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Experimental Investigation on Properties of Fiber Reinforced Concrete Related to Bridge Piers

by

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Initially I would like to acknowledge Immense Allah who offered me a chance to commence this innovatory and then I would like to pledgee entirely of this tough toil to my loving household, who assist me through each hurdle and concern of my lifespan and forfeited all the eases of their survives for my upcoming accomplishments. I would like to prompt my genuine appreciation to my supervisor for his unceasing provision, endurance, inspiration and enormous knowledge. His precious remarks and recommendations during the research work have backed to the triumph of this study.

CERTIFICATE OF APPROVAL

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Abstract

Most concrete piers failed due to insufficient shear and flexural strength caused by insufficient longitudinal/transverse reinforcement and lack of confinement. Glass fiber concrete with flexural and shear reinforcement can be a solution to overcome the flexural-shear failure of bridge pier. In this research work, an investigation has been carried out to study the behavior of glass fiber steel rebar reinforced concrete (GFRC) for application of bridge piers.

Glass fibers (GF) having a length of 50mm and a fiber content of 5% by weight of cement and steel rebar are used for preparing glass fiber steel rebar reinforced concrete (GFRC) prototype piers. Relative comparison of prototype piers of glass fiber steel rebar reinforced concrete (GFRC) and plain steel rebar reinforced concrete (RC) are made. Axial load carrying capacity of prototype piers with different shear and flexural reinforcement are determined experimentally in STM (Servo-hydraulic Testing Machine) for both materials. Cracking pattern is observed with naked eye. In addition, compressive strength, splitting-tensile strength and modulus of rupture of plain concrete (PC) and glass fiber reinforced concrete (GFRC) are determined experimentally. Stress-strain curves and load-displacement curves for plain concrete (PC) and glass fiber reinforced concrete (GFRC) are also determined.

It is found that glass fiber steel rebar reinforced concrete (GFRC) prototype piers have better performance than plain steel rebar reinforced concrete (PRC) prototype piers. Research is needed to investigate the performance of glass fiber steel rebar reinforced concrete (GFRC) bridge piers with different percentage of glass fiber (GF) content.

Key words: GFRC, PC, Bridge piers, Axial Loading.

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Abbreviations

CEm	Compressive Energy Absorption up to Maximum Load
Cr.E	Compressive energy absorption After Maximum Load
CE	Compressive Total Energy Absorption
CTI	Compressive Toughness Index
CS	Compressive Strength
FS	Flexure Strength
FEm	Flexure energy absorption up to maximum load
Feu	Flexure energy absorption from maximum load to ultimate load
FE	Flexure Total Energy Absorption
FTI	Flexure Toughness Index
$\mathbf{f}_l$	Longitudinal Frequency
$\mathbf{f}_t$	Transverse Frequency
$\mathbf{f}_r$	Rotational Frequency
Hz	Hertz
GF	Glass Fiber
GFRC	Glass Fiber Reinforced Concrete
kN	kilo-Newton
kJ	kilo-Joule
mm	Millimete
MPa	Mega Pascal
PC	Plain Concrete
s	Second
SEm	Split Energy Absorption up to Maximum Load
SEu	Split Energy Absorption from Maximum Load to Ultimate Load

STI Splitting Toughness Index

STS Splitting Tensile Strength

w/c Water Cement Ratio

Symbols

Δ	Deflection
$\oslash$	Diameter

Chapter 1

Introduction

1.1 Background

Bridges are the structures which connect the people of the world and the bridge piers are the fundamental part of the bridges. Most concrete piers failed due to inadequate load carrying capacity, shear and flexural strength caused by insufficient longitudinal/transverse reinforcement, inadequate confinement, lack of concrete strength and large unsupported lengths of longitudinal bars. So, it becomes important to enhance load carrying capacity, shear strength, flexural strength and concrete strength in order to achieve significant functionality and durability of bridge piers. Some of the failure of bridge piers are shown in Figure 1.1 (a), (b) and (c). Bridge failure emphasizes the need to understand the real response of service bridges and the quality of potential infrastructure under various conditions [1]. Because of combined flexure-shear failure modes of the bridge damages the vast number of RC bridges has been seriously impaired [2]. Owing to inadequate shear strength and lack of adequate shear enhancement confinement, both outside as well as inside the region of the 'plastic harnessing' the jacks struggled and displayed insufficient bend ductility. The properties of the bridge piers (shear strength, flexural strength and concrete strength) are therefore important to strengthen [3]. The ductility of piers diverges with the sort of lateral reinforcement [4]. The shear reinforcement has significant role on final failure mode of reinforced concrete piers. Shear reinforcing of both the concrete and longitudinal armor with robust shear stresses, thus increasing the shear strength of the piers. [5]. The glass fibers hold advantages like light weight and ductility [6, 7]. The mechanical- characteristics of GFRC with different MD ratios are explored. The mix design of 1:1.5:3 with a w/c ratio of 0.6 was utilized for plain concrete. Glass fibers of diverse stuffing (i.e. 0%, 0.5%, 1%, 1.5%, 2%, 2.5%, 3%, and 3.5%, by cement mass) were utilized. Specimens were casted and tested for compressive, flexural, and splitting-tensile strength. It was witnessed that 1.5% glass fiber content by mass of cement was the optimum percentage. The compressive, tensile, flexural strengths were enriched by 13%, 11%, and 50%, respectively, when contrasted with that of respective plain concrete samples [8].

The structural behavior can be predicted at four stages. Including:

I real-field full-size structure, (ii) full-scale structural elements with precise limits, (iii) scale-out of prototype structures or typical building elements, including appropriate raw material gradients, loading conditions and limits; (iv) small-scale structural prototype elements with no technique for scaling down compared with (c) Only simpler strategies (i.e. stage iv) are taken in the current study. In this review. In the light of these defects, the actions of the prototype Bridge reinforced concrete piers (FRC) must be investigated.

1.2 Research Motivation and Problem Statement

Bridge piers in bridge construction are very important. Bridges should remain functional for ensuring proper traffic flow. The majority of bridges have been severely damaged due to many reasons during their life span. The performance of bridges can be improved by using better material. Fibers are used to improve many mechanical properties of concrete in order to achieve toughness without compromising the economy and with less compromise on compressive strength.

Hence, the problem statement is as follows

"The most common damage of bridges includes shear-flexural failure of the pier [9]. Shear strength, splitting-tensile strength, flexural strength and toughness are enhanced by using GFRC [10]. But in depth behavior of GFRC is still unknown for particular properties related to bridge piers. Therefore, the experimental properties of GFRC related to the bridge piers are needed to be explored in detail."

1.2.1 Research Questions

Following are few research questions which is added in this work:

- How do mechanical behavior of GFRC show better performance than PC i.e. how much toughness is improved and compressive strength is reduced?
- How much dynamic properties of different GFRC specimens are better than PC?
- How much toughness is improved when GFRC is used?
- How much GFRC improve resistance to crack propagation?
- How much the capacity of prototype piers is effected by increasing flexural and shear reinforcement?

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

The overall aim of the research program is to explore materials for superior performance of bridge (deck, girders and piers) by using the concrete having enhancedf unctionality.

"In this Ms research work, an investigation has been carried out to study the behavior of GFRC for application of bridge piers. The relative comparison of prototype

piers of GFRC and RC is made. Compressive strength, splitting-tensile strength and modulus of rupture of plain concrete (PC) and glass fiber reinforced concrete (GFRC) are determined experimentally. Axial load carrying capacity of prototype pier is determined experimentally in STM (Servo-hydraulic Testing Machine) for both materials. Energy absorption and toughness of prototype piers are also calculated. Dynamic testing as per ASTM is also performed."

1.4 Scope of Work and Study Limitation

The PC and GFRC materials with a mix design ratio of 1:1:5:3 are used. There are 34 specimens (17 for PC and 17 for GFRC). To study the experimental behavior of the prototype PC and GFRC bridge piers with various flexural and shear reinforcement, a total of 16 cases are investigated (eight PC prototype bridge piers with steel bars and eight GFRC prototype bridge piers with steel bars).
The study focuses on relative comparison. Therefore, scale down technique is not applied for prototype testing.

1.4.1 Rationale Behind Variable Selection

The rationale behind the selection of these variables are:

- The variable explored in this research work are inclusion of glass fiber in concrete and variation in flexural and shear reinforcement in prototype bridge piers.
- Glass fibers are selected to avoid massive corrosion throughout cross-section. Thus, steel fibers are not selected.
- Variation of longitudinal steel rebars (i.e. flexural reinforcement) is twice i.e. 4-$\oslash$2 is increased to 8-$\oslash$2. This is to check the capacity of prototype piers when reinforcing rebars are increased.

- Variation of transverse bar of piers (i.e shear reinforcement) is reduced i.e. ⊘2-76 mm is reduced to ⊘2-64 mm. This is to check the capacity of prototype when spacing is reduced.

1.5 Research Novelty, Research Significance and Practical Implementation

To the best of authors knowledge and on the basic of limited literature review, no research has been carried out on prototype bridge piers having GFRC with steel rebars to examine its axial load carring capacity.
The significance of this reseach is to have in depth knowledge on axial capacity of vertical elements having GFRC with steel rebars.
The practical implementation of this research program outcomes can be utilization of glass fiber in concrete for structural elements for enhancing toughness with little compromises in compressive strength.
To increase performance of bridges, the strength of bridge piers has a vital role.

1.6 Research Methodology

PC and GFRC are classified for flexural strength, compressive strength and splitting of tensile strength. There is also a relative comparison of the load carrying capability of the prototype piers with specific PRC and GFSRC flexural and shear strengthening. Three specimens are cast separately from the PC and GFRC for the determination of mechanical properties. To assess prototype behavior, two samples are cast separately from PRC and GFSRC for each shift in flexural and shear reinforcement. Other researchers also used three samples for material properties [12] and one sample for prototype testing [13]. Even researchers have used two samples for material properties [10, 14]. The mix design ratio for PRC and GFRC is 1:1.5:3 and w/c is 0.71. For making of GFSRC, fiber of 5% contents by mass of cement and having length of 50mm are added in concrete. The standard specimens are cast and tested according to ASTM standards. Dynamic behavior of specimens is also observed as per ASTM.

1.7 Thesis Layout

This research work has five chapter which are given as follows:

Chapter 1: This chapter includes introduction. This chapter explains Research Motivation and Problem Statement, Overall Objective, Specific Aim, Research Methodology and thesis outline.

Chapter 2: This chapter includes literature review segment. It consists of background, failure of bridge piers and improvement in mechanical properties of concrete by using bers, prototype testing and summary.

Chapter 3: Consists of experimental program. It contains background, ingredients, concrete preparation procedure, specimens details, testing procedures and summary

Chapter 4: Consists of experimental evaluation. It contains background, results of testing for mechanical properties (i.e. compressive, split-tension and exure strength, behavior and energy absorption), prototype testing, resonance testing.

Chapter 5: Explains conclusion and recommendation. References are given at the end.

