specimens, such as fundamental frequencies and damping ratios are determined. The mechanical characteristics of PC and JFC Specimens were determined after dynamic testing. When compared to PC specimens, jute fiber Specimens had higher damping ratios and better performance. The behavior and crack Restraining features of PC and JFC specimens were examined using mechanical characteristics. Except for compressive strength, all attributes have improved. When compared to PC specimens, JFC specimens have a better overall performance.

Chapter 4

Data Analysis and Discussion

4.1 Background

Plain reinforced concrete (PRC) specimens are made with a mix design proportion of 1:2:3:0.7 (cement: sand: aggregate: water/cement). The same mix percentage is used to make jute fiber reinforced concrete (JFRC) specimens, with the addition of 5% jute fibers by mass of cement. Jute strands with a constant length of 50 mm are used throughout the project. The results of dynamic testing for prototypes, as well as the structural performance and behavior of prototype circular columns, are addressed in depth in this chapter.

4.2 Frequencies and Damping Ratios of Prototype Circular Columns

During any seismic event, the damping ratios and energy dissipation capability of the RC column are critical, as fundamental can create and induce catastrophic failures in seismically active areas. Chopra [59] found that increasing damping lowered the structure's reaction to external dynamic loads. The damping ratio was determined to test the efficiency of jute fibers in prototype circular columns. All prototype columns' fundamental frequencies, such as longitudinal frequency (fl), transverse frequency (ft), and torsional frequency (fr), as well as damping ratios (ξ), are shown in **Table 4.1**.

For comparison, prototype 5SJC with 5SPC it can be noted that longitudinal frequency (fl), transverse frequency (ft), and torsional frequency (fr) reduced up to 275Hz, 220Hz, 186Hz respectively and damping ratio increases up to 59.40%. When prototype 5GJC is compared with 5GPC that longitudinal frequency (fl), transverse frequency (ft), and torsional frequency (fr) reduced up to 231 Hz, 726 Hz, 88 Hz respectively and damping ratio increases up to 69.57%. Prototype 7SJC with 7SPC it can be noted that longitudinal frequency (fl), transverse frequency (ft), and torsional frequency (fr) reduced up to 309 Hz, 193 Hz, 200 Hz respectively and damping ratio increases up to 63.04%. Similarly, when prototype 7GJC is compared with 7GPC that longitudinal frequency (fl), transverse frequency (ft), and torsional frequency (fr) reduced up to 222Hz, 700Hz, 25Hz respectively and damping ratio increases up to 62.8%.

For comparison in replacement of GFRP rebars with steel rebars, prototype 5SPC with 5GPC shows reduction in longitudinal frequency (fl), transverse frequency (ft), and torsional frequency (fr) up to 100Hz, 111Hz, 99Hz respectively and damping ratio increases up to 19.7%. Prototype 5GJC with 5SJC shows reduction in longitudinal frequency (fl), transverse frequency (ft), and torsional frequency (fr) up to 56Hz, 395Hz, 1Hz respectively and damping ratio increases up to 27.3%. prototype 7GPC with 7SPC shows reduction in longitudinal frequency (fl), transverse frequency (ft) up to 120Hz, 103Hz, respectively and torsional frequency (ft) damping ratio increases up to 151Hz and 24.63% respectively. Prototype 7GJC with 7SJC shows reduction in longitudinal frequency (fl), transverse frequency (ft), and torsional frequency (fr) up 33Hz, 357Hz, 72Hz respectively and damping ratio increases up to 26.7%. Results show that in JFRC specimen's fundamental frequencies shows reduction as compared to PRC prototype specimens while damping ratio in JFRC prototype specimen's increases as compared to PRC specimens

The longitudinal frequency (fl), transverse frequency (ft), and torsional frequency (fr) of prototype 5SPC with spiral compared with 5SPC with ties reduced up to 43Hz, 128Hz, and 102Hz respectively and no change in damping ratio (ξ) is observed. Prototype 5SJC with spiral when compared with 5SJC with ties longitudinal frequency (fl), transverse frequency (ft), and torsional frequency (fr) reduced up to 58Hz, 100Hz, Hz respectively and damping ratio increase upto 3.7%. Prototype 5GPC with spiral when compared with 5GPC with ties longitudinal frequency (fl), transverse frequency (ft), and torsional frequency (fr) reduced up to 51Hz, 155Hz, 97Hz respectively and damping ratio increase up to 14.7%. Similarly, when Prototype 5GJC with spiral when compared with GJC with ties longitudinal frequency (fl), transverse frequency (ft), and torsional frequency (fr) reduced up to 98Hz, 98Hz, 142Hz respectively and damping ratio increase up to 3.38%. Increase in damping ratio demonstrates the value of using jute fibers for increased ductility demand capability. Results when compared to PC and JFC specimens' reduction in lingitudnal frequency, torsional frequency and rotational frequency and increased damping ration is observed.

As ductility capacity is enhanced, increasing damping ratios are one step closer to improving building safety and serviceability. As a result, by improving material qualities in active seismic zones, catastrophic collapse can be avoided. The results for fundamental frequencies and damping ratios of PRC and JFRC prototype circular columns are reported here:

Fig. 4.1 compares non-destructive dynamic properties for prototype columns of PRC with JFRC prototype columns. Fig illustrates that reduction in fundamental frequencies of JFC prototype specimens were observed due to presence of jute fiber in prototype specimens as compared to PC specimens. While damping ration JFC prototype specimens increases as compared to PC prototype specimens. Prototype 5SJC with 5SPC it can be noted that longitudinal frequency (fl), transverse frequency (ft), and torsional frequency (fr) reduced up to 16%, 10.8%, 9.8% respectively and damping ratio increases up to 59.40%. When prototype 5GJC is compared with 5GPC that fl, ft, and fr reduced up to 15.07%, 34.2%, 4.9% respectively and damping ratio increases up to 60.5%. Prototype 7SJC with 7SPC it can be noted that fl, ft, and fr reduced up to 19.6, 9.9%, 11.09% respectively and damping ratio increases up to 60.11%. Similarly, when prototype 7GJC is compared with 7GPC that fl, ft, and fr reduced up to 14.79%, 33.58%, 1.47% respectively and damping ratio increases up to 62.8%.

