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Improvement in Behavior of RC Beam-Column Joint with Jute Fibers and GFRP Rebars

by

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This thesis is dedicated to:

My Father and Mother

And everyone supported me in this journey, Who have been always a symbol of Affection, Happiness, and Bliss.

CERTIFICATE OF APPROVAL

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Abstract

Structural connections or beam column joints are critical points, under earthquake loading. Concrete fails during an event of earth quake, especially at column beam joints because concrete is a brittle material and weak in tension. Damages caused to concrete in such situations may be spalling and scrambling of the surface, large chunks are coming off, falling of concrete segments and ordinarily visible aggregates are un-cracked, surface parallel cracking, slits around aggregates in most of cases. Fibers are used to improve the mechanical properties of concrete by many researchers. Glass Fiber Reinforced Polymer Rebars (GFRP) are developing substitute of steel reinforcement for concrete structures due to its advanced properties like enhanced tensile strength, light weight, and corrosions resistance. Vegetable fibers (especially, jute Fiber) is a natural fiber with low cost, high tensile strength and available in large quantities in tropical areas. Jute fibers are used to improve durability, toughness, contraction and crack propagation in concrete. The general aim of the research program is to test jute fiber reinforced concrete (JFC) having GFRP rebars to study the performance of building connections by improving the properties of concrete. In the present research work, an experimental investigation has been carried out for comparative study the behavior of RC beam-cloumn joint prototypes having jute fibers and GFRP rebars.

A total of eight beam-cloumn joint prototype specimens were casted, two prototypes were casted with ordinary concrete reinforced with steel rebars and the next two specimens with jute fiber reinforced concrete having steel rebars. Other two specimens with ordinary concrete having GFRP rebars and two specimens with jute fibers having steel rebars. Specimens were placed in water at room temperature for 28 days. Prototype testing were carried out along with simplified boundary conditions. For preparation of PC and JFC similar mix proportion of 1:2:3:0.6 is used except, 5% jute fiber content having 50mm fiber length for JFC were tested. Dynamic properties were investigated as per ASTM C215-02. Relative comparison of beam-column joint for JFC prototype and PRC, having GFRP rebars has been prepared and cracking pattern were observed through naked eye.

The slump value of JFC specimen observed as 40% lower than PC. Density of JFC specimen is also low due to less weight of jute fibers. The damping ratio of JFC samples is higher than PC samples which shows more energy dissipations in comparison to PC samples. Beam-column joint prototype specimens were tested in a servo-hydraulic testing machine (STM). By the addition of jute fibers in ordinary concrete, behavior of concrete improved from spalling to bridging.

Contents

List of Figures

List of Tables

Abbreviations and Symbols

A	Aggregate
C	Cement
S	Sand
w/c	Water-cement
CS	Compressive strength
STS	Splitting tensile strength
FS	Flexural strength
P_{max}	Maximum load
Em	Energy-absorption upto maximum load
Cr. E	Cracked energy absorption after maximum load
TE	Total energy absorbed
TTI	Total Toughness Index
fl	Longitudinal frequency
ft	Transverse frequency
fr	Torsional frequency
s	Second
C. Em	Compressive energy-absorption upto 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

JFC	Jute fiber reinforced concrete
GFRP	Glass fiber reinforced concrete
NFRC	Natural fiber reinforced concrete
SHTM	Servo-hydraulic testing machine
MPa	Mega Pascal
kg	kilogram
KN	kilonewton
j	Joule
MJ	Mega Joule
m^3	Cubic meter
mm	millimetre
Hz	Hertz
δ	Stress
Δ	Delta
ξ	Damping Ratio

Chapter 1

Introduction

1.1 Background

Beam column joint is observed to be critical part in structural framework, thus it is significant to make it strong enough, to survive under different loadings. If we look over human history, earthquake is a worse natural disaster which has produced enormous destruction in many parts of the world. A major earthquake occurred in Quetta, Pakistan during year 1935, has caused large scale destruction. Another most significant earthquake of magnitude 7.6 occurred on October 8, 2005 at 08:52 am local time in the KPK province of Pakistan and parts of Pakistan-administered Kashmir caused injuries and loss of life over an area of 30,000 km^2 and same earthquake was also felt in northern india.

It destroyed roads in an area of 6,440 km, besides this, 60-70% of infrastructure including electricity, water supply lines and drainage system were badly damaged as shown in figure 1.1. About 400,153 domestic building structures, 6,298 school buildings and 796 hospital buildings were damaged as described in [1]. During earthquakes reinforced structures were failed, mainly due to unsuitable design such as weak beam-column joints, strong beam, weak column, soft and weak stories and in-plane/out-of-plane movement of the walls. Almost 35% brick masonry buildings and 50-60% reinforced concrete buildings, 60-65% block masonry buildings and 95% of the stone masonry buildings were moderately or extremely damaged in earthquakes [1]. Poor reinforcement detailing in RC structures does not posses adequate ductility and strength required to resist against earthquakes, which leads towards brittle failure, as failure of beam-column connections in such cases occurs due to bond and shear failure mechanism.

Using CFRP sheets, analytical study for reinforcement of beam-column joints reflected that increase in toughness, strength and energy dissipation capability increases [2]. For internal precast steel reinforced concrete (SRC) beam-column joints with slab is performed better than that of precast joints without slab under cyclic loading [3]. Strength and properties of the concrete are enhanced by using natural fibers. Natural fibers can be used in a variable ways, but still, it is essential for researchers to explore additional properties of fibers for a specific application [4]. Jute fibers improve bridging effect and durability of concrete and to confines concrete from extension of cracks. By using jute fibers flexural strength and durability of FRC is enhanced [5]. The mixed design ratio used for PC and JFC used is 1:2:3 and w/c ratio 0.60, except with the addition of 5% fiber content having 50mm length by mass of cement in JFC. The major concept to prepare PC and JFC is taken from Khan and Ali (2016) [6].

On viewing full scale experimental investigation on GFRP-RC external beam column joint, seismic loading showed enhancement in behavior of drift ratio and joint performance [7]. GFRP rebars are advance construction ingredients could be used as a replacement of steel re-bars due to its enhanced properties. GFRP rebars have developed properties such as, improved tensile strength, corrosion-resistant, economical in repairing and lighter in weight (1/4th of steel rebars) [8]. Latest studies on FRP rebars showed positive conclusions and prolonged use of FRP rebars for shear and flexure reinforcement. ACI 440.1R-15 [9] for bids use of FRP rebars in compression elements however CSA S806-12 [10] overlooks impact of FRP rebars in load carrying capability in the structural equations. However, current research focuses on represented efficiency of GFRP rebars in load carrying capabilities.

In this modern age, concrete is backbone material for the building construction. It is quite hard to anticipate the phenomenon of the material that might substitute the concrete. But concrete itself is a brittle material having very low tensile strength, compared to its compressive strength [11]. Because of this fact, properties of concrete are required to improve. Also, vulnerability to cracking, loading, and environmental issues, are the most promising factors which are causing reduction in functionality and serviceability of concrete [12, 13]. It is required to add fibers and admixtures in concrete to obtain high performance, attaining certain properties, and developing a sustainable material [14].

In the recent study, basic method is applied and behavior of a small prototype of PC and JFC beam-column joint embedded with GFRP rebars and steel rebars compared separately. There is a limitations of experimental work to explore structural behavior of jute fiber, for its utility for reinforcement of structural connections of buildings with steel and GFRP rebars under load.

Therefore, the recent study is focused to investigate the beam column joint prototype performance by adding jute fiber and GFRP rebars to increase the damping and ductility. Comparative observatory assessment on prototype specimens will be then made with respective conditions. To the best of author knowledge, on the basis of limited literature review, the study on the effectiveness of fiber reinforced concrete with jute fiber and GFRP rebars has not been carried out to investigate behavior of beam column joint. Moreover Pakistan is being in seismic zone, use of fiber reinforced concrete could be helpful in increasing the durability and to overcome the damage of buildings during earthquake.

Brittleness of concrete leads to the sudden failure thus, eventually leads towards failure of concrete structure. Therefore, to overcome this sudden effect in concrete, natural fibers are used in concrete. Various types of natural fibers are studied by researchers for improving mechanical properties of concrete. It is required to utilize economical and locally available materials in order to save cost without compromising on mechanical properties. Jute fiber has the ability to enhance dynamic properties and compressive parameters of concrete. JFC is easily available fiber which is low in price. Growing cost of steel rebars and corrosion problems have stimulated the use of further corrosion resistant reinforcement like GFRP rebars. Jute fiber reinforced concrete (JFC) is capable in generating bridging phenomena with less stable concrete while glass fiber reinforced polymer (GFRP) rebars plays a role as corrosion resistant reinforcement.

a) Domestic buildings fall down

b) Structural collapse

c) Destruction of roads

d) Retaining walls collapse along roads

FIGURE 1.1: Destructions during earthquake 2005

1.2 Research Motivation and Problem Statement

Pakistan lies in seismic zones extending from lower to extreme level. To overcome destruction during earthquake and to make buildings reinforced, it is essential to make beam-column joint strong enough to resist. In 2005 earthquake most of building were damaged due to failure of structural connections, inadequate concrete strength, inelastic concrete behavior, poor construction and low strength concrete. Many researchers reported that mechanical properties of concrete are improve by adding fibers in concrete. Therefore during it is important to consider the behavior of concrete by adding jute fibers with GFRP rebars to enhance performance of beam column joint performance. Thus, the problem statement is as follows:

"It is observed over period of time that buildings connections specifically beam column joints are critical points under different loading conditions. Concrete alone being a brittle in nature creates problems, therefore reinforcement are used to make it tough. Natural fibers are studied in recent past to be used in concrete to make it ductile. Concrete being brittle in behavior fails at beam column joints region under different loading, therefore steel stirrups are provided to make it ductile. Since steel have corrosion problem, therefore GFRP rebars are an alternate replacement to address this issue in addition to other properties. Previous studies are conducted on structural elements by using jute fibers in short discrete reinforcement and GFRP rebars as longitudinal reinforcement, however, their effect on behavior of beam column joints is not studied yet. Therefore, there is a need to explore the behavior of beam column joint having JFRC and GFRP rebars in both horizontal and vertical structural elements."

1.2.1 Research Questions

Followings are research questions which are explored in this study:

- How much improvement in concrete properties by adding jute fibers with selected mix design ?

- How much enhancement in STS in comparison with compromise in compressive strength due to addition of jute fibers ?
- What are combined effects of jute fibers and GFRP rebars on dynamic and mechanical properties of concrete ?
- What are effects of jute fibers and GFRP rebars on beam column joint prototype ?

1.3 Overall Objective and Specific Aim of this MS Thesis

The overall goal of this research program is to replace steel bars with FRP rebars in concrete structures with additional use of natural fibers for improved durability and performance. "In the present research work, an experimental investigation is carried out to examine the properties of prototype having GFRP rebars in JFRC for possible improvement in beam-column joint. Comparative assessment on RC beam-column joint prototype having jute fibers and GFRP rebars is performed."

1.4 Scope of Work and Study Limitation

Figure 1.2 shows the scope of work. Three samples each are taken to find out the mechanical properties of JFC and PC as per ASTM standards. Prototype testing is performed with basic boundary conditions. Same mix design ratio 1:2:3:0.6 is used, both for PC and JFC except 5% fibers addition having 50mm length in JFC as described by Zia and Ali [5] and ASTM C39. Relative comparison of prototype specimens is performed under loading between PRC and JFC extended with steel and GFRP rebars separately. Cracking pattern is then observed with naked eye. Compressive strength, split tensile strength, flexural strength, total energy absorbed, toughness index, cracked energy absorption and cracking pattern will be determined during experimental program as per ASTM standards. Cost comparison is not included in current scope of work.

1.4.1 Rationale behind Variable Selection

The justification behind selection of mix design and materials are:

- Due to high tensile strength, flexural strength and toughness, jute fibers are is preferable to use.
- By studying satisfying results as investigated by different researchers, the ratio 1(C):2(S):3(A) and 1%, 3% and 5% of fibre content by mass of cement and 50mm length of fiber is used [13].
- GFRP rebars are used due to their resistance to corrosion, high tensile strength, light weight, low maintenance cost [13].

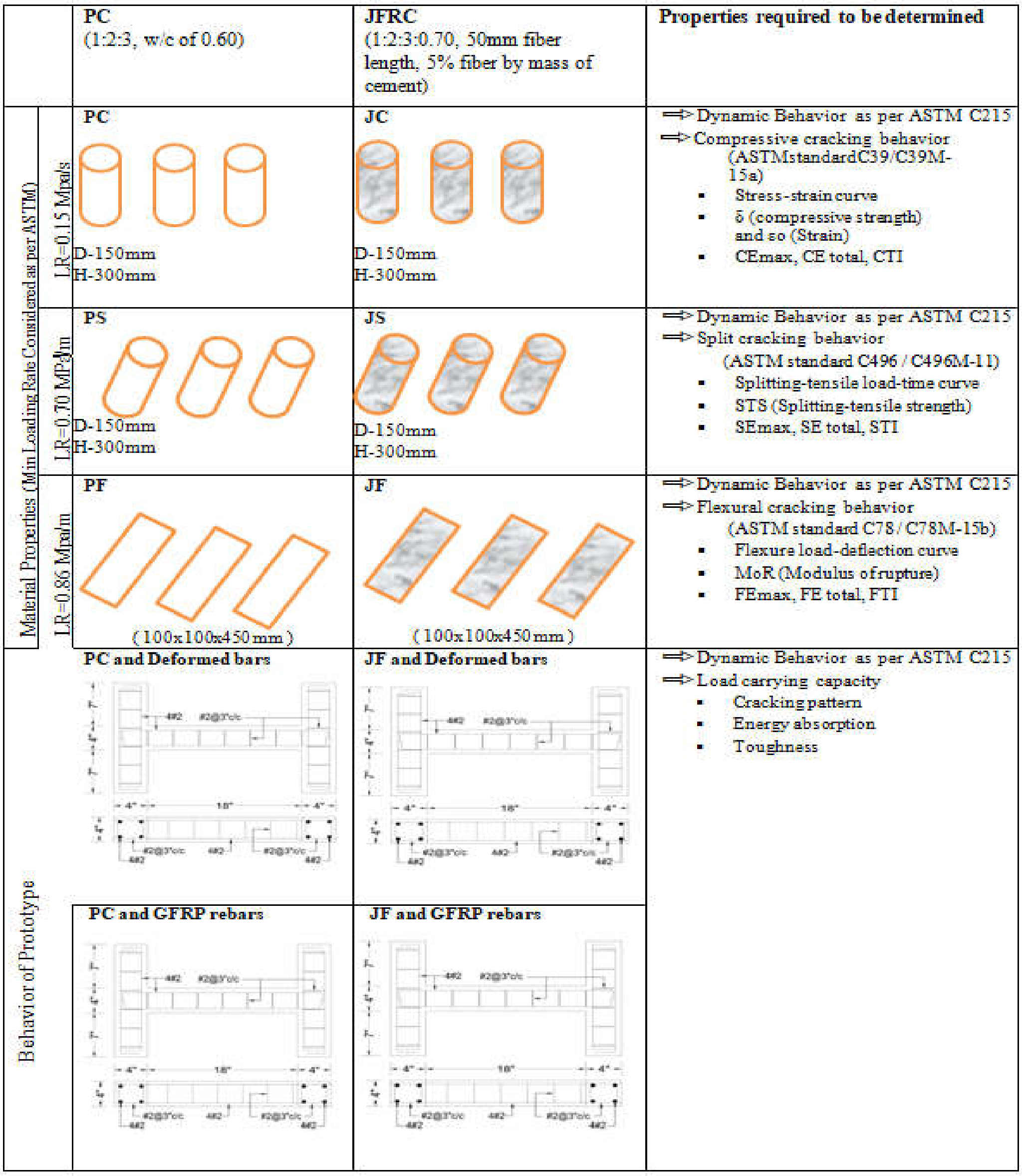


FIGURE 1.2: Scope of work

1.5 Novelty of Work, Research Significance and Practical Implementation

In an experimental work, it was revealed that resistance against impact loading significantly improved by the addition of the natural fibers in concrete [15]. The mechanical properties of concrete were observed to be improved by the addition of natural fibers [16]. Previous conducted studies show that properties of concrete and performance of structure were improved with different types of natural fibers and admixtures.

