CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Behavior of Jute Fiber Reinforced Concrete having Glass Fiber Reinforced Polymer Rebars for Possible Application in Bridge Pier

by

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in the

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Department of Civil Engineering

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First I would like to thank Great Almighty Allah who gave me an opportunity to undertake this milestone and then I would like to initiate all of this hard work to my caring family, who facilitate me through every obstacle and worry of my life and sacrificed all the comforts of their lives for my future endeavours. I would like to express my sincere gratitude to my supervisor for his continuous support, patience, motivation and immense knowledge. His invaluable comments and suggestions throughout the research work have contributed to the success of this research.

CERTIFICATE OF APPROVAL

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Abstract

Glass Fiber Reinforced Polymer Rebars (GFRP) has an emerging alternative solution of steel reinforcement for concrete structures due to its upgraded properties like high tensile strength, lightweight, and corrosions resistance. Vegetable fibers (especially, jute fiber) is a natural fiber, with low cost, having high tensile strength, and abundantly available in tropical regions. Jute fibers are used to improve the toughness, durability, shrinkage and crack propagation in concrete. The overall purpose of the research program is to replace longitudinal steel with GFRP rebars in Fiber Reinforced Concrete (FRC) for bridge pier to improve its performance. In this study, an investigation has been carried out to examine the behavior of prototype vertical members having a different number of GFRP rebars in JFRC for application of bridge pier. The lateral confining steel reinforcement will also be varied to incorporate the confining effect. The mix design fraction 1:2:3:0.60 (C:S:A:w/c) of PC and JFRC is used, with the addition of 5% jute fiber by mass of cement, having 50 mm length. The mechanical properties (splitting tensile, energies toughness indices, flexural and compressive strengths), are investigated as per ASTM standards. The dynamic characteristics of PC and JFRC specimens are also determined. A total of sixteen prototype specimens of PRC and JFRC (eight each) with a width of 100 mm, a height of 100 mm and a length of 450 mm were cast and tested under axial load condition.

The slump value of JFRC specimens is 40% less than PC with same mix design proportion. JFRC specimens' density is also less due to the light weight of jute fibers. The damping ratio of JFRC samples is higher than PC samples which shows more energy dissipations as compared to PC samples. PC and JFRC specimens are tested in a servo-hydraulic testing machine (STM). The behavior of concrete failure converted from spalling to bridging, energy, and toughness of concrete is also enhanced by the addition of jute fibers in ordinary concrete. In order to enrich the performance of jute fiber, concrete having GFRP with different diameter and admixtures with varying dosages shall be investigated.

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List of Abbreviations

A	Aggregate
C	Cement
S	Sand
w/c	Water-cement
CS	Compressive strength
STS	Splitting tensile strength
FS	Flexural strength
$\mathbf{P}_{max}$	Maximum load
$\mathbf{E}_{m}$	Energy-absorption upto maximum load
Cr. E	Cracked energy absorption after maximum load
TE	Total energy absorbed
TTI	Total Toughness Index
$\mathbf{f}_{l}$	Longitudinal frequency
$\mathbf{f}_{t}$	Transverse frequency
$\mathbf{f}_{r}$	Torsional frequency
s	second
C.Em	Compressive energy-absorption upto maximum load
Cr. E	Compressive cracked energy-absorption after maximum load
CE	Total compressive energy absorbed
CTI	Compressive toughness index
JF	Jute Fiber
PC	Plain concrete
PRC	Plain reinforced concrete
FRC	Fiber reinforced concrete

JFC	Jute fiber concrete
JFRC	Jute fiber reinforced concrete
GFRP	Glass fiber reinforced polymer
NFRC	Natural fiber reinforced concrete
STM	Servo-hydraulic testing machine
MPa	Mega Pascal
kg	kilogram
kN	kilonewton
J	Joule
MJ	Million Joule
$\mathbf{m}^3$	Cubic meter
mm	millimetre
Hz	Hertz

List of Symbols

ξ	Damping Ratio
ϕ	Diameter of rebar

Chapter 1

Introduction

1.1 Background

The study of numerous failed structures, particularly bridges during the earthquake, revealed that many of these low strength concrete bridge piers were structural defects like low containment and poor construction methodologies. When subjected to such large lateral deformations, the load carrying capacity was drastically reduced. The containment and load- carrying capacity and flexural strength of bridge pier loads is therefore important to improve the performance and durability under serious seismic loads. The research was therefore mainly emphasized in the damaged bridge piers that the deprived performance was due to inadequate strengthening properties [1]. It was observed that in plain concrete cracks are developed due to fragile behavior and environmental changes. According to Razmi and Mirsayar [2], the jute fibers were utilized to enhance the mechanical properties of concrete. The steel rebars have high density and corrosion problems, therefore, resulting in a degradation of concrete structures. The fiber reinforced polymer rebar was made of high-strength, vinyl ester resin-reinforced fiber. In order to overcome weathering issues, fiber reinforced polymer rebars as a substitute for steel bars have become realistic and economical. The fiber reinforced polymer rebars are more preferable than conventional steel bars, including low density, higher tensile strength than steel, and no erosion even in cruel cases [3].

1.2 Research Motivation and Problem Statement

Most of the bridges suffered high damages and complete failure in some other cases during the Earthquake of 2005. Instead of building new structures in place of existing damaged one requires a lot of financial resources. The project aims to improve the load carrying capacity of bridge piers in term of structural load carrying capacity. Bridge piers being the critical element in overall bridge geometry, they are required to transfer the loads safely to the ground. In order to improve the load transformation mechanism and ensuring the safety, the behavior of structural elements need to fully understand and then the proper technique of strengthening may be applied. The failure mechanism before and after FRP strengthening also needs to be verified. Most of the times the strengthening techniques improve the load carrying capacities but change the failure mechanism from flexure to shear i.e. the ductile failure mechanism transforms to brittle failure. The concept of using fibers to improve the characteristics of concrete is very old. Liu et al. [4] reported that the percentage increase of the compressive strength of various grade of jute fiber concrete was 20.44% and the percentage increase of flexural strength was 53.47%. So, the investigation of experiment properties of FRC related to bridge piers is important to be considered. Thus, the problem statement is as follows:

"The most common damage of bridges included shear-flexural failure of the pier Han et al. [5]. Compressive strength, splitting-tensile strength, flexural strength, and toughness were enhanced by using JFRC Razmi and Mirsayar [2]. FRP rebars as a substitute for steel bars have emerged as a realistic and economical solution to overcome the weathering issues. The FRP had numerous preferences over conventional steel bars, including a density of one-quarter to one-fifth that of steel, greater tensile strength than steel, and no erosion even in chemical environments

Ahmed et al. [3]. Flexural shear failure is a dominant failure mode in bridge piers. Increased corrosion adversely affects the load carrying capacity of bridge piers. The behavior of different materials especially natural fiber reinforced concrete need to be investigated to better understand the performance of bridge piers. GFRP rebars in fiber concrete piers need to be explored in details. Therefore, to achieve sufficient strength for the bridge piers, embedded GFRP rebar within JFC is to be investigated in current research."

1.3 Overall Objective and Specific Aim

The overall aim of this research program is to replace longitudinal steel rebars with GFRP rebars in FRC for bridge pier application to improve the performance, functionality and durability.

"In this research work, an investigation has been carried out to study the behavior of prototype vertical members having different number of GFRP rebars in JFRC for application of bridge piers under. The lateral confining steel reinforcement will also be varied to incorporate the confining effect."

1.4 Scope of Work and Study Limitation

Three samples were used to determine the mechanical properties of PC and JFC, whereas the average values of two samples for the behavior of prototype as reported by Zia and Ali [6] and ASTM C39.

Prototype testing has been performed along with simplified boundary conditions. The height of pier with respect to span varies in plain and mountainous regions. In some cases, height of pier exceeds than span in mountainous terrain. Hence, a more regular height of pier i.e. 18'-0" with scaling of 1:12 has been considered in present study. Single mix design ratio, fiber content, and fiber length have been used, as described by Zia and Ali [6]. Relative comparison between PRC and JFRC having GFRP rebars will also be determined.

1.5 Brief Methodology

Prototype specimen has been cast with GFRP rebars. Comparison between prototype piers of PC and JFRC will be made to find the effectiveness of jute fibers in improving the load carrying capacity and overall failure mechanism. Axial load carrying capacity will be determined experimentally in STM. The cracking pattern will be observed with a naked eye alongside the detail failure mechanism. In addition to this various other tests will be performed to evaluate the compressive strength, splitting tensile strength and modulus of rupture experimentally. The mix design proportion for plain concrete is 1:2:3:0.60 (cement: sand: aggregate: water) and the targeted strength of the specimen is greater than 20 MPa. Whereas, for the making of JFRC, 5% fiber content by mass of cement, and having a length of 50mm have been added to concrete. The standard specimen will be cast and tested according to ASTM standards.

1.6 Thesis Outline

There are six chapters in this thesis, which are described as follows:

Chapter 1 briefly describes the introduction. It also consists of background, research motivation and problem statement, objective and scope of work, methodology and thesis outline.
Chapter 2 explain the literature review. It consists of background, Failure in bridge piers, use of natural fibers in concrete (Jute Fiber), use of GFRP rebars with PC and NFRC (for vertical members), testing practice and summary.
Chapter 3 illustrate the experimental procedure. It contains background, selection of mix design for the current study, raw materials, mix design, and casting

procedure, specimens, testing procedures, and summary.

Chapter 4 consists of results and analysis. It contains background, frequencies and damping ratio, the behavior of prototype piers and summary.

Chapter 5 comprise of discussion on damping ratio, failure mode, comparison of prototype piers and summary.

Chapter 6 consist of a conclusion and recommendations.

References are presented right after chapter 6.