Table 4.1: Fundamental Frequency and Damping Ratios for Prototypes Specimens

Specimen	**No of Specimen for Average**	**Fundamental Frequency**			**Damping Ratio %**
		fl (Hz)	**ft (Hz)**	**fr (Hz)**	ξ
5SPC	2	1632 ± 19	2023 ± 21	1885 ± 43	3.35 ± 0.21
5SJC	2	1357 ± 63	1803 ± 290	1699 ± 95	5.34 ± 0.25
5GPC	2	1532± 98	2134 ± 108	1786 ± 94	4.01 ± 0.22
5GJC	2	1301 ± 101	1408 ± 54	1698 ± 378	6.8 ± 0.79
7SPC	2	1621 ± 78	1936 ±36	1803 ±201	3.41 ±0.32
7SJC	2	1312 ±54	1743 ±176	1603 ±94	5.46 ±0.12
7GPC	2	1501 ±102	2087 ±59	1700 ±103	4.25 ±0.26
7GJC	2	1279 ±132	1386 ±76	1675 ±176	6.92 ±0.31
5SPC*	2	1589 ±32	1895 ±141	1783 ±147	3.53 ±0.43
5SJC*	2	1299 ±70	1703 ±56	1567 ±69	5.54 ±0.21
5GPC*	2	1481 ±107	1979 ±123	1689 ±23	4.6 ±0.41
5GJC*	2	1203 ±74	1310 ±108	1556 ±112	7.03 ±0.35

fl = Longitudinal frequency, ft = Transverse frequency, fr = Rotational/ Torsional frequency.

For comparison in replacement of GFRP rebar's with steel rebar's, prototype 5SPC with 5GPC shows reduction in fl, ft, and fr up to 6.12%, 5.4%, 5.25% respectively and damping ratio increases up to 19.7%. Prototype 5GJC with 5SJC shows reduction in fl, ft, and fr up to 4.01%, 21.9%, 1% respectively and damping ratio increases up to 27.34%. Prototype 7SPC with 7GPC shows reduction in fl, ft, fr up to 7.4%, 7.79%and 5.4% respectively damping ratio increases up 24.6% respectively. Prototype 7GJC with 7SJC shows reduction in fl, ft, and fr up to 2.5%, 20.48%,20% respectively and damping ratio increases up to 21%.

The longitudinal frequency (fl), transverse frequency (ft), and torsional frequency (fr) of prototype 5SPC with spiral compared with 5SPC with ties reduced up to 2.6%, 6.3%, 5.4% respectively and no change in damping ratio (χ) is observed. Prototype 5SJC with spiral when compared with 5SJC with ties fl, ft, and fr reduced up to 4.2%, 5.5%, 87.7% respectively and damping ratio increase up to 3.7%.Prototype 5GPC with spiral when compared with GPC with ties fl, ft, and fr reduced up to 3.32%, 7.2%, 4.8% respectively and damping ratio increase up to 14.71%. Similarly, when Prototype 5GJC with spiral when compared with GJC with ties fl, ft, and fr reduced up to 8%, 7.5%, 9% respectively and damping ratio increase up to 3%. This increase in damping ratio demonstrates the value of using jute fibers for increased ductility demand capability. The structural response of an RC column to strong ground shaking is reduced as the damping ratios are increased. The calculated findings showed that JFRC prototype circular columns had higher damping ratios than PRC prototype circular columns. Enhancement in damping ratios was also observed by Yan and Chouw for coconut fiber-reinforced concrete [60]. Prototype 7SPC with 7GPC shows reduction in fl, ft, fr up to 7.4%, 7.79%and 5.4% respectively damping ratio increases up 24.6% respectively. Prototype 7GJC with 7SJC shows reduction in fl, ft, and fr up to 2.5%, 20.48%,20% respectively and damping ratio increases up to 21%.

In this study, longitudinal steel rebars were replaced by GFRP rebars. Steel rebars were used in both cases for transverse shear reinforcement, with the addition of jute fibers in scaled-down prototype circular RC columns. The effectiveness of jute fibers and GFRP rebars in compression members was investigated in all prototype circular columns.