To the best of authors knowledge, no research has been conducted on combined effect of JFC and and GFRP rebars on enhancing the properties of concrete for improvement in beam column joint . Thus, the current study is aimed to study the basic mechanical, dynamic and absorption properties of concrete using Jute fiber and GFRP rebars.

These material are resulted in production of improved properties of concrete for the use in civil engineering and construction industry. There are several flaws of concrete like cracking, spalling, weak in tension, etc. So, there is a need to mitigate these flaws of concrete. The addition of fibers in concrete resulted in improved durability and enhanced resistance against production and progression of cracks . Fiber reinforced concrete have shown the improved properties in comparison with respect to the properties of the PC.

According to a research, fiber reinforced concrete (FRC) beams along with fiber reinforced polymer bars as reinforcement has shown better performance [17]. In Previous studies, single fiber or combination of two fiber was used in concrete for improving its properties.

Very limited studies are available in which improvement in structural connections using natural fibers were used. Therefore, utilization of natural fibers and GFRP rebars are could be beneficial to be used for improving the structural connections specially in beam column joint. Hence, there is need to investigate their effect on behavior of beam-column joint.

1.6 Brief Methodology

In the recent experimental study, the mechanical properties such as compression, flexure and split tensile strength are investigated for the specimens of cylinders and beams with ordinary concrete and JFC. Material properties including elastic modulus, modulus of toughness, modulus of rapture and resilience modulus are considered. Modulus of toughness is the ability of a material to absorb energy in plastic deformation. It is the area under the stress-strain curve upto fracture point. Modulus of resilience is the maximum energy that can be absorbed per unit volume without creating a permanent distortion. It can be calculated by integrating the stressstrain curve from zero to the elastic limit. Tests are performed on beam column joint prototype specimen. Total of eight prototype specimens are tested and for each situation and average of two readings is obtained. Two Prototype specimens are casted with plain concrete and deformed bars as PD-1 and PD-2, two prototype specimens are casted with plain conctrete and addition of glass fiber reinforced rebars (GFRP) named as PG-1 and PG-2, two beam column joint prototype specimens are casted with Jute fiber reinforced concrete having deformed bars as reinforcement and same termed as JD-1 and JD-2 and final two prototype specimens are prepared with jute fiber reinforced concrete by adding glass fiber reinforced rebars and specimens are termed as JG-1 and JG-2. GFRP and steel / deformed bars are 6mm in diameter and 457mm in length. The size of prototype is 101mm $\times$ 101 mm and total length for beam and column is 457mm. Rings and ties are 7mm apart to hold main reinforcement of beam and column. load is then applied in STM to find the required parameters as per ASTM standards alongwith load deflection curve.

The mix design ratio of cement, sand, water and aggregates, designated is 1:2:3:0.6 which is generally used in the current research work. The filling of molds is done horizontally in four layers in order to avoid honey combing. Layers used for filling of molds are 25mm, 50mm, 50mm and then 25mm in thickness [18]. Proper compaction is made after every layer. To find out the compressive and splitting tensile strength, three cylinders are casted each for PCC and JFC having dimensions of 100mm diameter and 200mm in height.

To find the modulus of rupture, three beam-lets specimens are casted each for PCC and JFC having dimensions of 100mm × 100mm × 450mm. The steel reinforcement has provided with strut and tie method as per ACI-318 for an assumed applied load. To find the shear strength, energy absorption and toughness index eight prototype specimens of beam column joint are casted and tested.

GFRP rebars and steel rebars are used to examine the prototype specimen by the addition of jute fiber and without using fiber in concrete. Efficiency of jute fibers in enhancing the load carrying capacity and overall failure is examined. The performance of PRC and JFC with addition of steel and GFRP rebars are compared. Load carrying capacity is found along with the detailed failure mechanism, the cracking is observed through naked eye.

Tests are performed to analyze the tensile strength, compressive strength and modulus of rupture. The mix design ratio of (Cement, sand, aggregate, water) used is (1:2:3:0.6). For preparation of JFC, jute fibers having 50mm length and 5% fibers by mass of cement is mixed with concrete. ASTM standards are used to cast the standard specimen.

1.7 Thesis Outline

There are five chapters in this thesis, which are listed below:

Chapter 1: Chapter 1 concisely defines the introduction. It also contains of background, research inspiration and problem statement, objective and scope of work, thesis outline and methodology.

Chapter 2: Chapter 2 describes the literature review. It consists of background, beam column joints failure, use of natural fibers in concrete (jute fiber), use of GFRP rebars with PC and JFC, testing practice and summary.

Chapter 3: Chapter 3 demonstrates the experimental method. It contains background, selection of mixture design for the recent study, raw materials, casting procedure, testing procedure, mix design, specimens and summary.

Chapter 4: Chapter 4 covers analysis and consequences. It contains background, frequencies and damping ratio, the conduct of prototype piers and summary.

Chapter 5: Chapter 5 comprises of assumptions and recommendations.

Chapter 2

Literature Review

2.1 Background

Earthquakes can produce destruction effects in terms of human life and infrastructures. The damaging potential of earthquakes is influenced on many aspects such as focal deepness, local site disorders and epicenter distance. But the reasons of mortalities and the degree of harms depends on deficiency of engineering practices, faults in structural design, quality of materials used and workmanship. In recent past, fibers are used to improve the concrete behavior, performance and mechanical properties. Jute fibers are used to improve the toughness, durability, shrinkage and cracking propagation in concrete. Jute fibers are low in cost, high tensile strength and easily available in tropical regions. Glass fiber reinforced polymer rebars are a unique alternative of steel reinforcement for concrete structures in spite of other characteristics such as high tensile strength, low density, and weather resistant.

To investigate any structural behavior, four stages are involved, including (i) full scale structure in actual field environment [19], (ii) full scale structural elements with accurate boundary conditions [20], (iii) either scaling the sample structure or typical structural elements, containing the suitable gradient for raw material, size loading conditions and end-limits [21], and (iv) small sample structural elements for relative assessment in order to check the efficiency, only one variable provided and all other conditions are same [22, 23]. In the recent study, only a basic approach (i.e. stage iv) is applied. The performance of a small prototype of PC and JFC beam-column joint having GFRP and steel reinforcement, are compared.

2.2 Failure in Buildings

Field visit are conducted in earthquake effected areas and infrastructures. Along with certain other reasons, non-compliance with seismic provisions in the building structure, and the absence of quality control in construction, seems to be leading aspects in producing building failure and extensive damages caused increase in human life loss. The other reasons of failure of structures are heavy weighted roofs, insufficient reinforcement detailing in joints region and the poor quality of ingredients in concrete [1]. Few other reasons are:

- Non compliance of design codes.
- In elastic building connections.
- Insufficient reinforcement detailing specifically in joints region.
- Low standard concrete ingredients.
- Poor engineering practices in construction.

Elmasry et al. [2] investigated that poor reinforcement detailing in RC structures does not have sufficient ductility and strength needed to resist against earthquakes, which leads to brittle failure, as failure of beam-column joints in such cases originated by bond and shear failure mechanism.

Building failure caused when the building design codes/standards are not followed during execution. Hence, building failures can be characterized into the two groups, physical (structural) failures and performance failures (which means a decrease in function beneath an recognized standard limit). Structural failure corresponds to the excess of minimum strength of the load-carrying components, which contributes in the structural strength of the buildings. Therefore, this leads to extended destruction, partial or complete destruction of the building, which results in huge renovation cost as shown in figure 2.1.

FIGURE 2.1: Structural connections failure

Basic structural failure in construction involves compressive, tensile, twisting and deformation. Structural failure begins when the material is stressed to its higher strength limit, producing rupture or severe buckling. The strength of the material is the limit of its load carrying capacity. On attaining this limit, the building materials damaged badly and their load carrying capacity is rapidly reduced continuously. If the structure is designed properly, a local breakdown usually would not be a reason of immediate or steady failure of the building. To avoid failure the minimum strength of the structural elements should be prudently considered in the design.

In certain RC buildings, particularly at the ground floor, walls may not be continuous along the height of buildings for architectural, commercial and functional reasons. Although ground floor usually encompasses through glass window despite of brick infill walls, divider walls are built above this story for detachment of rooms for the domestic usage.

This condition comes brittle catastrophes at the end of the columns. Soft-story mechanism is the most common failure mode in mid-rise reinforced concrete buildings, mainly at the first story. Failures can be concerted at any story named as weak story in which the lateral strength rapidly changes between neighboring stories due to deficiency of dividing walls or reduction of cross section of columns.

Therefore, during an earthquake, partially and entire collapse occurred in these structures. Shear forces proliferates during earthquake specifically at beam-column joints. Accordingly, special consideration should be made for construction, design of columns and beam-column joints. Seismic design needs provision of ductility in structures in based design method. Specifically, columns of buildings can have inadequate transverse reinforcement in the plastic hinge region.

Consequently, structural elements having such characteristics shows minimum performance against dynamic loads and reduce their axial and shear load carrying capability. This kind of behavior normally arises at wall-to-wall connections and wall-to-roof joints when subjected to out-of plane displacements. During an earthquake, the stress concentrations rise at connection of the walls.

In this manner, vertical or visible cracks seem in the corners of stonework buildings. If bond beams are not used in construction and two walls are not connected with each other, then intensity of the cracks upsurges and these cracks spread along the diagonal of the wall. Likewise, cracking may be detected at adobe buildings [24].

A poor connection between connecting walls and in existence of bond beams, produces severe damages. In count, there are no suitable connections at the corner of the walls in damaged buildings, decrease in compression stress and rise seismic acceleration at higher stories, in such cases the common failures is perceived at the corners of the roof level. When there is no slab with some in-plane firmness at roof level, upper corners are more profound to fail due to cantilever-like behavior [24]. Damages of building due to failure of beam column joint is shown in below figure 2.2.

(a) (b) (c)

FIGURE 2.2: Damages in earthquakes (a) Beam column joint failure (b) Diagonal tension failure and (c) Short column

A high rise Margalla towers having 12-stories was collapsed, died most of its occupants under building, which triggered millions of financial loss. It was reported that 78 people died including childerns, and ladies, over hundred seriously injured and over fourty families becomes without homel due to Margalla tower collapse as shown in figure 2.3

An investigation on collapse of said tower revealed that unnoticed seepage from underground water-tank, just two meters away from the foundation-bed had caused the Margalla Towers collapse on october 8 as shown in figure 2.3. The report, compiled by an investigation agency, says that seepage of underground water tank, having dimension 40'× 40' with 8' feet depth, damaged the foundation and destabilized the main eastern columns supporting the tower which causes collapse of the building in initial jolts of the earthquake.

a)

b)

Figure 2.3: Collapse of Margalla tower during earthquake 2005

2.3 Use of Natural Fibers in Concrete

Natural fibers contribute in enhancing the properties and performance of reinforced concrete [25]. In recent past fibers are used for the improvement of concrete performance and to enhance its behavior and mechanical properties. Fibers are useful in improving energy absorption capacity, durability and crack proliferation. Researchers were ensure to use fibers due to their properties such as low in price, easily accessible and great strength were the reasons behind the importance of natural fibers. Sisal, jute and fibers are easily available in nature. Natural Fibers have some shortcomings as well such as they cannot be used in high temperature [26].

Khan and Ali [6] investigated the behavior of coconut fibers in fly ash, silica fume concrete. Overall ten batches were investigated. Fly ash dosages are altered between 0%,5%, 10%, and 15% respectively, content of silica fume is same i.e. 15% for fly ash silica fume ordinary concrete (FA-SPC) is used while similar configuration for fly ash silica fume coconut fibers reinforced concrete (FA-SCFRC) with the addition of 2% coconut fibers with 50mm length was used.

It was noticed that FA-SCFRC revealed better results at 10% content of fly ash in comparison to other substances of FA-SCFRC and FA-SPC. Momoh and Osofero [27] examined mechanical properties of concrete using oil palm broom fibers (OPBF) at 7, 14, 28, 56 and 112 days. Fiber length used was 50 mm with mix design ratio of cement, sand and aggregates is 1:1.5:3. It was determined that flexural, compressive and splitting tensile strength of OPBF-concrete was not enhanced expressively, while energy absorption capacity between 70 and 320% at 112 days was observed. Hari and Mini [28] examined effects of mechanical properties and toughness of self-compacting concrete using sisal and nylon hybrid fibers. Various proportions of hybrid fibers including 0/100, 25/75, 50/50, 75/25 and 100/0 was implied. It was assumed that fiber performance decreased due to water absorption and effected strength. Nylon fiber, when hybridized with sisal augments, the toughness and mechanical properties of concrete were improved. Fibers when randomly distributed in concrete acts as an additive for resistance of cracks and changed the behavior of concrete entirely against static and dynamic loading [29].

