Experimental Investigation on Properties of Concrete using Glass Fiber

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Abstract:- **Distress in building has become a common sight everywhere. Although the damage to concrete structure is unavoidable, it is necessary to repair the distressed portion and recover the original strength of the structure. Many of existing concrete structures have outlasted there useful life and it is rather dangerous to continue to use them without any strengthening, keeping in view the present day requirements. The seismic zones are also changed all over World in the current scenario and the seismic force level has been increased, which is vulnerable to the existing reinforced concrete. If any damage is caused by the insufficient load carrying capacity of the concrete structure, it is necessary to strengthen the structure to improve the load carrying capacity, instead of repairing only the defective portion.**

In this paper experimental investigations are done to know its compression and shear strength of the strengthened distress beams by wrapping with GFRP in different zones of the beams. Same type of wrapping is done in cylinders with 1 layer, 2 layers and 3 layers. The wrapped beams were analyzed and a curve has been plotted against load vs central deflection, load vs strains in compression and tension and moment vs curvature relationship. The strains at yield and ultimate load levels are also significantly reduced in strengthened beams. From the experimental results it was observed that flexural strength and stiffness of the reinforced concrete beams were increased and the efficiency of the strengthening technique by wrapping GFRP in different zones.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Worldwide, a great deal of research is currently being conducted concerning the use of fiber reinforced plastic wraps, laminates and sheets in the repair and strengthening of reinforced concrete members. Fiber-reinforced polymer (FRP) application is a very effective way to repair and strengthen structures that have become structurally weak over their life span. FRP repair systems provide an economically viable alternative traditional repair systems and materials. Experimental investigations on the flexural and shear behavior of RC beams strengthened using continuous glass fiber reinforced polymer (GFRP) sheets are carried out. The distress in building has become a common site everywhere. Although the damage to concrete structures is unavoidable, it is necessary to repair the distressed portion and recover the original strength of the structure. Many of the existing concrete structures have outlasted their useful life and it is rather dangerous to continue to use them without any strengthening, keeping in view the present day requirement. The seismic zones are also changed all over world in the current scenario and the seismic force level has been increased, which is vulnerable to the existing reinforced concrete. If any damage is caused by the insufficient load carrying capacity of the concrete structure, it is necessary to strengthen the structure to improve the load carrying capacity, instead of repairing only the defective portion. A basic understanding of the causes of concrete deficiencies is essential to meaningful evaluation of distress and application of successful repair method. If the cause of a deficiency is understood it is much more likely that an Appropriate r4pair system will be selected, and that, consequently, life of the repair will be obtained. The use of Fibre Reinforced Polymer(FRP)composites for repair, retrofitting and rehabilitation of structural elements viz., beams, columns, slabs ,etc., started about two decades ago with pioneering research performed at several research laboratories all over the world.

1.2 NEED FOR ALTERNATIVE TECHNIQUE

There is an urgent need for infrastructure rehabilitation worldwide. The strengthening of RC flexural members is one of the more challenging applications of FRP materials. Repair and retrofitting of reinforced concrete beams with GFRP became as an external reinforcements exhibited better overall structural performance. Modern developments in these fields is widespread, due to the beneficial characteristics of being non-corrosive, resistant to chemicals, high flexibility, easy to installation, negligible clearance loss, and high strength to weight ratio of FRP composites.

Strengthening techniques for RC beams are used more and more to meet the current requirements of load and to correct serious errors made in design calculations, construction faults or poor construction practices in civil engineering. A basic understanding of the causes of concrete deficiencies is essential to meaningful evaluation of distress and application of successful repair methods. One of the strengthening methods widely used these days involve the bonding of plates and laminates to the tension face of beams, using epoxy base materials. The use of fibre Reinforced polymer (FRP)composites for repair, retrofitting and rehabilitation of structural elements viz., beams, columns, slabs, etc., started about two decades ago with pioneering research performed at several research laboratories all over the world. Repair and retrofitting of reinforced concrete structures with fibre Reinforced plastic become as an external reinforcements in the recent years. Sing-Ping Chiew et al [1] conducted experiments on RC beam with GFRP as an external reinforcement and concluded that the strengthening Ratio increase linearly with increase of axial rigidity of external GFRP laminates. Sunderraja et al [2] studied the behaviour of externally bonded GFRP beams for flexural loading condition, by varying the number of GFRP layers and observed that significant increase in the flexural strength. Modern developments in these fields are widespread, due to the beneficial characteristics of being non-corrosive, resistant to chemicals, high flexibility, easy to installation, negligible clearance loss, and high strength to weight ratio of FRP composites. From their studies fibre reinforced polymer (GFRP) composite materials have found special favour with engineers and applicators because of their many advantages.

1.3 NEED FOR THE STUDY

In the present scenario, the seismic zones are changed all over the world and the seismic force level has been increased which is vulnerable to the existing building structures which needs to be strengtheing and retrofitting of existing concrete building are most important. The use of Fibre Reinforced polymer(FRP) composites for repair and retrofitting and rehabilitation of structural elements namely beams, columns, slabs, etc., starts about years ago with pioneering research performed at several research laboratories all over the world. Fibre reinforced plastic (FRP) reinforcement is playing very important in the retrofitting and rehabilitation of reinforced concrete (RC) structural elements as an external reinforcements. Recent developments in these fields is widespread, due to the easy installation and continuous to grow, lower cost, negligible clearance cost, and high strength to weight ratio of (FRP) materials. Several investigations carried out experimental and theoretical investigations on concrete beams retrofitted with GFRP to study its effectiveness. Many practical applications worldwide now confirm that the technique of bonding FRP laminates or plates t external surfaces is technically sound and practically efficient method of strengthening and upgrading reinforced concrete load bearing members that structurally inadequate damaged or deteriorated.

Of all the materials used as external plate reinforcement, glass fibre reinforced polymer (GFRP) composites materials have found special favour with engineers and applicators because of their many advantages. From technical point of view, GFRP laminate has compared with steel, a high tensile strength and comparable elastic modulus. GFRP laminates have a low specific mass that combined with significant reduction in the plate dimensions that can be achieved, enables easy handling when operating in constrained and enclosed zones.

1.4 ORGANIZATION OF REPORT

Chapter 1 discusses the information of the world thesis report.

Chapter 2 discusses about the aim, scope and objective of the present investigation.

Chapter 3 Rehabilitation and retrofitting of structural member.

Chapter 4 briefly explains about the experimental program, materials collection, mix design, casting progresses.

Chapter 5 is the discussions about the result of testing processes.

Chapter 6 Finally the summary and conclusion of the thesis is briefly concluded

CHAPTER 2
AIM, SCOPE AND LITERATURE REVIEW

2.1 AIM

To find efficiency of Glass FRP to increase the flexural strength of the beam and its effects to resist the shear failure.

To increase the strength of the failure beam based on the formation of the cracks using GFRP wrapping

2.2 SCOPE

The scope of this research was to study the feasibility of beneficial utilization of glass fibre in strengthening of RC beams.

Its effects in Seismic Strengthening of Structural elements

To compare the load and behavior of GFRP laminated beam with control one.

2.3 OBJECTIVES

To compare the load and behavior of GFRP laminated beam with control one.

To find its resistivity under compressive load in tensile and shear zone of the beam.

To analyse the type of cracks in each load with that of the control one.

2.4 LITERATURE REVIEW

A.Mukhejee,S.J.Arwikar (2006) They conducted an experimental investigations to visualize and identify the mechanism of degradation of sheet composites due to conditioning in tropical environment. The original sheet shows that there were no defects in the form of air bubbles and micro cracks which could form in the process of application of the epoxy coat. The tests also showed that sheets get damaged progressively due to conditioning. Damages in the form of voids can be seen in the micrographs. The voids are formed due to the degradation of the matrix. The fibres in the void get disintegrated with time resulting in loss of tensile strength of the sheet.