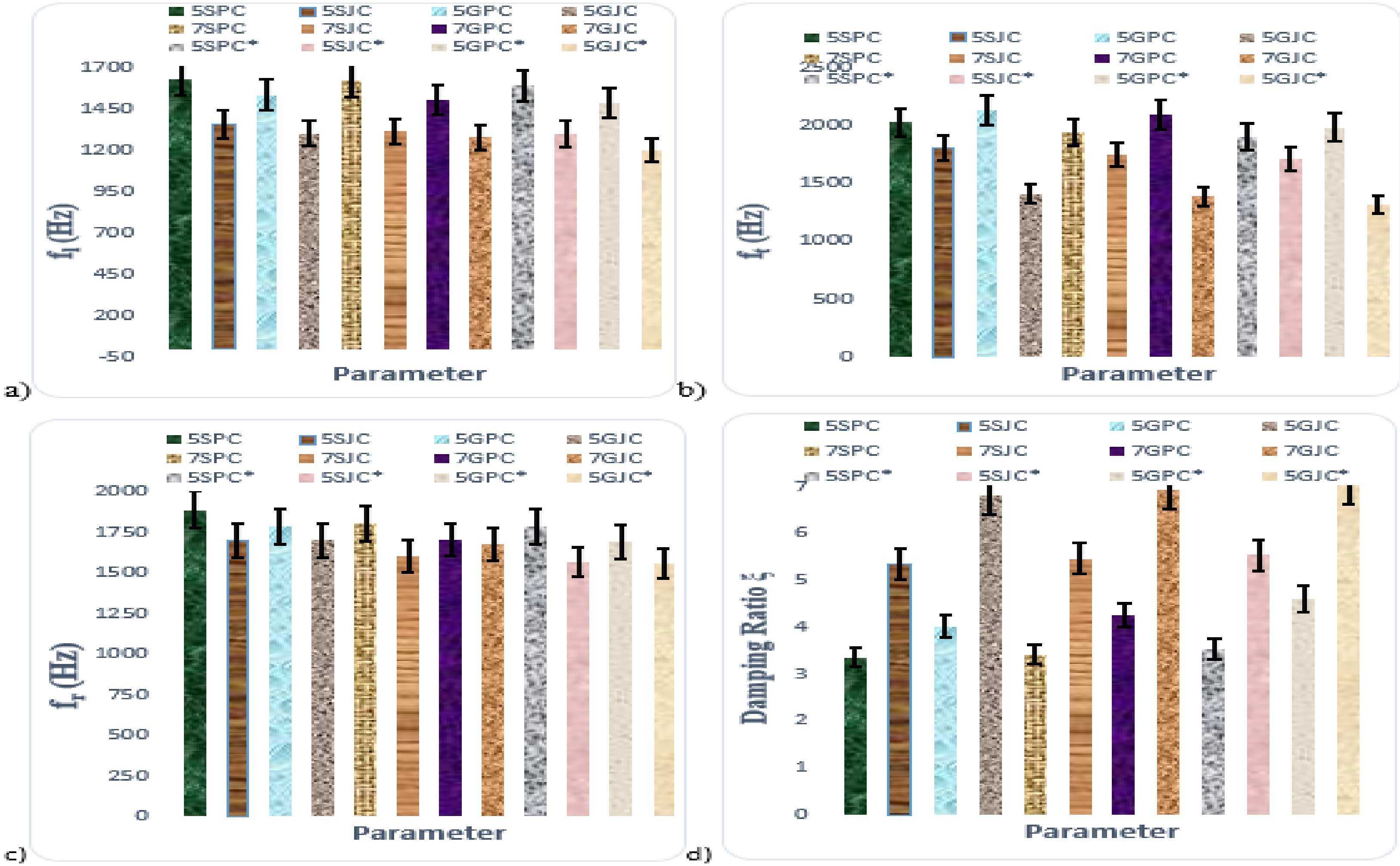

Figure 4.1: Comparison of Dynamic Testing Results for Prototypes

4.3 Structural Behavior of Prototype Circular Columns

The experimental results of the PRC and JFRC prototype circular columns examined are summarized in **Table 4.2**. PRC and JFRC prototype circular columns have properties such as maximum load has taken (P.m), strength in compression (S.C), compressive energy absorption from initial to maximum load (E1.C), energy absorption from maximum to ultimate load (Ecr. C), total energy absorption (T.E.C), total toughness index (T.T.I), and failure mode. JFRC prototype specimen shows reduction in load carrying capacity and compressive strength with comparison to PRC. When 5SJC JFRC prototype compared with 5SPC PRC prototype circular column reduction in compressive strength up to 20% was observed and increment in toughness index up to 67%. Prototype 5GJC compared with 5GPC reduction in compressive strength up to 26.8% was observed and increment in toughness index up to 49.46%. When 7SJC JFRC prototype compared with 7SPC PRC prototype circular column reduction in compressive strength up to 7.6% was observed and increment in toughness index up to 3.7%. Prototype 7GJC compared with 7GPC reduction in compressive strength up to 8.5% was observed and increment in toughness index up to 36%. When steel bars are replaced by GFRP rebar's reduction in load carrying capacity and compressive strength were observed and increment in energy absorption and toughness index was observed. Prototype 5GPC compared with 5SPC reduction in compressive strength up to 26.7% and increment of toughness index up to 24% was observed. Similarly when 5GJC is compared with 5SJC reduction in compressive strength up to 32.17% and increment of toughness index up to 11.02% was observed. Prototype 7GPC compared with 7SPC reduction in compressive strength up to 30.92% and increment of toughness index up to 12.02% was observed. Similarly when 7GJC is compared with 7SJC reduction in compressive strength up to 31.49% and increment of toughness index up to 15.7% was observed. Reduction in load carrying capacity and strength is observed in JFRC having GFRP rebar's and ties in prototype specimens as compared to PRC prototype specimens having steel bars. While Prototype with JFRC prototype having spirals have increased strength and load carrying capacity as compare to specimens having ties. The compressive strength of prototype 5SPC with spiral compared with 5SPC with ties compressive strength decreased up to 9.58% and toughness index increased up to 22%. Prototype 5SJC with spiral when compared with 5SJC with ties compressive strength increased up to 34.7% and toughness index reduced up to 6. 29%.Prototype 5GPC with spiral when compared with 5GPC with ties compressive strength increased up to 43.13% and toughness index increased up to 34.2%. Similarly, when Prototype 5GJC with spiral when compared with 5GJC with compressive strength increased up to 90% and toughness index reduce up to 9.6%. JFRC samples shows bridging behavior while PRC prototype samples shows crushing behavior. JFRC prototype specimen's shows bridging behavior due to presence of fibers where as PRC column shows crushing behavior.