Though, addition of synthetic fibers enhances the performance of concrete but they were obtained from costly and non renewable natural resources [30]. Addition of jute yarns and jute fibers to strengthen concrete composites contributes in attaining improved mechanical outcomes using specific length and quantity [31]. Jute fibers when mixed in high-fluidity concrete produce larger development in strength as compared to addition in standard concrete [32].

Universally, around 5% of carbon releases are due to cement manufacturing for industrial activities that classified as a poor component of concrete for environmental influence [33]. The mixing of fibers by mass of cement in concrete also showed that by keeping same values of strength for both fiber reinforced concrete (FRC) and PC, a obvious quantity of cement by mass can be protected [34]. Suitable length and content of jute fibers decreased minor cracks and sponginess of concrete besides delaying cracks commencement and proliferation [35]. Higher percentage of fiber and length produces greater resistance against projectile impression [18]. Higher content of fiber has positive effect on compressive strength of JFC with advancing curing age [36]. Investigative study using CFRP sheets for strengthening of beam-column connections designates improvement in strength and energy intemperance capability.

Experimental studies revealed that suitability of restricted boundary elements do not express a comprehensive ductile behavior when exposed to pure firmness in compliance to ACI 318-11 detailing necessities [37]. Hence, it is required to discover non-conventional material to improve the brittle mode of failure to ductile mode of failure. Natural fibers are inexpensive and locally available materials with a prospective for the revolution of post cracking manner of concrete deprived of compromising the mechanical properties of concrete. Izquierdo et al. [38] used sisal fiber in resonating concrete blocks, walls and wallets. It was noticed that sisal fibers augmented the ductility of the blocks as the fiber linked the introductory cracks and prohibited further incoherence of the material.

Due to little elastic modulus of sisal fiber, it become effective after cracking of concrete therefore, there is an enhanced energy absorption due to which wallets can survive in increased loading even after cracking. Madandoust et al. [39] inspected the impact of rice husk ash on properties of concrete and its toughness. The strength was evaluated by inserting the specimen in extreme environment for 11 months. It was detected that partial replacement of cement by rice husk ash enhanced the toughness of concrete and compressive strength of concrete also enhanced at later ages. Ali et al. [23] explored mechanical and dynamic properties of concrete. The variable constraints were fiber content (i.e. 1% - 5%) and fiber length. The testing result revealed rise in damping of coconut fiber reinforced concrete beams, while reduction in fundamental frequency of beam was detected due to destruction. Additional test results shows that 5% fiber content and 50 mm length enhances the compressive strength up to 21% in comparison to PC.

Islam and Ahmed [35] investigated the impact of jute fiber on the characteristics of concrete. The results revealed a positive influence on compressive strength of concrete with little percentage of fiber content (i.e. 0.25%). Compressive strength of jute fiber reinforced concrete rises with the enhancement of curing age.

The catastrophic configuration of specimen during compressive testing indicated that jute fiber reduces cracks width therefore, varying the cracking arrangement of concrete. Zakaria et al. [31] determined from his investigational study of jute fiber in concrete that mechanical properties increases by keeping the fiber content of 0.1% and 0.25% with varying fiber length between 10mm and 15mm. An improvement in load carrying capability and distortion capacity was detected using bamboo strip as reinforced concrete in comparison to ordinary concrete and reinforced cement concrete (RCC). Lima et al. [40] performed an experiment to assess the toughness of bamboo fiber. Specimens were passed through soaking and aeration cycles. Samples were placed in water and were retained in calcium hydroxide. The results of the tests revealed no obvious variations in mechanical properties of bamboo fiber.

Zia and Ali [5] deliberated the behavior of fibers in concrete to control cracking ratio in canal lining. It was noticed that fibers are useful in controlling cracking rate. 35% reduction in compressive strength of JFC was noticed as compared to PC, while 124% increase in compressive strength of JFC was reported in comparison to PC. There is no limit of conceded strength reported as the experimental studies directed on the basis of relative comparison. Mozzali et al. [41] determined that fibers like macro polypropylene and polyethylene are useful in reduction in cracks width and a initiation of cracks. Fibers are also capable to improve the dynamic properties of concrete. Table 2.1 shows the dynamic properties of fibers. John et al. [42] examined the toughness of coconut fiber. The fibers were 12 years old and were taken from inner and outer walls of houses. SEM analysis shows that fibers were unharmed even after being expose to natural environmental conditions for 12 years.

Lignin amount in fiber was similar for interior and exterior wall. Shivaraj et al. [43] highlighted the durability of coconut fiber. The process of testing was 2 years of dampening and ventilation cycles of specimens and it was determined that there was no reduction in mechanical properties of coconut fiber reinforced concrete.

TABLE 2.1: Dynamic properties of Natural Fiber reinforced composites

Sr. No.	**Reference**	**Fibre**	**Conclusion**
1	Ali et al. [23]	Coconut	Increase of fibre content increases the damping ratio and reduces the fundamental frequency especially after cracking of specimen. Fibre length of 5cm and 5% fibre content has the best dynamic properties.
2	Hussain and Ali [23]	Jute	Addition of jute fibre in concrete increases the damping ratio and dynamic elastic modulus by 100% and 68%, respectively.
3	Yan and Chouw [23]	Coir	Fibre decreases the fundamental frequency, dynamic Poisson's ratio and modulus of elasticity but significantly increases the damping ratio. It was observed that jute fibre reinforced composite showed a better dynamic behavior.
4	Omer et al. [44]	Jute and kenaf	Jute fibre had more compressive modulus, flow stress and compressive strength increased upon dynamic loading compared to kenaf fibre.

Prasannan et al. [45] examined the compressive, split tensile and textural strength of banana fiber. Amount of fiber content used was 1% and 1.5%. It was detected that split tensile strength and flexural strength amplified whereas compressive strength stayed unaffected after 28 days of curing. The proliferation was directly proportional to the quantity of fiber. It was perceived that banana fiber has slight elongation and is lighter in weight. Banana fiber advances the post cracking behavior of concrete due to its useful bridging property.

Farooqi and Ali [16] investigated the compressive behavior of wheat straw reinforced concrete(WSRC). It was noticed that the compressive strength of natural wheat straw reinforced concrete improved up to 14% as compared to plain concrete. There was a bridging effect in case of WSRC however brittle failure was noticed for PC.

As stated in table 2.1, Omar et al. [44] examined the dynamic properties of jute and kenaf fiber. It was detected that under dynamic loading, jute fiber reinforced complexes had advanced dynamic response than kenaf fibre composites in terms of flow modulus, compression modulus and compression strength. Hussain and Ali [43] stated that by adding jute fibers in concrete reduced compressive strength by 26% than that of ordinary concrete. Damping ratio increases up to 100% and elastic modulus of JFC rises up to 68%, , in assessment with plain concrete. There is a need to promote low cost and easily available materials in order to save price without compromising on mechanical properties. Therefore JFC satisfies these standards.

Chin and Nepal [46] performed tests on straw fiber reinforced concrete to inspect concrete performance. It was determined on comparing with ordinary concrete compressive and flexural strength of wheat straw fibers enhanced by 0.25% by volume fraction. Importance of plant fibers was deliberate such as wheat straw and examined flexure and shear strengthening. For PC wheat straw was taken by mass of concrete; fiber length taken was 25 mm with mix design ratio of (1:2:4). Properties such as energy absorption, flexure strength and toughness index and flexural strength were enhanced up to 7.5%, 11.1% and 30.4% respectively. Using wheat straw crack proliferation reduced to some extent. In stiff pavements wheat straw fibers revealed improvement in behavior and yields comparable design.

The coconut fiber reinforced concrete showed better results in mechanical properties and dynamic behavior. Fiber lengths varying 25 mm, 50 mm and 75 mm were implied and in concrete mixture fiber contents of 1%, 2% and 3% were used. It was noticed that fiber with 5% content having 50mm length showed better results [23]. Elsaid et al. [47] studied that natural fibers and kenaf fibers improves mechanical properties such as concrete resistance.

To examine the behavior of fiber nearly 53 samples were casted having average size 22, while 12 and 19 samples were casted for splitting tensile strength to check the modulus of rupture. For concrete 1.2%-2.4% fibers by volume proportion was taken practically. Hence, it is designated that the kenaf fibre reinforced concrete, expressively improves tensile strength, enhanced cracking behavior and was responsible to providing three times more durability than the normal concrete.

Wahyuni et al. [48] considered the splitting-tensile strength of concrete using bamboo fibers 0.5% by weight of cement while 2cm length of bamboo fiber was used. After 28 and 90 days splitting tensile strength of cylinder was verified. It was detected that on comparison with PC the tensile strength of BFRC was raised up to 26%.

Fibre is primarily used in concrete to inhibit tensile crack growth thus significantly increasing the post-crack tensile strength of the concrete. Addition of fibre to concrete significantly alters the mechanical properties of the member such as increase in toughness (energy absorption), ductility, tensile strength and flexural strength [49]. Fibres may be metallic, organic or synthetic and may be available in various geometries. The philosophy underlying the applicability of fibre reinforced concrete in relation to seismic applications is illustrated in Figure 2.4.

The fibre mechanisms have also been viewed as constituting two different levels of interactions. The spacing mechanism constitutes the micro-level arrangement of well distributed fibres that will arrest the micro-cracks and inhibits further propagation. The crack bridging mechanism constitutes the macro-level which comprises bridging the flexural cracks thus facilitating improved post-cracking tensile strength, increased energy absorption, and improved ductility [50].

Figure 2.5. presents the general response of fibre reinforced concrete in comparison with that of plain concrete. Fibre reinforced concrete provides better energy absorption (toughness), postcracking behaviour, and the capacity to undergo large plastic deformation while maintaining the load carrying capacity thereby assuring relatively ductile failure.

In other words, cracked fibre reinforced concrete exhibits much better energy absorption capacity by undergoing large plastic deformation before failure than plain concrete which will fail suddenly in a brittle manner once the peak load is reached. This post-cracking property of fibre reinforced concrete is a very useful property for seismic applications.

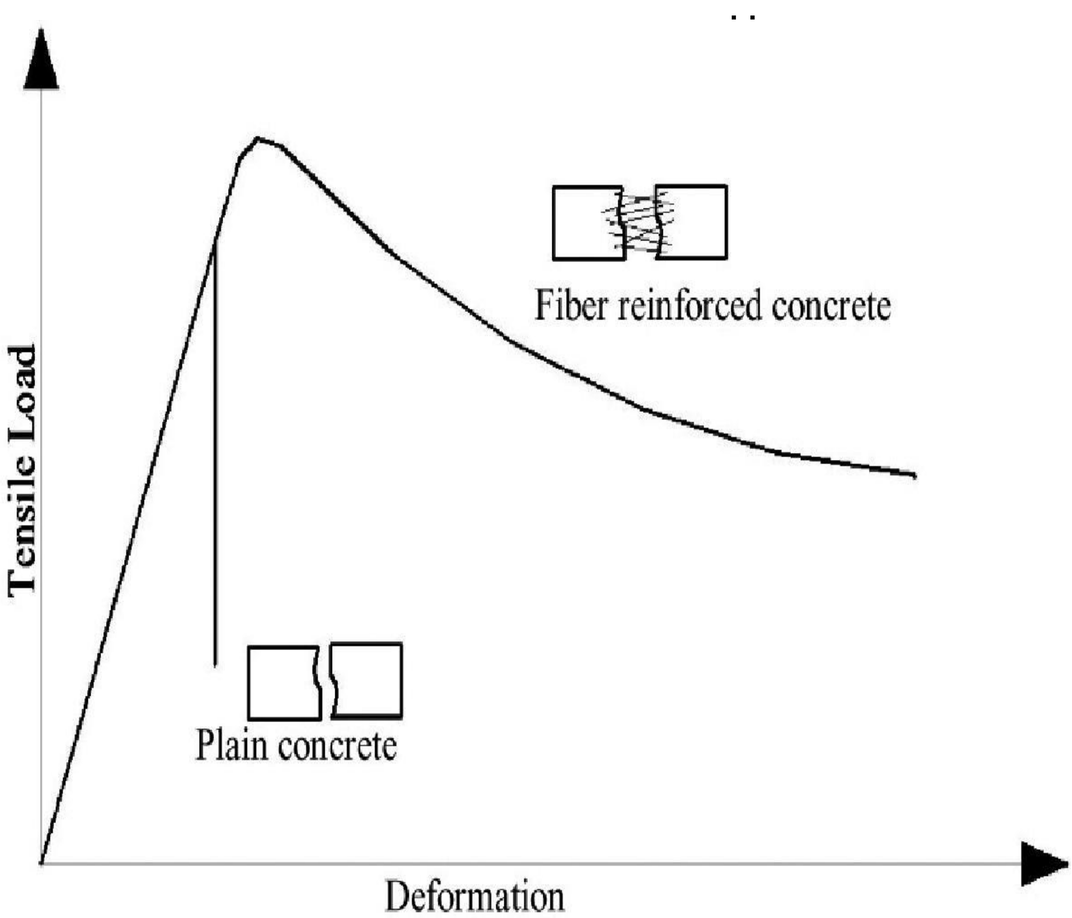


Figure 2.4: Structural response of fibre reinforced concrete.