Chapter 2

Literature Review

2.1 Background

In old times fibers have been used to enlarge concrete behavior, performance, and mechanical properties. Jute fibers are used to improve the toughness, durability, shrinkage and crack propagation in concrete. Jute fibers have low cost, high tensile strength, and richly available in tropical regions. Glass fiber reinforced polymer rebars has a unique alternative steel reinforcement solution for concrete structures. In spite of all these characteristics such as high tensile strength, low density, and weathering resistance.

2.2 Failure in Bridge Piers

The investigation of many failed structures, particularly bridges in the earthquake of Oct 2005 revealed that most of these Low Strength Concrete (LSC) bridge piers had structural deficiencies such as low confinement and poor construction methodologies. The load carrying capacities had been drastically dropped when subjected to such large lateral deformations. The buckling of the main longitudinal reinforcement resulted in poor performance of bridge pier in a seismic event.

Therefore, it is vital to improve the confinement and thereby load carrying capacity and flexural strength to achieve enhanced performance and durability of bridge piers under severe earthquake loading. In the past, most of the research focused on the damaged bridge piers concluded that the poor performance was as a result of insufficient strengthen properties [1]. The huge number of reinforced concrete bridges was damaged due to blended flexural-shear failure modes of the bridge piers [7]. Han et al. [5] reported that the most common damage of bridges included shear-flexural failure of the pier. Figure. 2.1 shows bridge pier failures that can be improved by adding jute fibers and GFRP rebars.

FIGURE 2.1: Bridge Pier Failures

2.3 Use of Natural Fibers in Concrete

Natural fibers contribute to improving behavior and capacity of reinforced concrete [8]. Elsaid et al. [9] investigated the mechanical properties of natural fiber especially kenaf fiber reinforced concrete. A total of 53 samples of standard size are casted in which 22 samples for compressive strength test, 12 samples for splitting tensile strength and 19 samples for modulus of rupture. 1.2% and 2.4% fiber content by volume fraction of concrete was considered. The results indicate that kenaf fiber reinforced concrete significant improvement in splitting tensile strength, better cracking behavior and three times toughness than plain concrete.

Many researchers have been interested in the durability of natural fibers. Detailed research in the literature on natural fibers and their composites is presented here. The variations in chemical composition and strength of four natural fibres, i.e. coconut, sisals, jute and hibiscus cannabinus fibers, were investigated by Ramakrishna and Sundarararajan [10] in alternative wetting and drying, continuous immersion in water for 60 days, saturated lime and sodium hydroxide. Due to immersion in the solutions considered, the chemical composition of all fibers had changed. The loss of tensile strength resulted in continuous immersion. However, in all the test conditions, coconut fiber was best reported to retain a good percentage of its original tensile strength. The durability of coconut fibers, as a strength loss occurred over 420 days, was studied by Toledo Filho et al. [11] in three types of processes: pH8.3 fiber kept in the tap water, pH12 calcium hydroxide solution, and pH11 sodium hydroxide solution container fibers. For calcium hydroxide solution a significant decrease in strength was observed. It was found that 58.7% of the original strength of coconut fibers retained after 210 days. After 420 days, coconut fibers (immersed in sodium hydroxide) retained 60.9% of their initial strength. The increased alkaline calcium hydroxide attack was probably associated with the pores' lime crystallization. In addition, Toledo Filho et al. [11] found a decrease in natural fiber strength (sisal and coconut) of strengthening composites when different ageing conditions (stored at about 18 oC in water, controlled wetting and drying cycles, open-air weathering in London) were considered. Toledo Filho et al. [12] had studied several approaches to improve the durability of composites having natural fibers. These included carbonization of the matrix in a CO2-rich environment; immersion of fibers in slurried silica fume (SF) before incorporation into the matrix of the Ordinary Portland Cement (OPC); and partial replacement of OPC by intensified SF or blast furnace slag. The behavior was analysed with regard to the effects on flexural behavior of ageing in water, exposure to wetting and drying cycles, and open-air weathering. Immersion of natural fibers in a SF slurry before adding them to the composites based on cement was found to be an effective means of reducing the composite's fragility under the conditions considered. In a CO2-rich environment, early cured composites and partial replacement of OPC with intensified silica fume were also effective approaches to obtaining natural fibers with enhanced durability. Park et al. [13] investigated the durability of jute fibers using micromechanical test and non-destructive acoustic emission. It was established that the tensile strength of jute fibers reduced considerably during boiling water test as the fibers expanded and deteriorated. Sen et al. [14] explored the durability and mechanical properties of jute fiber composites when subjected to a variety of conditions. It was deduced that the salt water media exposure lead to more detrimental effects on durability and mechanical properties as compared to distilled water.

2.4 Use of Jute Fibers in Concrete

Vegetable fibers (especially, jute fiber) is a natural fiber, with low cost, having high tensile strength, and abundantly available in tropical regions. A smaller dose of jute fiber (0.25% by volume fraction) had a positive effect on hardened concrete properties. Analysis result showed that the length and volume of fibers have a positive impact in early and extended treatment periods on the hardness of the concrete [15]. Good bond properties against the pull-out test for cement based matric with jute fibers where the length of jute fibers is greater than 10mm [16]. Razmi and Mirsayar [2] reported that by using jute fibers in concrete to enhance the mechanical properties of FRC. Jute fibers improve the fracture toughness of concrete and to restrain the extension of cracks in concrete. Chakraborty et al. [17] described that the mechanical properties of cement mortar by using jute fibers improved significantly. The mechanical properties of jute fibers as illustrated by Table 2.1 were investigated by [18, 19].

Table 2.1: Mechanical Properties of Jute Fibers Ali (2012),Warke and Dewangan (2017)

Properties	**Values**
Length	50mm
Diameter	0.4mm
Aspect ratio L/D	125
Density	1460 kg/m^3
Specific gravity	1
Water Absorption	13\%
Tensile Strength	393-773 MPa
Elongation	1.5 – 1.8%
Stiffness	10 – 30 kN/mm^2

Jute fiber properties are shown in Table 2.1. The use of the jute fiber may be shown to contain adequate advantages reported by different investigators, even with good strength properties. The increased tensile strength, light mass, low price and easy obtainability of jute fibers from other natural fibers. Liu et al. [4] investigated the mechanical behavior of jute fiber reinforced cement-based materials. Two groups are used to identify the jute fiber behavior. In the first group, the percentage of fibers was fixed while fibers length was changed gradually 10-50mm length and in the second group, the length of the fibers was fixed while the percentage of fibers was changed gradually 0.5-0.6 kg-m- 3. It was concluded that the percentage increase of the compressive strength of various grade of jute fiber concrete is 20.44% and the percentage increase of flexural strength is 53.47%. Zakaria et al. [20] investigated the performance of jute fibers for concrete material strengthening. Two different mix design proportion 1:2:4 and 1:1.5:3 with the volumetric fraction of jute fibers having varying length 10 - 25mm were used. It was concluded that the compressive strength, splitting tensile strength and flexural strength was improved meaningfully. Both researchers studied results of jute fiber concrete are shown in Table 2.2.

Table 2.2: Different Mix Design Proportion, Jute Fiber Content, and Length Tested Results from Earlier Studies

Fiber Content	Mix Design Proportion	Length of Fibers (mm)	CS	STS	FS	References
PC	-	-	100	100	100	
JFC						
0.6 kg/m^3	1:1.74:3.24	30	119	-	154	[4]
0.25% [a]	1:1.5:3	15	105	105	119	[20]
0.50% [a]	1:1.5:3	15	98	78	90	[20]
0.25% [a]	1:2:4	15	102	101	111	[20]
0.50% [a]	1:2:4	15	88	113	101	[20]

Note: [a] fiber content by volume fraction of concrete

Fiber reinforced concrete comportment to control the crack rate in canal line. Flexural strength and toughness of FRC are improved by using jute fibers [6]. The mix design fraction of PC and JFRC is 1:2:3:0.6 used, except with the addition of 5% fiber content by mass of cement having 50 mm length. The major concept to prepare PC and FRC is taken from Khan and Ali [21].

2.5 Fiber Reinforced Polymer Rebars

The FRP rebars are made from high strength glass fiber reinforced with vinyl ester resin. FRP rebars as a substitute for steel bars have emerged as a realistic and economical solution to overcome the weathering issues. The FRP has numerous preferences over conventional steel bars, including a density of one-quarter to one-fifth that of steel, greater tensile strength than steel, and no erosion even in cruel situations [3]. As compared with black steel reinforced concrete, the construction cost of GFRP is expecting 20% less because of having less weight than the normal reinforced concrete [22]. Davalos et al. [23] explored that FRP reinforced concrete is quite complex and moderately reinforced. Moreover, it is recognized that FRP bars, especially GFRP bars, are vulnerable to attack under exposure to moisture, alkaline solutions, and high heat. The use of FRP rods together with high-strength concrete, particularly in highly corrosive locations, will solve some problems due to its non-corrosive and lightweight FRP rods, as well as high water and moisture content [24].

2.6 Use of GFRP rebars with PC and FRC

Hosen et al. [25] glass fiber reinforced polymer rebars for improving the flexural strength of reinforced concrete beams by using side near-surface mounted (SNSM) technique. It was concluded that improved flexural performance from the tested specimen compared with the control specimen. The first crack and ultimate loads of energy absorption capabilities, ductility and stiffness were also enriched. Maranan et al. [26] evaluating the flexural strength and serviceability performance of geopolymer concrete beams having glass fiber reinforced polymer (GFRP) rebars under four-point bending test. It was concluded that, based on experimental results, the enactment of a beam improved when the reinforcement ratio of glass fiber increased. The bending capacity of the GFRP strengthened geopolymer concrete beams shows up to be higher than GFRP fortified concrete beams basically due to the improved mechanical properties of the geopolymer concrete than the orthodox concrete of the same review. Increase in the reinforcement ratio of GFRP rebars resulted in improved performance, including post-crack stiffness, load capacity, and flexibility (or deformation) [27]. Zhu et al. [28] investigated the flexural behavior of partially steel fiber reinforced high strength concrete with fiber reinforced polymer rebars. A total of 12 beam specimens are tested under four-point bending load. Different percentage of steel fibers were used in the tension zone of the beam. It was reported that the steel fibers have been successfully expanded in the tension zone and have taken care of overcoming large bending and partitioning width FRP bar reinforced beams. Ductility decreased with the increasing thickness of layer FRHSC and division of the steel fiber volume in FRHSC bars enforced in part with FRP bars. Including steel fibers in the full depth of the structures with high ductility requirements is essential.