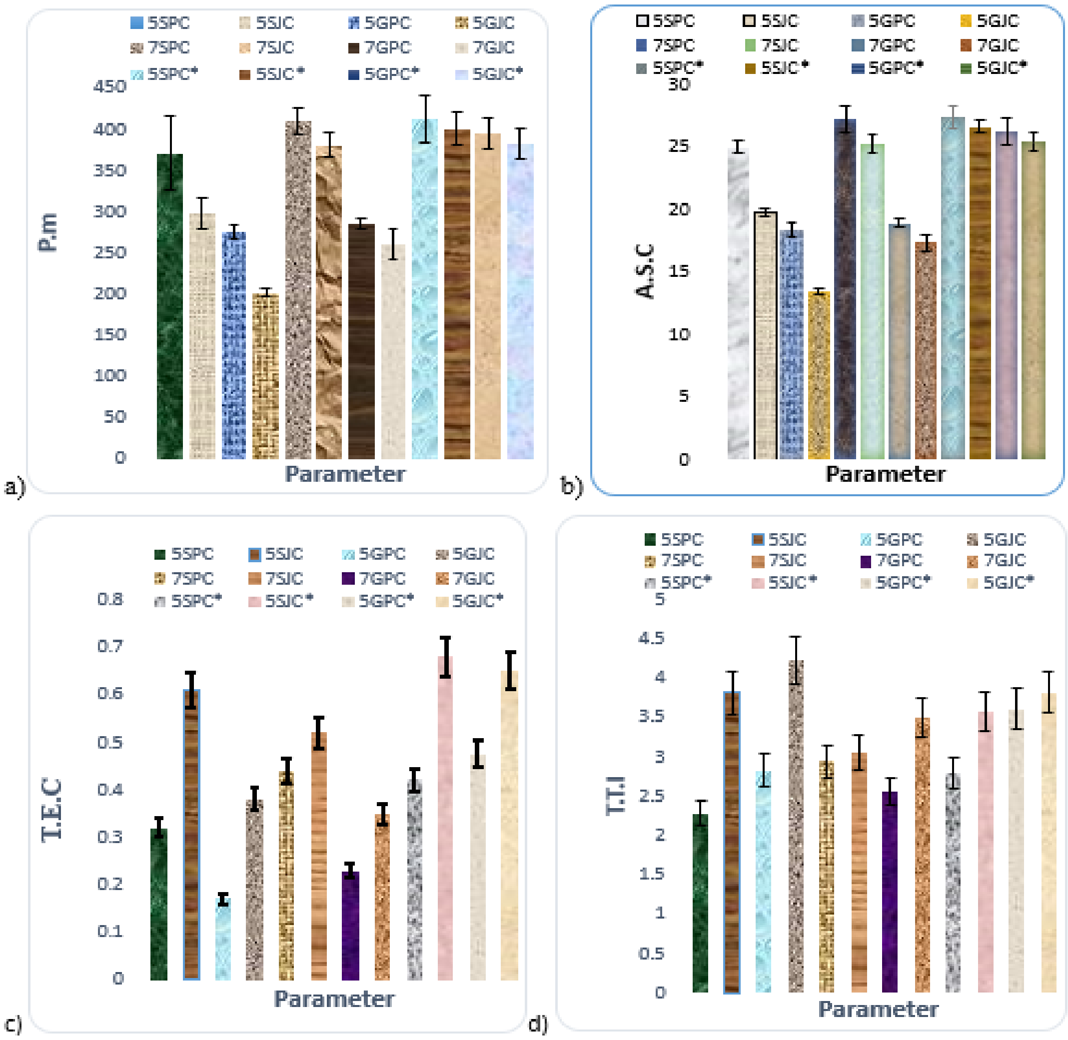

FIGURE 4.2: Comparison of Various Properties of Prototype Circular Column

TABLE 4.2: Experimental Results of Tested Prototypes

Specimen	**P.m (kN)**	**A.S.C (MPa)**	**E1.C (MJ/m3)**	**Ecr. C (MJ/m3)**	**T.E.C (MJ/m3)**	**T.T.I (-)**	**Failure Mode**
5SPC	376±12	25.01±0.8	0.14±0.05	0.21±0.01	0.32±0.06	2.28±0.3	Crushing
5SJC	298±6	19.8±0.6	0.16±0.03	0.45±0.01	0.61±0.04	3.81±0.7	Bridging
5GPC	276±3	18.36±0.3	0.06±0.07	0.11±0.01	0.17±0.09	2.83±0.3	Crushing
5GJC	202±2	13.43±0.2	0.09±0.02	0.29±0.02	0.38±0.04	4.23±0.5	Bridging
7SPC	410±4	27.27±0.1	0.15±0.002	0.29±0.01	0.44±0.01	2.94±0.21	Crushing
7SJC	381±11	25.34±0.21	0.17±0.11	0.35±0.03	0.52±0.14	3.05±0.27	Bridging
7GPC	285±2	18.96±0.52	0.09±0.1	0.14±0.3	0.23±0.4	2.56±0.35	Crushing
7GJC	261±7	17.36±0.23	0.10±0.2	0.25±0.21	0.35±0.41	3.5±0.2	Bridging
5SPC*	412±5	27.41±0.12	0.15±0.2	0.27±0.11	0.42±0.21	2.8±0.4	Crushing
5SJC*	401±7	26.67±0.3	0.19±0.10	0.49±0.21	0.68±0.31	3.57±0.3	Bridging
5GPC*	395±6	26.28±0.2	0.13±0.02	0.31±0.03	0.47±0.05	3.61±0.1	Crushing
5GJC*	382±3	25.41±0.32	0.17±0.03	0.48±0.2	0.65±0.23	3.82±0.2	Bridging

Note: Two readings are averaged together. For compressive strength testing, ASTM standard C39/C39M-18 specifies a loading rate of 0.19 MPa/sec and 0.27 MPa/sec.

C. Em = Compressive energy absorption up to maximum load. C. Ecr = Compressive cracked energy-absorption after maximum load. C. E = Total compressive energy absorption. C.T.I = C.E/C.Em = Compressive toughness index.