After chapter 5, the bibliography is presented.

Chapter 2

Literature Review

2.1 Background

The major defects that ultimately mitigate the robustness and serviceability of the concrete bridging piers are the mixed shear-flexural failures and the lack of load power. Along with these defects, the mechanical properties of concrete can also be diminished by the other defects in the bridges pier. The compressive, tensile and flexural strength of concrete can be decreased by reducing these defects. Whether by reinforced fiber concrete (FRC) and/or admixtures, these mechanical properties can be strengthened. The use of flexural and shear reinforcement of GFRC can contribute to reducing the combined shear/flexural failures and increased load capacity in the concrete bridge piers. This chapter explores in depth the reason for failure in bridge piers, reinforced concrete without and with rebars and concept experiments of different researchers.

2.2 Flaws in Concrete Bridge Piers

Pier structures can, for a variety of reasons, be weakened, broken or aged to varying degrees during use. There have been rapid changes in the recent economy and infrastructure, different forms of river-crossing and sea-crossing bridges, which have contributed to ship-bridge collision crashes. Therefore it is extremely necessary to evaluate the damage of the reinforced concrete pier in order to ensure the stability and durability of pier structures The analysis of many collapsed structures, in particular bridges during the October 2005 earthquake showed that most of these bridge piers had structural methodologies. Once exposed to these large lateral deformations, the load carrying capacity had dramatically decreased. The buckling of the main reinforcement in longitude resulted in a seismic event with poor bridge performance. The serious damage done to large number of RC bridges due to mixed flexural shear bridge pier failures. Experimentally, a non-linear cyclic load check is conducted on six reinforced concrete (RC) cross-sectional bridge piers. The harm states, ductility and energy dissipation parameters, degradation of the rigidity and shear strength of the piers are investigated and compared. Experimental results show that each pier has a stable flexural response at displacement ductility up to four before it is broken. Shear capacity takes over the decisive performance of the piers [2]. The participant component of collapse bridge piers is: lack of containment, inadequate shear power, critical section shifting and inadequate lap break length [15]. Failures were often linked to insufficient column shear strength. As none different researcher mentioned, so there are several explanations for the failure of the bridge piers. Some of the main reasons for the failures of the bridge piers are: shear and bending strength defects, inadequate load capacity resulting from insufficient longitudinal / transverse strengthening, poor imprisonment, lack of concrete strength and wide, unsupported lengths of longitudinal bars [16]. There have been a number of recent incidents of overturning and failure in China. Highly loaded transit as failure was the main cause of the complex operation of a bridge. The failure started with the disconnection of the support and the whole bridge collapsed as a result. Bridge failure also improved by surrounding conditions of border communication, material quality etc. Bridge not collapses with many supports if few supports disconnects. It collapsed, however, when many supports were disconnected and others were on line. The result was broad bridge rotation and failure mode [17]. The goal is to test probabilization by means of a correlation study of failure limit states in the different parts of the St.

Giorgio Island Bridge piers subject to a barge collision. With the aid of a Finite Element modeling program, LS-DYNA, the structural capacities and demands for internal shear forces and bending moments are computed and reliability tests are carried out using the Monte Carlo simulations against bending and shear failures. The reliability analysis findings describe the base and impact areas for the insulated cases and the top region of the affected pier systems as critical zones for the located pi failure. Furthermore, it has been shown that, from the statistical study of associations, the shear failure mode is the dominant mode for a relatively stern pier. In isolated situations the flexural insufficiency mode of the pier is the more versatile pier. However, a range of sensitivity tests by specific impact loading parameters of the reliability indices of both shears and bending failures indicate that the shear failure is prone to impact variables rather than bending failure [18]. Pedestrian concrete bridge collapsed during construction in Miami , Florida. This bridge's collapse caused several casualties and raised several serious questions about the bridge's design and construction including the new idea of rapid bridge construction (ABC). The results of the study and simulations provide valuable insights into the process for collapse and demonstrate lessons that could be learned in the future to avoid similar catastrophic failures [19]. The additional loads caused by the road construction and later on operation with heavy trucks potentially risked the safety of bridges. To facilitate the analysis, a detailed three-dimensional finite element (FE) model was developed that can address the interactions between pier columns, pile foundations, surrounding soils and heavy truck loads [20]. Failure in bridge piers is shown in figure 2.1.

(a) **(b)** **(c)**

FIGURE 2.1: Bridge Piers Failure (a), (b) and (c).

2.3 Use of Artificial Fibers

Asbestos fibers were used in construction at the beginning of the 1900s, and one of the subjects of concern was the search for composite materials in the 1950s. The asbestos contained in construction had to be replaced. By the 1960s, concrete was used for steel , glass (GFRC) and synthetic fibers such as polypropylene fibers, and today research is ongoing on the new reinforced fiber concrete. In general, tensile strength of concrete is weak and compressive strength high. The main goal is to improve concrete tensile strength by researchers or concrete technologists. The partial integration of fibers is used in order to resolve this severe defect. Large quantities of steel waste fiber are produced from the lath, empty metal boxes and soft drink bottle caps industries. This is an environmental problem, as steel waste fibers are not easily biodegradable and involve recycling or reuse processes. Over the last two decades, fiber reinforced concrete is an important subject that many researchers explored [21]. FRC is an effective way to increase toughness, shock resistance and resistance to plastic shrinkage cracking of the mortar. Such fibers have a lot of advantages. Steel fibers can improve structural strength in order to reduce the demand for heavy steel reinforcement. The concrete's freeze thaw resistance is enhanced. To that crack widths, the toughness of the concrete is increased. The resistance to impact is strengthened with polypropylene and Nylon fibres. Many developments in fiber reinforced concrete were made and the addition to fiber improves concrete ductility and the carriage capacity of this concrete after cracking [22]. Steel 50, 60 and 67 aspect ratio fibers are added. Analyzed and comparable to the control (0 percent fiber) data obtained have been collected. The relationship between compressive strength and aspect ratio, aspectratio versus flexural strength and aspect ratio versus split strength is graphically described. Compressive strength , split tensile strength and bending strength are stated to be 3 % higher on the other side than that of 0 % , 1% and 2% fibers. Both power characteristics are shown to be higher on the side of the aspect ratio 50 compared to 60 and 67. Compression pressure increases with the addition of s between 11 and 24 percent [23]. The effect of using waste materials like washed was studied at a dosage of 1% of the weight of concrete as a fiber by using soft drinking bottle caps, empty tins and waste metal pulver from the workshop. The waste late, the empty tins and the bottle covers for soft drinks were deformed into 3 mm wide by 10 mm long rectangular strips. The study was carried out with an M25 mix and the testing was performed with the correct codes in compliance with the prescribed procedures. The results were compared with conventional concrete, and a 41.25% increase in its compressive strength and tensile strength of the concrete blocks incorporated with steel pulver. Reinforced blocks with soft drink bottle caps showed a 25.88 percent growth in the bending strength of concrete. The compression compressor with a compressive strength of 41.25 percent greater than standard concrete displayed strong steel powder specimen as a waste material [24]. In a dose of 0,5 percent by weight of cement, we investigated the effect of added polythene (domestic waste plastics). The studied properties include compressive strength and bending strength. Tests were done with an M20 mix and experiments were conducted according to prescribed protocols of the respective code. The result was that the cube-compressive strength of concrete increases to 0.68% in 7 days. In 28 days, the cube 's compressive strength of concrete increases to 5.12%.The improvement in the mechanical properties of concrete mixtures with polythene fibers is not in line with that of steel fibres. [25]. The aim of study is to determine the effect of the fiber form and content on uniaxial compressive strength (UCS) as well as the microstructure features of reinforced concrete (FRC). For the testing of the strength properties of the non-FRCs, a total of three (3) nonFRC samples (NFCs) and 27 FRC samples were made, reinforced with 0% glass and 0.4% polypropylene (PP) and polyacrylonitrile fibres. Following UCS research, a variety of microstructure experiments have been performed including a simulated scan of tomography and electron microscopy scanning coupled with energy dispersive spectroscopy for an advanced exploration of FRC morphology. Results show that (1) All FRC samples increase and decrease in UCS values, while the fibre content decreases. This results. With rising fibre content the UCS ratio in FRC is gradually decreasing. (2) The PP fiber improved its quality and strength than both glass and PAN fibers. This was primarily due to an enhanced bonding efficiency in the matrix, which decreases the absorption of water by FRC. In general, with an increasing amount of fiber, the peak strain increases linearly. Finally, the results of this study may provide a significant guide in the design and use of the FRC as an artificial pillar for underground mines [26]. The additives in this analysis are hooked steel fibers. For the composition of ALWA Styrofoam, 0%, 0%, 15% and 50%, and 100 % respectively, are used in split-resistance studies. Stain fibers are the same as 0,5%, 1.5% and 1.5% respectively. The tensile strength test tests are optimally made of concrete composites for bending strength testing. Concrete tests with a 15% styrofoam mixture and 1,5% stainless steel fibers have obtained optimum split tensile strength, the highest tensile strength test of 5,29 MPa and for full load of bending strength test results of 9,47 MPa [27]. Presents the review of the selective works of various researchers and presents a comparative study on the advantage and disadvantage of various fibers in the beam column joints [28]. Failure of fiber reinforced concrete is initiated by pulling out of fibers, failing to utilize their full capacity. In this study, closed steel fibers (CSF) are proposed for addition into concrete. The objective was to avoid the pulling out of fibers in tension for full capacity utilization. When CSF are embedded into concrete, they are expected to reach the breaking point, utilizing their maximum capacity due to the presence of concrete matrix within the closed geometry of fibers [29].