2.7 Use of GFRP rebars with PC and NFRC (For Vertical Members)

Afifi et al. [29] investigated the axial capacity of a circular column having GFRP rebars and spirals. A total of twelve full-scale concrete columns were tested under axial load. It was concluded that the elasticity and confining effectiveness can be enhanced with small GFRP spirals with nearer spaces instead of larger diameters with larger spacing. Mohamed et al. [30] examined the behavior assessment of concrete columns with GFRP and CFRP rebars and reported a considerable reduction in compressive strain for GFRP specimens. Karim et al. [31] reported an increase in ductility of columns by incorporating GFRP rebars in concrete. Wang et al. [32] reported better durability characteristics of GFRP rebars. Pantelides et al. [33] examined the performance of concrete columns confined with GFRP spirals under axial load to avoid corrosion problems. It was described that the smaller corrosion rate on the column and higher ductility than all-steel corroded columns. Tobbi et al. [34] investigated the behavior of reinforced concrete columns reinforced with fibers reinforced polymer with different reinforcement types and ratios. A total of twenty concrete specimens with a width of 350mm, length of 350 mm and a height of 1400mm are casted and tested under axial load. Glass fiber reinforced polymer rebars, Carbon fiber reinforced polymer rebars and Steel bars are used as a longitudinal and transverse reinforcement. The results showed that FRP rebars contribute to the concrete columns subjected to axial load as a longitudinal reinforcement and that the combination of FRP cross-reinforcement and longitudinal steel bars provides adequate strength and ductility.

In case of a harsh environment with elevated temperature, humidity, and marine environment, the bars get corroded and convert to powder form resulting in loss of flexural strength and ultimate failure of a structure. This reduces the service life of a structure and requires the considerable financial resource to rehabilitate the structure. In order to reduce this burden of rehabilitation cost, the present researched, looked into various advanced materials like FRP which started their applications also in various Civil Engineering structures. Presently, the GFRP rebars are being used as vertical main reinforcement embedded in JFRC pier columns of bridges. The behavior of small prototype specimens of PRC and JFRC bridge piers will be compared with different GFRP rebars and varying transverse steel reinforcement configuration. To the maximum extent of the author's knowledge based on a limited revision of literature, no study has been conducted on the suitability of JFRC with GFRP for the application of bridge piers so far.

2.8 Testing Practice

There can be four stages to predict the behavior of any structure. Includes (i) full-scale structure in real field conditions [35], (ii) full scale structural elements with precise boundary conditions [36], (iii) either scaling the prototype structure or typical structural elements, including the appropriate gradient for raw material, size, loading conditions and end-limits [37], and (iv) small prototype structural elements for comparative comparison to check the effectiveness, only one variable provided all other conditions are similar [38, 39]. In the current study, only a simplified approach (i.e. stage iv) is adopted. The behaviors of a small prototype of PC and JFC bridge piers embedded with various main GFRP and transverse steel reinforcement configurations are compared.

2.9 Summary

From the literature review that fiber can be used to improve the mechanical properties of concrete. Jute fibers have high tensile strength, low cost, and richly existing in tropical areas. Jute fibers had a positive effect on hardened concrete properties. Glass fiber reinforced polymer rebars are more effective and efficient as compared to steel reinforcement with a subject to their mechanical properties including low density, higher tensile strength than steel, and no erosion even in harsh environment.

To the best of author knowledge on the basis of a limited revision of the literature, no study has been conducted on JFRC's suitability with GFRP rebars for application of bridge piers up to now. In this study, sixteen prototype piers having different longitudinal main GFRP rebars, confine steel reinforcement with varying spacing were cast and tested. Reinforcement details are used for PRC and JFRC specimens (4-Ø6, 8-Ø6 with Ø6-64 mm, Ø6-76 mm) respectively. The clear cover is provided on the top and bottom faces of 25 mm and all sides of 12.5 mm for specimens. The cut length of the GFRP rebars 400mm is used. Mechanical properties, different frequencies, and damping ratio and axial strength of PRC and JFRC specimen are calculated.

Chapter 3

Experimental Program

3.1 Background

Usage of fibers for increasing the mechanical properties of jute fiber concrete having glass fiber reinforced polymer rebars. Increased in mechanical properties, toughness, and energy absorption are the main returns of fiber reinforced concrete. Performance of jute fiber for enhancing the resistance with GFRP rebars is discovered through the experimental work. This chapter demonstrates in detail the selection of mix design, raw materials, mix design, and casting procedure, specimens, testing procedures.

3.2 Selection of Mix Design

With reference to Gul and Ali [38] research, it has already been tested with the ratio of 1:2:4:0.7 with the addition of 5% synthetic (glass fibers) content by mass of cement having 50mm length has resulted in the light of said result the compressive strength was 22.5 MPa. Therefore, enlighten of these results to modify the mix design proportion 1:2:3:0.6 with replicate 5% natural (jute fibers) content by mass of cement having 50mm length. The mix design ratio of PC and JFRC is 1:2:3:0.60 used, with the addition of 5% fiber content, by mass of cement, having 50 mm length. The aggregate content is reduced from 4 to 3 because to have more mortar for fiber grabbing for high toughness and less compromise to compressive strength. The main purpose to use this mix design proportion is to achieve the targeted compressive strength at 20 MPa in order to the enactment of fiber reinforced concrete practically in the field.

3.3 Raw Materials

For the preparation of PC and JFRC constituents which are utilized coarse aggregates, sand, ordinary portland cement, fresh water, jute fibers, steel and glass fiber reinforced polymer rebars. The maximum size of the coarse aggregates was 10mm. GFRP rebars are imported having 0-6mm and 400mm lengths which are shown in Figure 3.1. Jute fibers are available in a raw form which is prepared by hand at the rate of 50mm length shown in Figure 3.2. The mechanical properties of glass fiber reinforced polymer rebar provided by the company which is shown in Table 3.1.

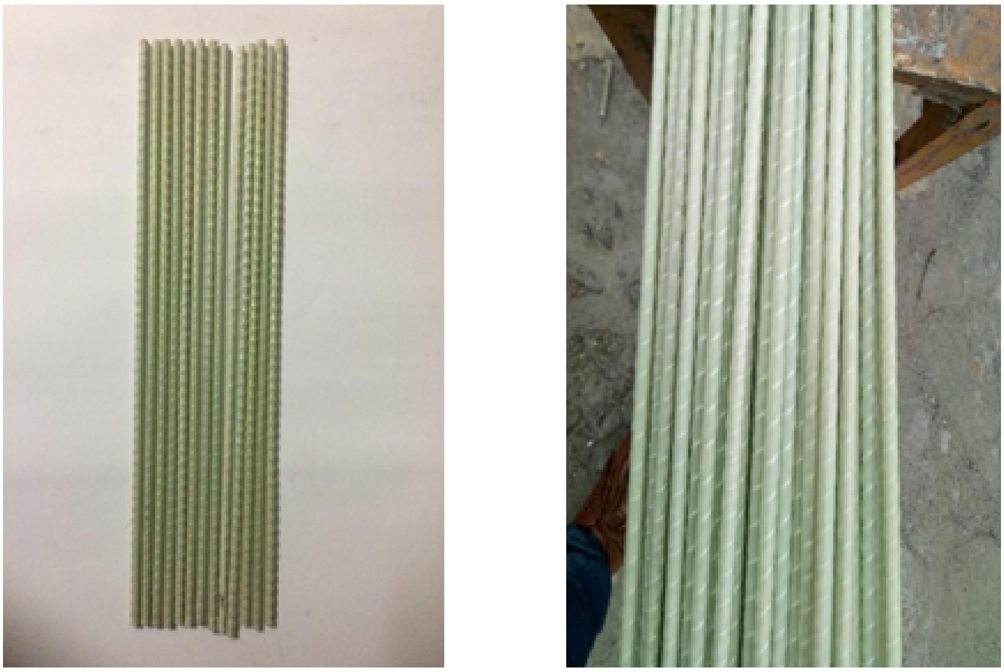


FIGURE 3.1: Glass Fiber Reinforced Polymer Rebars

Figure 3.2: Jute Fibers

Table 3.1: Mechanical Properties of Glass Fiber Reinforced Polymer Rebar

Properties	Values
Diameter	6mm
Cross Section Area	28.27mm
Density	2200 kg/m^3
Weight	0.051 kg/m
Ultimate Tensile Load	28.34 kN
Tensile Strength	>600 MPa
Ultimate Shear Strength	>110 MPa
Elastic Modulus E	>46 GPa
Ultimate Tensile Strain ε	>1.9%

3.4 Mix Design and Casting Procedure

The proportion of 1:2:3:0.6 (C:S:A:w/c) is used for the preparation of plain concrete and JFC except for 5% jute fiber by mass of cement, having 50mm length. All ingredients are measured by mass excluding water in liter which is shown in