Fig. 4.4 shows the stress-strain relationship for 5SPC, 5JC, 5GPC and 5GJC prototype circular columns. It is observed that the strain increased for 5SJC and 5GJC prototypes however decrement in strain is observed for 5SPC and 5GPC prototypes. Furthermore, prototype 5SPC and 5GPC show maximum compressive strength followed by prototype 5SJC. It is observed from the graph that the prototype 5SPC and 5GPC carries more strength as compared to 5SJC and 5GJC but shows less ductile behavior as the curve drops immediately after reaching a certain point and strain stops at a certain point.

However, 5SJC carry low strength but demonstrate more ductile behavior than 5SPC and 5SPC and curve fall gradually as the strain is increased after a certain point. A similar increasing trend in strain is seen for 5GJC prototype as compared to 5GPC and. The addition of jute fibers in 5SJC and 5GJC is the reason for the increment in strain and a more gradual drop of the curve. As a result, it is possible to conclude that the bridging effect between jute fibers and concrete in JFRC prototypes is the cause of increased strain, ductility, and improved performance.

An average of two reading is taken. As per ASTM standard C39/C39M-18 loading rate is 0.19 MPa/sec and 0.27 MPa/sec for compressive strength test.

The appearance of crack propagation in a prototype circular column is depicted in Fig. 4.3 with an actual situation and schematic diagrams at initial, maximum, and ultimate loads for prototype circular column of 5SPC, 5SJC with ties, 5GPC with ties, 5GJC with ties, 7SPC with ties, 7SJC with ties, 7GPC with ties, 7GJC with ties, 5SPC with spirals, 5SJC with spirals, 5GPC with spirals, 5GJC with spirals. The applied concentric load is clearly evident from the actual scenario image and schematic diagram. For prototype 5SPC with spiral and ties and 7SPC small cracks at initial stage occurred.

However, cracks were smaller in width and length, and there were fewer cracks, but at the maximum load, more visible and larger cracks in breadth, length, and quantity emerged. Furthermore at ultimate load prototype 5SPC with spiral and ties and 7SPC some of the fragments were fractured and fell down, demonstrating spalling and crushing failure.

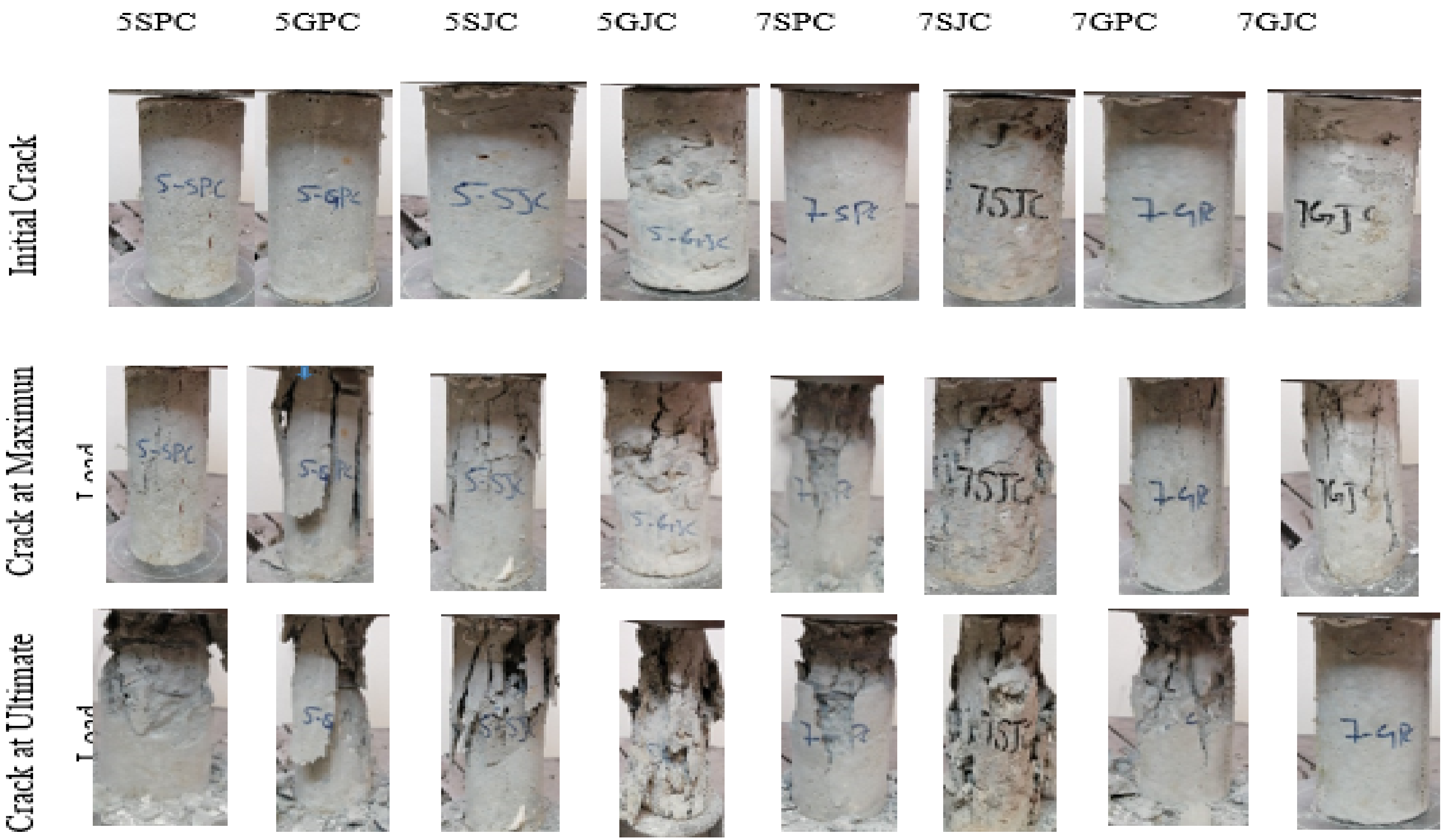

FIGURE 4.3: Crack Propagation

5SPC(S) 5SJC(S) 5GPC(S) 5GJC(S)