2.4 Glass Fiber Reinforced Concrete

Worldwide researchers create a high-performance concrete (HPC) with the help of admixtures, engineered cement content and/or fibers that are integrated into the concrete to a certain degree. The four basic mixtures of concrete: (a) plaine (PC) containing normal natural fiber-free aggregates, (b) sisal reinforced concrete (SFRC), (d) sisal reinforced concrete (SGFRC), (d). Compressive strength, splitting strength of the tensile, flexurity and workability were investigated. The findings were contrasted with the tests of fiber reinforced cement mixture with single concrete. Adding various types of fibers (natural and synthetic) has been proven to be extremely useful for making concrete. The addition of fibers resulted in increased resistance to stress, separation and tensile resistance. However, due to the inclusion of fibers in the concrete the working strength of the fiber reinforced concrete was less than the flat concrete [30]. The increase in compressive force of different glass fiber concrete grades is 20% to 25%. The increase in the bending and split tensile strength of different steel grades is 15% to 20% [31]. Therefore, it is important to consider investigating the experimental properties of fiberglass reinforced concrete linked to the bridge piers. Seismic performing columns with various reinforcement configurations of coco fiber ropes have been investigated for reinforced coco fiber, and satisfactory results were found. Because of steel rebar, cocoon fibre clothes were used. Within the next sub-section, FRC with Rebar is explored in detail. The inclusion of fibers in concrete avoided an increase in the width of cracks due to the increase in rigidity and ultimate capacity for load carrying [32]. To test for future use EAMC reduction in bridge-decks the strength properties of NFC and GFRC. The scientists have used 5% cement fiber content with 50 mm of concrete cut volume. A water cement ratio of 0.71 for NFRC and GFRC was used for the same MD ratio of PC (i.e. 1: 3.33: 1.67). Samples of strength properties were then tested. The slumps of GFRC and NFRC were found to decrease respectively by 68,7% and 37,5%. Although NFRC and GFRC densities were 1.8% and 2.4% respectively, they were lower than the PC densities. GFRC power of 5.6% and 11 % , respectively, is increased in comparison to the flexural and splitting tensile forces (FS and SS, respectively) NFRC SS and FS were respectively increased by 84% and 3%. Although NFRC and GFRC's compressive strengths decreased by 2.8% respectively and 5.8%, they were effective [10]. GFRC mechanical features with different MD ratios. For plain concrete, the MD is 1:1.5:3 with a w / c ratio of 0.6. Glass fibers of various materials (i.e. 0.5%, 0.5%, 1 % , 1.5%, 2 % , 3%, and 3.5%, respectively, by cement mass) were utilized. Samples for compressive, flexible and dividing tensile strength were cast and tested. The maximum level was found to be 1.5% glass fibre, by mass of cement. In comparison with the respective single concrete samples, the compressive, tensil, bending performance was increased by 13 percent, 11 percent and 50 percent (Table 2.1) [8]. An experimental research on behavior of steel and glass-fiber-reinforced-concrete composites. The MD ratio of 1:1.75:2.87 with a w / c ratio of 0.5 was used for PC. The same MD was used for composites made out of steel and glazed fiber concrete except for steel fibers (0,5% by volume fraction) and glass fibers (0,25% by weight of cement). Compressive strength of steel and fiber-reinforced beta has been increased respectively by 13.6% and 9.1%.In comparison to the respective PCs, it was also observed that the splitting power of steel and glass fibre-reinforced cements was respectively increased by 22,7% and 18,2% (Table2.1). It was found that the reinforced concrete was more effective than the reinforced concrete of glass fiber [33]. An experimental study was conducted in order to examine PC and GFRC resistance to fire and power. The use of glass fibers in concrete by volume fraction of 450 mm in length was used up to 1 percent in this experimental analysis [34]. The consistency increases as the crack resistance, ductility, as flexural strength and toughness of the fibers given in a certain percentage of the concrete. We also use glass fiber to increase the reliability of the frame. GFO is a component of a cement matrix of cement, sand, water and admixture that consists of short period glass fibers. The GFC is a material of cemented matrix composed of cement, sand or water. In the development business, non-structural elements, such as faade doors, piping and channels are commonly used. GFRC provides various advantages, including light weight, thermal efficiency, acceptable appearance and power We may conduct a particular test like pressure strength after casting the blocks, beams and cylinders with the aforementioned quantity fractions. Tensile strength respectively bending strength. Once this study has been done we equate the effects of reinforced concrete with glass fiber with those of regular concrete. We can see from an examination of all of them whether the inclusion of the fibers influences the mechanical properties of traditional concrete and whether or not the addition of fibers increases the strength of concrete [35]. Mechanical properties of GFRC by different researchers are shown in Table 2.1.

Plain and glass fiber reinforced samples were tested for examing the fresh and rheological properties. While nanosilica (NS) was utilized as replacement cement

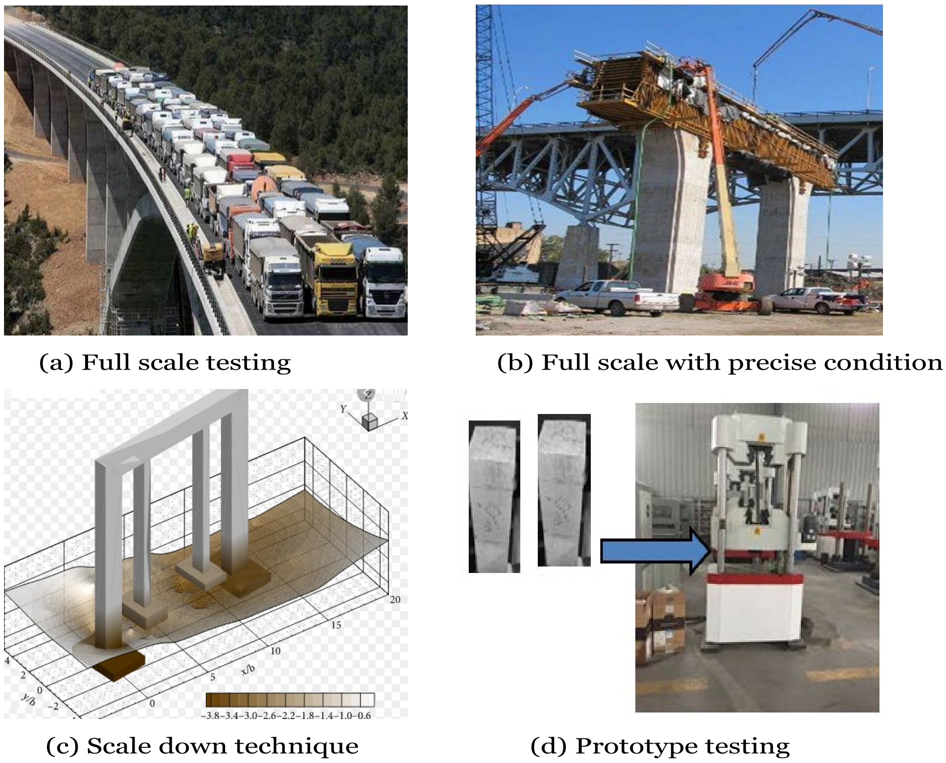
Table 2.1: Mechanical properties of GFRC by different researchers.

Fiber content	MD	CS (%)	SS (%)	MoR (%)	Reference
PC	—	100	100	100	
GFRC (5%) [a]	1:3.33:1.67	97.2	111	105.6	Khan and Ali (2016)
GFRC (1.5%) [a]	1:1.5:3	113	111	150	Qureshi and Ahmed (2013)
GFRC (0.25%) [a]	1:1.75:2.87	109.1	118.2	—	Kene et al. (2012)
GFRC (0.5%) [b]	1:2:4	113	120	142	Ravikumar and Thandavamoorthy (2011)
GFRC (1%) [b]	1:2:4	135	137	175	
GFRC (0.025%) [b]	1:3.24:5.1	110	—	108	Deo (2015)
GFRC (0.03%) [b]	1:1.31:2.54	119	115	115.1	Chandramouli et al. (2010)
GFRC (0.75%) [b]	1:1.21:2.59	107.5	126.7	135	Kizilkanat et al. (2015)

in quantities of 0%, 2%, and 4% with an unvarying fly ash inclusion of 25%. Experiments were performed to show the properties of the mixtures in the context of slump flo. Glass fiber reinforced samples shos better characteristics than plain concrete specimens [36]. The results show that the additional amount of glass fibers used for enhancing the compressive strength of the concrete should be appropriate. When short glass fiber is added to concrete, the flexural strength of concrete will be reduced when the amount of fiber is too large; when the length of glass fiber added to concrete is long enough, the flexural strength of concrete will increase with the increase of the amount of fiber. Under the effect of high temperature, the residual compressive strength of concrete increases with the amount of glass fibers added and increases with the glass fiber length [37]. Therefore glass fiber reinforced concrete having a capability to increase the compressive strength, flexural strength and split tensile strength of concrete.

2.5 Prototype Testing by Researchers

There can be four stages through which the behavior of any structure can be predicted. It includes (i) full scale structure in real field conditions [38] (ii) full scale structural elements with precise boundary conditions [39], (iii) either scaled down prototype structure or prototype structural elements including proper scaling down of raw material size, loading and end boundary conditions [40] and (iv) small prototype structural elements with no scale down technique for relative comparison to check the effectiveness of only one variable provided all other conditions are same [41, 12].In current study, only simplified approach (i.e. stage iv) is adopted. Figure 2.2 illustate all these four conditions.



(a) Full scale testing **(b) Full scale with precise condition**

(c) Scale down technique **(d) Prototype testing**

FIGURE 2.2: Different testing techniques (a), (b), (c) and (d).

2.6 Summary

From previous studies it can be claimed that the properties to improve structural durability, tensile and flexural strengths of concrete are compressive. The presence of concrete fibers prevents the width of cracks that cause rigidity and ultimate capacity to increase. Thanks to their solid existence and lengthy practical life, Artificial fibers are frequently poured into concrete. The density, highly durable and safe, additional ductility and lightweight, economic, energy-efficient, meteorological and firing resistance of glass fibers gained significant consideration. Glass fibers can therefore be suitable. Experimental work with glass fiber reinforced concrete small prototype bridge girders with various shears and bending reinforcement. The reference was small RC prototype girders with the same shear and bending reinforcement design for comparison to test the performance of glass fibers in concrete for the improvement of bridge girders reliability. Glass fibre reinforced concrete is considered to be solid and long-lasting. The concept is extended to bridge piers in this work. Comparison shall be made between the behavior of small prototype reinforced concrete and fiber-based concrete bridge piers with different main and cross armor [35]. The results may apply to columns in any other structure of the same nature provided faults. The study on the suitability of fiber reinforced concrete with glass fibers for application of Bridge piers has not so far been performed to the best knowledge of the author based on limited literature reviews.

Chapter 3

Experimental Program

3.1 Background

The axial load carrying capacity rises day by day in order to boost mechanical properties. The key benefits of fibre-reinforced concrete are improved bending power, tightness and energy absorption. The experimental work investigates the effectiveness of the glass fiber for improving the prototype bridge piers. Mixing design and casting process, material properties, prototype bridge pier specimens and test procedures are discussed in detail in this section.

3.2 Ingredients

The standard specimens of cylinders and beam lets were made of ordinary portland cement, locally available fiber, aggregate, drying water and glass fibers. It takes time and is a problem to prepare glass fibers for a required length. Glass fibers are separated and cut to a required length of 50 mm from the sheets as shown in figure 3.1. Alongside this material the steel rebar of 2, the prototype bridge piers made from reinforced concrete (RC) and reinforced steel glass fiber (GFRC) were also used for the preparation of the bridge piers. The aggregate size was 12 mm maximum.

(a) (b)

Figure 3.1: Glass fiber a) Glass fiber sheet b) Prepared glass fiber

Shear reinforcement of 40 grade Steel rebrs of Ø2@64 mm and Ø2@76 mm having four and eight flexural reinforcement for prototype piers are shown in Figure 3.2.

Figure 3.2: Steel reinforcement for prototype piers

3.3 Concrete Preparation

3.3.1 Mix Design Ratio

The cement, sand and aggregates ratio for PCs is 1:1.5:3 and 0.7 w / c. The same MD ratio is used for preparing GFRC, except for added 5% cement-mass fiber content with a length of 50 mm. There was no saturated dry surface condition.