Table 3.2. JFRC and PC are prepared by using the non-tilting rotary type drum concrete blender. For the preparation of PC, all ingredients are poured in the drum of the mixer along with water, and the duration of mixing in the blender is three minutes. For preparing JFC, a different method is used as stated by [17]. Jute fibers are immersed for 24 hours into the water, to absorb the required amount of water. Then, left into the air for a half hour. After that, ingredients are placed into the blender layer by layer in order to prevent the balling effect. One-third part of materials (cement, sand, aggregate and jute fibers) are placed into blender drum turn by turn. After entire insertion of materials into the blender drum, initially, about 33% of total water is spread on all material. The remaining water (67%) is added slowly and gradually during the rotation of the machine. The blender is rotated for 6 minutes (2 minutes for each layer) to get a homogenous concrete. Slump test as per ASTM standards C143/C143M15a are practice to determining the workability of PC and JFC at an early stage before pouring in moulds. The slump is low in case of JFC as related to PC because of the water absorption ability of jute fibers are shown in Figure. 3.3. This variance might be furthermore in case of dry insertion of jute fibers. The slump value of JFC is 40% less than PC. Moulds are filled in three layers with 25 number of blows done with the help of tamping rod as per ASTM Standards and then 75-100mm moulds free fall to reduce the air voids. Specimens of PC and JFRC are cast by following the same process. After 48 hours samples are extracted from moulds label them and placed into a water container for curing of specimens for 28 days. After 28 days, afore the density test of PC and JFC is calculated by dividing the average mass of PC and JFC specimens with measured averaged volume as per ASTM standard C642-13. The method followed for obtaining the densities and workability of JFC is same as for PC, because of non-availability of any separate criteria for fiber reinforced concrete (FRC) in codes. The density of JFC specimens is lower than PC specimens, because of the lightweight of jute fibers. Slump and density of PC and JFC are displayed in the third and fourth column of Table 3.3.

FIGURE 3.3: Slump of PC and JFC

TABLE 3.2: Mix Design Proportion for PC and JFRC (1:2:3:0.6)

Batch	Cement (kg)	Fine Aggregates (kg)	Coarse Aggregates (kg)	Water (liter)	Fiber (kg)
PC	25	50	75	15	-
JFRC	25	50	75	15	1.25

TABLE 3.3: Water Cement Ratio, Slump and Density of PC and JFRC

Sample	Water cement ratio	Slump (mm)	Density (kg/m^3)
PC	0.60	64	2532±3
JFRC	0.60	38	2468±3

Note: For density, an average of three readings is taken.

3.5 Specimens

In this study, the determination of mechanical properties of PC and JFC, cylinders and beamlets were cast. The dimension of cylinder moulds, having 100mm in diameter and 200mm in height whereas beam-let moulds, having 100mm in width, 100mm in height and 450mm in length. Compressive strength and splitting-tensile strength testing twelve specimens are cast (i.e. six for PC and six for JFC). While for flexural strength testing six specimens are cast (i.e. three for PC and three for JFC). Three different minimum loading rates are considered for compressive test 0.15 Mpa/s, splitting-tensile test 0.78 Mpa/min and for flexural test 0.86 Mpa/min as per ASTM standards C-39M-18, C-496M-17 and C-293M-16. An average of three samples values is taken. A total of sixteen prototype column samples were cast and tested under axial load condition. The set of two specimens for axial test and material (i.e. PC and JFRC) is considered. All samples were 100 mm in width, 100 mm in height and 450 mm in length. The size of prototype specimens was selected to be meet for the condition and capacity of the available testing apparatus in the laboratory. All specimens were prepared as a beam and tested as a column. The specimens are identified by the longitudinal GFRP rebars, material, varies confinement steel spacing, and its number. In the prototype specimen, smaller diameter Ø6mm are used. Basically, four and eight number of longitudinal GFRP rebars are used with varying steel reinforcement spacing at the rate of 64mm and 76mm. Loading rate for axial strength test is 0.15 Mpa/s. The average of two values also verifies by ASTM C39M-18, [6]. Non-destructive dynamic testing as per ASTM C215-14 was also performed before destructive testing for mechanical properties and prototype specimen. Labeling scheme for specimens is shown in Figure. 3.4.

Figure 3.4: Labelling Scheme of Specimens

3.6 Testing Procedure

The compressive strength and corresponding to the stress-strain curve, splitting tensile strength similar to load-time curve and flexural strength similar to the load-displacement curve. The resonance frequencies, dynamic modulus of elasticity and damping are determined. Axial strength and corresponding to the stress-strain curve are found. PRC and JFRC prototype specimens test matrix and labels are shown in Table 3.4. Testing setup for a prototype column i.e. schematic diagram and experimental setup is shown in Figure. 3.5.

TABLE 3.4: PRC and JFRC Prototype Specimen Test Matrix with labels

S. No.	Longitudinal GFRP	Steel Ties	GFRP ratio (ρ)	Labels PC	Labels JFRC
1	4-Ø06	Ø6-64mm	0.012	4P64-A/B	4P64-A/B
2	4-Ø06	Ø6-76mm	0.012	4P76-A/B	4P76-A/B
3	8-Ø06	Ø6-64mm	0.024	8P76-A/B	8P76-A/B
4	8-Ø06	Ø6-76mm	0.024	8P76-A/B	8P76-A/B

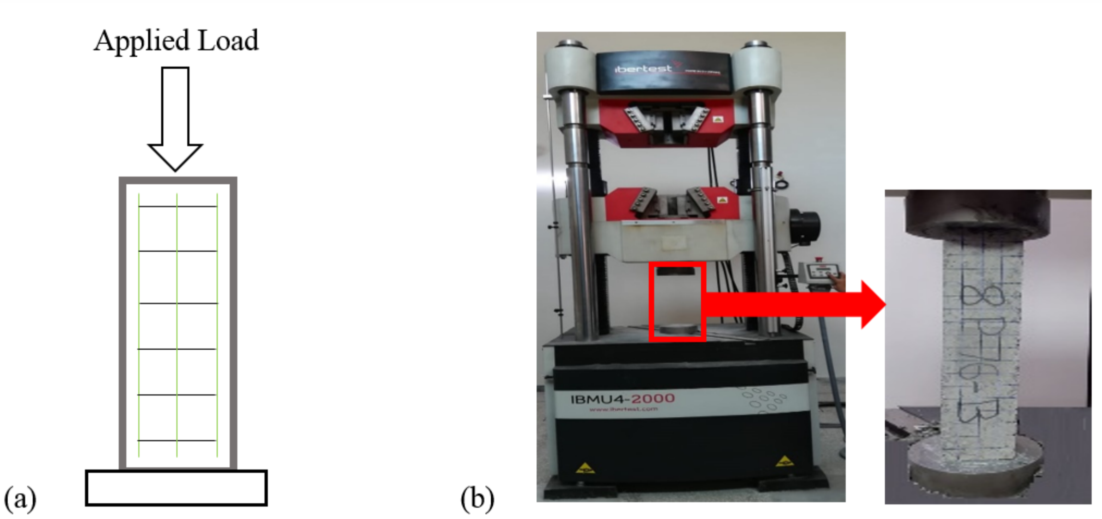


FIGURE 3.5: Testing of Prototype Columns with rebars: (a) Schematic Diagram, and (b) Experimental Setup

3.6.1 Dynamic Properties

During present research, all the prototype specimens are tested before destructive testing for obtaining the results of longitudinal frequency, transverse frequency and torsional frequency according to ASTM standard C215-02. Damping ratio is also determined.

3.6.2 Mechanical Properties

3.6.2.1 Compressive Strength

Servo-hydraulic machine (STM) is utilized as per ASTM standard C39/C39M-15a to determining the compressive properties of PC and JFC cylinder specimens such as compressive cracking behavior, stress-strain curve, compressive strength, energy absorption, and total toughness index.

3.6.2.2 Splitting Tensile Strength

In order to determine the split tensile properties of PC and JFC cylinder specimens are tested in STM as per ASTM standard C496/496M-11 to obtained split cracking behavior, splitting tensile load time curve, splitting tensile strength, energy absorption, and total toughness index.

3.6.2.3 Flexural Strength

ASTM standard C78/C78M-15b is used to determine the properties of specimens of PC and JFC beam-lets to obtain flexural cracking behavior, flexure load-deflection curve, MoR (modulus of rupture)/flexural strength, energy absorption, and total toughness index.

3.6.3 Axial Load Test

ASTM C39/C39M-18 was followed for axial strength of all PRC and JFRC prototype specimens. All the prototype specimen were capped with plaster of paris before testing for uniform distribution of load. STM was used for testing all prototype specimen to study compressive behavior, to determine compressive strength and to calculate compressive energy absorption and toughness index in compression.

3.7 Summary

PC specimens are making with a mix design of 1:2:3:0.6. With the addition of 5%, Jute fiber by mass of cement is added to prepare JFRC with same mix design. A total number of 34 specimens out of which 12 are cylinders and 6 are beamlets used to measure mechanical properties like compressive, split and flexural strength. Furthermore, prototype piers are 16 which are used for determining axial strength and behavior.

Chapter 4

Experimental Evaluation

4.1 Background

Mix design proportion of 1:2:3:0.6 (cement: sand: aggregate: w/c) are used for making of PC. JFRC is ready with a similar mix design except for 50 mm length of jute fibers in addition of 5% mass of cement. Experimental results of PC, JFC, PRC and JFRC specimens to examine the dynamic properties, mechanical properties, and behavior of prototype piers being discussed in this chapter.

4.2 Frequencies and Damping Ratio

Various frequencies and damping ratios of PC, JFC, PRC and JFRC specimens are determined before destructive testing which is present in Table 4.1. For cylinders, an average of six readings is taken and an average of three readings is taken for the beam. Whereas an average of eight readings is taken in the case of a column. The method followed for obtaining the frequencies and damping ratio of JFC and JFRC is same as for PC and PRC specimens, because of non-availability of any separate criteria for fiber reinforced concrete (FRC) in codes. In the case of cylinder longitudinal frequency of JFC is greater than PC whereas, the transverse and rotational frequency is less than PC. For beam case, the longitudinal, transverse and rotational frequency is less than PC. For prototype column, the longitudinal frequency of JFRC is less than PRC whereas, the transverse frequency and the rotational frequency is greater than PRC.