Initial Crack

Crack at Maximum Load

Crack at Ultimate Load

Similar behavior was observed for prototype 5GPC with spiral and ties and 7GPC at initial loading but at maximum load the crack were much larger than 5SPC with spiral and ties and 7SPC and some of the fragments fallen down as a result of crushing failure. Prototype column 5SJC with spiral and ties and 7SJC at initial loading, a hair line crack was visible, and as the load was raised, only the crack diameter, length, and number grew. Furthermore, the failure mode was switched from crushing to bridging effectThis bridging effect of jute fibers has prevented fracture propagation from becoming much larger, resulting in more load being taken and more strain is produced in 5SJC with spiral and ties and 7SJC and 5GJC with spiral and ties and 7GJC prototype columns. Durability of 5SJC with spiral and ties and 7SJC and 5GJC with spiral and ties and 7GJC prototype enhanced due to better bonding mechanism of jute fibers. In addition, several JFRC prototypes were purposely broken in order to learn more about how jute fibers fail. 60% of the jute fibers had been damaged, while the remaining 40% had been removed from the matrix. The utilization of jute fibers in concrete is demonstrated by the crack restraining mechanism, increased ductility capacity, and improved structural performance of JFRC prototypes. The compressive strength of JFRC specimens is lower than that of PRC specimens, however characteristics like as energy and toughness index have enhanced greatly in JFRC specimens.

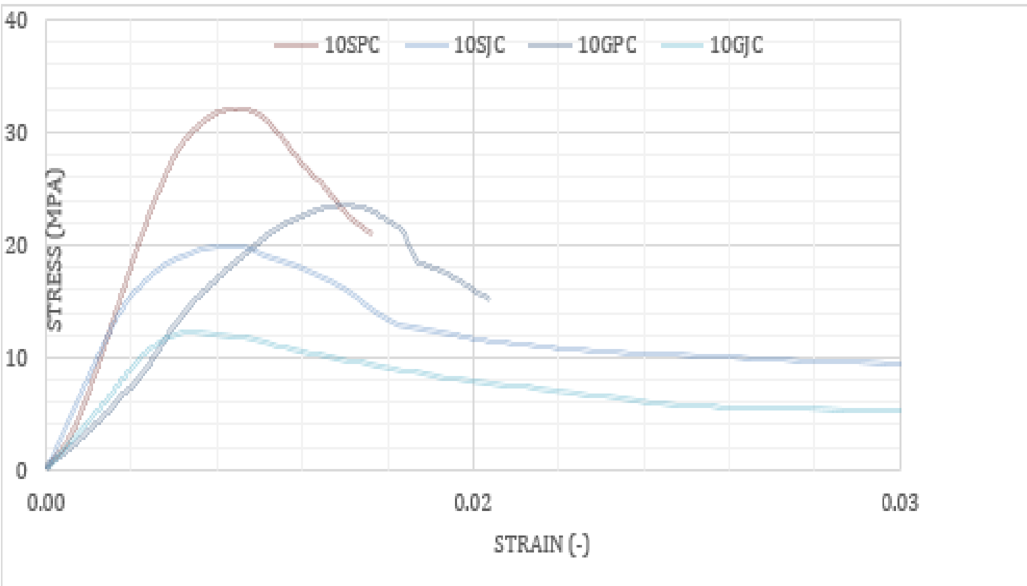

FIGURE 4.4: Compressive Behavior of Prototype Circular Columns, a) Cracking Behavior and b) Stress-Strain Relationship