For this reason, the concrete mix was fairly high in w / c ratio. Also, during workability testing and mold filling (which may not cause GFRC to lose strength) no bleeding has been observed.

3.3.2 Casting Procedure

All materials are layer by layer added to the concrete matrix for a consistent distribution of fibers. In layers, dry components are added. First of all, one third of the sheet Coarse aggregates are then applied to the mixer to a fiber sheet. The next layer of a third thin product shall be put, and a layer of fiber shall be placed above. The blender will be rotated for 4 minutes, after inserting a new collection of these layers, and replaced by two thirds of water after three minutes of rotation. After this, apply the remainder of the dry material in the same layering technique and rotate the mixer for 2 minutes while adding the remaining water. The slowdown test is performed according to ASTM C143[42] specifications to verify workability of 58 mm and 36 mm PC and GFRC. Cylinders measuring 100 mm x 200 mm and 100 mm x 40 mm beams are lined by means of a specific procedure for lining in three layers and tamping 25 times in each layer using the same tamping rod to evaluate the mechanical characteristics and the tampings. The exemplars are stored for 28 days in water and then dynamic tests per ASTM C215[43] are carried out.

3.3.3 Slump and Density for PC and GFRC

Table 3.1 indicates the decrease in fresh concrete and hard concrete density. The PC downturn is greater than the GFRC estimate. The slump of PC is more than GFRC by 30 mm water cement ration of 0.7 for both.. The reduction in the GFRC drop value is due to the absorption by glass fiber of more water. PC has a 2490 kg / m3 density and GFRC a 2398 kg / m3 density. The GFRC density indicates a decrease of 92 kg / m3. The density decline percentage of GFRC is 1.98%. This drop is due to the distributed concrete glass fiber. Slump for PC and GFRC are shown in figure 3.3.

TABLE 3.1: W/C ratio, Slump and densities of PC and GFRC.

Description	W/C ratio	Slump (mm)	Density (kg/m^3)
Plain Concrete	0.7	65	2490
Glass-Fiber-Reinforced-Concrete	0.7	35	2398

(a) (b)

FIGURE 3.3: Sump Test a) Slump of PC b) Slump of GFRC.

3.4 Properties of PC and GFRC

The Servo hydraulic (STM) system shall be used to assess compressive properties such as compression cracking behavior, stress strain curve, compressive strength, energy absorption, and total strength in compliance with ASTM Standard C39 / C39M-15, ASTM Standard C39 / C39M-15a [44]. Of both PC and GFRC specimens shown in Figure 3.4(a), compressive strength test, stress strain curves are considered. Figure 3.4(a) displays PC and GFRC compressive actions on the left side, while crack propagation is seen on the right side. At three rates of preparation, the cracking pattern was noted. In the case of PC samples, cracks on the surface in all three different loading phases were slightly deeper than in GFRC samples. It shows that the addition of glass fibers influences the development and spread of cracking phenomena in concrete and is effectively controlled. The maximum tension of the stress-strain curve is compressive pressure. The energy absorption capacity was determined by the area under the stress pressure curve and given in units of MJ / m3 per unit of concrete material. Compression energy absorption (Em) is measured under the stress curve up to the full load. As the cracked energy absorption in compression (Cr. E), the field below the stress stream curve from the initial load to the final load. Compressive total energy absorption (TE) is determined from the original to the ultimate stress region under the stress-strain curve. Compressed strength index (TI) is the proportion of full energy uptake in compression and energy uptake in compression to highly stressful compression (i.e. TE / Em). Table 3.2 displays the compressive power, Em, Cr. E, TE and TI for PC and GFRC, with a 1:1.5:3 mixing style proportion. The GFRC specimen's compressive strength is decreased by 6 MPa while other Em, Cr properties. E, TE and TI, respectively in comparison with the PC specimen, are increased to 0.04 MJ / m3, 0.26 MJ / m3, 0.31 MJ / m3 and 1.36. In the Figure 3.4 (a) you can see a comparison of mechanical properties. In which all properties are measured in a percentage by PC and GFRC specimens. The compression force of GFRC in relation with the PC was reduced by 20 percent. In assessment with PC, the GFRC specimen is increased by 38 percent and 148 percent respectively, at full energy and total energy absorption. The total toughness index for the PC was also raised to 90 points. The compressive performance strength tabulated in Table 3.2. While compressive strength decreased marginally, it can be concluded. The energy absorption and total toughness index values in all the GFRC specimens have therefore increased considerably.

To evaluate PC and GFRC cylinder split tensile properties, STM tests for the split crack, splitting tensile load curve, splitting tensile strength, energy absorption, and total power index have been carried out in compliance with ASTM standard C496/496M-11 [45]. Of all the PC and GFRC specimens shown in Figure 3.4(b) splitting tensile strength, load-time curves will be considered. The tensile activity on the left side of PC and GFRC specimens is shown in figure 3.4(b), while on the right-hand side the crack propagation of specimen is shown. At three rates of preparation, the cracking pattern was noted. The cracks were seen to form during the initial loading phases in the PC specimen. Nevertheless, at this initial loading stage, the GFRC specimens demonstrated very little cracking. The load was increased to greater concentrations. In contrast to the crack pattern formed on the GFRC specimen surface, the break propagation was substantial with PC specimens. This demonstrates the efficiency of the introduction of glass fibers to monitor and restrict the production and dissemination of a concrete cracking phenomenon. As the high charge from the load-time curve, splitting tensile strength is taken. As the region below the loading time curve up to the peak load, energy absorption in splitting tensile (Em) is measured. The area from peak load to ultimate load below the loading time curve is taken as splitting energy absorption (Cr. E). As the region below the load- time curve from initial to final load, total energy absorption in the divisive processes (TE) is estimated. Toughness index (TI) is the ratio of total energy absorption when spreading to full load (i.e. TE / Em), to energy absorption. The PCs and GFRC's Splitting tensile strength, Em, Cr. E, TE and TI are shown in Table 3.2. The tensile force breaking, Em, Cr. The specimens STS, Em, TE, and TI of GFRC are increased in comparison to the specimen PC by 0.35 MPa, 9.8 J, 36.1J, 42 J and 0.79. In the Figure 3.4 (b) you can see a comparison of mechanical properties. In which all properties are measured in a percentage by PC and GFRC specimens. GFRC's tensile splitting strength is improved in PC terms by 9 percent. The GFRC specimen is measured at 35 percent and 130 percent respectively in full energy and in total energy absorption for PCs. Also, the total toughness index in comparison to PC has been raised to 79%.

The ASTM C78 / C78M-15b [46] standard is used for determining PC and GFRC beam specimen properties for the purpose of flexural cracking behavior, flexural curve for the load deflecting, MoR (rupture module) / flexural resistance, energy absorption, and total toughness index are cast with flexural steel reinforcement and shear reinforcement. Of all PC and GFRC specimens shown in Figure 3.4(c), flexural strength tests and load-displacement curves are considered. The activity of PC and GFRC specimens on the left side is shown in figure 3.4(c), while the

TABLE 3.2: Compressive, flexural and splitting-tensile properties of PC and GFRC specimens with MD ratio of 1:1.5:3:0.7

Intended Properties	**Compressive**		**Splitting-tensile**		**Flexural**	
	PC	**GFRC**	**PC**	**GFRC**	**PC**	**GFRC**
P (kN))	210	170	149.3	163.7	9.67	10.85
Strength	29	23.21	3.15	3.50	7.20	7.80
Em	0.14	0.18	32.80	42.1	7.31	6.90
Cr E	0.12	0.38	0	36.1	0	13.32
TE	0.23	0.54	32.80	75.4	7.31	18.87
TTI	1.64	3.00	1	1.79	1	2.73

crack propagation of specimens on the right side is shown. At three stages of preparation, the cracking pattern was noted. The cracks were seen to form during the initial loading phases in the PC specimen. However, at this initial loading level the GFRC specimens showed very little cracking. With loading increased to a higher level, crack propagation in comparison with crack patterns on the surface of GFRC specimens for PC specimens was pronounced. As the peak charge from the load-displacement curve, flexural strength is taken. Flexural energy absorption (Em) is measured in the load-displacement curve up to full load as the area below. As a broken energy absorption flexural (Cr. E) the field underneath the load-displacement curve from peak load to ultimate load. When the region below the load-displacement curve from initial to final load, the total energy absorption (TE) is measured. Toughness Index (TI) is the ratio from total energy absorption to flexural absorption of the energy to peak load (i.e. TE / Em). Table 4.2 displays the flrexural strength Em, Cr. E, TE and TI of PC and GFRC with a 1:1.5:3 mix configuration. The flexural strength, Em, Cr. The GFRC specimen E, TE, TI was increased in terms of PC specimens by 0.06 MPa, 0.41 J, 13.32 J, 11.56 J and 1.73, respectively. In the Figure 3.4(c) you can see a comparison of mechanical properties. In which all properties are measured in a percentage by

PC and GFRC specimens. The capacity of GFRC in conjunction with the PC is increased by 8%. The GFRC specimen is measured by 10% and 150% respectively for the average energy at the full load and overall energy absorption with PC. The total toughness index in connection with the PC has also improved to 173%. The flexural tests showed an improvement in all the properties, including resistance, energy absorption ability and complete tightness of the GFRC specimen, relative to PC specimens, in comparison with the results of compressive studies.