TABLE 4.1: Resonance Frequencies and Damping Ratios

Specimen		No. of specimen for average	Resonance Frequency			Damping Ratio ξ (%)
			f_l (Hz)	f_t (Hz)	f_r (Hz)	
Cylinder	PC	6	3247±175	2973±400	2715±450	4.2±0.05
	JFC	6	3839±225	2500±475	1809±600	4.9±0.04
Beam	PC	3	4009±250	3610±400	3358±500	3.4±0.02
	JFC	3	2958±300	1627±350	2293±300	4.4±0.04
Column	PRC	8	4128±150	4119±600	4085±800	3.0±0.04
	JFRC	8	3256±275	3479±375	2341±100	4.1±0.05

Note: f_l = Longitudinal frequency, f_t = Transverse frequency, f_r = Rotational/torsional frequency

The main purpose of determining dynamic properties of material is to check any increase in damping due to addition of jute fibers. The damping can reduce the response of structure and its associated forces [40]. Thus JFRC bridge piers can also have reduced forces. But there is a need to explore damping in piers with real boundary conditions which is outside the scope of this thesis. It can be clearly seen from Table 4.1 that the damping ratio of PC cylinder, PC beam, and PRC column is less than that of JFC cylinder, JFC beam, and JFRC column, respectively. Therefore, the energy dissipation will be more in JFC members as compared to PC members. The damping ratio between JFC and JFRC has been increased in all three cases up to 0.7, 1.0 and 1.1 correspondingly as related to PC cylinder, beam, and PRC column specimens.

4.3 Mechanical Properties

Compressive strength test, stress-strain curves are considered for all PC and JFC specimens which are shown in Figure 4.1(a). In figure 4.1(a) compressive behavior of PC and JFC specimens at left side whereas crack propagation of specimens are shown at the right side. The cracking pattern was noted at three different level of loading. The cracks developed on the surface at all the three different stages of loading were comparatively more pronounced in case of PC specimens as compared to JFC specimens. This shows the effectiveness of adding jute fibers to control and limit the development and propagation of cracking phenomenon in concrete. Compressive strength is taken as the extreme stress from the stress-strain curve. The energy absorption ability, namely the energy absorbed per unit volume of concrete material, was defined by the area under the stress strain curve and given in units of MJ/m3 as reported by [41, 42]. Energy absorption in compression (Em) is measured as the area below the stress-strain curve up to the peak load. The area below the stress-strain curve from peak load to the ultimate load is taken as the cracked energy absorption in compression (Cr.E). Total energy absorption in compression (TE) is measured as the area below the stress-strain curve from initial to ultimate stress. Toughness index in compression (TI) is the ratio of entire energy absorption in compression to the energy absorption in compression up to extreme stress (i.e. TE / Em). The compressive strength, Em, Cr.E, TE, and TI of PC and JFC with mix design proportion of 1:2:3 are shown in Table 4.2. The Compressive strength of JFC specimen is decreased by 3.87 MPa while other properties Em, Cr. E, TE, and TI are increased by 0.04 MJ/m^3, 0.26 MJ/m^3, 0.30 MJ/m^3 and 1.64 respectively as related to PC specimen. Comparison of mechanical properties is shown in Figure. 4.2. In which all properties of PC and JFC specimens are compared in percentage. The compressive strength of JFC is decreased by 16% as related to the PC. In evaluation with PC, the maximum energy at maximum load and total energy absorption of the JFC specimen is increased by 35% and 145.7% respectively. The overall index of toughness has also been increased up to 85.8% as related to PC. From the results of compressive strength tabulated in Table 4.2, it can be concluded that although there was slight decrease in compressive strength. However the values for energy absorption and total toughness index have considerable increased in all the JFC specimens.

Splitting tensile strength test, load-time curves are considered for all PC and JFC specimens which are shown in Figure 4.1(b). In figure 4.1(b) splitting tensile behavior of PC and JFC specimens at left side whereas crack propagation of specimens are shown at the right side. The cracking pattern was noted at three different level of loading. In case of PC specimen the cracks were observed to develop at initial stages of loading. However, the JFC specimens showed very little cracking at this initial level of loading. As the loading was increased to higher levels, the crack propagation was pronounced in case of PC specimens when compared with crack pattern developed on the surface of JFC specimens. This shows the effectiveness of adding jute fibers to control and limit the development and propagation of cracking phenomenon in concrete. Splitting tensile strength is taken as the peak load from the load-time curve. Energy absorption in splitting tensile (Em) is measured as the area below the load-time curve up to the peak load. The area below the load-time curve from peak load to the ultimate load is taken as the cracked energy absorption in splitting (Cr.E). Total energy absorption in splitting (TE) is measured as the area below the load-time curve from initial to ultimate load. Toughness index in splitting (TI) is the ratio of total energy absorption in splitting to the energy absorption in splitting up to maximum load (i.e. TE / Em). The Splitting tensile strength, Em, Cr.E, TE, and TI of PC and JFC with mix design proportion of 1:2:3 are shown in Table 4.2. The splitting tensile strength, Em, Cr. E, TE, and TI of JFC specimen are increased by 0.11 MPa, 11.19 J, 33.15 J, 44.34 J and 0.93 respectively as related to PC specimen. Comparison of mechanical properties is shown in Figure. 4.2. In which all properties of PC and JFC specimens are compared in percentage. The splitting tensile strength of JFC is increased by 4.41% as related to the PC. In evaluation with PC, the maximum energy at maximum load and total energy absorption of the JFC specimen is increased by 45.25% and 79.34% respectively. The overall index of toughness has also been increased up to 93.19% as related to PC.

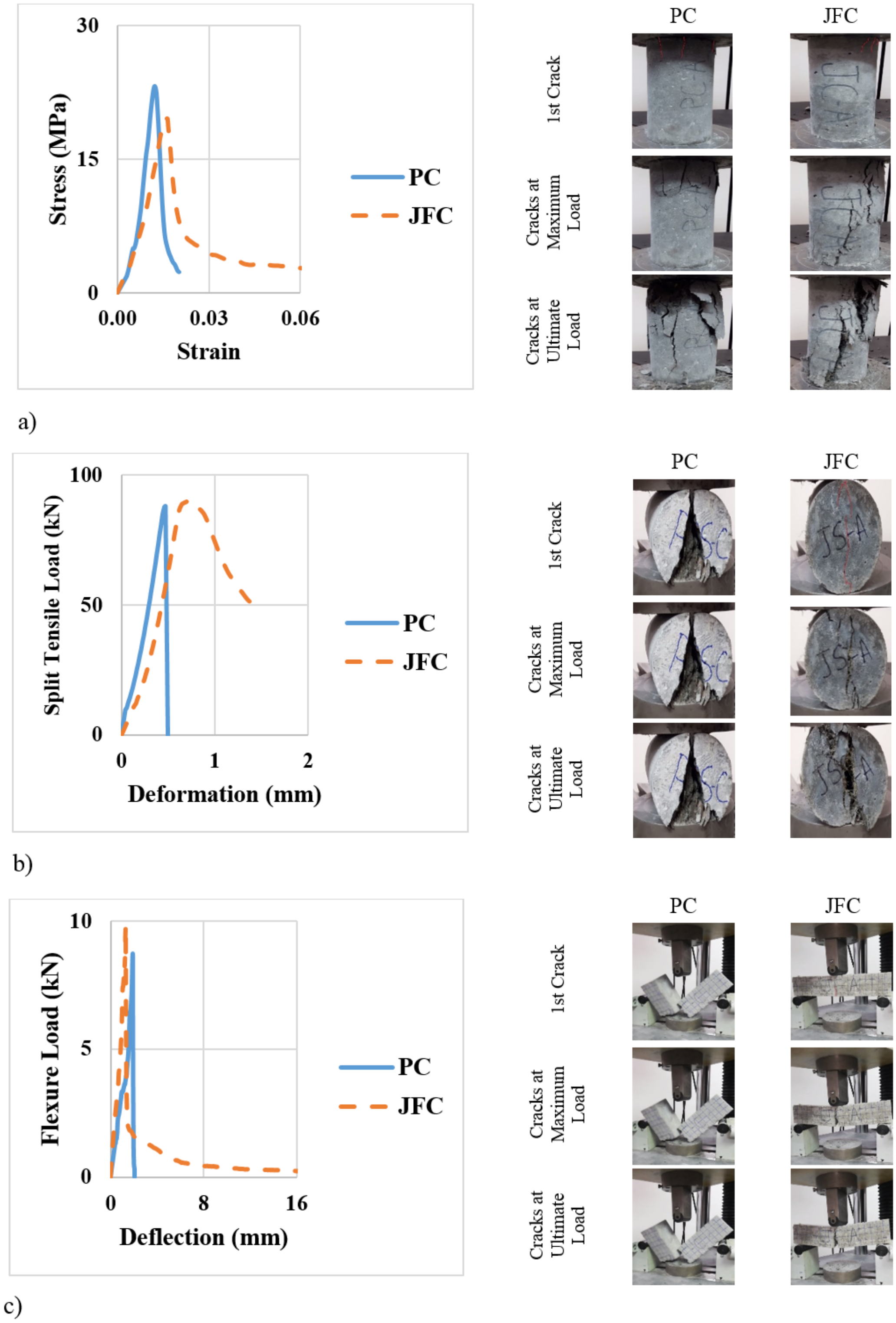


FIGURE 4.1: Mechanical behavior (left) and Crack propagation (right); a) Compressive Strength, b) Split-Tensile Strength, and c) Flexural Strength