K.Balasubramianian,et.al(2007), conducted an experimental investigation to evaluate the performance of the GFRP wraps used fo retrofitting of the beams and columns and concluded that, the performance of the RC beams was found to be improved after retrofitting using RP wrapping. But the performance of both CFRP and GFRP were almost similar. In case of the shear strengthening, the RC beams provided with CFRP wrap along the entire span was found to be better among the various methods of carbon fibre wrap that were investigated. This increased shear strength is limited by the bond between concrete repair material interfaces. The strength of the repair material has limited role to play. For RC columns retrofitted with single layer or GFRP wrap, peak load maximum strains as well as ductility index were higher than the control RC columns for both the lateral tie spacing.

Sing-Ping Chiew et al (2007),conducted an experiment and conducted that by bonding GFRP laminates to the tension face of flexural RC beams, both strength and stiffness of the beams can be increased. The strengthening ratio increases linearly with the increase of the axial rigidity of the external GFRP laminates. In contrast, the variation of bond length in the shear span has little effect as long as larger than 0.56 the interfacial debonding is progressively activated with the increase of the external load from below the loading point toward the end of the laminate. The interfacial shear stress concentration due to the cut of effect is less significant than that caused by flexural cracking. Debonding failure occur when the interfacial bond in the shear span is fully utilised.

Pannirselvam N et.al (2008),Studied and presented a general regression Neural network(GRNN)basedcomputational model for predicting the yield load,Ultimate load,Yield deflection,Ultimate deflection,Deflection ductility and energy ductility of such beams.The GRNN model can provide an easy and low error alternative to the traditional regression and finite element techniques of modelling. The strength of GFRP plated beams was higher than corresponding unplanted beams. The yield strength increased by a maximum of 79.49 and 11.78% for 3mm and 5mm thick GFRP plating. The maximum deflection levels achieved by the GFRP plated beams where up to 10.71 and 34.67% higher for 3mm and 5mmthick GFRP plating, when compared to the unplanted reference beams. The ductility value for beams increased by a maximum of 38.61 and 141.63% for 3 and 5mm thick GFRP platting respectively. The general regression neural network (GRNN) model can be used for predicting the properties of GFRP plated RC beams.

K.H.Tan,K.H et al (2009) they carryout an analytical and experimental investigations on glass FRP-strengthened RC beams under the combined effect of sustained loading and tropical weathering. They concluded that FRP-strengthened RC beams under sustained loads exhibited larger deflections and crack widths when subjected to tropical weathering at the same time. They showed smaller deflections and crack width when strengthened with a higher FRP reinforcement ratio. Both the strength and ductility of beams under sustained loads decreased with the longer weathering periods. However, beams with, more FRP laminates showed less degradation in strength and ductility. The failure modes changed from concrete crushing are flexural crack induced FRP debonding to FRP rupture indicating degradation in the properties of the FRP system. The proposed analytical approach, utilizing the degraded modulus of concrete and FRP laminates, give a reasonable accurate estimate of the long-term deflection of beams subjected to sustained loading under tropical climate. The degradation in flexural strength and change in failure mode are also predicted reasonably well.

Mady M A et al (2009) A studied to full scale exterior reinforced concrete beam column joints where constructed and tested to failure under stimulated seismic load conditions.One specimen was reinforced with conventional steel bars stirrups and the other one was reinforced with GFRP bars and stirrups based on the experimental results they concluded that GFRP bars and stirrups can be used as reinforcement in the beam column joints subjected to seismic loading conditions. The GFRP bars where capable of resisting tension-compression cycles with no problems. The GFRP-reinforced joints can be designed to satisfy both strength and deformability requirements. The tested GFRP-reinforced concrete beam – column joint reached 4.0% drift capacity with insignificant damage. The drift capacity is more thanthe 2.5% and 3.5% required by the National Building Code of Canada (NBCC ,2005)and the ACI recommendations(ACI,2005),respectively.The low modules of elasticity for the GFRP reinforcement led to reducing the overall stiffness of the specimen which resulted in reaching the same drift ratios while attracting lower forces from the acting earth quake loading.

Chote Soranakom and Barzin Mobasher (2009),presented a design guide line for strain softening FRC is presented using closed from analytical equations that relate geometrical and material properties to moment and curvature capacity.Conservative reduction factors are introduced for using post crack tensile strength in design and a conversion design chart is proposed for developing FRP systems equivalent to traditional reinforced concrete the moment – curvature response for a strain softening deflection – hardening FRC can be approximated by linear model while a geometric relationship between curvature and deflection can be used for serviceability deflection checks.

Rol KIlickap,(2010)in this study glass fibre reinforced plastic composites is selected as experimental material for investigation of cutting parameters (cutting speed,feed rate and tool geometry)affecting the delaminating in drilling operation.More over the taguchi method is used to determine optimal cutting parameters fordamage- free drilling material.
A plan of experiments based on L'16 taguchi design method,is performed drilling with cutting parameters in a GFRP composite.The orthogonal array,signal-to-noise(S/N) ratio and analysis of variance (ANOVA)are employed to investigate the optimal drilling parameter of GFRP composires using four different drills.The experimental results demonstrate that the feed rate is the major parameter among the controllable factors that influence the delaminating.

M.J.Roth,M.J.et.al(2010)presented the results of a study on the mechanical behaviour of the newly developed ultra-high-strength, glass fibre reinforced concrete(UHS-GFRC)material are presented. Third point bending experimentsdirect tension experiments and finite element analysis where used to study the materials responses under various loading conditions: and an understanding of the tensile failure characteristics and their relationship to flexural response was developed. Elastic and post first crack stiffness modulii were determined as were first crack strength and recommended tensile failure function based on the influence of the randomly distributed glass reinforcing fibre. Finite element analyses using the measured tensile failure function were also used to model flexural response and comparisons are made to the third point bending experimental data.

Reda Taha,M.M et.al [2010] their objective of the experiments was to asses the significance of creep in the epoxy adhesive and whether such creep might allow the FRP strip to unload overtime. Slip movements at the ends of the FRP strips were also monitored. The work described herein indicates that assessment of the long-term effects of strengthening a beam with externally applied FRP should include to the effect of creep in the epoxy layer joining the FRP to the concrete. Both analytical models, despite being fundamentally different , showed good ability to simulate long-term effects Rc beams strengthened with FRP. Results from both models matched experimental observation with good accuracy. Further investigation is warranted into the effects of the interaction of concrete and epoxy time-dependent characteristics on RC beams strengthened with FRP.

G.B. Kim,G.B et.al [2010] studied and presented a design orientated conclusions are deduced from the experimental, analytical and parametric studies. Anchors in GFRP-reinforced GFRC behave and exhibit a pull-out mode of failure as expected form steel or FRP reinforced plain concrete. The pull-out resistance in GFRP is slightly greater in GFRC than in plain concrete. The flexural capacity and deformations of GFRP-reinforced GFRC elements can be predicted by FEA provided the tensile properties of the GFRC are determined and modelled correctly.

Khaled Galal, et al [2011] they conducted an experiment and analytical study on the tested full-scale GFRP-reinforced concrete masonry beams and auxiliary prisms. Compression tests conducted on masonry prisms conducted using conventional concrete cinder bocks demonstrated that the CSA S303.1-4 [2004a] slightly overestimate the actual compressive resistance fm of the masonry assemblage parallel to its bed joints. Cross-sectional nominal flexural capacity and stiffness of the reinforced concrete masonry beams significantly improve as the internal GFRP reinforcement ratio increased.