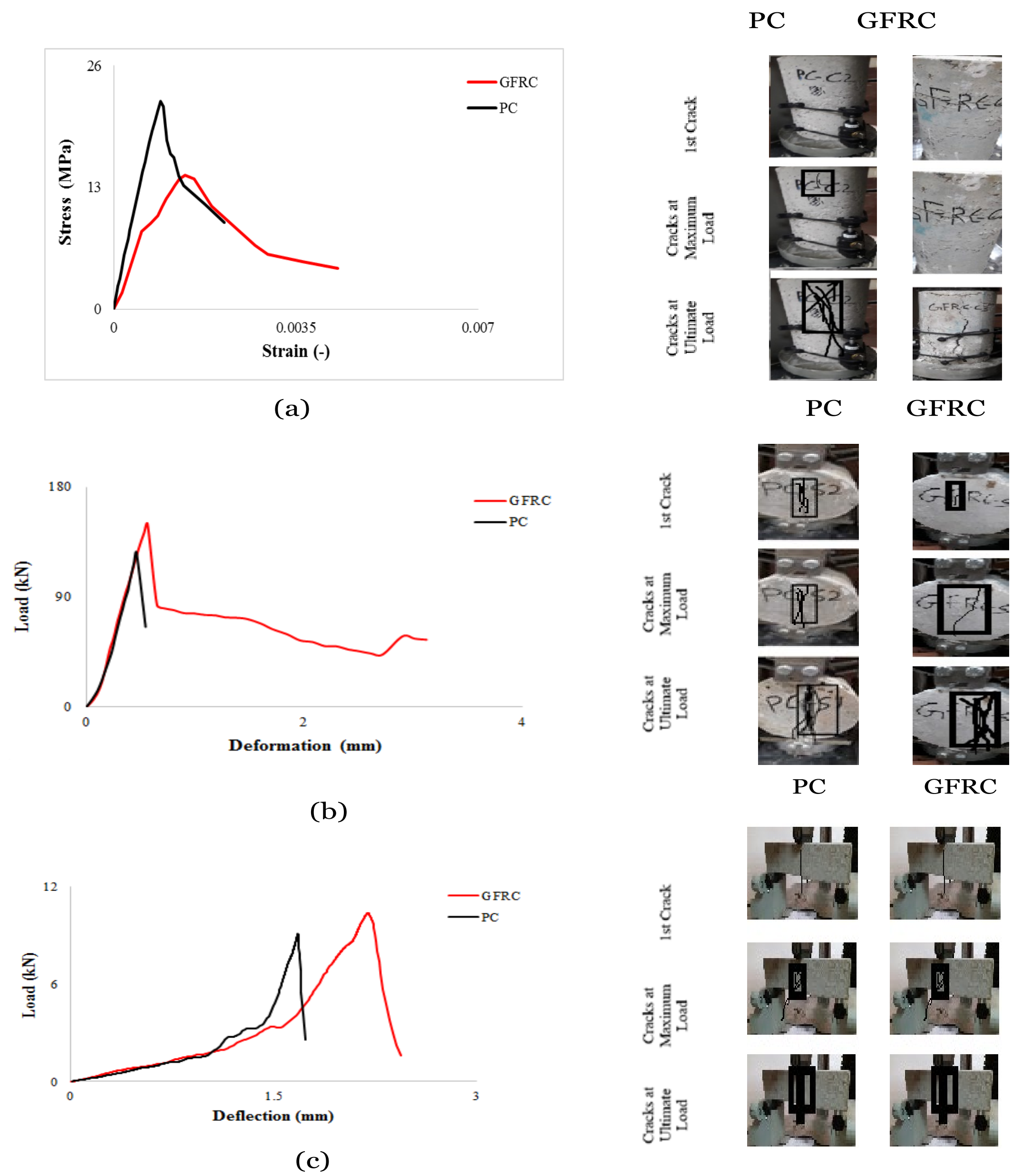
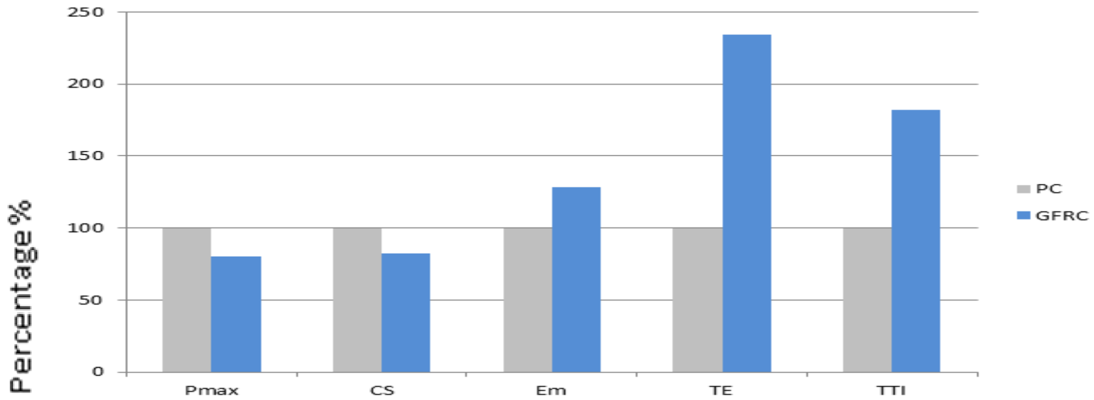
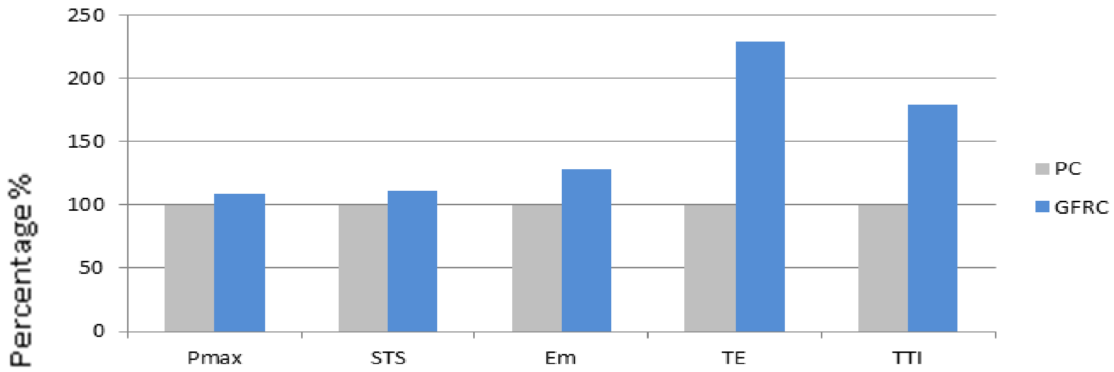


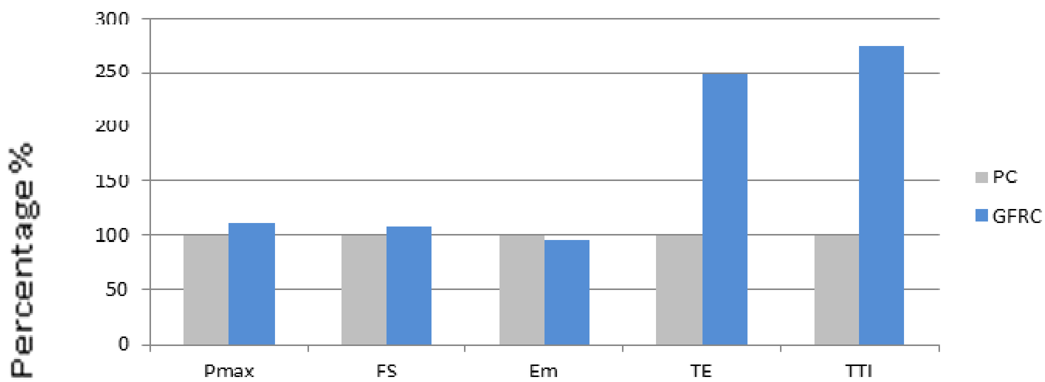
FIGURE 3.4: Mechanical behavior (left) and Crack propagation (right); a) Compressive Strength, b) Split-Tensile Strength, and c) Flexural Strength.



(a)



(b)



(c)

FIGURE 3.5: Comparison of Mechanical Properties of PC and GFRC; a) Compressive Strength, b) Split-Tensile Strength, and c) Flexural Strength.

3.5 Details of Specimens

Scope of work with specimens details are shown in table 3.3.

TABLE 3.3: Detail of specimens prepared.

	PC (1:1.5:3, w/c 0.7)		GFRC (1:1.5:3, w/c of 0.7, 50mm fiber length, 5% fiber by mass of cement)		Properties required to be determined
Material Properties	PC-C D-150mm H-300mm		GF-C D-150mm H-300mm		• Stress-strain curve • δ (compressive strength) and ε (Strain) • CEmax, CEtotal, CTI • Compressive cracking behavior (ASTM standard C39 / C39M15a). • Dynamic behavior as per ASTM
	PC-S D-150mm H-300mm		GF-S D-150mm H-300mm		• Splitting-tensile load-time curve • STS (Splitting-tensile strength) • SEmax, SEtotal, STI • Split cracking behavior (ASTM standard C496 / C496M-11. • Dynamic behavior as per ASTM.
	PC-F (100*100*450mm)		GF-F (100*100*450mm)		• Flexure load-deflection curve • MoR (Modulus of rupture) • FEmax, FEtotal, FTI • Flexural cracking behavior (ASTM standard C78 / C78M-15b) . • Dynamic behavior as per ASTM
Behaviour of Prototype	RC-4/76 4-Ø2 Ø2-76mm	RC-8/76 8-Ø2 (Ø2-76mm	GFRC-4/76 4 - Ø 2 Ø2-76mm	GFRC-8/76 8 - Ø 2 Ø2-76mm	• Load carrying capacity. • Cracking pattern • Energy absorption. • Toughness • SEM • Dynamic behavior as per ASTM.
	RC-4/64 4 - Ø 2 Ø2-64mm	RC-8/64 8 - Ø 2 Ø2-64mm	GFRC-4/64 4 - Ø 2 Ø2-64mm	GFRC-8/64 8 - Ø 2 Ø2-64mm	

For this analysis, cylinders and beamlets were casted to determine the mechanical properties of PC and GFRC. The size of the cylinder molds with a diameter of 150 mm and a height of 300 mm while beam molds with a width of 100 mm, height 100 mm and a length of 450 mm. Twelve specimens (i.e. six for PC and six for GFRC) are cast for compressive strength and split tensile strength checking. While six specimens (three for PC and three for GFRC) are cast for flexural strength testing. For a test of 0.15 Mpa / s compressive, 0.78 Mpa / min splitting, and 0.86 Mpa / min flexural test according to ASTM C-39M-18, C-496M-17, and C-293M-16, three minimum levels of loading shall be considered. On average, 3 sample values are collected. A total of 16 column samples of prototype were casted and tested under conditions of axial load. Two specimens are taken into consideration for axial examination and content (i.e. PC and GFRC). Every sample was 100 mm wide, 100 mm high and 450 mm long. For the condition and capability of the laboratory test apparatus available, the size of the prototype specimens were selected. Every person was made as a beam and checked as a column. The specimens are identified by the steel rebar longitudinal, material, varied by the spacing and number of the confinement steel. A smaller diameter of 6 mm is used in the prototype specimen The ASTM C39M-18 also has the average of two values. Non-destructive dynamic testing according to ASTM C215-14 was also performed for mechanical properties and prototype specimens before destructive testing.

3.6 Labeling Scheme of Prototype Bridge Piers

The RC illustrates the reinforced concrete and GFRC illustrate the glass fiber reinforced concrete. Spacing of shear reinforcement is kept as 76 mm and 64 mm whereas flexural reinforcement of four and eight steel bars are also shown in each specimens label. Table 3.4 illustrate the labeling scheme for prototype bridge piers. Total of sixteen prototype bridge piers are cast to perform axial testing. Eight prototype bridge peires are for RC and similarly eight for GFRC.

TABLE 3.4: Labeling scheme for prototype bridge piers.