Flexural strength test, load-displacement curves are considered for all PC and JFC specimens which are shown in Figure 4.1(c). In figure 4.1(c) flexure behavior of PC and JFC specimens at left side whereas crack propagation of specimens are shown at the right side. The cracking pattern was noted at three different level of loading. In case of PC specimen the cracks were observed to develop at initial stages of loading. However, the JFC specimens showed very little cracking at this initial level of loading. As the loading was increased to higher levels, the crack propagation was pronounced in case of PC specimens when compared with crack pattern developed on the surface of JFC specimens. This shows the effectiveness of adding jute fibers to control and limit the development and propagation of cracking phenomenon in concrete. Flexural strength is taken as the peak load from the load-displacement curve. Energy absorption in flexure (Em) is measured as the area below the load-displacement curve up to the peak load. The area below the load-displacement curve from peak load to the ultimate load is taken as the cracked energy absorption in flexure (Cr.E). Total energy absorption in flexure (TE) is measured as the area below the load-displacement curve from initial to ultimate load. Toughness index in flexure (TI) is the ratio of entire energy absorption in flexure to the energy absorption in flexural up to peak load (i.e. TE / Em). The flexural strength, Em, Cr.E, TE, and TI of PC and JFC with mix design proportion of 1:2:3 are shown in Table 4.2. The flexural strength, Em, Cr. E, TE, and TI of JFC specimen are increased by 0.13 MPa, 0.24 J, 10.4 J, 10.6 J and 1.87 respectively as related to PC specimen. Comparison of mechanical properties is shown in Figure. 4.2. In which all properties of PC and JFC specimens are compared in percentage. The flexure strength of JFC is increased by 2.1% as related to the PC. In evaluation with PC, the maximum energy at maximum load and total energy absorption of the JFC specimen is increased by 4.4% and 167.7% respectively. The overall index of toughness has also been increased up to 161.6% as related to PC. Unlike the results of compressive testing, the flexural testing showed an increase in all the various properties including strength, energy absorption capacity and total toughness index of JFC specimen when compared with PC specimens.

TABLE 4.2: Compressive, Flexural and Splitting-tensile properties of PC and JFC specimen with Mix design proportion of 1:2:3:0.6

Properties	Compressive		Splitting-tensile		Flexural	
	PC	JFC	PC	JFC	PC	JFC
Pmax (kN)	189.95	159.55	80.47	84.01	9.09	9.28
Strength (MPa)	24.18	20.31	2.56	2.67	6.14	6.27
Em	0.11 MJ/m^3	0.15 MJ/m^3	24.7 J	35.9 J	5.48 J	5.72 J
Cr.E	0.10 MJ/m^3	0.36 MJ/m^3	0 J	33.2 J	0 J	11.24 J
TE	0.21 MJ/m^3	0.51 MJ/m^3	24.7 J	69.1 J	6.34 J	16.96 J
TTI	1.92	3.56	1	1.93	1	3.03

Note:

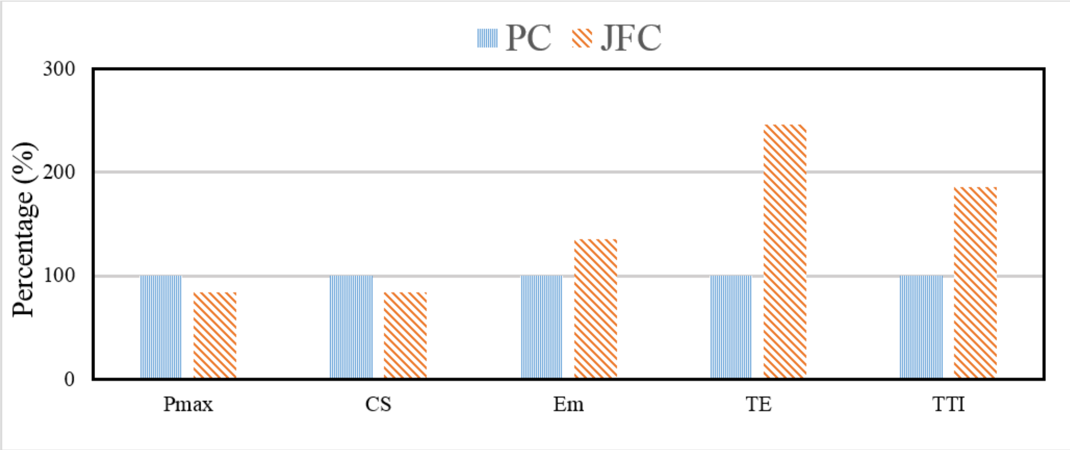
Pmax= Maximum load, Em= Energy-absorption up to maximum load, Cr. E= Cracked energy-absorption after maximum load, TE= Total energy absorbed, TTI= E / Em = Total toughness index

An average of three readings is taken.

Loading rate for compressive strength test is 0.15MPa/s according to ASTM standard C39 / C39M-18

Loading rate for split tensile strength test is 0.70 MPa/min according to ASTM standard C496 / C496M-17

Loading rate for flexural strength testis 0.86 MPa/min according to ASTM standard C293 / C293M-16



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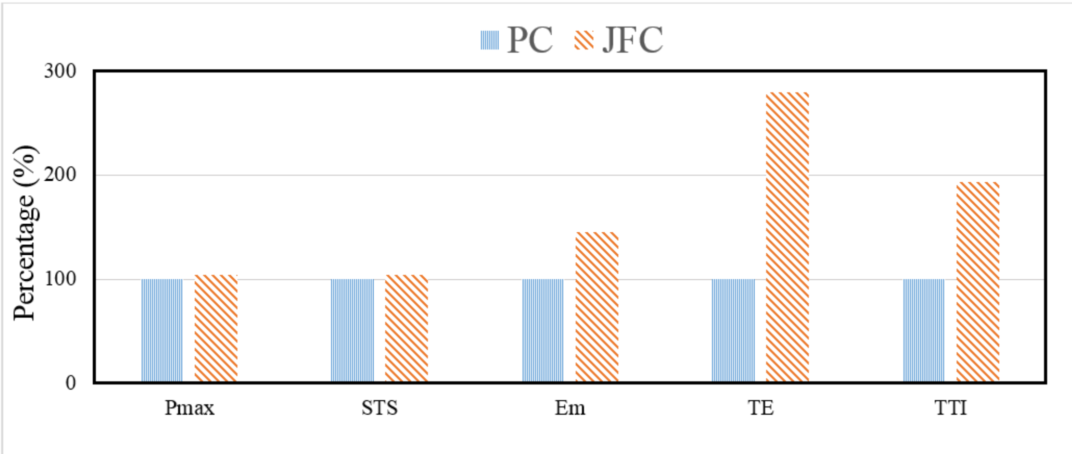

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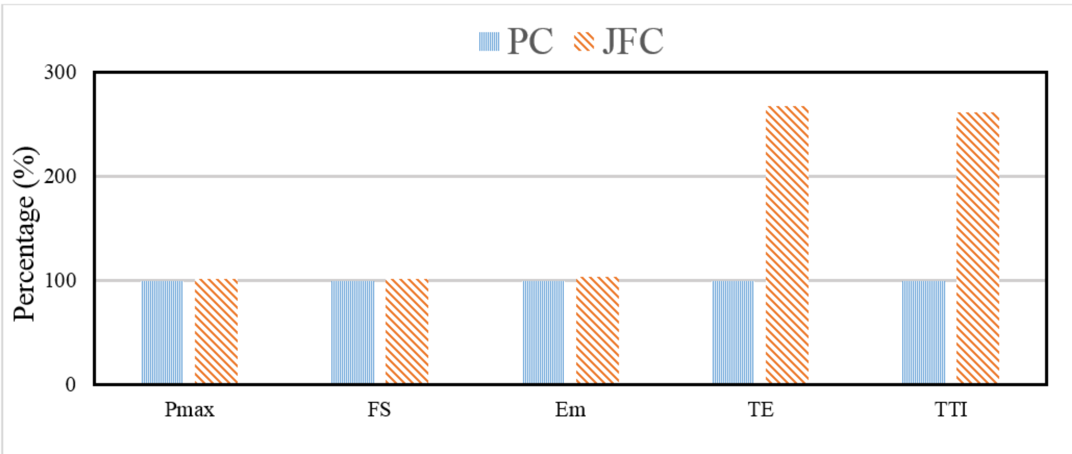


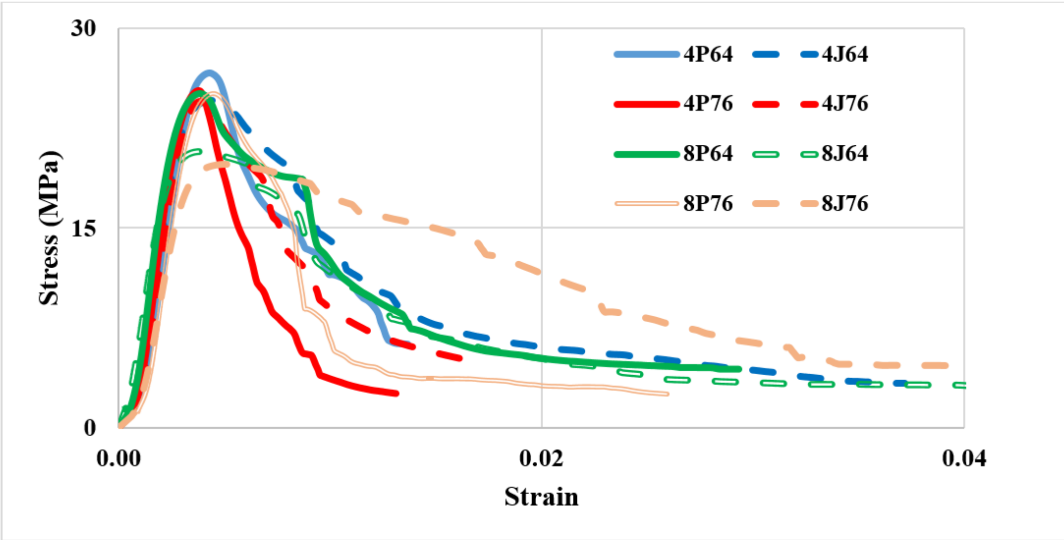
c)