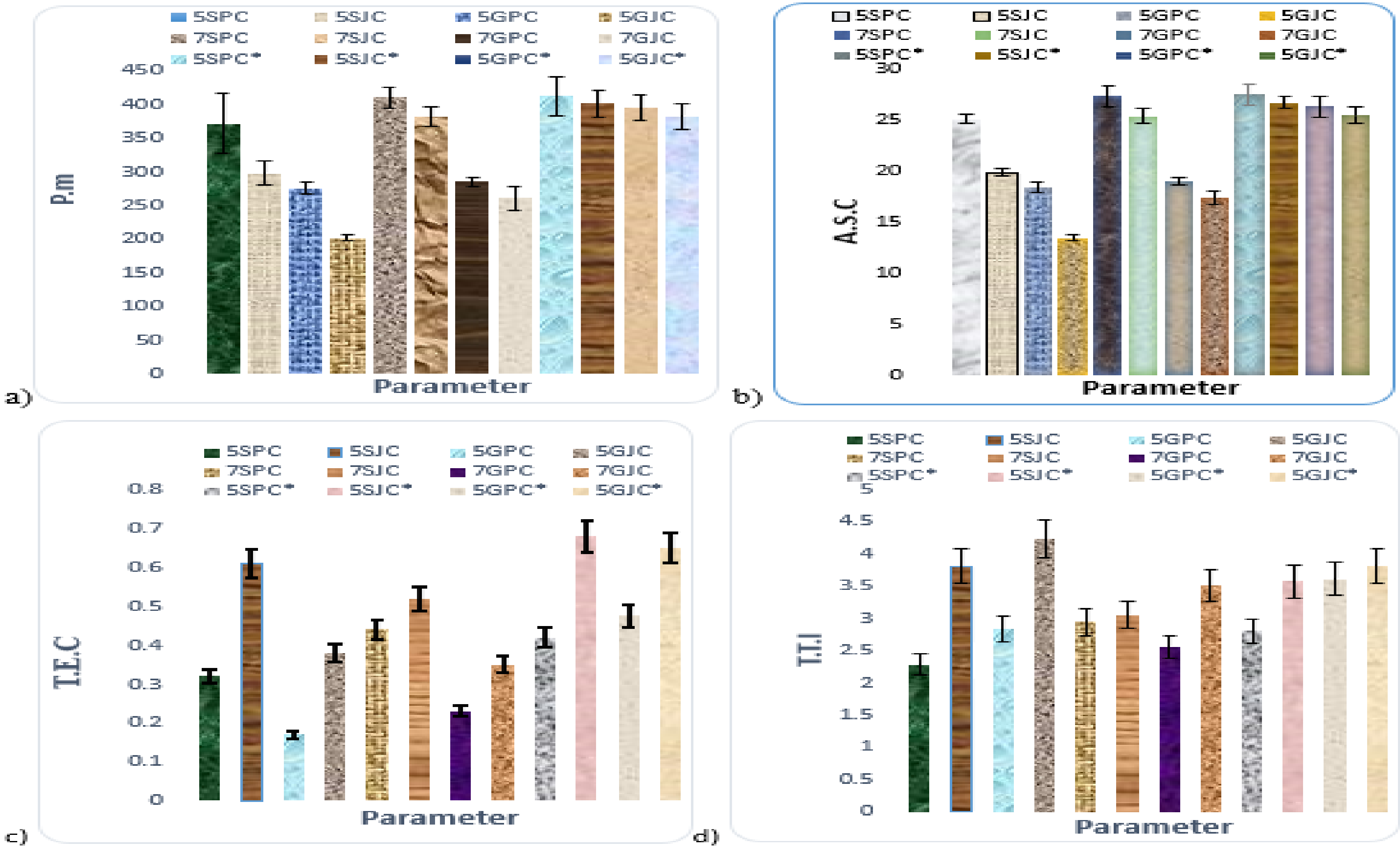

Figure 4.5: Comparison of Various Properties of Prototype Circular Column

Figure. 4.5 Displays a comparison of prototype columns' compressive characteristics. S.C, E.C, E1.C, Ecr.C, T.E.C, and T.T.I have all been compared using 5SPC with spiral and ties and 7SPC as a reference prototype. It is evident from the graph that prototype 5SPC with spiral and ties and 7SPC shows increase in load carrying capacities up to 30%, 18% and 48% as compared to prototype 5SJC with spiral and ties and 7SJC, 5GPC with spiral and ties and 7GPCand 5GJC with spiral and ties and 7GJC. The compressive strength was increased up to 43%, 22% and 94% for prototype 5SPC with spiral and ties and 7SPC as compared to 5SJC with spiral and ties and 7SJC, 5GPC with spiral and ties and 7GPC and 5GJC with spiral and ties and 7GJC. This reduction in compressive strength for 5SJC with spiral and ties and 7SJC and 5GJC with spiral and ties and 7GJC may be due to assimilation of jute fibers in concrete.

The post cracked energy absorption (Ecr.C) for 5SJC with spiral and ties and 7SJC, 5GJC with spiral and ties and 7GJC increased up to 350%, 160% whereas Ecr.C for 5GPC with spiral and ties and 7GPC reduced up to 20% as compared to prototype 5SPC with spiral and ties and 7SPC. The total energy absorption increased for 5SJC with spiral and ties and 7SJC and 5GJC with spiral and ties and 7GJC up to 211% and 88% whereas for 5GPC with spiral and ties and 7GPC T.E.C reduced up to 16.6% as compared to prototype 5SPC with spiral and ties and 7SPC. Enhancement in energy absorption is observed for all JFRC prototypes as compared to PRC prototypes. The T.T.I for prototype 5SJC with spiral and ties and 7SJC and 5GJC with spiral and ties and 7GJC increased up to 126% and 88% as compared to 5SPC with spiral and ties and 7SPC prototype column. When compared to PRC prototype circular columns, JFRC prototype circular columns showed improved mechanical properties except for compressive strength. Furthermore, as compared to PRC prototypes, JFRC prototypes showed ductile behaviour due to jute fibers.

4.4 Summary

The non-destructive dynamic features of the PRC and JFRC prototype circular columns, such as fundamental frequencies and damping ratios, are determined.

The compressive characteristics of PRC and JFRC prototype circular columns were established during dynamic testing. When compared to PRC prototype circular columns, JFRC prototype circular columns had higher damping ratios and improved structural performance. The structural behavior of PRC and JFRC prototypes, as well as crack restraining phenomena, have been investigated. Except for compressive strength, all attributes have improved. In general, JFRC prototype circular columns outperform PRC prototype circular columns in terms of structural performance

Chapter 5

Discussion

5.1 Background

In Chapter 4, the outcomes of the experimental study are discussed. JFRC prototypes showed improved damping ratios, improved crack restraining phenomena, and overall improved structural performance. The nominal capacity equation is updated in this chapter, and a link between material properties and prototype performance is established.

5.2 Relationship between Material Properties and Prototype Performance

JFC specimens showed less frequency and greater damping ratio as compared to PC specimens. The increment in JFC specimens is up to 1.7 times. Compressive, split and flexural strength of JFC specimens is decreased but the total energy and toughness index is increased. JFRC prototypes 5SJC with ties, 7SJC demonstrated less frequency and greater damping ratio as compared to PRC 5SPC with ties, 7SPC prototypes. Damping ratio increased up to 1.6mand 1.7 times for JFRC prototypes respectively as compared to the PRC 5SPC with ties, 7SPC prototypes. Prototype 5SJC with ties, 7SJC indicates lesser compressive energy and lesser compressive index as compared to 5SPC with ties, 7SPC prototypes. Utilization of jute fibers in concrete caused reduction in compressive strength however energy and toughness index significantly increased. Incorporation of jute fibers changed failure mode from crushing to bridging under eccentric compressive load. Both PC and PRC showed similar behavior as some of the fragments are broken down at ultimate load. However, JFC and JFRC due to the addition of jute fibers produced bridging effect. The width of cracks in PRC specimens is greater than JFRC specimens whereas in JFRC specimen's hair lines cracks were appeared.