Sr. No	**Flexural**	**Shear**	**Label**	
			RC	GFRC
1	4-∅2	-∅ 2-76mm	RC1-4/76	GFRC1-4/76
2	4-∅2	-∅ 2-76mm	RC2-4/76	GFRC2-4/76
3	4-∅2	-∅ 2-64mm	RC1-4/64	GFRC1-4/64
4	4-∅2	-∅ 2-64mm	RC1-4/64	GFRC2-4/64
5	8-∅2	-∅ 2-76mm	RC1-8/76	GFRC1-8/76
6	8-∅2	-∅ 2-76mm	RC2-8/76	GFRC2-8/76
7	8-∅2	-∅ 2-64mm	RC1-8/64	GFRC1-8/64
8	8-∅2	-∅ 2-64mm	RC2-8/64	GFRC2-8/64

3.7 Testing Procedure

3.7.1 Axial Load Testing

For axial power of all prototype specimens of the RC and GFRC, ASTM C39 / C39M-18 was followed. Upon checking for uniform load distribution, all the prototype samples were capped with Paris plaster. STM was used for evaluating the compressive compression behavior of all prototype specimens, determining compressive strength and determining compressive energy absorption and compressive toughness index. Testing system for a prototype column i.e. schematic diagram and experimental setup is shown in Figure 3.6.

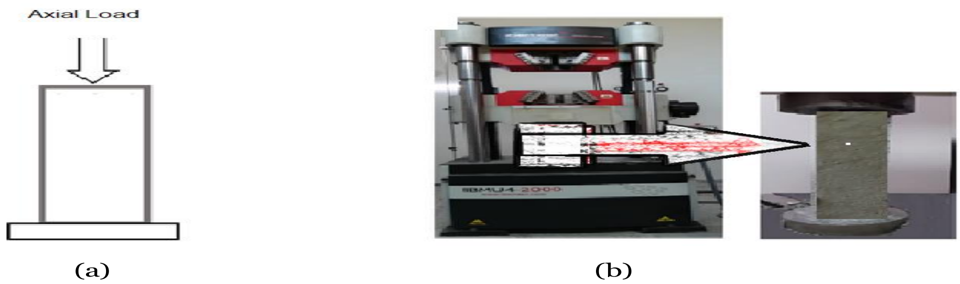


FIGURE 3.6: Testing of prototype bridge piers: (a) Schematic Diagram, (b) Experimental Setup.

3.7.2 Dynamic Properties

The tests of longitudinal frequency, transverse frequency and torsial frequency according to ASTM standard C215-02 will be tested prior to destructive testing during present study. Damping ratio is also calculated. Schematic diagram for dynamic testing is shown in figure 3.7.

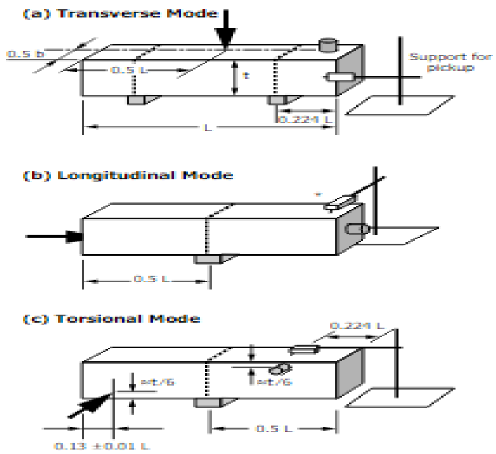


FIGURE 3.7: Dynamic test setup (a) For Transverse mode (b) For Longitudinal mode (c) For Rotational mode.

3.7.3 Fiber Failure in Specimens

At the micro level of the tested specimens, the broken surface is further analyzed with images. GFRC research result is taken in photographs of the specimens examined. The objective is to identify the failure mechanism and to connect concrete components to fibers.

3.8 Summary

The mix design of 1:1.5:3:0.7. is used for preparation of plain concrete (PC). 5% of glass fiber by mass of cement is auxiliary to make glass fiber reinforced concrete (GFRC) with same mix design. Four and six steel bars of 2 are used for flexural reinforcement. Shear reinforcement of 2@76 mm and 64 mm are also added in specimen to prepare reinforced concrete (RC) and glass fiber reinforced concrete (GFRC). A total of sixteen prototype bridge piers of reinforced concrete (RC), glass fiber reinforced concrete (GFRC) are prepared. Twelve cylinders are also tested to find compressive and split-tension strength of plain concrete (PC) and glass fiber reinforced concrete. Six beam lets are tested to find modulus of rupture of plain concrete (PC) and glass fiber reinforced concrete (GFRC). All specimens are also tested to find damping ratios.

Chapter 4

Experimental Evaluation

4.1 Background

The samples are casted with ratio of 1:1.5:3 having water cement ratio of 0.7 for PC as well as for GFRC. 5% of glass fiber by weight of cement is esed. The length of glass fiber is 50 mm. The test performed on PC and GFRC having flexural shear steel rebar are debated in all aspect in this chapter.

4.2 Behavior of Prototype Bridge Piers under Axial Load

The peak axial force divided by cross-sectional area is taken as stress in stress strain curve. The energy absorption capacity in units MJ / m3 was recorded in [47, 48] which correlates with the region of the curve under stress. In addition, compression energy absorption (C.Em) as the area below the stress strain curve to the maximum charge is measured. As a cracked energy absorption in compression (Ccr. E), the region below the stress-straining curve between the peak-load and the final load). Compression (CE) total energy absorption is measured from initial to final stress as an region under the stress curve. The CTI is the ratio of total energy absorption during compression and energy absorption to extreme load in compression (i.e. CE / C.Em) compression tightness index. Table 4.1 displays the axial power of RC and GFRC, C.Em, Ccr. E, CE and CTI. The figure shows the compressive behaviour, during axial pressure, of prototype bridge piers with regard to the relation of stress / strain and crack propagation. The prototypes of RC are stronger than the GFRC specimens shown in figure 4.1. Although the pressure of GFRC prototype specimens in RC is lowered. The confinement for longitudinal bars was varied in current research by increasing the gap between the shear reinforcement in concrete. The distance between the shear reinforcement has been decreased from76 mm (RC 4/76 and RC 8/76) to 64 mm (RC 8/64 and RC 8/64) and the end load has been increased considerably Figure 4.4. In specimens GFRC 4/64 and RC 4/64, where confinement refinement spacing was preserved equal to 64 mm, the same increasing tendency of strain can be found, but the addition of glass fibers has led to a relatively higher tension of concrete. The that tendency of strain can also be observed for specimens GFRC 4/76 and RC 4/76 where the gap between confinement reinforcement was preserved in the same way as 76 mm but the introduction of glass fibers helped achieve a comparatively greater strain in concrete. Specimens GFRC 8/64 and RC 8/64, where the separation of confinement strengthened equally is retained (that is, 64 mm) display a similar-strain pattern. But the addition of glass fibers contributed in achievement of relatively more strain in concrete. The that strain pattern is equally evident with the GFRC 8/76 and RC 8/76 specimens, where confinement reinforcement spacing was maintained equal, i.e. 76 mm, but the addition of glass fibers led to the achievement of comparatively more concrete straining. As the bridging effects limiting the opening of cracks and the resulting failure showed more straining potential and ductility. The crack is present in all prototypes of GFRC, as the gap between first cracks in all RC specimens can be significant. As we have shown that after having the full axial load on all GFRC specimens the number of cracks and their sizes have increased. Some bits of concrete from RC specimens are removed at ultimate axial load. Durability of GFRC specimens due to glass fibers has been closely related. For study, some GFRC specimens were intentionally broken up by the fiber failure mechanism. 60% of the fibers dropped and 40% of the specimens are pulled out. The axial force reduction of specimens RC 4/64, RC 4/76, RC 8/64 and RC 8/76 was seen as GFRC 4/64, GFRC 4/76, GFRC 8/64 and GFRC 8/76.

TABLE 4.1: Experimental Results (stress-strain) of tested prototype specimens with varying longitudinal and Shear Steel reinforcement.

Specimens	**Axial Strength MPa**	**C.Em MJ/m$_3$**	**Ccr.E MJ/m$_3$**	**CE MJ/m$_3$**	**CTI (-)**	**Failure Mode**
RC 4/76	23.7	0.09	0.12	0.19	2.11	Crushing
GFRC 4/76	26.2	0.08	0.24	0.33	4.12	Bridging
RC 4/64	33.7	0.07	0.15	0.20	2.82	Crushing
GFRC 4/64	22.5	0.08	0.19	0.25	3.12	Bridging
RC 8/76	27.5	0.07	0.28	0.33	4.71	Crushing
GFRC 8/76	6.3	0.09	0.50	0.57	6.33	Bridging
RC 8/64	42.4	0.08	0.21	0.27	3.37	Crushing
GFRC 8/64	8.4	0.09	0.32	0.39	4.33	Bridging

Note:

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

Ccr. E= Compressive cracked energy-absorption after maximum load CE= Total compressive energy absorbed

CTI= CE / C.Em = Compressive toughness index

An average of two readings is taken.

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

The specimens GFRC 4/64, GFRC 4/76 and GFRC 8/76 were axial pressure reduction, respectively. GFRC specimens have also stored more compressive energy than RC specimens. The cumulative values for RC 4/64, RC 4/76, RC 8/64, and RC 8/76 have been 0.07 MJ / m3, 0.09 MJ / m3, 0.08 MJ / m3, 0.07 MJ / m3 respectively. In contrast to RC specimens, the GFRC compressive Toughness index is measurable higher. An increase of 10 Mpa compared to RC 4/76 of the axial force of specimen RC 4/64. Examine the rise in test specimens due to the decrease in the gap between the reinforced steel. Differentiate of GFRC specimen with respect to their same longitudinal and varying confinement steel rebars. 0.4 Mpa is increased in axial strength of GFRC 4/64 in relation to GFRC 4/76. The axial strength of the specimens GFRC 8/64 is higher than GFRC 8/76. Furthermore this increased axial strength effect is caused by a reduced spacing within the specimen. Relative to GFRC, the overall axial force of RC prototypes is increased. The reduction of GFRC intensity may be caused by air cavity formation. Due to increase in flexural rebars in RC-8/64 and GFRC 8/64 specimens, placing of concrete was perhaps was not proper in molds during casting. Therefore reduction in axial strength is noted.

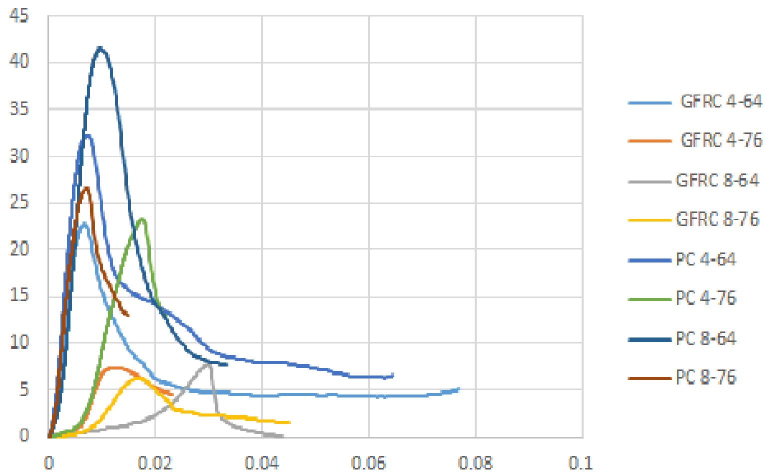


FIGURE 4.1: Compressive behaviour of prototype bridge piers.