FIGURE 4.2: Comparison of Mechanical Properties of PC and JFC; a) Compressive Strength, b) Split-Tensile Strength, and c) Flexural Strength

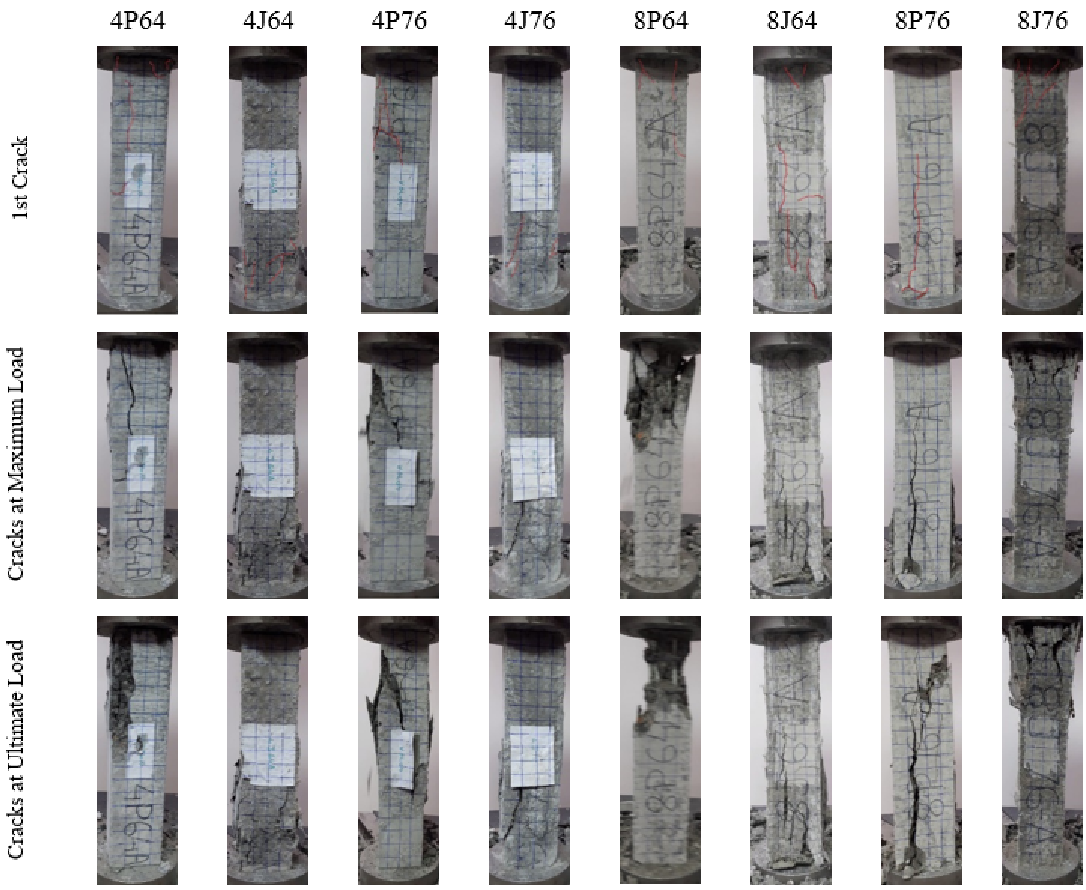
4.4 Behavior of Prototype Piers

Axial strength is taken as the extreme stress from the stress-strain curve. As reported by [41, 42], the ability of energy absorption was given in units MJ/m^3 and is equivalent to area under the stress strain curve. Similarly, energy absorption in compression (C.Em) is measured as the area below the stress-strain curve up to the peak load. The area below the stress-strain curve from peak load to the ultimate load is taken as the cracked energy absorption in compression (Ccr.E). Total energy absorption in compression (CE) is measured as the area below the stress-strain curve from initial to ultimate stress. Compressive toughness index in compression (CTI) is the ratio of entire energy absorption in compression to the energy absorption up to extreme load in compression (i.e. CE / C.Em). The axial strength, C.Em, Ccr.E, CE, and CTI of PRC and JFRC is shown in Table 4.3. Compressive behavior of prototype piers regarding the stress-strain relationship and crack propagation during axial strength is shown in Figure. 4.3. PRC prototype specimens have higher strength as compared to JFRC which is shown in figure 4.3 (a). Whereas strain is reduced in PRC as related to JFRC prototype specimens. In present research, the confinement to longitudinal bars was varied by changing the spacing of confinement reinforcement as well as addition of jute fibers in concrete. It is worth noting from stress strain graph Figure 4.3, as the spacing of confinement reinforcement was reduced from 76mm to 64mm (4P76 and 4P64) the ultimate strain was appreciably increased. The similar increasing trend of strain can be observed in specimens 4J64 and 4P64 where the spacing of confinement reinforcement was kept same i.e 64mm but the addition of jute fibers contributed in achievement of relatively more strain in concrete. Similarly, the increasing trend of strain can also be observed for specimens 4J76 and 4P76 where the spacing of confinement reinforcement was kept same i.e 76mm but adding jute fibers contributed in attainment of comparatively more strain in concrete. The similar increasing trend of strain can be observed in specimens 8J64 and 8P64 where the spacing of confinement reinforcement was kept same i.e 64mm but the addition of jute fibers contributed in achievement of relatively more strain in concrete. Similarly, the increasing trend of strain can also be observed for specimens 8J76 and 8P76 where the spacing of confinement reinforcement was kept same i.e 76mm but adding jute fibers contributed in attainment of comparatively more strain in concrete.

Therefore, JFRC samples showed more strain capacity and ductility due to the bridging effect restricting the opening of cracks and subsequent failure. In each case regarding PRC specimen's first crack has been developed from 92 to 96% of the maximum axial load. Therefore, in the form of JFRC specimen's first crack being developed from 83 to 86% of the maximum axial load. The crack arises in all JFRC prototype specimens are much minor as distinguishing between first cracks in all PRC specimens. As we have seen that the number of cracks and their sizes has been increased after getting the axial maximum load on all JFRC specimens. At axial ultimate load, certain pieces of concrete are dropped down from PRC specimens. The durability of JFRC specimens has seen strong bonding due to jute fibers. To analyses, the fiber failure mechanism of some JFRC specimens has been broken deliberately. 60% of the fibers are collapse while 40% are dragged out from the specimens. The decreased of 3.1 MPa, 2.1MPa, 4.2MPa and 5.0MPa in axial strength of specimen 4P64, 4P76, 8P64, and 8P76 is being seen as related to 4J64, 4J76, 8J64, and 8J76. Therefore, JFRC specimens have absorbed more compressive energy as compared to PRC specimens. An increase of 0.14 MJ/m^3, 0.05 MJ/m^3, 0.24 MJ/m^3, 0.12 MJ/m^3 CE isved in 4J64, 4J76, 8J64, and 8J76 are being seen as related to 4P64, 4P76, 8P64, and 8P76. Compressive toughness index of JFRC specimens is observed more as compared to PRC specimens. Comparing PRC prototype specimen according to their same longitudinal GFRP and varying confine steel reinforcement. An increase of 0.99 Mpa in axial strength of specimen 4P64 as compared to 4P76. Moreover, an increase of 0.4 Mpa in the strength of specimen 8P64 as compared to 8P76. Examine that strength of prototype specimens increased due to the decrease in confine steel reinforcement spacing. Differentiate of JFRC specimen with respect to their same longitudinal and varying confine steel rebars.



a)



b)

FIGURE 4.3: Compressive behavior of prototype piers, a) Stress-strain relationship, and b) Crack propagation

TABLE 4.3: Experimental Results (stress-strain) of tested prototype specimens with varying longitudinal GFRP rebars (4- 06 / 8-06) and Shear Steel Reinforcement (06-64mm / 06-76mm)

Specimens	Axial Load (kN)	Axial Strength (MPa)	C.Em (MJ/m^3)	Ccr. E (MJ/m^3)	CE (MJ/m^3)	CTI (-)	Failure Mode
4P64	267	26.7	0.06	0.09	0.15	2.7	Crushing
4J64	236	23.6	0.05	0.24	0.29	5.6	Bridging
4P76	257	25.7	0.04	0.12	0.16	3.1	Crushing
4J76	235	23.5	0.05	0.16	0.21	4.2	Bridging
8P64	245	24.5	0.04	0.25	0.29	6.3	Crushing
8J64	203	20.3	0.06	0.47	0.53	8.4	Bridging
8P76	244	24.4	0.05	0.18	0.23	4.3	Crushing
8J76	194	19.4	0.06	0.29	0.35	6.3	Bridging

Note:

C.Em= Compressive energy-absorption up to maximum load

Ccr. E= Compressive cracked energy-absorption after maximum load

CE= Total compressive energy absorbed

CTI= CE / C.Em = Compressive toughness index

An average of two readings is taken.

Loading rate for compressive strength test is 0.15Mpa/s according to ASTM standard C39/C39M-18

In axial strength of specimen 4J64 as related to 4J76, 0.4 Mpa is increased. Furthermore, an increase of 0.9 Mpa in axial strength of specimen 8J64 as compared to 8J76. This incremental effect of axial strength is due to reduced spacing in the specimen. The overall axial strength of PRC prototype specimens is increased as compared to JFRC. The strength reduction in JFRC might be due to the formation of air cavities.