Wai How Soong, et.al [2011] they conducted an experimental program was designed to measure the debond load [Fd], the pullout load [FP], and the frictional load [Ff]. The maximum value of the interface bond strength for the concrete-bar specimen used in this study in 1.01 MPa. The resistance from lugs to bar pullout is comparable to the form sand particles bonded to the bar. Bearing resistance due to lugs is a function of shear strength of the bar-lug interface. Lug dimensions, pitch of the lug , and number of lugs, and is limited by the concretes compressive or shear strength. Bearing resistance due to stand particles is a function of surface roughness amplitude and is limited by the shear strength of the bond between the sand particles and the bar. Frictional resistance is a function of surface roughness and it may vary during loading due to progressive shearing of lugs or sand particles.

CHAPTER 3

REHABILITATION AND RETROFITTING OF STRUCTURAL MEMBERS

3.1 EPOXY RESINS

Epoxy is a thermosetting epoxide polymer that cures [polymerizes and cross links] when mixed with a catalyzing agent are “hardener”. Most common epoxy resins are produced from a reaction between epichlorohydrin and bisphenol-A. The first commercial attempts to prepare resins from epichlorohydrin occurred in 1927 in the United states Credit for the first synthesis of bisphenol- A based epoxy resins is shared by Dr. Pierre Castan of Switzerland and Dr. S.O.Greenlee in the United States in 1936.

Properties

In general, epoxies are known for their excellent adhesion, resistance to moisture chemical and heat resistance, good to excellent mechanical properties and very good electrical insulating properties, but almost any property can be modified. They are suitable for production of composite material in the civil engineering field. The epoxy pre-polymer is usually a viscous fluid, with viscosity depending on the polymerization degree. A reticulating agent [typically an aliphatic amine] is to be added in this mixture in the exact quantity to obtain the correct structure and properties of the cross linked resin. It can be carried out at both room and high temperatures, according to the technological requirements and the target final properties.

Application

The applications for epoxy based materials are extensive and include coating, adhesives and composite materials such as those using Carbon fibre and glass Fibre reinforcements. The chemistry of epoxies and the range of commercially available variations allows cure polymers to be produced with a very broad range of properties.

Usage and applications of epoxy:

Use of powder coatings for washers, driers.

Bonded Epoxy Powder Coatings [FBE] are extensively used for corrosion protection of steel pipes and fittings used in the oil & gas industry, potable water transmission pipelines [steel], concrete reinforcing rebar etc.

Epoxy coatings are also widely used as primers to improve the adhesion of automotive and marine paints especially on metal surfaces where corrosion [rusting] resistance is important.
Metals cans and containers are often coated with epoxy to prevent rusting especially for foods like tomatoes and are acidic.
Epoxy resins are also used for high performance & decorative flooring applications especially terrazzo flooring, and collared aggregate flooring.
Epoxy resin formulations are also important in the electronics industry and are used in many parts of electrical systems.
In electrical power generation, epoxy systems encapsulate or coat motors, generators, transformers, switchgear, bushings, and insulators.
Epoxy resins are excellent electrical insulation materials and they protect electrical components from short circuiting, dust, humidity and other environmental factors that could damage the electrical equipment.
In the electronics industry, epoxy resins are the primary resin used in overmoulding integrated circuits and transistors, and making printed circuit boards.
Epoxy resins area also used in bonding copper foil to circuit board substrates and are a major component of the solder mask used on many circuit boards.
Epoxies typically are not the outer layer of a boat because they are negatively affected by long term exposure to UV light.
In the aerospace industry , epoxy is used to stabilize a Fibre matrix. Usually, these Fibres are made of one or any of the following: glass, carbon, Kevlar, boron, etc.
Epoxy systems are also used in industrial tooling applications to produce molds, master models, laminates, castings, fixtures, and other industrial production aids.
Epoxies are also used in producing Fibre reinforced or composite parts. They are more expensive than polyester resins and vinyl ester resins, but generally produce stronger more temperature resistant composite parts.

3.2 FIBRE REINFORCED POLYMER MATERIALS

Introduction of FRP

Fibre reinforced plastics have been a significant aspect of this industry from the beginning. There are three important categories of fibre used in FRP, glass, carbon, and aramid. Glass
fibre reinforcement was tested in military applications at the end of the World War II, carbon fibre production began in the late 1950s and was used, though not widely, in British industry beginning in the early 1960s aramid fibres were being produced around this time also, appearing first under the trade name Nomex by DuPont. Today each of the fibres is used widely in industry for many applications than require plastics with specific strength or elastic qualities. Glass fibres are the most common across all industries, although carbon fibre and carbon fibre aramid composites are widely found in aerospace, automotive and sporting good applications.

Properties of FRP

Continuous Fibre- reinforced materials with polymeric matrix [FRP] can be considered as composite, heterogeneous, and anisotropic materials with a prevalent linear elastic behaviour up tp failure. They area widely used for strengthening of civil structures. There are many advantages of using FRPs: light weight, good mechanical properties, corrosion resistant etc. Composites for structural strengthening are available in several geometries from laminates used for strengthening of members with regular surface to bi-directional fabrics easily adaptable to the shape of the member to be strengthened. Composites are also suitable for applications where the aesthetic of the original structures need to be preserved or where strengthening with traditional techniques can not be effectively employed.

The manufacture of fibre fabric

Reinforcing fibre is manufactured in both two dimensional and three dimensional orientations.
Two dimensional fibre reinforced polymer are characterized by a laminated structure in which the fibres are only aligned along the plane in x-direction and y-direction of the material. This means that no fibres are aligned in the through thickness of the z - direction; this lack of alignment in the through thickness can create a disadvantage in cost and processing.
Three dimensional fibre reinforced polymer composites are materials with three dimensional structures that incorporate fibres in the x-direction, y-direction and z-direction. The development of three dimensional orientations across from industry s need to reduce fabrication costs, to increase through-thickness mechanical properties, and to improve impact damage tolerance; all were problems associated with two dimensional fibre reinforced polymers.

The manufacture of fibre pre forms

Fibre pre forms are how the fibre area manufacture before being bonded to the matrix. Fibre pre forms are often manufactured in sheets, continuous mats, or as continuous filaments for spray applications. The four major ways to manufacture the fibre pre form is through the textile processing techniques of Weaving, knitting, braiding and stitching.

Weaving can done in a conventional manner to produce two-dimensional fibres as well in multilayer weaving that can create three=dimensional fibres. However, multilayer weaving is required to have multiple layers of wrap yarns to create fibres in the z-direction creating a few disadvantage in manufacturing.

The second major way of manufacturing fibre performs is Braiding. Brading is suited to the manufacture of narrow width flat or tubular fabric and is brought as capable as weaving in the production of large volumes of wide fabric. Braiding is done over top of mandrels that vay in cross-sectional shape or dimension along their length.

Knitting fibre performs can be done with the traditional methods of Wraps and [Weft] Knitting, and the fabric produced is often regarded by many as two-dimensional fabric, but machines with two or more needle beds are capable of producing multilayer fabric with yams that traverse between the layers. This has allowed the fabric to form itself into the required three-dimensional perform shape with a minimum of material wastage. Stitching is arguably the simplest of the four main textile manufacturing techniques and one that can be performed with the smallest investment in specialized machinery. Basically the stitching process consists of inserting a needle, carrying the stitch thread, through stick of fabric layers to form a 3D structure.