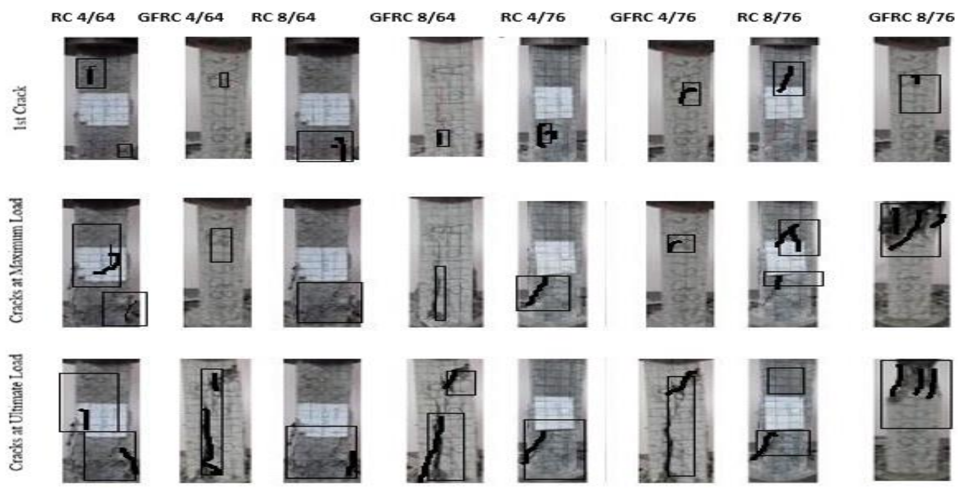
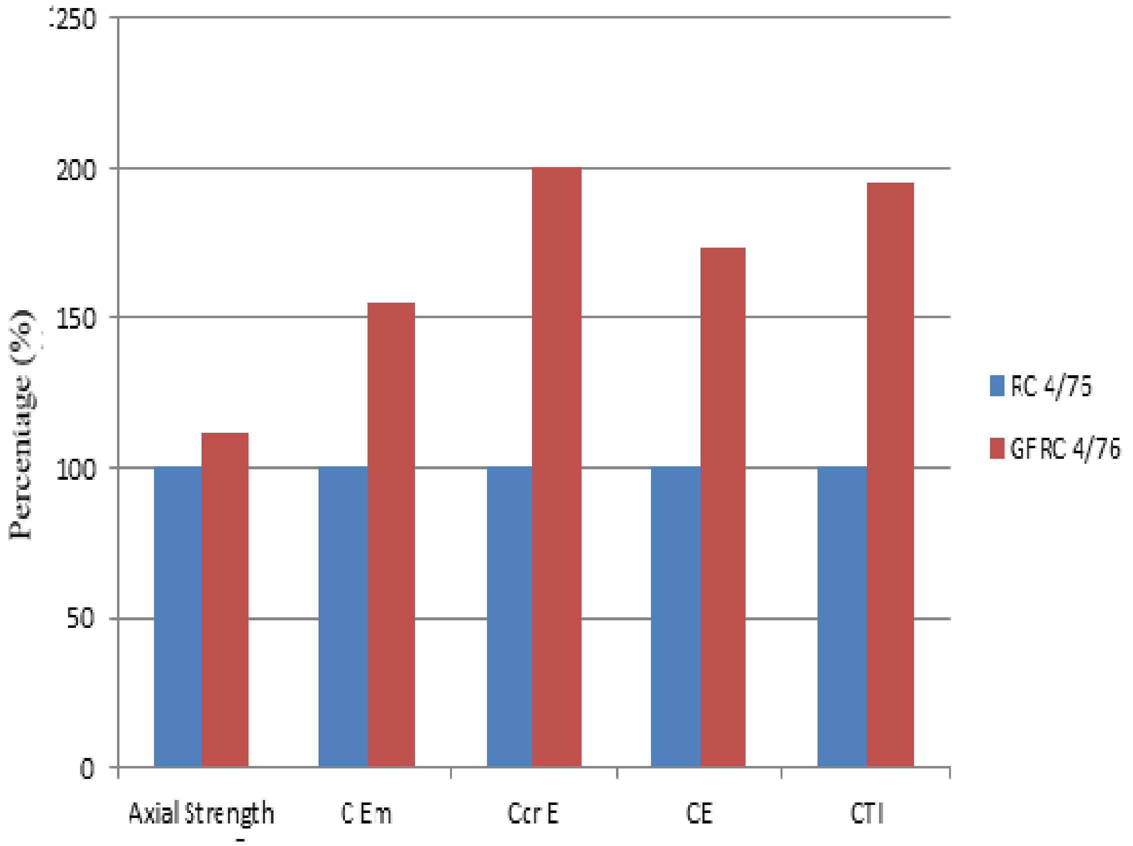
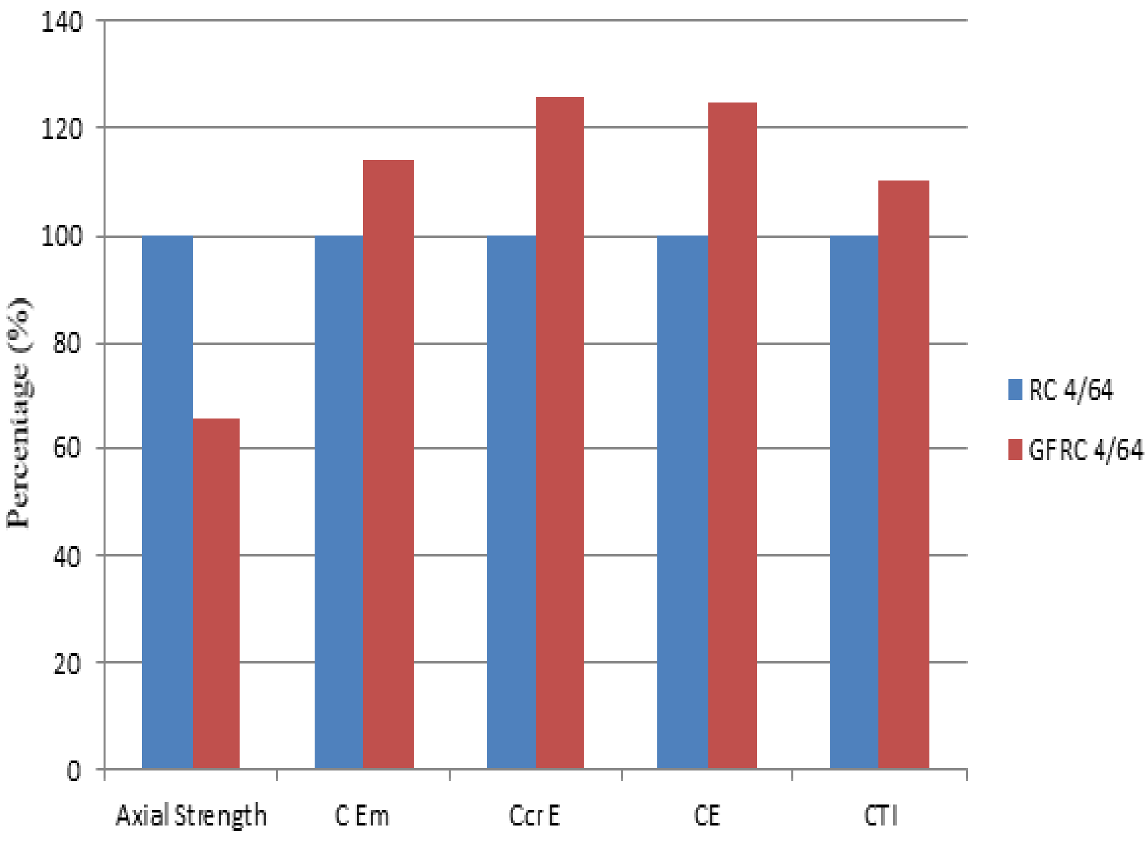


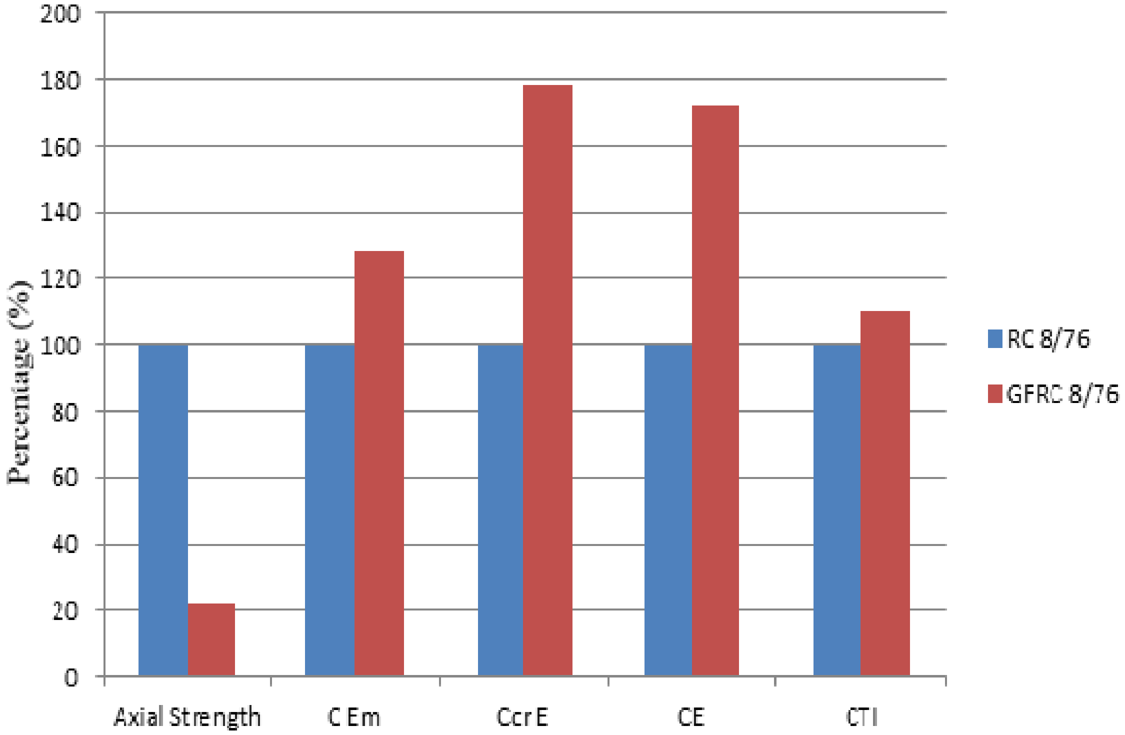
FIGURE 4.2: Cracks propagation of prototype specimens.