4.5 Summary

The mechanical properties, dynamic properties and behavior of prototype piers of PC and JFRC are determined. Damping ratio of JFC and JFRC specimen is much better than PC and PRC specimen. Stress-strain curve of selected PRC and JFRC specimens with subject to axial loads have been occupied to study the behavior of fiber in them. Increase in all mechanical properties (except compressive strength) of JFRC is being witnessed as compared to PRC. Above figure shown the well supplement of jute fibers with concrete matrix.

Chapter 5

Discussion

5.1 Background

The experimental test results for dynamic properties and mechanical properties have already been explained in Chapter 4. A significant enhancement in the flexural strength, splitting tensile strength, energy absorption and toughness of JFRC specimens was observed as related to the PC specimens. The damping ratio, failure mode, and comparison of prototype specimens are discussed in this chapter.

5.2 Damping Ratio

The damping ratio of PC cylinder, beam and PRC column is less than that of JFC cylinder, beam, and JFRC column. There is an increment of JFC cylinder, JFC beam, and JFRC column 14.2%, 22.7% and 26.8% individually. Therefore, the energy dissipation is more in JFC cylinder, JFC beam, and JFRC column as related to PC cylinder, PC beam, and PRC column.

5.3 Failure Mode

In this study, two different types of failure will be discussed which were encountered in all prototype specimen tested. The main longitudinal GFRP and varying confined steel reinforcement PRC specimen's fail in crushing and concrete pieces have been gradually dropped down. Whereas, JFRC specimens failure weren't happened in a crushing way rather than in a bridging effect due to the addition of jute fibers. The PRC and JFRC, prototype columns looks similar primary behavior up to maximum axial load. While, testing of prototype columns for axial loading, crack development wasn't constant on all face of the specimens.

5.4 Comparison of Prototype Piers

The mix design proportion for PRC and JFRC is 1:2:3:0.60 (cement: sand: aggregate: water). The jute fibers are added 5%, by cement mass. The length of jute fiber is 50 mm. The addition of jute fibers gets enhanced the compressive properties of concrete. The comparison of axial strength, C.Em, CE and CTI of prototype piers are shown in Figure. 5.1. PRC is taken as a reference. Despite that, the overall axial strength of the JFRC prototype specimen is decreased due to the assimilation of jute fibers. Axial strength, C.Em is reduced by 11.5% and 8.3%, while Ccr.E, C.E, and CTI are increased with 89.5%, 146.9%, and 104.5% respectively for the 4J64 specimen. The axial strength for 4J76 is decreased at 8.3% whereas all the properties i.e. C.Em, Ccr.E, CE, and CTI are increased with a value 1.9%, 53.1%, 36.8%, 34.2%, respectively. For 8J64 specimen, the strength is reduced at 17.3% or rest of all properties i.e (C.Em, Ccr.E, CE and CTI) are getting higher accordingly 33.7%, 88.5%, 79.7%, 33.8%. Axial Strength For 8J76 specimen is reduced to 20.4%. Hence all related properties enhance with 4.21%, 65%, 50.9%, and 45.1% individually. The mechanical properties of JFRC prototype specimens were enriched with a subject to their results except for axial strength. In the light of testing and result regarding mechanical properties, it is

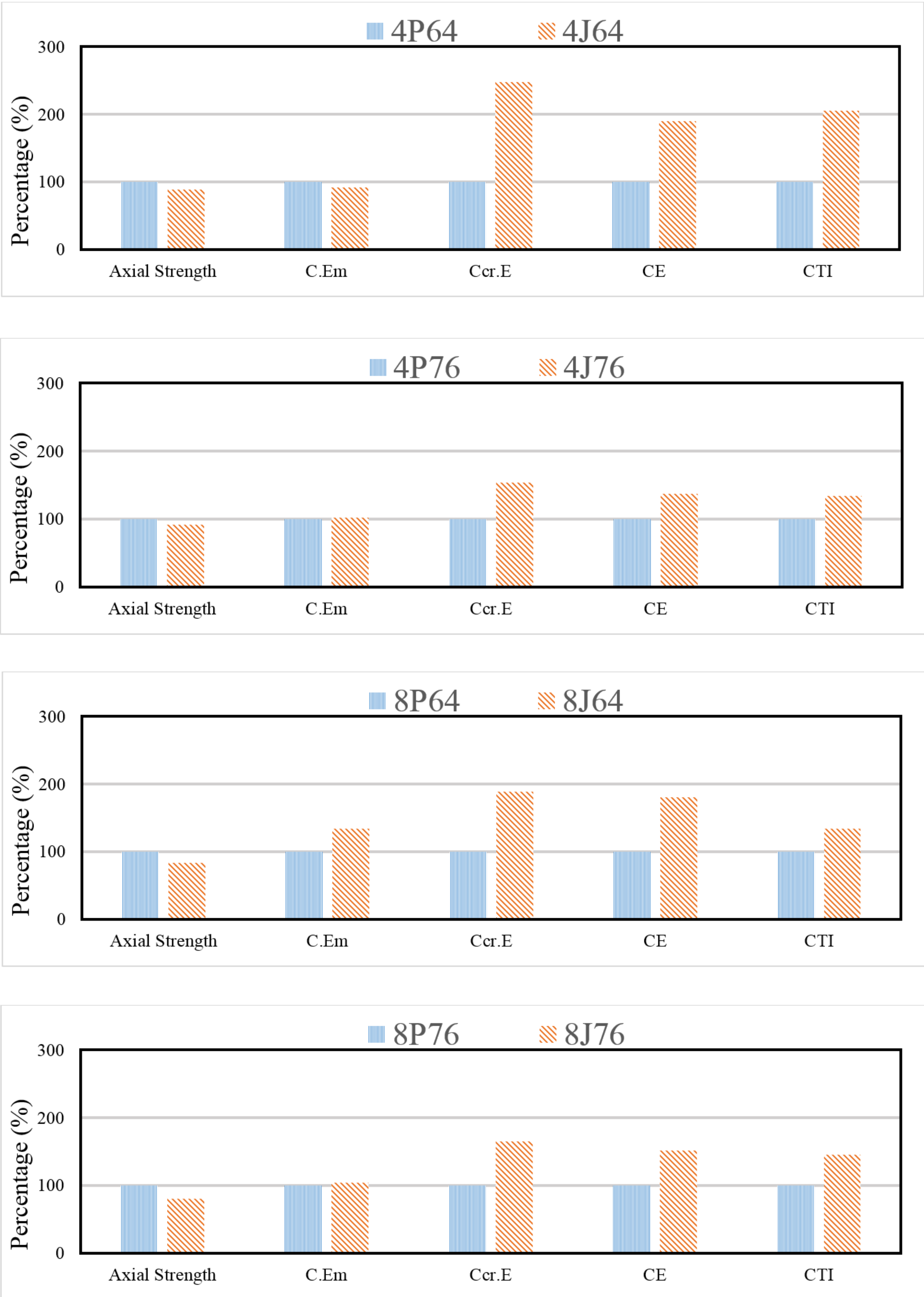


FIGURE 5.1: Comparison of prototype piers

observed that the behavior of JFRC specimen is ductile. Comparison of previous studies with current research is elaborated in following paragraph:

In past, GFRP rebars were used as longitudinal and tie reinforcement. Longitudinal bars were buckled as reported by Tobbi et al.[34]. However, for present research GFRP rebars are used as longitudinal rebars and steel as tie reinforcement and buckling of longitudinal reinforcement was not observed.

5.5 Summary

An increment in damping ratio of JC cylinder, beam, and JFRC column was observed as compared to PC and PRC specimens. The JFRC prototype specimens showed ductile behavior due to the bridging effect of jute fibers while PRC prototype specimens were failed in a crushing way. All the mechanical properties of JFRC specimens were significantly improved except, axial strength as related to PRC.

Chapter 6

Conclusion and Future Work

6.1 Conclusions

In this research, jute fiber reinforced concrete (JFRC) having GFRP rebar is examined for the bridge pier application. The jute fiber content is 5%, by cement is used for the preparation of JFRC. The mix design proportion of JFRC is 1:2:3 (C: S: A) with a water-cement ratio of 0.60. Resulting conclusions are made:

- The improved properties of JFRC enhance the durability of concrete which favors its utility for the structural application like bridge pier.
- The energy dissipation has increased up to 14.2%, 22.7%, and 24.4% in JFC cylinder, JFC beam, and JFRC column, respectively, as compared to respective PC specimens.
- The compressive strength of JFC samples reduced up to 16% and other properties namely energy maximum, cracked energy, total energy, and toughness index increased up to 36.4, 260%, 143%, and 85.4%, respectively, w.r.t that of PC samples.
- The splitting tensile strength, energy maximum, cracked energy, total energy absorption, and toughness index of JFC specimens are increased up to 4.41%,

45.25%, 33.15%, 79.34%, and 93.19%, respectively, as compared to that of PC samples.

- Flexural strength, energy maximum, cracked energy, total energy, and toughness index of JFC specimens are increased up to 2.11%, 4.38%, 11.24%, 167.51, and 203%, respectively, as compared to PC samples.
- The JFRC specimen have performed likewise to the PRC specimen and displayed linear stress-strain behavior in the rising portion.
- The crack-arresting mechanism of jute fibers has resulted in high energy dissipation and toughness.
- Increasing the longitudinal main GFRP rebars, the axial load capacity reduces.
- Reduction of the confine steel reinforcement spacing from 76 to 64 mm has led to an enhancement in axial load capacity of the PRC and JFRC specimens.

Hence, based on the above results, the JFRC having GFRP rebars can be used to enhance the durability of structural members. Future study should be carried out on the optimization of GFRP rebars.

6.2 Future work

Following are recommendations for future work:

- The durability of JFRC over a longer period needs to be explored.
- Testing of full-scale elements with real field condition.
- Experimental results may be verified by carrying out analytical modelling.

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