Advantage and limitation

FRP allows the alignment of the glass fibres of thermoplastics to suit specific design programs. Specifying the orientation of reinforcing fibres can increase the strength and resistance to deformation of the polymer. Glass reinforced polymers are strongest and most resistive to deforming forces when the polymers fibres are parallel to the force being exerted, and are weakest when the fibres are perpendicular. Thus this ability is at once either an advantage or a limitation depending on the context of use. Weak spots of perpendicular fibres are used for natural hinges and connections, but can also lead to material failure when production processes fail to properly orient the fibres parallel to expected forces. When forces are exerted perpendicular to the orientation of fibres the strength and elasticity of the polymer is less than the matrix alone.

Failure modes

Structural failure can occur in FRP materials when:
Tensile forces stretch the matrix more than the fibres, causing the materials to shear at the interface between matrix and fibres.
Tensile forces near the end of the fibers exceed of the tolerances of the matrix separating the fibres from the matrix.
Tensile forces can also exceed the tolerances of the fibres causing the fibres themselves to fracture leading to material failure 2

Material requirements

The matrix must also meet certain requirements in order to first be suitable for the FRP process and ensure a successful reinforcement of it itself. The matrix must be able to properly saturate, and bond with the fibres with in a suitable curing period. The matrix should preferably bond chemically with the fibre reinforcement for maximum adhesion. The matrix must also completely envelope the fibres to protect them from cuts and notches that would reduce their strength, and to transfer forces to the fibres. The fibres must also be kept separate from each other so that if failure occurs it is localized as much as possible, and if failure occurs the matrix must also debond from the fibre for similar reasons. Finally the matrix should be of a plastic remains chemically and physically stable during and after reinforced and moulding process. To be suitable for reinforcement material fibre additives must increase the tensile strength and modulus of elasticity of the matrix and meet the following conditions: fibre must exceed critical content; the strength and rigidity of fibres itself must exceed the strength and rigidity of the matrix alone; and there must be optimum bonding between fibres and matrix.

3.3 Flexural strengthening

Introduction

Flexural strengthening is necessary for structural members subjected to a bending moment larger than the corresponding flexural capacity. Flexural strengthening with FRP materials may be carried out by applying one or more laminates or one or more sheets to the tension side of the member to be strengthened. Perfect bond exists between FRP and concrete, and steel and concrete. Concrete does not react in tension.

Ductility

For flexural members ductility is a measure of the member capability of evolving in the plastic range is depends on both section behavior and the actual failure modes of the overall structural member. FRP strengthened members, greater ductility is ensure when failure takes place due to crushing of concrete. Collapse due to FRP rupture leads to brittle failures. Regardless of the type of cross section, ductility is mainly controlled by the member failure mode. It can be considered totally absent if debonding starts prior to any other failure mechanism.

FRP-confined members under concentric Load

Confinement of RC member with FRP is necessary for structural members subject to concentric or slightly eccentric axial loads larger than the corresponding axial capacity. Good confinement can only be achieved by installing FRP Fibres orthogonally to the member axis. When FRP reinforcement is spirally arranged around the member perimeter, the confinement effectiveness shall be properly evaluated. The confinement action becomes significant only after cracking of the concrete and yielding of the internal steel reinforcement due to the increased latural expansion exhibited by the strengthened member. Prior to concrete craking FRP is practically unloaded.

Circular sections

GFRP confinement is particularly effective for a circular cross section subjected to both concentric or slightly eccentric axial loads. Fibres installed transversely to the longitudinal axis of the strengthened member induce a uniform pressure that opposes the radial expansion of the loaded member.

Square and rectangular sections

FRP confinement of members with Square or rectangular sections produces marginal increase of the member compressive strength. There for such application shall be carefully validated and analysed.
Prior to FRP application, the cross section edges shall be rounded to avoid stress concentration that could lead to a premature failure of the system. Yhe corner radius shall satisfy for regular cross sections, the effectively confirmed

concrete area may be considered to be only a fabrication of the overall concrete cross section.

3.4 Structural applications of FRP

Structural Engineering application

FRP has recently become somewhat of a hot topic in the field of structural engineering, surprisingly enough, due to cost –effectiveness .For example, many of the excising structures in the world were designed to tolerate for lower service loads then they are subject to today, and compared with the cost of replacing the damaged structures, reinforcing it with GFRP is quite cheap. The material has many advantages over conventional steel, mainly that it is much stiffer and corrosion resistant. There is however some hesitation among the engineering community about implementing these new materials until more real-world evaluation has been done.

FRP materials adopted for civil infrastructure that are subjected to environments typical of civil structure. The list of environmental exposure identified is as follows

Alkaline environment (FRP embedded in concrete)
Moisture
Creep effects
Material ageing
Fatigue load conditions
Freeze/ Thaw environments
Temperature (Both elevated (although below the glass transmission temperature) and reduced)
Load rate effects
Exiting corrosion
Salt (Road salt exposure and marine environment)
Damage
accumulation
Ultra violet radiation
Unique environments (Chemical exposure etc.,) and
Abrasion

The unique properties of FRP material suggest there suitably for integration in hybrid structure systems as well as the development of the hybrid systems in particular, connections, both FRP to FRP and FRP concrete represent a critical research need a hybrid material leverage the beneficial properties of different FRP materials in a single element-often such approach is used to develop “pseudo-ductility”.

Retrofitting has became the increasingly dominant use of the material in civil engineering, and applications include increasing the load capacity of old structures (such as bridges) that where designed to tolerate for lower service load then they are experiencing today, seismic retrofitting , and repair of damaged structures. Retrofitting is proper in many instances as the coast of replacing the deficient the structure can greatly exceeded its strengthening using GFRP wrapping.

FRP can be applied to strengthen the beams, columns and slab in building, It possible to increase strength of the structural members even of these has been severely damaged due to loading conditions. For strengthening beams, to technique adopted. First one is paste FRP place to bottom (generally the tension face)of abeam. This increases the strength of a beam, deflection capacity of a beam and stiffness (load required to make unit deflection). Alternatively, FRP strips can be pasted in U shape around the side and bottom of the beam, resulting higher Shear resistance.

3.5 Material used to rehabilitation and retrofitting

Fig:3.1: Glass Fiber Reinforced Polymer

- “GFRP” is abbreviation of Glass Fiber Reinforced Polymer.
- It is a fiber reinforce polymer made of a plastic matrix reinforced by fine fibers of glass.
- It is relatively a new construction material developed through extensive research and development work during the last two decades.

Glass Fibre Reinforced Polymer [GFRP] Formation

Glass fibre is formed when thin strands of silica-based or other formulation glass is extruded into many Fibres with small diameters suitable for textile processing. Glass is unlike other polymers in that, even as a Fibre, it has little crystalline structure. The properties of the structure of glass in its softened stage are very much like its properties when spun into Fibre. The technique of heating and drawing glass into fine fibres has been known to exist for thousands of years.

Chemical formation of Glass Fibres

The basis of textile grade glass Fibres is silica, SIO_2. In its pure form it exits as a polymer, $[SIO_2]_n$. It has no true melting point but soften up to 2000 degree C, where it starts to degrade. At 1713 degree c, most of the molecules can move about freely. If the glass is then cooled quickly, they will be unable to form an ordered structure. In the polymer it forms SIO_4 groups which are configured as a tetrahedron with the silicon atom at the centre, and four oxygen atoms at the corners. These atoms then form a network bonded at the corners by sharing the oxygen atoms.

A new type, E-glass was formed that is alkali free [<2%] and is an alumino-borosilicate glass. This was the first glass formulation used for continuous filament formation. E-glass still makes up most of the Fibre glass production in the world. Its particular components may differ slightly in percentage, but must fall within a specific range. The letter E is used because it was originally for electrical applications. S-glass is a high strength formulation for use when tensile sstrength is the most important property. C-glass was developed to resist attack from chemicals, mostly acids which destroy E-glass.