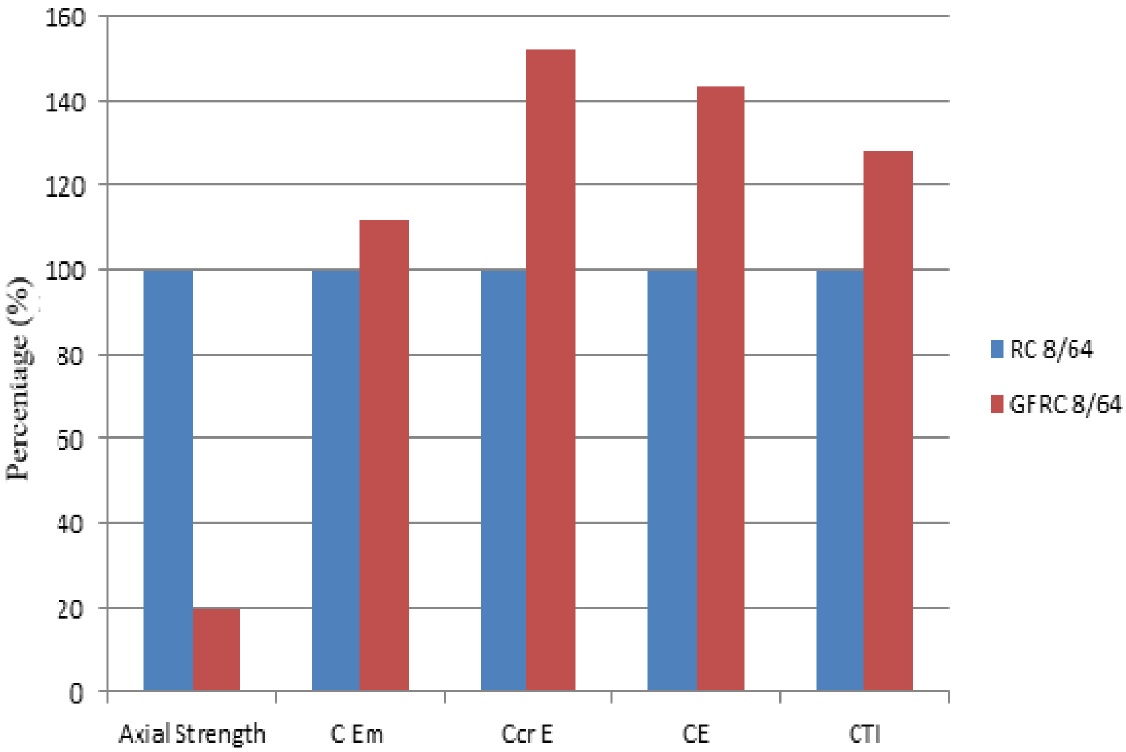
(a) RC 4/76 and GFRC 4/76



(b) RC 4/64 and GFRC 4/64



(c) RC 8/76 and GFRC 8/76



(d) RC 8/64 and GFRC 8/64

FIGURE 4.3: Comparison of prototype bridge piers.

4.3 Frequencies and Damping Ratio

Various frequencies and damping ratios of PC, GF, RC and GFRC specimens are calculated before destructive testing which is present in Table 4.2. For cylinder, an average of six readings is taken and an average of three readings is taken for the beam. In the case of a prototype bridge piers there is an average of eight readings. As a consequence of the non-availability of separate parameters for fiber enhanced concrete (FRC) in codes, a procedure for obtaining the frequency and damping ratio of RC and GFRC is the same as for PC and GF specimens. . In the case of cylinder longitudinal frequency of GF 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 piers, the longitudinal frequency of GFRC is less than RC whereas, the transverse frequency and the rotational frequency is greater than RC.

TABLE 4.2: Resonance frequencies and Damping Ratio

Type	**Specimen**	**No. of Average**	**Resonance Frequency**			**Damping Ratio**
			f$_l$ (Hz)	**f**$_t$ (Hz)	**f**$_r$ (Hz)	%
Cylinder	PC	6	3506 ± 150	3163 ± 250	2998 ± 350	4.6 ± 0.03
Cylinder	GF	6	4034 ± 120	2726 ± 225	2198 ± 450	5.2 ± 0.04
Beam	PC-F	3	4254 ± 240	3798 ± 300	3590 ± 400	3.8 ± 0.02
Slab	GF-F	3	3060 ± 200	1837 ± 400	2493 ± 500	4.9 ± 0.04
Prototype	RC	8	4388 ± 200	4319 ± 600	4390 ± 600	3.9 ± 0.04
Slab	GFRC	8	3480 ± 150	3680 ± 380	2580 ± 100	4.7 ± 0.04

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

An increase in damping due to the introduction of glass fibers is the primary objective of assessing the dynamic properties of the material. Damping will reduce the structure response and its related strength. This can also raising forces for GFRC bridge piers. Nonetheless, damping in piers with specific limits beyond the framework of this study needs to be addressed. Figure 4.4 clearly indicates that the PC cylinder, PC beam and RC prototype bridge piers damping ratio are less than the GF, GF-F and GFRC, respectively.

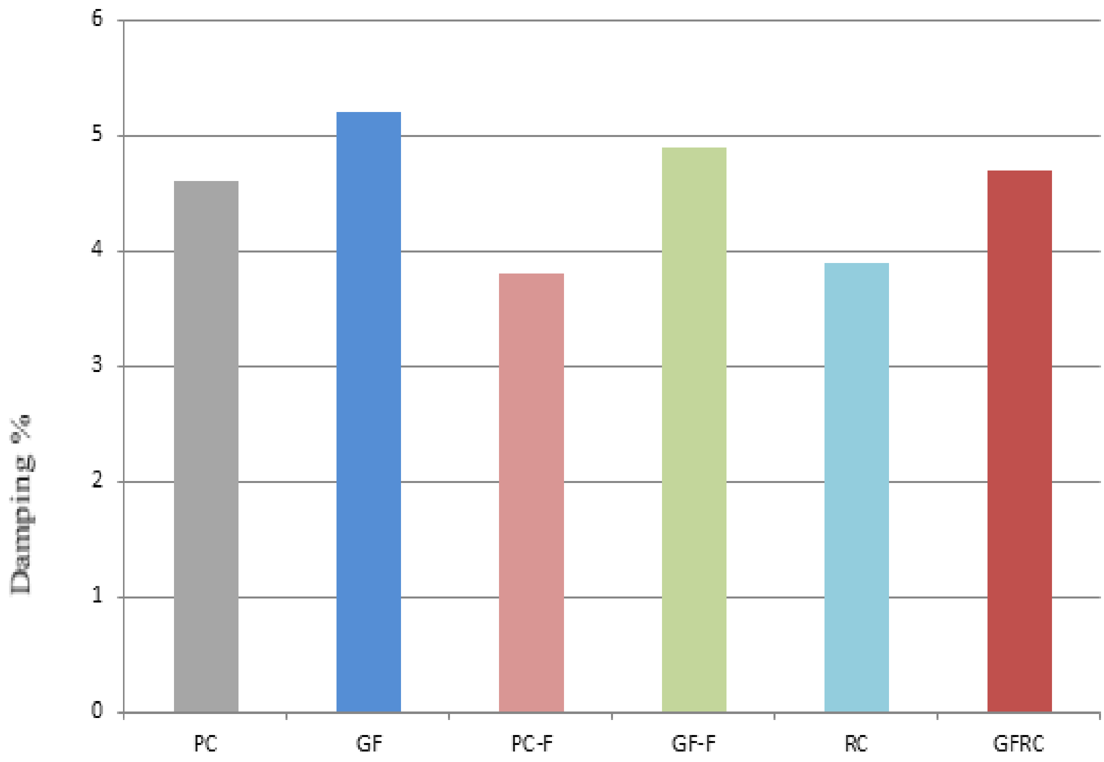


Figure 4.4: Comparison of damping ratios.

4.4 Failure Pattern of Fibers in Concrete

Fiber binding and concrete matrix is studied. Itindicates failure of JFRC surface images following mechanical checks and impact testing. The pull-out of concrete fibers is evident from these images. The close connection between the fibers and their concrete components. The proper mixing of concrete also reveals. Very small voids and voids are very small and eventually converted into small particles. The fractured concrete particles are connected by fiber to each other. This indicates the strong bridging of fibers with concrete composites. Glass fibers are not improved in relation to 1st crack concrete composites. Breaked concrete composites are tied together due to glass fibers. Also after mechanical packing, the majority of fibers can be used to remove concrete, rather than breaking into pieces. After processing, the glass fibers are 50 mm long, equivalent to the length used during GFRC planning. The voids of fiber are less serious; they imply a better mixing and bonding of the fiber with concrete components.

4.5 Summary

The mechanical characteristics, dynamic characteristics and behavior of PC and GFRC prototype piers are determined. The GF and GFRC sample damping ratio is much superior to that of the PC and RC samples. The axial load test was used to find stress strain curve of fiber behavior of selected RC and GFRC specimens. Increased mechanical properties of GFRC are observed in comparison to RC (except for pressure strength).

Chapter 5

Conclusion and Future Work

5.1 Conclusion

Within this work, the application of the bridge-pier is studied within glass fiber reinforced concrete (GFRC) with steel rebar having different shear and flexural reinforcement. The glass fiber content is 5%, is used to prepare GFRC. The GFRC specification ratio of mixture of cement, sand and aggregate is 1:1.5:3 (C: S: A) and w/c is 0.70. The findings are made.

- The enhanced properties of GFRC increase the durability of concrete which favours its utilization for the concrete application like bridge pier.
- The energy dissipation has improved up to 13%, 28%, and 20% in GF cylinder, GF-F beam, and GFRC prototype, respectively, as compared to respective PC samples.
- The compressive strength of GF samples reduced up to 23%. Due to low density of glass fibers, GFRC's strength under compression loading is decreased as compared to that of PC. Other properties namely energy maximum, cracked energy, total energy, and toughness index increased up to 28%, 216%, 134%, and 82%, respectively, w.r.t that of PC specimens..

- The splitting tensile strength, energy maximum, cracked energy, total energy absorption, and toughness index of GF specimens are increased up to 11.1%, 28.3%, 36.1%, 129%, and 89.2%, respectively, as compared to that of PC samples.
- Flexural strength, energy maximum, cracked energy, total energy, and toughness index of GF specimens are increased up to 8.3%, 5.9%, 13.3%, 158.1% and 173%, respectively, as compared to PC samples.
- The GFRC specimen also exhibited linear stress strain behavior in the growing portion of a RC specimen.
- The crack mechanism of glass fibers has resulted in better energy dissipation and toughness.
- Reduction of the shear steel reinforcement spacing from 76 to 64 mm has led to an improvement in axial load ability of the RC and GFRC specimens.

5.2 Future Work

Following are recommendations for future work:

- The durability of GFRC with real field conditions needs to be explored.
- Different admixture should be used along with fiber reinforced concrete.

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