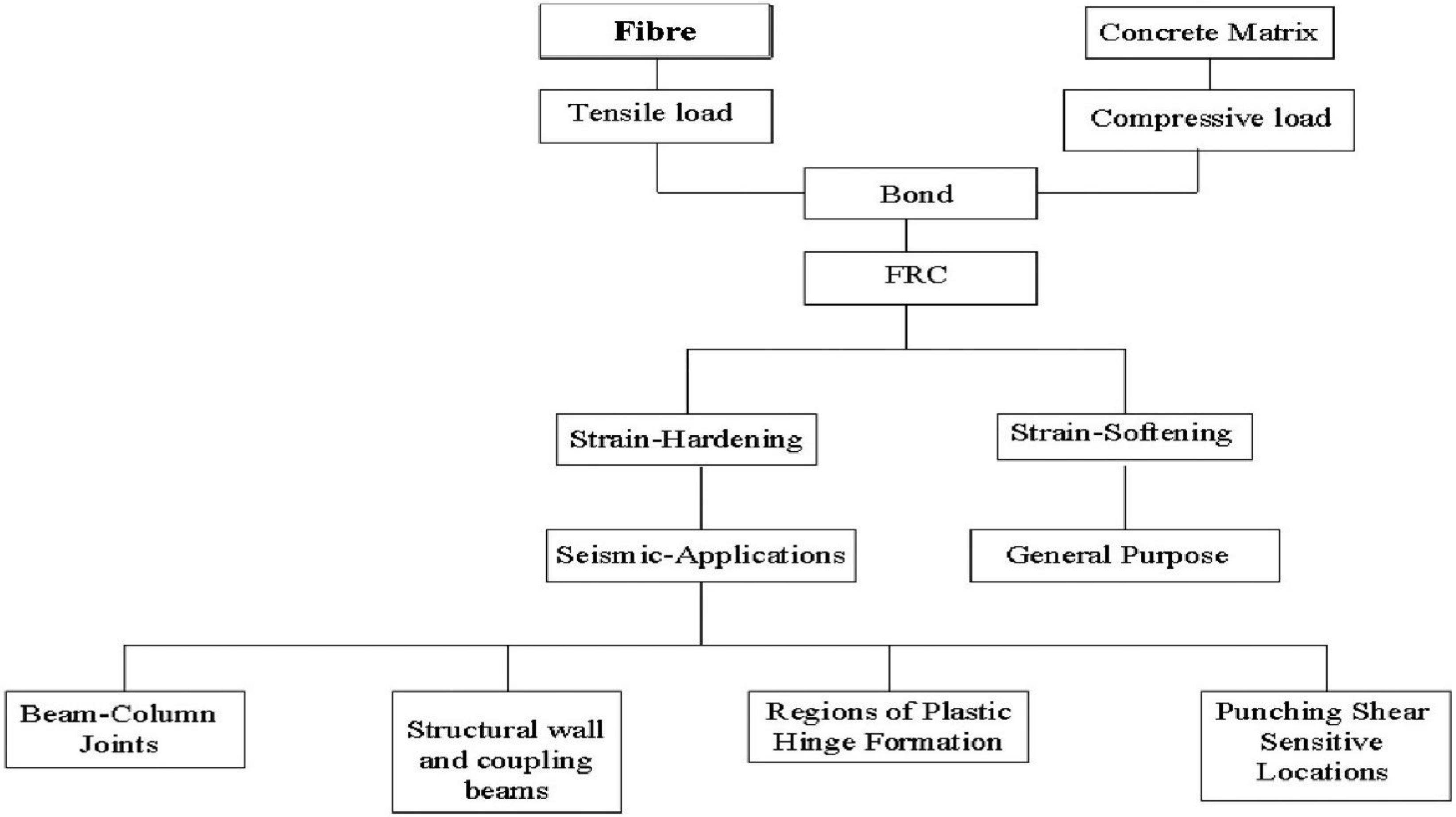


FIGURE 2.5: Fibre reinforced concrete in relation to seismic applications.

2.3.1 Use of Jute Fibers in Concrete

Zia and Ali (2017) [5] studied that by using jute fibers durability and flexural strength of FRC was improved. Ahmed et al. (2018) [35] examined ordinary and toughened properties of concrete using jute fiber having lengths of 10-50 mm in different volumes . The outcomes from factorial investigation revealed that positive impact was shown by fiber length and volume on hardening concrete properties at early and extended stages.

Natural fibers (particularly, jute fiber) is economical, possess great tensile strength, and plentifully found in tropical areas. A slighter dosage of jute fiber (0.25% by volume proportion) had a positive impact on reinforced concrete properties. Investigational result revealed that length and volume of fibers have a progressive effect in primary and extended treatment periods on the toughness of the concrete [35]. Good bonding properties shown using jute fibers having length greater than 10mm against the pull-out test for cement based matric [18]. Razmi and Mirsayar [12] stated that mechanical properties of FRC are improved by using jute fibers in concrete. Jute fibers increase the breakage durability of concrete and to confine the extension of cracks in concrete. Leakage durability of concrete and the extension of cracks in concrete. Polymer modified alkali treated jute fibre as a reinforcing agent, substantially improves the physical and mechanical properties of cement mortar with a mix design cement:sand:fibre:water::1:3:0.01:0.6. The workability of the mortar is found to increase systematically from 155 $\pm$ 5mm (control mortar) to 167 $\pm$ 8mm (0.2050% polymer modified mortar). The density of the mortar is increased from 2092 kg/m^3 to 2136 kg/m^3 with a concomitant reduction of both water absorption and apparent porosity. Optimal polymer content in emulsion (0.0513%) is found to increase the compressive strength, modulus of rupture and flexural toughness 25%, 28%, 387% respectively as compared to control mortar. Based on the X-ray diffraction and infra-red spectroscopy analyses of the mortar samples a plausible mechanism of the effect of modified jute fibre controlling the physical and mechanical properties of cement mortar has been proposed. Chakraborty et al. [36] designated that the mechanical properties of cement mortar enhanced significantly using jute fibers. Tensile strength values of 393-773 MPa for jute fibers as mentioned in table 2.2, are tested around the globe [4 , 51]. However, for the region of subcontinent, these values are 275 - 335 MPa [36]. These values may be taken as the representation of tensile strength of jute fibers used in current study due to the reflection of small range.

TABLE 2.2: Mechanical Properties of Jute Fibers Ali (2012) [4],Warke and Dewangan (2017) [51]

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/m^2

Zakaria et al. [31] explored the performance of jute fibers for reinforcement of concrete material. Two varied mix design proportions with volumetric fractions of jute fibers taken are 1:2:4 and 1:1.5:3 and the length of fibers were changed from 10 - 25mm. It was determined that splitting tensile strength, flexural strength and compressive strength were enhanced expressively. Results of jute fiber on concrete by both researchers are represented in Table 2.3.

Table 2.3: 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**
PC	-	-	100	100	100
JFC					
0.6 kg/m^3	1:1.74:3.24	30	119	-	154
0.25%[a]	1:1.5:3	15	105	105	119
0.50%[a]	1:1.5:3	15	98	78	90
0.25%[a]	1:2:4	15	102	101	111
0.50%[a]	1:2:4	15	88	113	101

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

Concrete reinforced using jute fibers controls cracking rate in canal line. Jute fibers also improve flexural strength and toughness of FRC [5]. The major concept to prepare mix design fraction of PC and JFC in ratio of 1:2:3:0.6 except with the addition of 5% fiber content by mass of cement comprising 50 mm length is taken from Khan and Ali [6]. Addition of jute fibers on the fresh and hardened properties of Concrete[35]. Locally produced jute fibers having two different lengths of 10mm and 20mm and four different volumes of 0.00%, 0.25%, 0.50%, and 1.00% were added to prepare concrete cylinders and beams. The cylinder specimens were tested for the compressive strength at 7, 28 and 90 days and for the split tensile test at 28 and 90 days, whereas the beam specimens were assessed for the flexural tensile strength at 28 days.

Additionally, various factorial analyses were conducted on the experimental results to detect the effect of the volume and size of jute fibers on concrete properties. The experimental results revealed that the addition of 0.50% jute fiber had an adverse impact on the fresh properties of concrete. However, a smaller dosage (0.25%) of jute fiber showed a positive influence on the hardened properties of concrete. The results obtained from factorial analysis demonstrated that the fiber length and volume showed a positive influence on hardened concrete properties at early and extended curing ages, respectively

2.4 Fiber Reinforced Polymer Rebars

In last two decades the use of fibre reinforced polymer (FRP) rebar has been extraordinarily increased due to their developed properties such as outstanding corrosion resistant properties, having high tensile strength, light in weight and low repairing cost. FRP rebars has been used as strengthening agent in buildings bridges and other structures [52]. High strength glass fiber reinforced with vinyl ester resin is used to prepare FRP rebars. FRP rebars can be used as a substitute for steel bars and to overwhelm the weathering issues it is an accurate and inexpensive solution.

Over conventional steel bars FRP has numerous preferences such as they possess a density of one-quarter to one-fifth that of steel, more tensile strength than steel, and no erosion even in unpleasant conditions [53]. Sadrie et al. [54] explored that the use of GFRP rebars in concrete structures in harsh environmental conditions extends the life duration of the structure and the overall maintenance cost of the structure. The use of GFRP rebars with high strength concrete will solve the solution of strength and corrosion problems in harsh environments. Furthermore, with adjustment in spacing of transvers reinforcement strength problems can be solved to gain high strength and ductility [55].

2.4.1 Use of GFRP rebars in Concrete is Fundamental Element for improved Stability

Fiber reinforced polymer (FRP) rebars are beneficial due to great stability, non-conductive and lighter in weight, in comparison to steel rebars. But when sufficient anchorage is required steel rebars are favored due to their bending ability [56]. In GFRP rebars reinforced concrete post cracking reinforcement strains are higher until failure due to inferior axial stiffness arises. The bond strength of GFRP rebars is implanted in drift fiber-reinforced composites is higher as compared to those implanted in normal concrete [29]. Total mass and geometrical properties performs chief role in struggling dynamic forces. In the beginning force of inertia regulate resistance under loading impact followed by the influence of flexural behavior . Rebars which contributes in strengthening of concrete against loading impact delivers resistance against punching distortion. However, use of GFRP rebars for designing compression elements is proscribed by ACI440.1R-15 [57] but the constant advancement of strong literature may result in their approval for use by international codes in future. ACI 318-14 [51] is not effective for strengthening design against GFRP rebars.

Hosen et al. [58] studied glass fiber reinforced polymer rebars for enhancing the flextural strength of reinforced concrete beams by using the technique of side near-surface mounted (SNSM). It was determined that flexural performance of the tested specimen is enriched as compared to the controlled specimen. The first crack and ultimate loads of energy absorption competencies, strength and rigidity were also increased. Maranan et al. [59] estimated serviceability performance and flexural strength of geopolymer concrete beams with glass fiber reinforced polymer (GFRP) rebars using four-point bending test. It was concluded that, based on investigational results, the performance of a beam enhanced as the reinforcement ratio of glass fiber is increased. The twisting ability of the GFRP supported geopolymer concrete beams seems to be greater than GFRP stimulated concrete beams essentially due to the developed mechanical properties of the geopolymer concrete than the orthodox concrete of the identical review. Proliferation in the strengthening ratio of GFRP rebars bring about better performance, including post cracking rigidity, loading capability, and exibility (or deformation) [60]. Zhu et al. [61] examined the flexural performance of moderately steel fiber reinforced high strength concrete with fiber reinforced polymer rebars. Under four-point bending load entire of 12 specimens were tested. In the tension zone of the beam different percentages of steel fibers was use. It was described that the steel fibers have taken care of overwhelming large bending and apportioning width FRP bar reinforced beams and effectively expanded in the tension zone. Ductility reduced with increasing thickness of FRHSC layer and partitioning of the steel fiber volume in FRHSC bars imposed in part with FRP bars. Including steel fibers in the full depth of the structures with great ductility requirements is necessary.

Rizkalla et al. [63] directed the study on design of FRP for reinforcement of concrete structures. Different FRP bars were used in concrete such as glass fibre and aramid polymer rebars . It was determined that rise in temperature from 20 to 250 deg C easily reduced the bonding of FRP bars in concrete up to 80% to 90%. Steel bars revealed 38% decrease in bonding strength.

Physical properties of GFRP bars in compression are inspected by Deitz et al. [62]. The diameter of bars of 15mm was used with varying operative length from 50mm to 380mm. An overall of 45 rebars were verified under compression load. It was determined that 15mm diameter GFRP rebars have ultimate compressive strength 50% of its definitive tensile strength. Elasticity of tensile module was found equivalent to the compressive modulus of elasticity. Almusallam and Al-salloum [49] deliberate stability of GFRP rebars in concrete beams under constant loading. The whole 36 beams having dimensions of 100 $\times$ 100 $\times$ 2000mm were casted and verified up to the failure. 10mm diameter of bars was used for all the specimens. It was determined that, due to sustained load condition the tensile strength of GFRP rebars was reduced.

Almost 16.3% loss in tensile strength was noticed. The tensile strength was decreased from 743 MPa to 622 MPa. Hadi et al. [64] studied circular columns reinforced with GFRP rebars. Overall twelve specimens were casted having diameter of 250mm and 800mm height and tested up to failure. The results decided that load carrying capacities was decreased due to increase in positioning of transverse reinforcement as compared to steel reinforced specimens. Though, the ductility of concrete column specimens was noticed higher by reducing spaces of spirals. Karim et al. [65] deliberated moment and load communication diagrams of circular concrete columns alongwith GFRP rebars. Twelve specimens were casted with No.3 helices and No.4 GFRP rebars in concrete. It was determined that GFRP reinforced specimens represented reduction in load carrying ability on comparing with steel reinforced specimens.

Besides this, it was also resolved that inadequate longitudinal reinforcement leads to brittle failure of GFRP reinforced specimen earlier moment interaction diagram approaches the pure textural strength. Vakili et al. [66] inspected special effects of glass fibres on the shear strength of GFRP reinforced concrete beams. Three beams with rectangular cross sectional area of 100 x 200 x 1500mm were reinforced with 8mm diameter GFRP rebars. It was revealed that adding glass fibre enriched the shear strength of GFRP reinforced beams from 55% to 233% as related to the beams reinforced deprived addition of glass fibres. Maranan et al. [59] estimated under Four point bending test the flexural strength and service ability enactment of geo polymer concrete beam having GFRP rebars. It was assessed that by increasing reinforcement ratio of glass fibre effectiveness of a beam also increases, based on the results of experimental evaluations.

The response of geo-polymer concrete beams was observed higher than GFRP fortified concrete beams that was reinforce by the bending capacity of the GFRP. The mechanical properties of geo-polymer concrete were primarily enhanced as compared to the orthodox concrete of the same review. Advanced proficiency includes post cracking, difficulty, loading aptitude and distortion was caused by the addition in the fortification ratio of GFRP rebars. Zhu et al. [50] examined efficiency of fiber reinforced polymer rebars and moderately steel fibre reinforced great strength concrete and the textural behavior was also scrutinized. Twelve beams specimens were tested under four point bending load. The tension zone of the beam strengthens by steel fibers of various proportions. The tension zone grabbed large bending moments and was effectively extended by the steel fibers. Considering FRP rebars ductility declined by increasing thickness of fiber layers supported high strength concrete (FRHSC). Mohamed et al. [13] observed the behavior of concrete columns with GFRP and CFRP rebars and stated a significant decline in compressive strain for GFRP specimens.