Properties of Glass Fibre

Glass Fibres are useful because of their high ratio of surface area to weight. However, the increased surface makes them much more susceptible to chemical attack. Glass strengths area usually tested and reported for "virgian" Fibres which have just been manufactured. The freshest, thinnest Fibres are the strongest and this is thought to be due to the fact that it is easier for thinner Fibres to bend. The more the surface is scratched, the less the resulting tenacity is. Because glass has an amorphous structure, its properties are the same along the Fibre and across the Fibre. Humidity is an important factor in the tensile strength. Moisture is easily absorbed, and can worsen microscopic cracks and surface defects, and lessen tenacity. In contrast to carbon Fibre, glass can undergo more elongation before it breaks. End uses for regular Fibre glass are mats, insulation, and reinforcement. Heat resistant fabrics, corrosion resistant fabrics and high strength fabrics.

CHAPTER 4
EXPERIMENTAL PROGRAM

4.1 MATERIALS AND METHODS.

Details of investigation

General

This chapter presents the details of the various materials used in the investigations preparation of the test specifications, repair methodology adopted and the testing procedure.

Cement

Ordinary Portland cement of 43 grade was used in the preparation of the various test specifications. The properties of the cement are shown in Table no.1

Table 4.1 properties of cement

Fineness	Consistency	Setting time		Sp.Gravity
		Initial	Final	
%	%	(minutes)	(minutes)	
5	32%	27.00	290.00	3.15

Fine aggregate

River sand passing through 2.36mm IS sieve conforming to IS 383 was used as fine aggregate.

Coarse aggregate

The coarse aggregate of maximum size 20mm confirming to IS 383 was used.

Water

Portable water for drinking purpose was used. The water-cement ratio of 0.45 was used for casting of beams and column specimens.

Concrete

Concrete mix proportion of **1.0 : 1.37 : 2.59** (cement: fine aggregate: coarse aggregate) was used for the casting of reinforced concrete beams and columns. The average cube compressive strength of concrete at 28 days moist curing is 32 MPa. The split tensile strength the cylinder failed under the compressive load of 265 kN. It gives the horizontal stress of 2.123N/mm^2, which is lies in between 1/7 to 1/10 of the compressive strength of cubes.

Reinforcement

The tensile stress, yield stress and percentage elongation of 12mm TMT bar are 720MPa,510 MPa and 25%, for compressive reinforcement of 8mm TMT bar are 560Mpa,440 Mpa and 23% respectively. All the beams were provided with 0.786%(pt)main tensile reinforcement and 0.534%(pt) as compression reinforcement. The properties of mild steel bar of dia.6mm are 260MPa, 380MPa and 25% of tensile stress, yield stress and percentage of elongation respectively.

Fibre – Reinforced Polymer Laminates

GFRP laminate is used for strengthening the control and repaired beams. Epoxy resin system used in this work was made of two parts namely resin and hardener as bonding agent for preparing FRP composites.The properties of GFRP is given in Table no.2

Table 4.2 Properties of FRP Laminates

Fibre	Weight (gm/ Sq.m)	Thick (mm)	Fibre Cont. (%)	Resin Cont.(%)	Tensile Strength (Mpa)	Flexural Strength (Mpa)	Poisson's Ratio
Glass	2934.00	2.80	59.50	40.50	355.50	423.00	0.32

Epoxy Resin for crack filling and wrapping

A two part epoxy system (Araldite- 250 and Aradur 2963), consisting of a base and a hardner was mixed in the following proportion(1 : 0.45) and injected into the cracks.

Base 100 parts by weight
Hardener 45 parts by weight

Properties of epoxy

Tensile modulus : 3.3GPa
Elongation at break : 0.04
Density at 25^0 C(ISO167) : 1.17g/cm^3
Flash Point : 200^0 C
Viscosity at 25^0 C : 11500 MPa s

4.2 SPECIMEN DETAILS

Cubes

Altogether nine cubes os size 150mm X 150mm X 150mm were casted, out of these three cubes were tested at 3days, further three cubes tested on 7 days and finally three cubes tested on 28days.

Fig:4.1: Cubes casted for testing

Cylinders

Altogether six cylinders of 150mm dia. X 300mm height were cased, out of these one cylinder is tested for Split Tensile test, One control cylinder remaining three cylinder in which one is wrapped with one layer of GFRP, second one with two layers of GFRP and the third on was wrapped with three layers of GFRP. These four cylinders are tested in compression to find its compressive strength.

Fig:4.2: Cylinders casted for testing

Beams

Totally five beams Beam size 1700mm*150mm*100mm were casted.

Fig 4.3: Beams ready for concreting

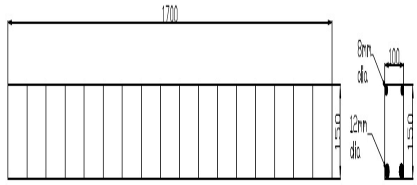

Fig 4.4: Reinforcement details of beams

Fig 4.5: Five beams casted for testing

After the curing of beams ,wrapping with GFRP is done in different zones as detailed below.

BEAM 1. Control Beam

BEAM 2. GFRP strengthened on bending zone along with 'U' type wrap near the support to resist shear as Case 1.

BEAM 3. GFRP strengthened on Bending zone of the beam for (2/3)L distance along with 'U' type wrap near the support to resist shear as Case 2.

BEAM 4 GFRP strengthened fully on tensile zone along with 'U' type wrap near the support to resist shear as Case 3.

BEAM 5 GFRP strengthened on both tensile and compressive zone along with 'U' type wrap near the support to resist shear as Case 4.

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CHAPTER 5
RESULTS AND DISCUSSION

5.1 INTRODUCTION
This chapter discuss the experimental results which are presented. Each of the testing result data plotted in tables and graphs corresponding to the mean value of the test results of concrete specimens in a series.

5.2 TESTING
Testing of hardened elements plays an important role in controlling and confirming the quality of cement concrete works. Systematic testing of raw materials, fresh concrete and hardened concrete are inseparateable part of any quality control programme for concrete, which helps to achieve higher efficiency of material used and greater assurance of the performance of the concrete with regard to both strength and durability. The test methods should be simple, direct, and convenient to apply.

- Compressive test
- Split tensile test
- Flexural test

5.2.1 Compressive Strength
Compressive Strength is the capacity of a material or structure to withstand loads tending to reduce size. It can be measured by plotting applied force against deformation in a testing machine. Some materials fracture at their compressive strength limit; others deform irreversibly, so a given amount of deformation may be considered as the limit for compressive load Compressive strength is a key value for design of structures. Measurements of compressive strength are affected by the specific test method and conditions of measurement. Compressive strengths are usually reported in relationship to a specific technical standard .

5.2.1.1 Compressive strength of cubes
Compressive strength measurements were performed on an CTM machine with a loading capacity of 3000 kN under a load control regime with a loading rate of 2.3 kN/S for cubes specimens of size 150mmx150mmx150mm as per IS standards. A minimum of three cubes were tested for each data point. The specimens were tested at 3,7 and 28 days after casting.The testing results of compressive strength of dry cured and open air cured specimens are been tabulated in Table:5.1, Table 5.2 and Table 5.3.

Compressive strength of cubes using M25 design mix concrete.

Table 5.1 Compressive strength at 3 Days
Table 5.2 Compressive strength at 7 Days
Table 5.3 Compressive strength at 28 Days

5.2.2 Compressive strength on cylinders
5.2.2.1 Compressive strength of Control cylinder


Fig:5.1:Compression Test on control Cylinder

Tensile strength is one of the basic and important properties of the concrete. The concrete is not usually expected to resist the direct tension because of its low tensile strength and brittle nature. However, the determination of tensile strength of concrete is necessary to determine the load at which the concrete members may crack. The cracking is a form of tension failure.