The increment in damping of concrete by addition of JF helps a lot to have improved damping of columns having JFRC in all cases. There has been a significant reduction in material strength of concrete having JF and this considerable reduction is not observed in case of column performance. There is reduction of axial capacity of columns having JFRC but its reduction magnitude is less as compared to that observed in material strength. When steel rebar are replaced by GFRP rebar's Prototypes 5GJC with ties, 7GJC showed lesser frequencies and increase in damping ratio of 1.2 and 1.3 times as compared to 5SJC with. Prototype 5GJC with ties, 7GJC indicates lesser compressive energy and lesser compressive index as compared to 5GPC with ties, 7GPC prototypes. When prototype 5SJC with spiral and ties compare with 5SPC with spiral and ties reduction in frequency and increment in damping ratio is observed. Similarly when prototype 5GJC with spiral and ties compare with 5GPC with spiral and ties reduction in frequency and increment in damping ratio is observed. Utilizing GFRP rebar with jute fibers under an axial load situation is appropriate in a real-world scenario for a bulky cross sectional architectural circular column. Since jute fiber has a higher tensile strength than other natural fibers, it is the ideal choice for preventing fracture propagation.

5.3 Guidelines for Practicing Engineers

Columns are important elements in a structure. Its transfers load from beams to foundation. As bulky cross sectional circular columns are provided for architectural purposes in front of houses. These columns do not required normal strength concrete. GFRP rebar and JF should be used in these columns to reduce the corrosion and cracks. For column design, the quantity of reinforcement is based on the area of the column section. Oversized columns, widely referred to as "Architectural Columns", are often needed for aesthetic purposes resulting in less reinforcement ratio Engineers are encouraged to use GFRP rebar's and JF in architectural columns to reduce corrosion and cracks propagation. The steps for design of such columns are same with the consideration of taking into account the reduced compressive capacity of GFRP rebar's and JFRC.

5.4 Summary

There is created a relationship between the damping ratios of the JC and JFRC specimens. When compared to PC and PRC specimens, damping ratios for JFC and JFRC increased. Crushing is the mode of failure in PC and PRC specimens, but bridging owing to the inclusion of jute fibers was the mode of failure in JFC and JFRC specimens. Inclusion of jute fibers resulted in bridging effects in JFRC specimens and improved crack resistance. All other specimens were outperformed by prototypes made using glass rebar's and jute fibers.

Chapter 6

Conclusion and Future Work

6.1 Conclusions

The Axial Capacity of Circular Jute-Fiber-Reinforced-Concrete Columns with GFRP Rebar's is being investigated as part of an ongoing research program at Capital University of Science and Technology Islamabad. For the manufacturing of JFRC, a mix design ratio of 1:2:3:0.70 (C: S: A: W) with 50 mm fiber length and 5% jute fiber content by mass of cement was used. Experiments are carried out, the data are examined, and conclusions are drawn.

- Strengths of JFRC are reduced as compared to that of PC but the energy absorption and toughness indices are increased. Similarly damping of JFRC is also enhanced.

- Splitting tensile strength of JFC specimens decreased up to 31.87% while total energy and toughness index increased up to 338.38% and 85%, respectively than that of PC.

- The flexural strength of JFC specimens decreased up to 18.16% while total flexural energy and flexural toughness index increased up to 138.78% and 197%, respectively than that of PC.

- The compressive strength of JFC cylinder decreased up to 49.45% however the compressive energy and compressive toughness index increased up 18.1% and 150%, respectively as compared to PC cylinders.

- The damping ratio of columns in all cases having JF is increased and frequencies are decreased as compared to column having PC.
- Longitudinal frequencies (fl), transverse frequencies (ft), and torsional/rotational frequencies (fr) of columns prototypes are reduced by the addition of jute fibers in all considered cases.
- In the case of ties, the damping ratio improved by 7GJC in comparison with 5GJC and 7SJC in comparison with 5SJC. But, the use of steel spiral in 5GJC has enhanced damping than 5SJC with spirals.
- The axial capacities of columns having JF are reduced with increased in toughness.
- Compressive strength of 5SJC, 5GJC, 7SJC and 7GJC reduced up to 20%, 26.8%, 7.07% and 8.4% respectively as compared to 5SPC, 5GPC, 7SPC and 7GPC.
- Total energy absorption of 5SJC, 5GJC, 7SJC and 7GJC increased up to 90.6%, 123.5%, 18% and 53% respectively as compared to 5SPC, 5GPC, 7SPC and 7GPC.
- Total toughness index of 5SJC, 5GJC, 7SJC and 7GJC increased up to 67.10%, 49.46%, 3.7% and 36.7% respectively as compared to 5SPC, 5GPC, 7SPC and 7GPC
- Columns having GFRP rebar with spirals have been shown improved damping efficiency
- Columns having JFRC with significance reduced compressive strength can have reasonable performance

As a nutshell, jute fibers combined with GFRP rebar can be a useful building materials for use in concrete where strength is not a primary requirement and architectural aesthetics is of prime importance as columns in major structures to improve structural performance. It is recommended that international design codes assess their own member's design codes.

6.2 Future Work

- Dynamic response of columns for post crack stage may be explored in detail.
- Full-scale testing with real boundaries conditions should be done before practical implementation in the construction industry.
- Experimental outcomes of scaled down and full-scale specimen may be validated by analytical approach or simulation with ABACUS software.

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