Peculiarity in square concrete columns reasons twisting moments in columns which decreases the load carrying capability of columns due to which failure of columns arises. Corrosion of steel rebars is one the leading factors in decreasing load carrying capacity which eventually compact the strength and reasons the failure of columns. In recent study GFRP rebars are operated in jute fiber reinforced concrete (JFC) column prototypes to scrutinize the behavior of eccentric square columns. The performance of prototype columns of PRC and JFC with GFRP rebars were inspected and equated under peculiar loading. According to the best information of author no study has been accomplished before on square peculiar concrete columns with jute fibres and GFRP rebars as fortification.

2.5 Summary

It is investigated from literature review that mechanical properties of concrete improve by adding natural fibers. Fibers such as jute fiber have high tensile strength, easily accessible and low in cost. Jute fires enhance mechanical properties. GFRP rebars have high tensile strength and corrosion resistant, light in weight and have low maintenance price in comparison to steel strengthening bars. GFRP rebars can even be operative in tough environment. To the greatest of author's understanding, on the basis of literature review, no research has been performed before on strengthening of beam column joint using jute fibers and GFRP rebars as reinforcement agent. In the recent research work, total eight prototype specimen of beam column joint for PC, JFC by using steel and GFRP rebars have been casted and tested separately. A concrete cover of 12.5mm is provided on the top and bottom of prototype and 12.5mm concrete cover is maintained on both sides of prototype. Altered frequencies, damping ratio mechanical properties and strength of PRC and JFC beam column prototype are investigated.

Chapter 3

Experimental Program

3.1 Background

Usage of fibers for enhancing the mechanical properties of jute fiber concrete having glass fiber reinforced polymer rebars (GFRP). The mechanical properties of jute fibers are investigated with jute fibers reinforced concrete with glass fiber reinforced polymer (GFRP) rebars. The main objective in fiber reinforced concrete are improvement in mechanical properties, durability and energy absorption. Through experimental evaluations jute fibers along with GFRP rebars are used to proliferate the crack resistance. This chapter demonstrate in detail the selection of raw materials, mix design and casting and testing procedures.

Gul and Ali [22] investigated, using ratio of 1:2:4:0.6 with the addition of 5% synthetic (glass fibers) content by mass of cement having 50mm length as resulted in the light of previous result the compressive strength was found to be 22.5 MPa. The mix design ratio used for PC and JFC is 1:2:3:0.60 along with the addition of 5% fiber content, by mass of cement, having 50mm length. The aggregate content is decreased 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 ratio is to attain the targeted compressive strength of 20 MPa in order to utilize fiber reinforced concrete practically in the field.

3.2 Raw Materials

PC and JFC concrete are prepared using ingredients such as coarse aggregates, sand, fresh water, ordinary Portland cement, steel and glass fibers and jute fibers reinforced polymer rebars. The coarse aggregates used with a maximum size of 10mm. GFRP rebars are introduced having 45cm lengths and 6mm in diameter which are elaborated in Figure 3.1. Jute fibers are obtainable in a raw form which is organized by hand with 50mm length as shown in Figure 3.2. The mechanical properties of glass fiber reinforced polymer rebar given by the coMPany which is represented in Table 3.1.

FIGURE 3.1: Glass fiber reinforced polymer rebars

(a) Raw fibers

(b) Prepared fibers

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 MPa
Ultimate Tensile Strength ξ	>1.9%

3.3 Mix Design, Casting Procedure and Specimens

For the preparation of concrete, mix proportion of 1:2:3:0.6 (C:S:A:w/c) is used and for JFC, 5% addition of jute fibers by mass of cement having 50mm in length is added. All the ingredients are measured by mass except water which is taken in liter. The non tilting rotary featured drum concrete mixer was used for mixing JFC and PC. For preparing PC, all ingredients are placed in mixer and water is then added. The mixer is operated for three minutes for mixing the components. JFC is prepared by a different method as stated by [36].

Jute fibers are saturated by dipping in water for 24 hours and then, placed in air for an hour. Later, ingredients are placed in the mixer layer by layer in order to avoid the balling effect. One-third part of materials (cement, sand, aggregate and jute fibers) are placed into mixer drum one after the other. After the entire insertion of materials into the concrete mixer drum about 33% of total water is added on all material. The remaining 67% of water is added gradually during the rotation of the machine. To obtain the homogeneous mixture of concrete mixer is rotated for 6 minutes (2 minutes for each layer).

Slump test as per ASTM standards C143/C143M15a are performed to conclude the workability of PC and JFC at an initial stage before pouring in moulds. The slump of JFC as coMPared to PC is low because of the water absorbing capacity of jute fibers. In case of dry insertion of jute fibers this modification may be furthermore. The slump value of JFC is lower than PC i.e 40% as shown in figure 3.3. Moulds are packed 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 spaces. Specimens of PC and JFC are casted by similar procedure. After 48 hours samples are removed from moulds, labeled and soaked in water for 28 days for curing the specimen. After 28 days density test of PC and JFC is performed by dividing the average mass of PC and JFC specimens with measured average volume as per ASTM standard C642-13. The process used to obtain the density and workability of JFC is similar to that of PC, because any other distinct criterion is not available for fiber reinforced concrete (FRC) in codes. The density of JFC specimens observed is lower than PC specimens, because jute fibers are light in weight. Values of slump and density of PC and JFC are shown in the Table 3.2.

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

Table 3.2: Water Cement Ratio, Slump and Density of PC and JFC

Sample	**Water Cement Ratio**	**Slump (mm)**	**Density** kg/m^3
PC	0.6	66	2532 ± 3
JFC	0.6	39	2468 ± 3

In the present study cylinders and beam-lets were casted to calculate the mechanical properties of JFC and PC specimen. The measurement of cylinder is 100mm in diameter and 200mm in height while beam-lets are 100mm in height, 100mm in width and 450mm in length. To compute compressive strength and splitting-tensile strength twelve samples are casted (i.e. six for JFC and six for PC) six testing specimens are casted and tested for flexural strength (i.e. three for PC and three for JFC). Three different loading rates are deliberated for compressive test 0.15 MPa/s, splitting-tensile test 0.7 MPa/min and for flexural test 0.84 MPa/min as per ASTM standards C-39M-18, C-496M-17 and C-293 M-16. An average of three samples is taken. Under load condition total eight specimens of beam column joint prototypes were casted and tested. Total of eight prototype tests are performed and for each situation average of two readings is taken. Two prototype specimens are casted with plain concrete and deformed bars as PD-1 and PD-2, two prototype specimens are casted with plain conctrete and addition of glass fiber reinforced rebars (GFRP) named as PG-1 and PG- 2, two beam column joint prototype specimens are casted with Jute fiber reinforced concrete having deformed bars as reinforcement and same termed as JD-1 and JD-2 and final two prototype specimens are prepared with jute fiber reinforced concrete by adding glass fiber reinforced rebars and specimens are termed as JG-1 and JG-2. GFRP and steel / deformed bars are 6 mm in diameter and 457mm in length. The size of prototype is 101 mm x 101 mm and total length for beam and column is 457mm. Rings and ties are 7mm apart to hold main reinforcement of beam and column. load is then applied in STM to find the required parameters as per ASTM standards alongwith load deflection curve. The set of two beam-column joint specimens is taken for testing (i.e. PC and JFC). The size of prototype samples were carefully chosen to meet the condition and capability of the testing apparatus available in the laboratory. In the prototype specimen, smaller diameter i.e. 6mm is used. For strength, test loading rate used is 0.15 MPa/s. ASTM C39M-18 is used to distinguish between the averages of two values [11]. Non-destructive dynamic testing as per ASTM C215-14 was also performed before destructive testing for mechanical properties and prototype specimen. Labeling of specimen is shown in Figure 3.4.

Compressive Spliting Tensile Flexure

a) For Mechanical properties

b) For prototype Analysis

FIGURE 3.4: Labeling Pattern of Specimens

3.3.1 Dynamic Properties

In current research, before destructive testing, dynamic properties are determined through non-destructive testing using resonant apparatus (containing accelerometer and hammer) as per ASTM standard C215-02. Damping ratio is also calculated.

3.3.2 Mechanical Properties

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

Split tensile behavior of PC and JFC cylinder specimens are tested in STM as per ASTM standard C496/496M-11 is used to formulate split cracking behavior, splitting tensile load time curve energy absorption, splitting tensile strength and total toughness index. ASTM standard C78/C78M-15b used to investigate the properties of specimens of PC and JFC beam-lets. Flexure cracking behavior, MoR (modulus of rupture)/flexural strength, energy absorption and total toughness index are studied. Cracking pattern is observed on load at first crack, peak load and ultimate load. Peak load is the maximum load taken by the specimen and ultimate load is point were the test is stop on the basis of visual observation and it is on decline side on the curve.

3.3.3 Beam-Column Joint Testing

PRC and JFC prototype specimens test matrix and labels are expressed in Table 3.3 (Test Matrix with Labeling of Prototype). Testing setup for a prototype specimen i.e. schematic diagram and experimental format is shown in Figure. 3.5. In order to calculate strength of all PRC and JFC prototype specimens ASTM C39/C39M-18 was followed. Surface of all the prototype specimens are made smooth with plaster of paris before testing.

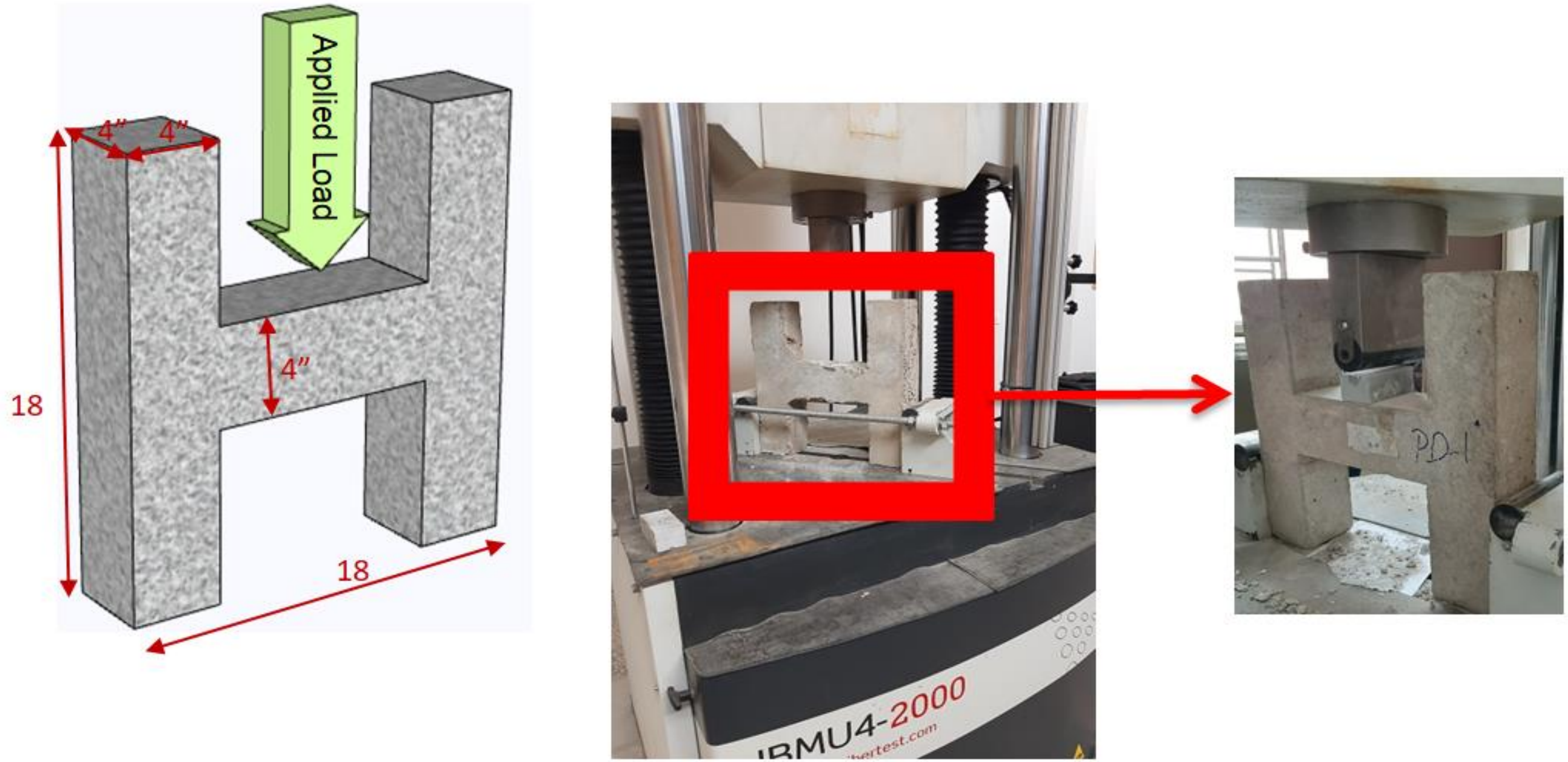


FIGURE 3.5: Testing of prototype with rebars

STM was used for evaluating all prototype specimens to determine compressive strength and to compute compressive energy absorption and stiffness index in compression. PRC and JFC prototype specimens test matrix and labels is shown in Table 3.3 and prototype detailing is shown in figure 3.6. It may be noted that, static testing of prototype (scale down or full scale), usually one specimen is taken [15, 2]. However in current work the average of two readings is taken, just to have robust results because of presence of jute fibers (i.e. short discrete reinforcement).