Table 5.4 Compression test result on control cylinder

Load	Stress (N/mm^2)	Demec Direct reading			Reading in mm	Strain
		d1	d2	Mean		
50	2.831	0.023	0.015	0.019	1.90E-05	9.50E-08
100	5.662	0.032	0.035	0.034	3.35E-05	1.68E-07
150	8.493	0.045	0.047	0.046	4.60E-05	2.30E-07
200	11.323	0.074	0.077	0.076	7.55E-05	3.78E-07
250	14.154	0.121	0.125	0.123	1.23E-04	6.15E-07
300	16.985	0.151	0.129	0.140	1.40E-04	7.00E-07
350	19.816	0.185	0.152	0.169	1.69E-04	8.43E-07
400	22.647	0.201	0.171	0.186	1.86E-04	9.30E-07
450	25.478	0.231	0.219	0.225	2.25E-04	1.13E-06
Ultimate Breaking Load					**490.55 kN**	

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5.2.2.2 Compressive strength of cylinder wrapped with GFRP (1 layer)

Fig5.2: Cylinder wrapped with GFRP (1 layer)

Table 5.5 Compression test result on cylinder wrapped with GFRP (1 layer)

Load	Stress (N/mm^2)	Direct reading			Reading in mm	Strain
		d1	d2	Mean		
100	5.6617127	0.020	0.023	0.022	2.15E-05	1.08E-07
200	11.323425	0.074	0.080	0.077	7.70E-05	3.85E-07
300	16.985138	0.091	0.150	0.121	1.21E-04	6.03E-07
400	22.646851	0.149	0.221	0.185	1.85E-04	9.25E-07
500	28.308563	0.225	0.230	0.228	2.28E-04	1.14E-06
600	33.970276	0.243	0.251	0.247	2.47E-04	1.24E-06
700	39.631989	0.310	0.341	0.326	3.26E-04	1.63E-06
800	45.293701	0.331	0.359	0.345	3.45E-04	1.73E-06
900	50.955414	0.397	0.410	0.404	4.04E-04	2.02E-06

Ultimate Breaking load 920 kN

5.2.2.3 Compressive strength of cylinder wrapped with GFRP (2 layer)

Fig5.2: Cylinder wrapped with GFRP (2 layers)

Table 5.6 Compression test result on cylinder wrapped with GFRP (2 layers)

Load	Stress (N/mm^2)	Demec Direct reading			Reading in mm	Strain
		d1	d2	Mean		
100	5.662	0.062	0.042	0.052	5.20E-05	2.60E-07
200	11.323	0.091	0.082	0.087	8.65E-05	4.33E-07
300	16.985	0.131	0.110	0.121	1.21E-04	6.03E-07
400	22.647	0.153	0.174	0.164	1.64E-04	8.18E-07
500	28.309	0.201	0.220	0.211	2.11E-04	1.05E-06
600	33.970	0.252	0.277	0.265	2.65E-04	1.32E-06
700	39.632	0.288	0.310	0.299	2.99E-04	1.50E-06
800	45.294	0.340	0.323	0.332	3.32E-04	1.66E-06
900	50.955	0.390	0.370	0.380	3.80E-04	1.90E-06
1000	56.617	0.450	0.473	0.462	4.62E-04	2.31E-06

Ultimate breaking load 1200 kN

5.2.2.4 Compressive strength of cylinder wrapped with GFRP (3 layers)

Cylinder wrapped with GFRP (3 layers)

Fig 5.2: Cylinder wrapped with GFRP (3 layers)

Table 5.7 Compression test result on cylinder wrapped with GFRP (3 layers)

Load	Stress (N/mm^2) Layer 3	Direct reading			Reading in mm	Strain
		d1	d2	Mean		
100	5.66	0.043	0.044	0.044	4.37E-05	2.18E-07
200	11.32	0.120	0.132	0.126	1.26E-04	6.30E-07
300	16.99	0.152	0.160	0.156	1.56E-04	7.80E-07
400	22.65	0.257	0.290	0.274	2.74E-04	1.37E-06
500	28.31	0.319	0.328	0.324	3.24E-04	1.62E-06
600	33.97	0.392	0.399	0.396	3.96E-04	1.98E-06
700	39.63	0.434	0.466	0.450	4.50E-04	2.25E-06
800	45.29	0.547	0.552	0.550	5.50E-04	2.75E-06
900	50.96	0.663	0.610	0.637	6.37E-04	3.18E-06
1000	56.62	0.750	0.730	0.740	7.40E-04	3.70E-06
1100	62.28	0.830	0.780	0.805	8.05E-04	4.03E-06
1200	67.94	0.870	0.882	0.876	8.76E-04	4.38E-06

Ultimate breaking load 1480 kN

Comparison of cylinders wrapped with GFRP in different forms

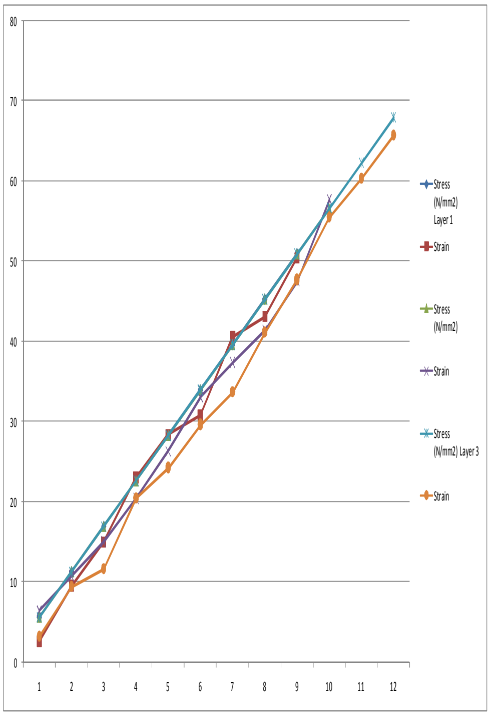

Fig 5.3: Comparison of cylinders wrapped with GFRP

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Table 5.8 **Test Results of Cylinders wrapped with GFRP**

Element	Test conducted	GFRP Wrapping	Ultimate Breaking Load	Avg. Stress value (N/mm2)	Avg. Strain value	Young's modulus (N/mm2)
cylinder	Compression test	No layer	491 kN	15.154	5.06E-06	2.99E+06
		1 layers	920 kN	28.308	9.76E-06	2.90E+06
		2 layers	1200 kN	31.139	1.18E-06	2.64E+07
		3 layers	1480 kN	36.800	2.24E-06	1.64E+07

Fig 5.4: Test Results of Cylinders wrapped with GFRP

5.2.3 Split tensile Test on Cylinder

Split tensile strength measurements were performed on an CTM machine with a
loading capacity of 3000 kN under a load control regime with a loading rate of 1.2 kN/S for cylinder specimens of size 75mmx150mm as per IS standards.
A minimum of three cylinders were tested for each data point. The specimens were tested at 28 days after casting.

Fig:5.5:Split tensile Test on Cylinder

The testing results of Split Tensile strength of dry cured and open air cured specimens are as follows.'

- Cylinder failed under the compressive load of 265 kN
- It gives the horizontal stress of 2.123N/mm^2 which is lies in between 1/7 to 1/10 of the compressive strength of cubes.

5.2.4 Flexural Strength

Flexural strength testing were performed on a universal testing machine (UTM) which is under computerized control.
The beams to be tested for flexure are of size 1700mmx110mmx150mm.
The flexural test of beams which is dry cured and ,wrapped with GFRP is done in different zones as detailed below.
BEAM 1. Control Beam
BEAM 2. GFRP strengthened on bending zone along with 'U' type wrap near the support to resist shear as Case 1.
BEAM 3. GFRP strengthened on Bending zone of the beam for (2/3)L distance along with 'U' type wrap near the support to resist shear as Case 2.
BEAM 4 GFRP strengthened fully on tensile zone along with 'U' type wrap near the support to resist shear as Case 3.

BEAM 5 GFRP strengthened on both tensile and compressive zone along with 'U' type wrap near the support to resist shear as Case 4.

The results are been tabulated and also the results are shown in graphs

5.2.4.1 BEAM 1- *Flexural Test Results of control beam*

Fig:5.6: Testing of control beam

Table 5.9 Flexural Test Results of control beam

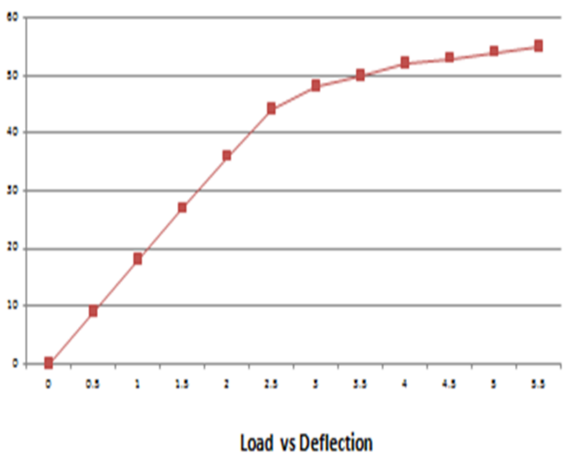


Fig:5.7: Graphical representation of control beam

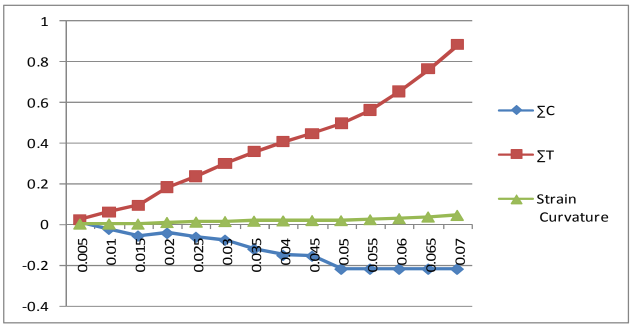


Fig:5.8: Strain deviation in comp and tension zone – control beam

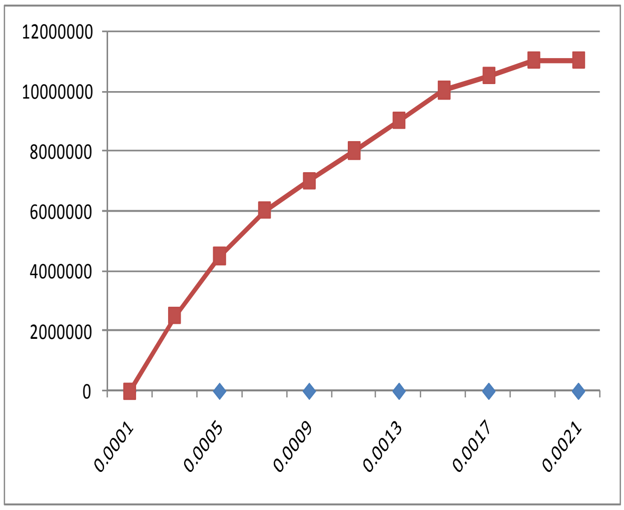


Fig: 5.9: Moment vs Deflection curvature – control beam

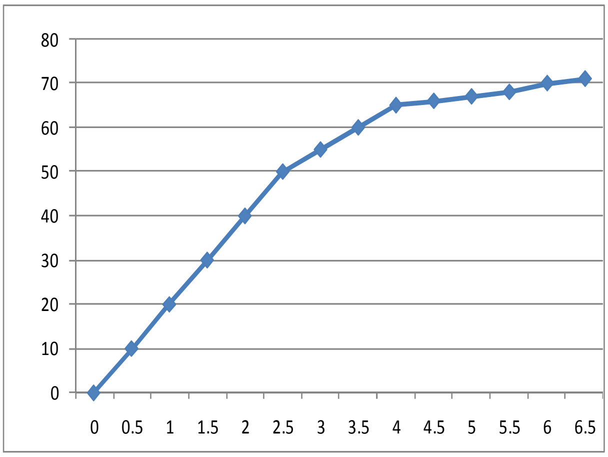
Fig:5.10: Tested of control beam

5.2.4.2 BEAM 2- Flexural Test Results of beams strengthened with GFRP on bending zone along with 'U' type wrap near the support to resist shear as Case 1.

Fig:5.11: Testing of GFRP wrapped beam(case 1)

Table 5.10 Flexural Test Results of GFRP wrapped beam (case 1)

Load	∑C	∑T	Strain Curvature	d1	d2	d3	Mean	Deflection Curvature	Moment	Stress
5	-0.014	0.009	-0.00035	31	31	21	44.00	0.005632	1250000	2.55
10	-0.013	0.053	0.0028	61	61	40	86.25	0.01104	2500000	5.10
15	-0.073	-0.05	-0.00861	86	89	60	125.50	0.016064	3750000	7.65
20	0.045	0.281	0.02282	85	89	79	130.00	0.01664	5000000	10.20
25	-0.014	0.091	0.00539	95	88	65	128.00	0.016384	6250000	12.76
30	-0.013	0.097	0.00588	80	83	71	120.75	0.015456	7500000	15.31
35	-0.011	0.073	0.00434	81	79	69	116.50	0.014912	8750000	17.86
40	-0.010	0.105	0.00665	101	94	78	138.75	0.01776	10000000	20.41
45	-0.025	0.066	0.00287	83	188	82	229.25	0.029344	11250000	22.96
50	-0.021	0.091	0.00490	103	98	97	148.00	0.018944	12500000	25.51
55	-0.013	0.024	0.00077	100	-4	72	39.00	0.004992	13750000	28.06
60	-0.020	0.114	0.00658	107	115	107	168.50	0.021568	15000000	30.61
65	-0.067	0.290	0.01561	405	375	445	587.50	0.0752	16250000	33.16



Load vs Deflection

Fig:5.12: Graphical representation of GFRP –case 1

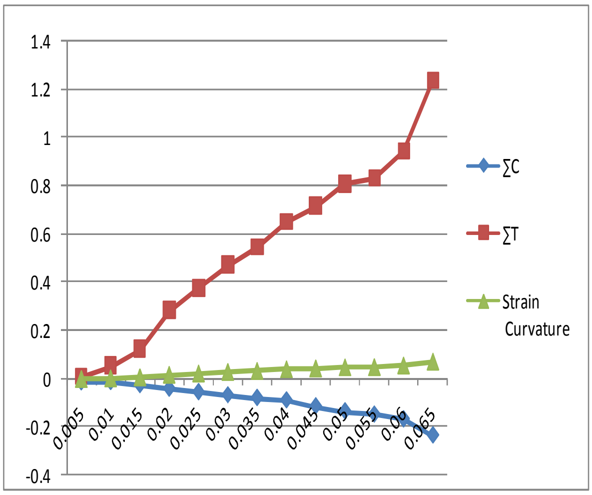


Fig:5.13: Graphical representation of Strain deviation in comp and tension of GFRP –case 1