TABLE 3.3: Test Matrix with Labeling of Prototype

Sr. No.	**Main Reinforcement for Column Beam**		**Steel Ties**	**Ratio**	**Labels**	
	Deformed Steel	**GFRP**			**PC**	**JFC**
1	4-ϕ6		ϕ6-76mm	0.012	PD-1/2	JD-1/2
2		4-ϕ6	ϕ6-76mm	0.012	PG-1/2	JG-1/2

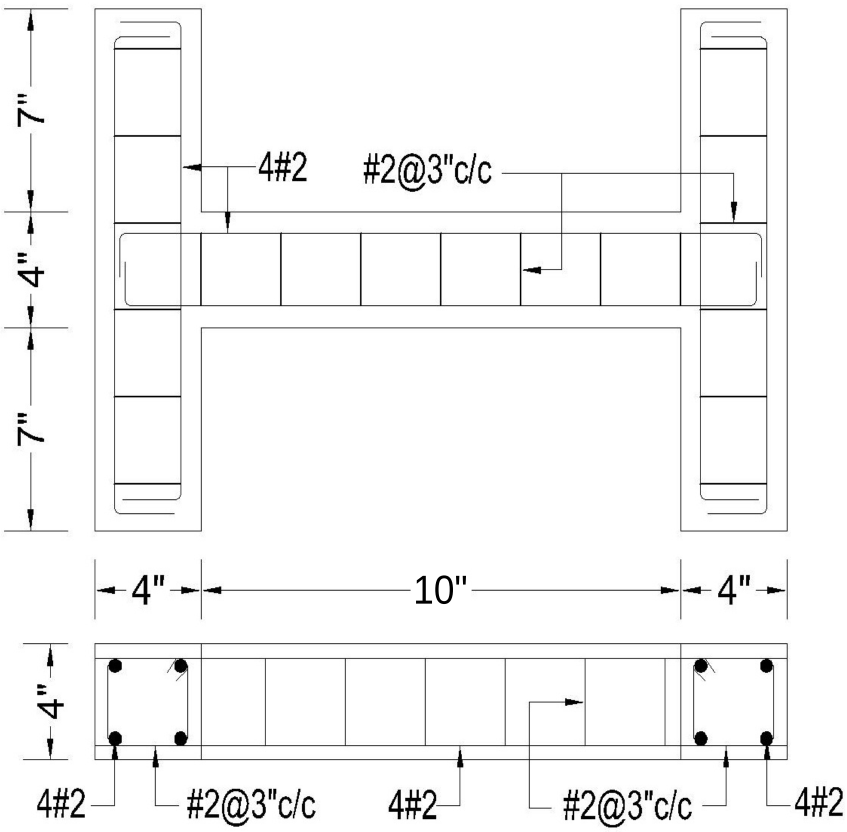


FIGURE 3.6: Prototype detailing

3.4 Summary

PC specimens are made with a mix design proportion of 1:2:3:0.6 along with the addition of 5% jute fiber by mass of cement is added to prepare JFC with same mix design. Total number of specimens casted were 26 out of these 12 are cylinders and 6 are beam lets used to measure mechanical properties like split, compressive and flexural strength. Furthermore, prototype beam-column joint which are used for determining the strength and behavior are 8 in numbers.

Chapter 4

Results & Discussions

4.1 Background

PC is prepared by using combination of percentages of 1:2:3:0.6 (cement: sand: aggregate: w/c). JFC is prepared with a comparable mix design except 50mm length of jute fibers addition by 5% mass of cement. Experimental results of JFC, PC, JFC and PRC specimens are inspected to examine the mechanical properties, and behavior of prototype.

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

4.2 Frequencies and Damping Ratio

Frequencies and damping ratios of PC, JFC, PRC and JFC specimens are calculated before destructive testing which is represented in Table 4.1. For cylinders, an average of six readings is taken and an average of three readings is taken for beam. While an average of two readings taken in the case of a prototype as shown in Table 4.2. The method used for obtaining the frequencies and damping ratio of JFC and JFC 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, the longitudinal frequency of JFC is less than PRC whereas, the transverse frequency and the rotational frequency is greater than PRC.

TABLE 4.1: Resonance frequencies and damping ratios of samples

Specimen		No. of specimen for average	Resonance Frequency			Damping Ratio
			f_l (Hz)	f_t (Hz)	f_r (Hz)	ξ (%)
Cylinder	PC	6	3763±75	1997±325	1776±56	2.9±0.41
	JFC	6	2032±86	1199±296	1726±472	4.9±0.36
Beam	PC	3	1767±150	1888±352	1862±284	3.1±0.4
	JFRC	3	1380±210	1428±198	1386±240	4.7±0.5

TABLE 4.2: Resonance frequencies and damping ratios of prototype

Specimen	No. of specimen for average	Resonance Frequency			Damping Ratio
		f_l (Hz)	f_t (Hz)	f_r (Hz)	ξ (%)
PD	2	2002±63	2063±80	1889±22	3.8±0.5
PG	2	2034±24	1560±65	1774±65	3.6±1.1
JG	2	1745±28	1732±31	2092±23	7.9±2.3
JD	2	1667±42	1574±56	2063±81	6.6±2.8

The foremost purpose of determining dynamic properties of material is to check any increase in damping due to addition of jute fibers. The prime objective for performing the dynamic test is to investigate the dynamic properties and to check any increase in damping by the addition of jute fibers. It can be noted that energy dissipation has increased by the addition of jute fibers in JFRC prototypes as compared to PRC prototypes. The damping ratio has been increased for JG and JD specimens.

Chopra [69] reports that greater damping ratio significantly reduces response of the structures against dynamic loading. This damping relates to the energy losses due to material type as more energy absorption produces more damping ratios. Thus, more energy absorption results in greater damping. Since JFRC prototypes has more energy absorption due to jute fiber incorporation. Thus, it increases the damping ratio. This increment in energy absorption results in better structural performance. The trend of increment in damping ratios in prototypes is similar to that of cylinder and beam specimens.

There is a need to explore damping structural connections like beam column joints with real boundary conditions which is outside the scope of this thesis. It can be clearly seen from Table 4.1 and Table 4.2 that the damping ratio of PC cylinder, PC beam, and PRC beam column joint prototype is less than that of JFC cylinder, JFC beam, and JFC prototype, respectively. Therefore, the energy dissipation will be more in JFC members as compared to PC members. The damping ratio between JFC and JFC has been increased in all three cases as related to PC cylinder, beam, and PRC Prototype 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 is 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/m^3 as reported by [67, 68].

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 4.3.

The Compressive strength of JFC specimen is decreased while other properties Em, Cr. E, TE, and TI are increased as related to PC specimen. Comparison of mechanical properties is shown in Figure. 4.1(a). In which all properties of PC and JFC specimens are compared in percentage. The compressive strength of JFC is decreased by 18% 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 respectively. The overall index of toughness has also been increased up to 71% as related to PC. From the results of compressive strength tabulated in Table 4.3, 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.

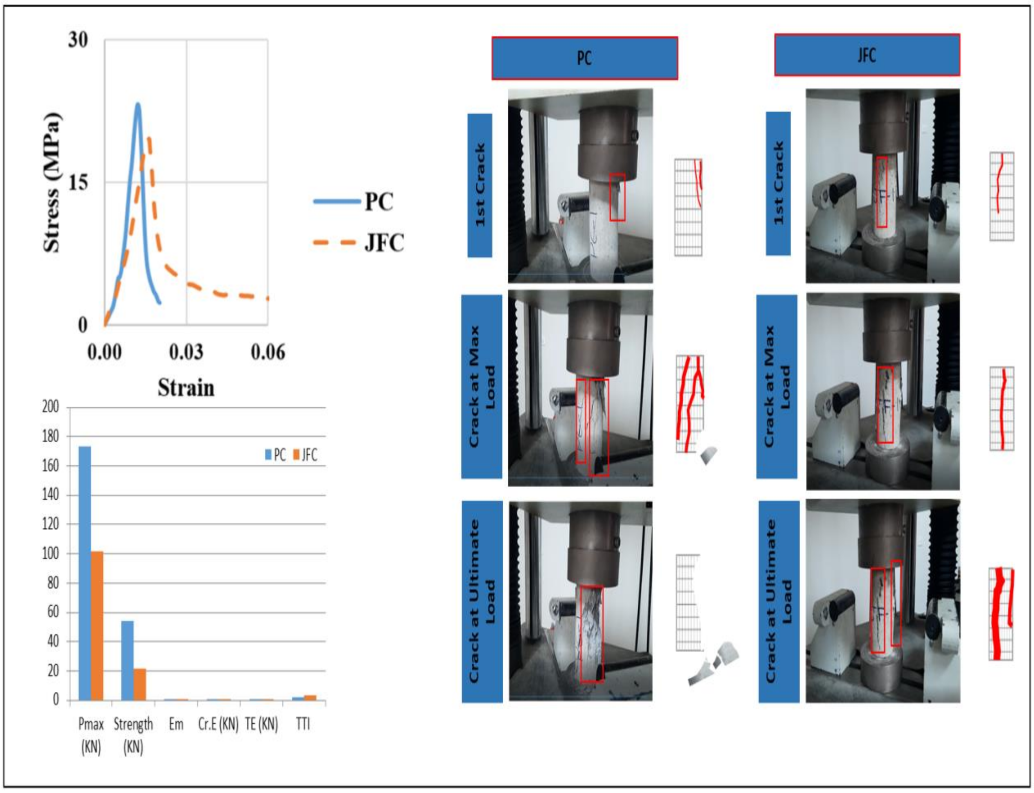
Splitting tensile strength test, load-deflection curves are considered for all PC and JFC specimens which is shown in Figure 4.1(b). In figure 4.1(b) splitting tensile behavior of PC and JFC specimens at left side whereas crack propagation of specimens are shown at the right side. The cracking pattern 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-deflection curve.

Energy absorption in splitting tensile (Em) is measured as the area below the load-deflection curve up to the peak load. The area below the load-deflection 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-deflection curve from initial to ultimate load.

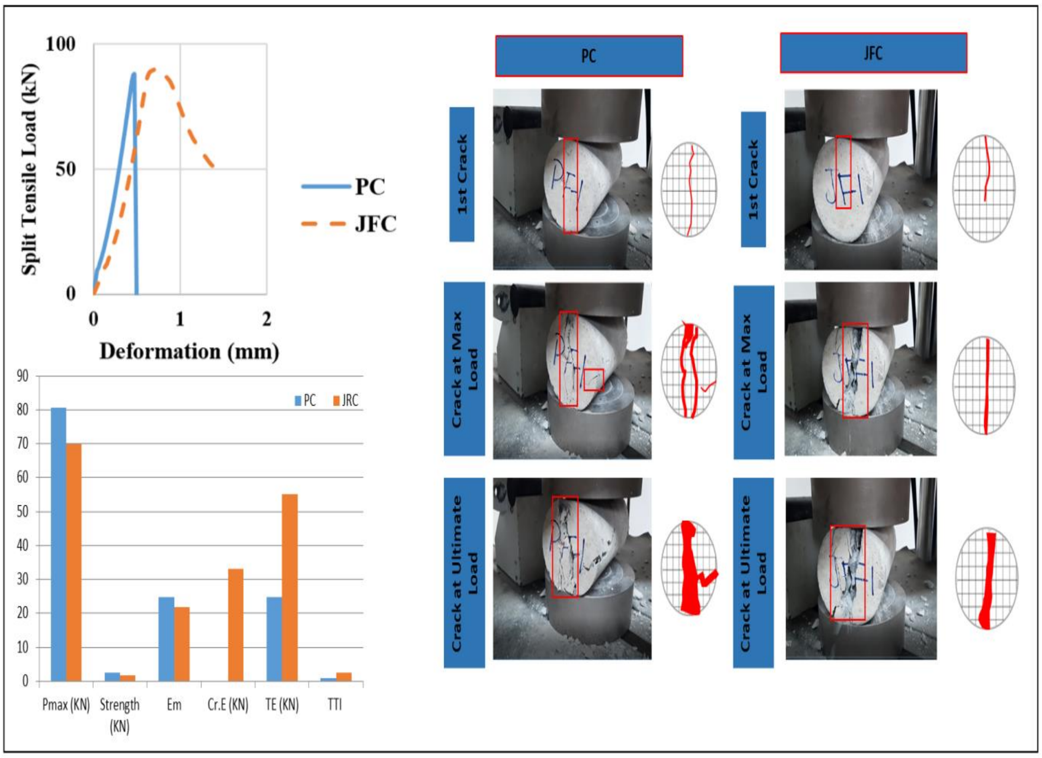
Toughness index in splitting (TI) is the ratio of total energy absorption in splitting to the energy absorption in splitting up to maximum load (i.e. TE / Em).The Splitting tensile strength, Em, Cr.E, TE, and TI of PC and JFC with mix design proportion of 1:2:3 are shown in Table 4.3. The splitting tensile strength, Em, Cr. E, TE, and TI of JFC specimen are increased as related to PC specimen.

Comparison of mechanical properties is shown in Figure. 4.1(c). In which all properties of PC and JFC specimens are compared in percentage. The splitting tensile strength of JFC is increased by 3.7% 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. The overall index of toughness has also been increased as related to PC.

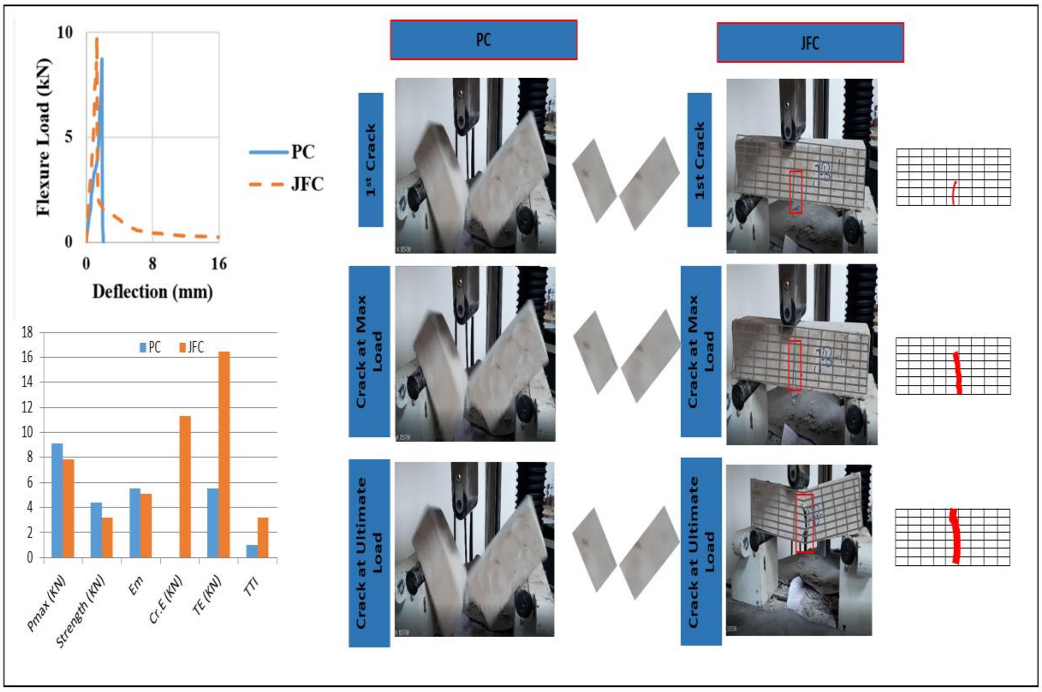
The damping ratio of PC cylinder, beam and PRC prototype is less than that of JFC cylinder, beam, and JFC beam-column prototype specimen. There is an increment of JFC cylinder, JFC beam, and JFC prototype 14.2%, 22.7% and 26.8% individually. Therefore, the energy dissipation is more in JFC cylinder,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


30
15
0
Stress (MPa)
0.00
0.03
0.06
Strain
PC
JFC
200
180
160
140
120
100
80
60
40
20
0
PC JFC
Pmax (KN)
Strength (KN)
Em
Cr.E (KN)
TE (KN)
TTI
PC
JFC
1st Crack
Crack at Max Load
Crack at Ultimate Load

(a)


100
50
0
Split Tensile Load (kN)
0
1
2
Deformation (mm)
PC
JFC
90
80
70
60
50
40
30
20
10
0
PC JRC
Pmax (KN)
Strength (KN)
Em
Cr.E (KN)
TE (KN)
TTI
PC
JFC
1st Crack
Crack at Max Load
Crack at Ultimate Load

(b)



(c)

FIGURE 4.1: Mechanical properties; (a) Compressive behavior, (b) Split tensile behavior and (c) Flexural behavior

Flexural strength test, load-displacement curves are considered for all PC and JFC specimens which are shown in Figure 4.1 flexure behavior of PC and JFC specimens at left side whereas crack propagation of specimens is 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) ismeasured as the area below the load-displacement curve from initial to ultimate load. Toughness index in exure (TI) is the ratio of entire energy absorption in exure to the energy absorption in exural 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 4.3. The exural strength, Em, Cr. E, TE and TI of JFC specimen are increased 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 26% 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. The overall index of toughness has also been increased up to 69% 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 4.3: 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**		**Flexure**	
	PC	**JFC**	**PC**	**JFC**	**PC**	**JFC**
P_{max} (kN)	189.95	159.55	80.47	84.01	9.09	9.28
Strength (MPa)	26.2	21.5	2.56	2.67	6.14	6.27
Strain (-)	0.015	0.021	-	-	-	-
Em	0.11 MPa	0.15 MPa	24.7 Nm	35.9 Nm	6.34 Nm	5.72 Nm
Cr.E	0.10 MPa	0.36 MPa	0	33.2 Nm	0	11.3 Nm
TE	0.21 MPa	0.51 MPa	24.7 Nm	69.1 Nm	6.34 Nm	17.02 Nm
TTI (-)	1.92	3.42	1	1.93	1	3.03

Note:

P= Area under load deflection from maximum load to ultimate load. E= P1 + P.E + P = Total energy absorbed. TTI= E / P.E = Total toughness index. Cr.

E= Cracked energy absorption An average of three readings is taken. Loading rate for compressive strength test is 0.15 MPa/s. according to ASTM standard C39/C39M-15. Loading rate for split tensile strength test is 0.7 MPa/Min according to ASTM standard C496/C496M11. Loading rate for flexural strength testis 0.86 MPa/min according to ASTM standard C78/C78M-15b.

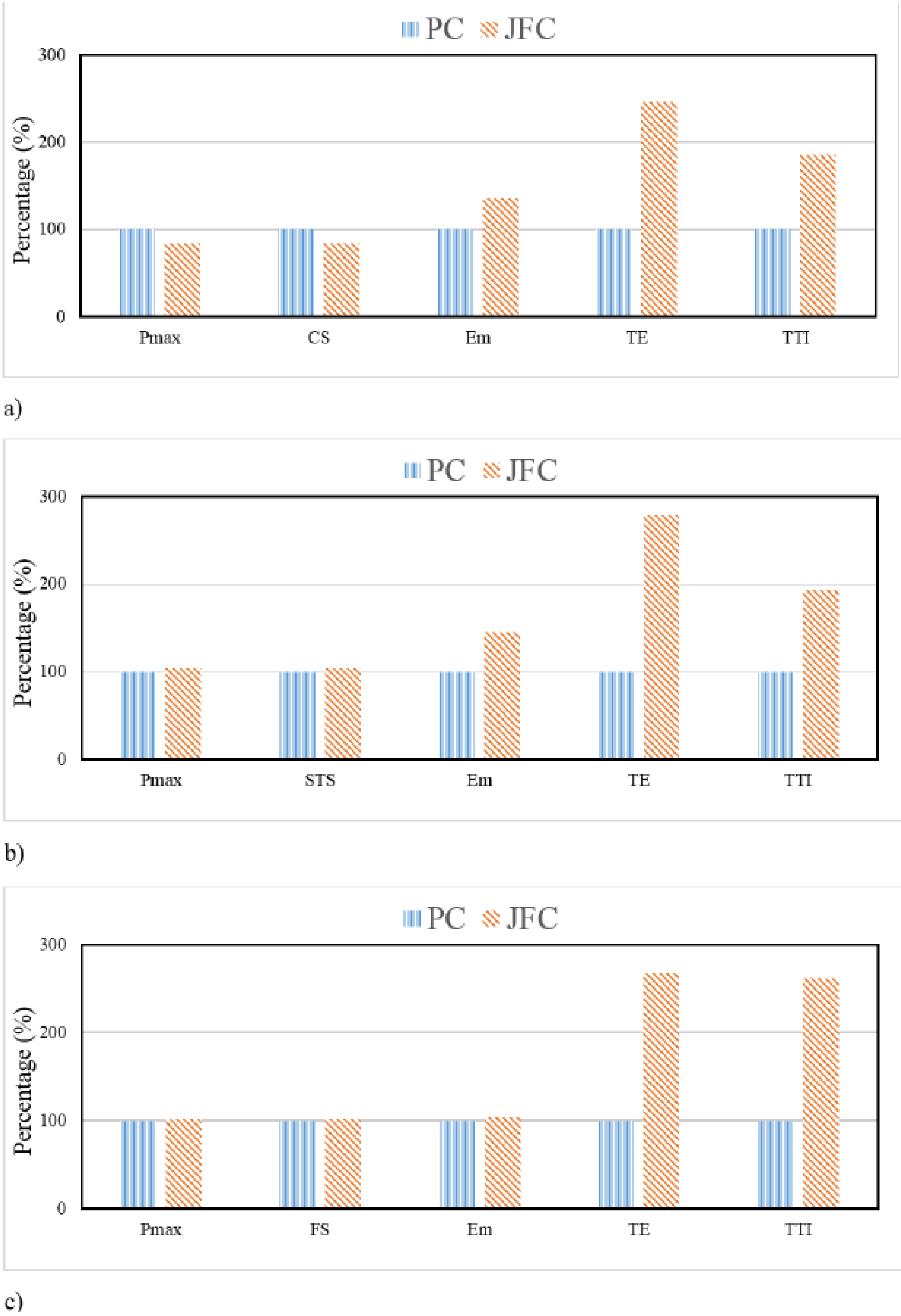


FIGURE 4.2: Comparison of Mechanical Properties of PC and JFC; a) Compressive Strength, b) Split-Tensile Strength, and c) Flexural Strength

4.4 Behavior of Beam-Column Joint

4.4.1 Impact on Beam Column Joint

In this study, the mix design for PRC and JFC contains 1:2:3:0.60 (cement: sand: aggregate: water) in proportion. The jute fibers with length of 50mm are added 5%, by mass of cement. Different types of failure will be discussed which were discussed in all tested prototype specimens. The main longitudinal GFRP confined with steel reinforcement PRC specimen's fail in crushing way and concrete pieces were gradually dropped down. Whereas, JFC specimens failure weren't happened in a crushing way rather than in a bridging effect due to the addition of jute fibers up to maximum load. While, testing of prototype for loading, variable crack development on all face of the specimens. The addition of jute fibers improves the properties of concrete as shown in figure 4.3. By taking PRC as a reference strength of the JFC prototype specimen is reduced due to the accumulation of jute fibers. Strength, C.Em is reduced however Ccr.E, C.E, and CTI are increased with addition of jute fibers in case of JD and JG specimen.

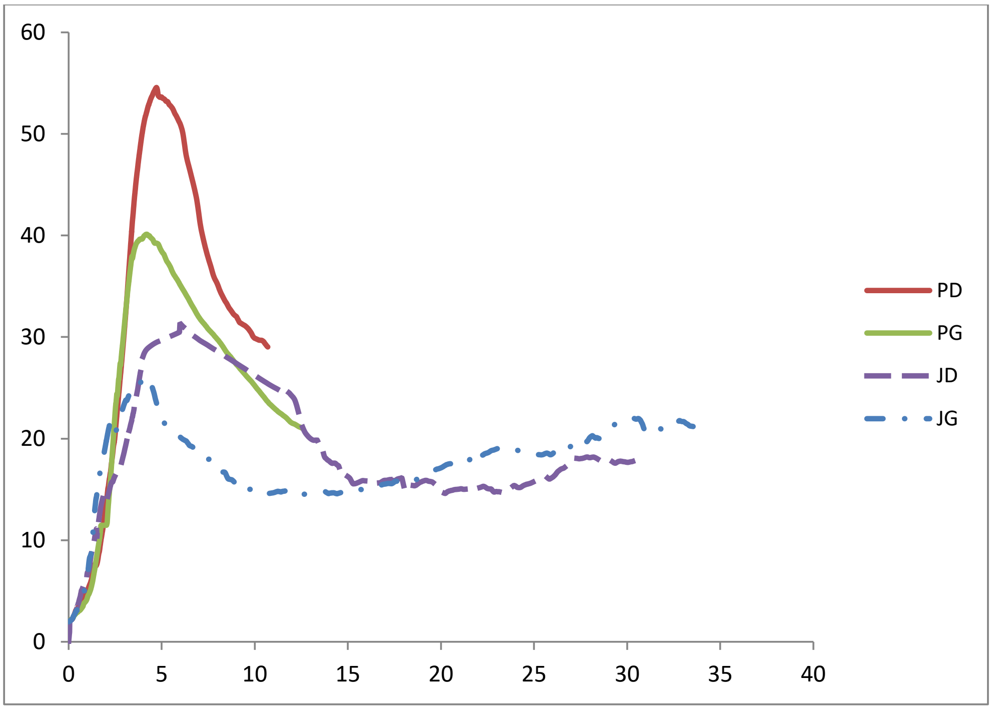
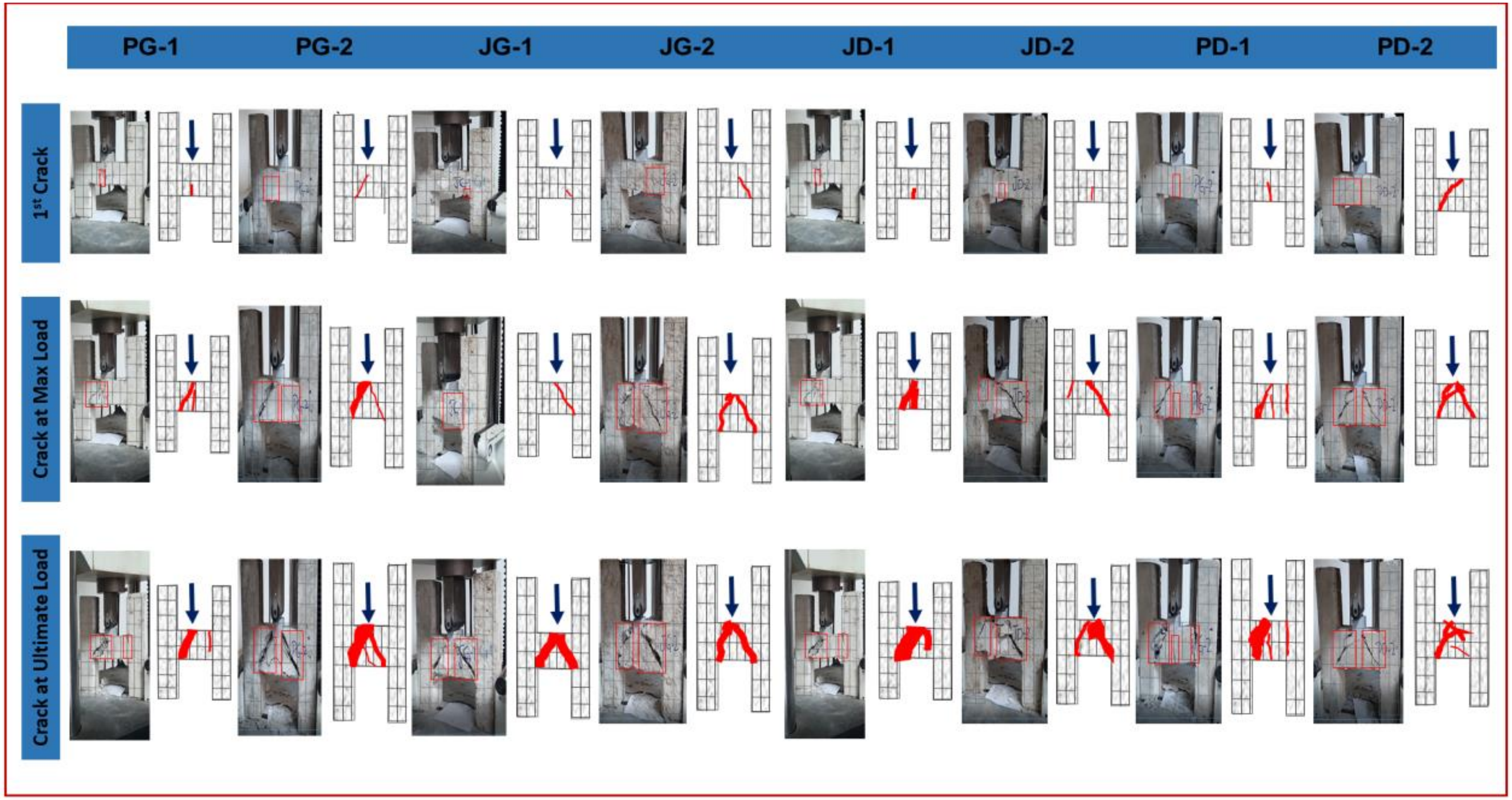


FIGURE 4.3: Load deflection curve



Tested Specimens

FIGURE 4.4: Behavior of prototypes

The mechanical properties of JFC prototype specimens were enriched with a subject to their results except for strength. In the light of testing and result regarding mechanical properties, it is observed that the behavior of JFC specimen is ductile.

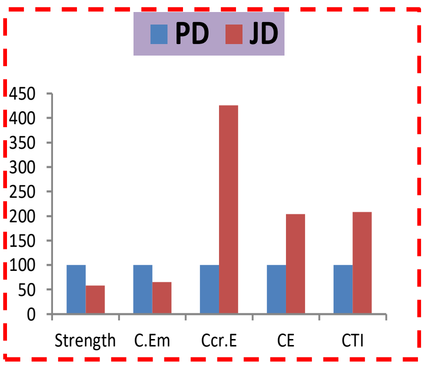
TABLE 4.4: Experimental outcomes of Tested Prototypes

Sample	**Load (kN)**	**Strength (MPa)**	**C.Em (Nm)**	**Ccr.E (Nm)**	**CE (Nm)**	**CTI (-)**	**Failure Mode**
PD	55.2	5.52	164	130	294	2.5	Flexure
PG	39.52	3.95	118	200	318	2.6	Flexure
JG	27.21	2.72	70	560	630	5.7	Bridging
JD	32.31	3.23	72	528	600	5.2	Bridging

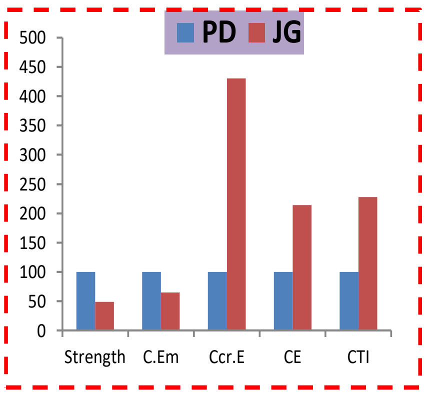
Note:
C.Em = Energy-absorption up to extreme load
Ccr. E = Cracked energy-absorption after extreme load
CE = Total energy absorbed
CTI= CE / C.Em = Total toughness index
An average of two readings is taken. Loading rate for test is 0.15 Mpa/s according to ASTM standard C39/C39M-15.

Crack propagation behavior of beam column joint prototype is expressed in Figure 4.4. The figure 4.4 illustrates that strength of PRC prototypes is reduced as compared to JFC prototypes. Prototypes having GFRP rebars with jute fibers have more strength as compared to prototypes having steel rebars with jute fibers. The Figure 4.3 graph indicates decline of peak loading and strength of JFC prototypes as compared to PRC prototypes while total energy, absorption and toughness index of JFC prototypes rises as compared to PRC prototypes. In case of PRC prototypes spalling of concrete was noticed at peak and optimum loading, as compared to JFRC prototype walls. In JFRC prototype, bridging effect was detected due to the presence of fiber with broadening of cracks, which hold the concrete matrix together. In PRC prototype with steel rebars (PD), the crack proliferation was greater as compared to PRC prototypes having GFRP rebars (PG). It was noticed in schematic diagram that PD prototypes shows a higher spalling of concrete as compared to PG prototypes.

JFRC prototypes having GFRP rebars (JG), represents thinner and lighter cracks as compared to JFRC prototype with steel rebars (JD). PRC prototypes faced irreparable loss while in case of JFRC prototypes complete failure is not happen as shown in figure 4.4. JFRC prototypes avoids the sudden failure in beam column joints, thus it leads to avoids the catastrophic failure of structures. Energy absorption till peak load (CEm), peak load (Pmax), strength, energy absorption from peak load to ultimate load (Ccr.E), total energy absorption are shown in Table 4.4 (CE) and compressive prototypes. In figure 4.5 comparison of properties of prototypes specimens is shown in bar graph. There is a decrease of 42% in strength of JD prototype specimens as compared to PD specimens whereas an increase of 104% and 108% in CE and CTI, respectively, for JD specimens as compared PD prototypes as shown in figure 4.5 (a). There is a decrease of 31% in strength of JG prototype specimens as compared to PG specimens whereas an increase of 157% and 119% in CE and CTI, respectively, for JG specimens as compared to PG prototype specimens as shown in figure 4.5(d).



a)



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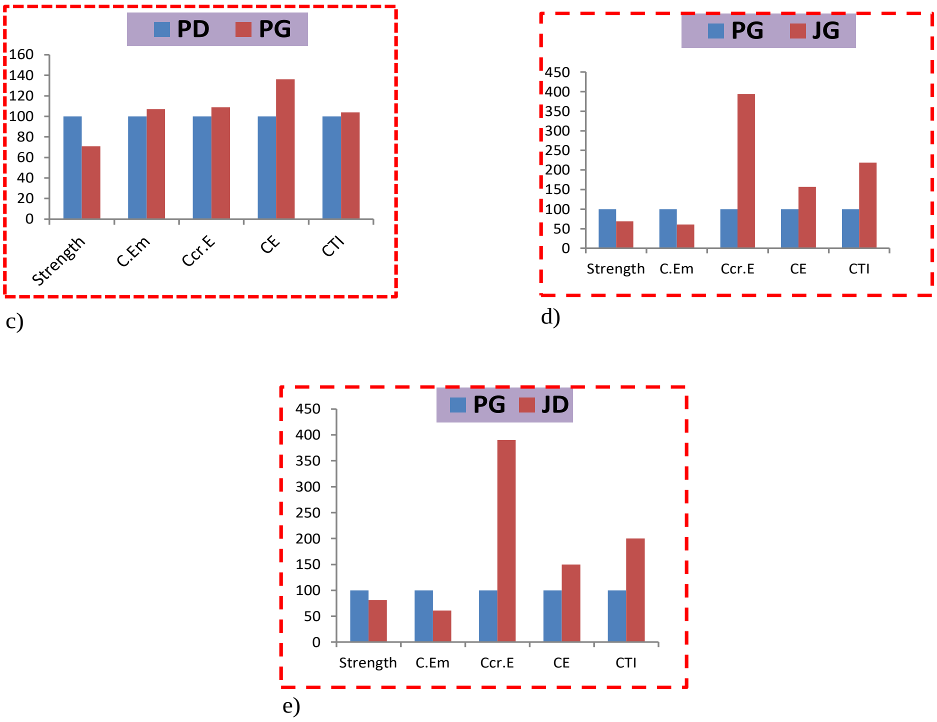

FIGURE 4.5: Comparison of properties of prototype

Strength reduction of 28% is observed for PG prototypes as compared to PD prototypes whereas an increase of 36% and 4% is observed in CE and CTI respectively, for PG prototypes as compared to PD prototypes as shown in figure 4.5 (c). Similar trend is observed for PD specimens and JG specimens as there is a decrease of 51% in strength of JG prototype as compared to PD prototype. An increase of 53% is observed in CE of JG as compared to PD while 100% CTI increased for JG as compared to PD prototypes as shown in figure 4.5 (b). There is a decrease of 5% in strength of JD as compared to PG whereas an increase of 16% and 62% in CE and CTI, respectively, for JD as compared PG prototype as shown in figure 4.5 (e). For JG and JD strength, CE & CTI results are almost same.

4.4.2 Observation on Beam Column Joint

In Figure 4.4 crack propagation behavior is explained for all eight beam column joint prototypes with four different conditions and crack pattern is shown through schematic diagram. It can be seen that cracks has occurred on the beam column joint portion of prototypes when load has been applied on the center of beam. For maximum load the cracks has propagated up to 2 to 2.5 inch inside joint region. Furthermore, at ultimate load further broadening of crack has occurred in joint region for all prototypes. Bridging effect is also seen for JFRC prototypes as compared to PRC prototypes where some particles of concrete has broken and fallen down.

In Figure 4.4 crack propagation and crack pattern in PD specimens is shown through schematic diagram. It can be seen that cracks has occurred near joint portion of both prototypes when load has been applied at the center of beam. For maximum load the cracks has propagated up to 2 inch towards the joint portion. Furthermore, at ultimate load crack has further enlarged and spalling of concrete occurred along with exposure of reinforcement seen at joint region due to dropping of concrete particles. Graph of PD specimens in figure 4.3 also shows sudden drop after attaining peak. For JD specimens very thin crack observed at initial load and further increase in crack has observed at maximum load. At ultimate load crack has further propagated towards joint portion however bridging effect is seen for JD prototypes as compared to PD prototypes where some particles of concrete has broken and fallen down. Graphs for JD also witnessed bridging effect where after attaining peak graph is smooth straight line. For JG prototype specimens cracks pattern shows thin line on application of load and same propagates very little towards joint region at maximum load. At ultimate load cracks in joint region further expands however breakage / spalling of concrete is not observed rather bridging effect has seen. Graph of JG specimens in figure 4.3 also shows that on attaining peak, gradual decline of graph line has seen and flat line observed after decline. In PG prototype specimens crack pattern in figure 4.4 shows that on application of load first crack seen near joint region and at maximum load crack further get enlarged and deeper an joint region. At ultimate load failure of concrete occurred and concrete got broken and fallen at joint region and complete reinforcement got exposed. Graph of PG specimens in figure 4.3 also shows that after attaining peak, graph suddenly drops down. In dynamic properties of RC beam column joint with jute fiber addition, longitudinal frequencies are more in general but damping ratio is less as shown in figure 4.6. Thus addition of jute fibers produces bridging and resists crack initiation, crack propagation and ultimately results in better structural performance. The overall performance in terms of damping ratio, post cracking energy absorption and toughness index of JG and JD prototype specimens is better as compared to the PD and PG prototype specimens.

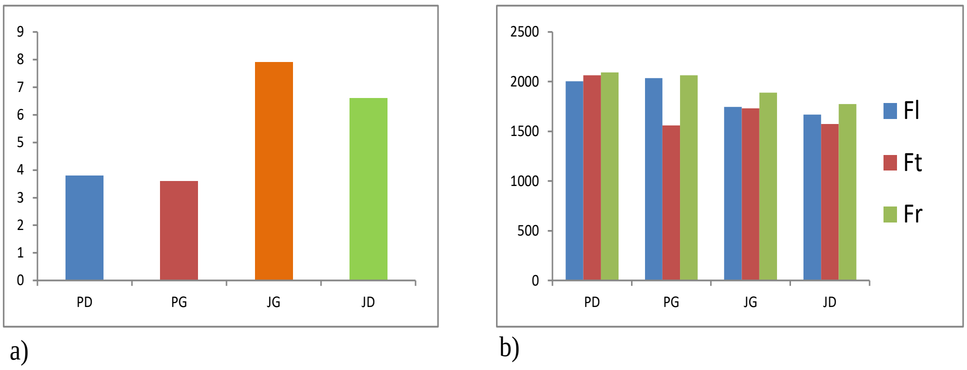

FIGURE 4.6: Comparison of dynamic properties of prototypes a) Damping ratios and b) Frequencies.

Damping ratio with addition of Jute fibers is increased as compared to specimens without jute fibers addition as shown in figure 4.6 (a) while frequencies comparison is shown in figure 4.6 (b). Therefore energy dissipation is more in JFRC than PRC. Moreover due to lower density of GFRP rebars as compared the steel rebars specimens having GFRP rebars have more damping ratio than specimens having steel rebars. This shows improved structure performance of prototype column by utilization of GFRP rebar and jute fiber.

4.5 Relation between Materials Properties and Prototypes Performance

JFC specimens showed less frequency and greater damping ratio as compared to PC specimens. Compressive, split and exural strength of JFC specimens is decreased but the total energy and toughness index is increased. JFRC prototypes demonstrated less frequency and greater damping ratio as compared to PRC prototypes. Utilization of jute fibers in concrete caused reduction in strength however energy and toughness index significantly increased. Incorporation of jute fibers changed failure mode from crushing to bridging under 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 specimens hair lines cracks were appeared. Prototypes PD and PG showed greater load capacity but lesser energy and toughness index as compared to the JD and JG respectively. To restrict the crack propagation and enhancement in damping ratio it is suitable to use jute fiber with GFRP rebars in concrete. Because better performance is observed in experimental work for prototype specimens having GFRP with jute as compared to steel rebar without jute fiber specimens. Better ductility was observed for GFRP prototypes under load condition due to the high tensile strength of GFRP rebar. In a real field scenario for beam column joint utilization of GFRP rebar with jute fibers real load condition needs to be studied further.

4.6 Summary

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

An increment in damping ratio of JC cylinder, beam, and JFC prototype was observed as compared to PC and PRC specimens. The JFC prototype specimen 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 JFC specimens were significantly improved except, strength as related to PRC.

Chapter 5

Conclusion and Future-Work

5.1 Conclusions

In the current research work, jute fiber reinforced concrete (JFC) having GFRP rebar and deformed bars is studied for the application of Beam column joint. The jute fiber content used for preparing JFC is 5%, by mass of the cement. JFC is prepared with a mix design proportion of 1:2:3 (C: S: A) with cement water ratio of 0.60. Resultant following conclusions are made:

- The enhanced properties of JFC improve the properties of concrete, which is helpful in improving structural application of beam column joint.
- As we compare to PC specimen, energy dissipation has raised in JFC beam, JFC cylinder, and JFC prototype.
- The strength of JFC samples has reduced and other properties namely maximum energy, cracked energy, total energy, and toughness index is increased, 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, as compared to that of PC samples.

- Flexural strength, energy maximum, cracked energy, total energy, and toughness index of JFC specimens are increased, as compared to PC samples.
- The JFC 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.

Hence, based on the above results, the JFC having GFRP rebars can be used to enhance the durability of structural members.

5.2 Future work

Following are recommendations for future work:

- The durability of JFC confined with GFRP rebars over a longer period for application in improvement of beam-cloumn joint needs to be explored.
- Testing of full-scale elements with real field conditions alongwith cost comparison may be carried out in further continuation of the study.
- Experimental results may be verified by carrying out analytical modelling.

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