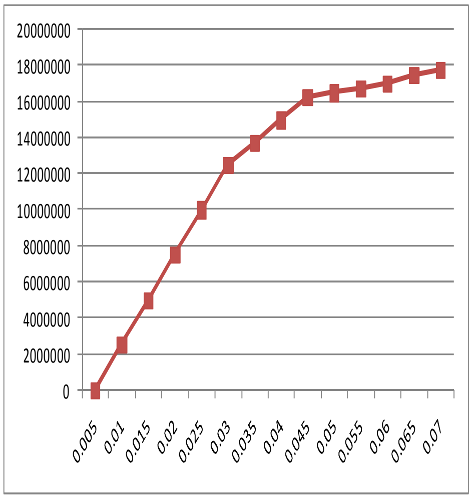
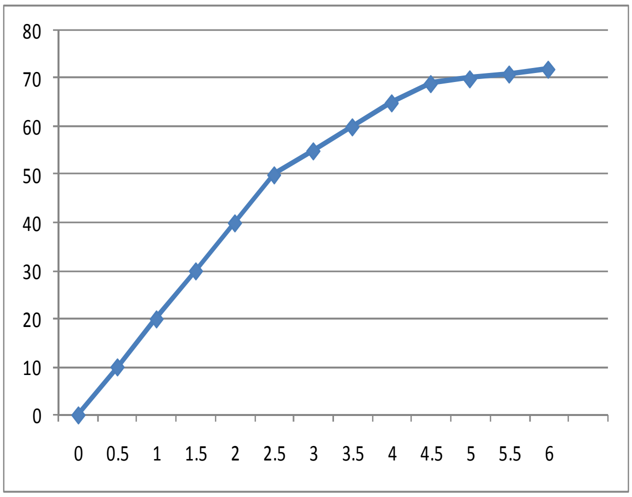


Fig:5.14: Graphical representation Moment vs Deflection curvature of GFRP –case 1

5.2.4.3 BEAM 3- Flexural Test Results of beams strengthened with GFRP on Bending zone of the beam for (2/3)L distance along with 'U' type wrap near the support to resist shear as Case 2.

Table 5.11 Flexural Test Results of GFRP wrapped beam (case 2)

Load	∑C	∑T	Strain Curvature	d1	d2	d3	Mean	Deflection Curvature	Moment	Stress
5	-0.014	0.009	-0.00035	31	31	21	44.00	0.005632	1250000	2.55
10	-0.013	0.053	0.0028	61	61	40	86.25	0.01104	2500000	5.10
15	-0.026	0.122	0.00672	147	150	100	211.75	0.027104	3750000	7.65
20	-0.041	0.284	0.01701	232	239	179	341.75	0.043744	5000000	10.20
25	-0.055	0.375	0.0224	327	327	244	469.75	0.060128	6250000	12.76
30	-0.068	0.472	0.02828	407	410	315	590.50	0.075584	7500000	15.31
35	-0.079	0.545	0.03262	488	489	384	707.00	0.090496	8750000	17.86
40	-0.089	0.650	0.03927	589	583	462	845.75	0.108256	10000000	20.41
45	-0.114	0.716	0.04214	672	771	544	1075.00	0.1376	11250000	22.96
50	-0.135	0.807	0.04704	775	869	641	1223.00	0.156544	12500000	25.51
55	-0.148	0.831	0.04781	875	865	713	1262.00	0.161536	13750000	28.06
60	-0.168	0.945	0.05439	982	980	820	1430.50	0.183104	15000000	30.61
65	-0.235	1.235	0.07	1387	1355	1265	2018.00	0.258304	16250000	33.16



Load vs Deflection

Fig:5.15: Graphical representation of GFRP wrapped beam –case 2

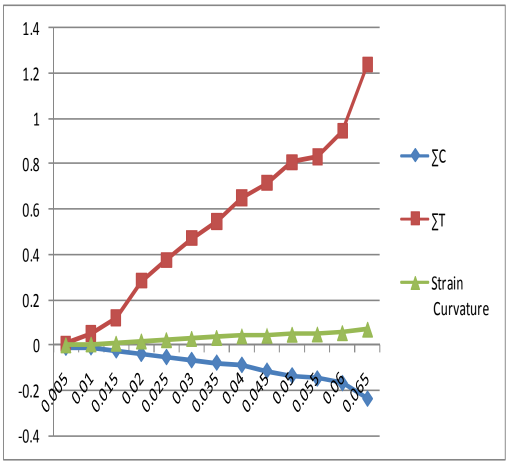


Fig:5.16: Graphical representation of Strain deviation in comp and tension of GFRP wrapped beam–case 2

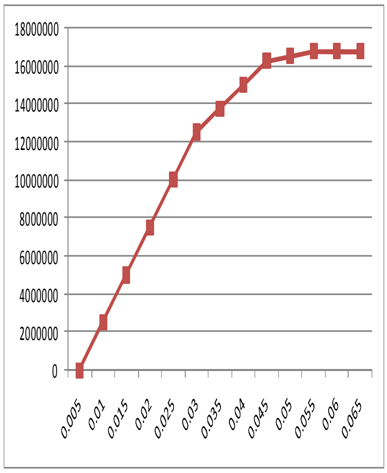


Fig:5.17: Graphical representation Moment vs Deflection curvature of GFRP wrapped beam – case 2

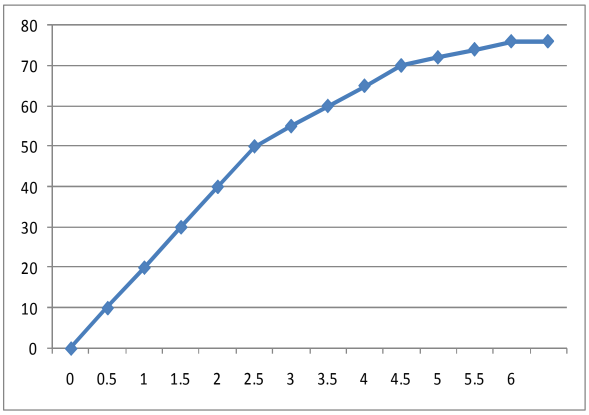
Fig:5.18: Tested GFRP strengthened beam–case 2

5.2.4.4 BEAM 4 - Flexural Test Results of beams strengthened with GFRP fully on tensile zone along with 'U' type wrap near the support to resist shear as Case 3.

Fig:5.19: Testing of GFRP wrapped beam (case 3)

Table 5.12 Flexural Test Results of GFRP wrapped beam (case 3)

Load	∑C	∑T	Strain Curvature	d1	d2	d3	Mean	Deflection Curvature	Moment	Stress
5	-0.015	0.006	-0.00063	29	128	332	218.25	0.027936	1250000	2.55
10	-0.043	0.017	-0.00182	71	129	369	239.00	0.030592	2500000	5.10
15	-0.067	0.038	-0.00203	147	159	440	305.75	0.039136	3750000	7.65
20	-0.095	0.06	-0.00245	213	231	504	410.25	0.052512	5000000	10.20
25	-0.122	0.046	-0.00532	303	324	580	544.75	0.069728	6250000	12.76
30	-0.14	0.08	-0.0042	359	387	642	637.25	0.081568	7500000	15.31
35	-0.174	0.112	-0.00434	444	479	716	769.00	0.098432	8750000	17.86
40	-0.200	0.165	-0.00245	523	566	690	869.25	0.111264	10000000	20.41
45	-0.222	0.21	-0.00084	578	629	850	986.00	0.126208	11250000	22.96
50	-0.244	0.312	0.00476	658	716	924	1111.50	0.142272	12500000	25.51
55	-0.292	0.401	0.00763	750	820	1010	1260.00	0.16128	13750000	28.06
60	-0.341	0.418	0.00539	881	969	1129	1471.50	0.188352	15000000	30.61
65	-0.343	0.541	0.01386	1068	1189	1325	1787.25	0.228768	16250000	33.16
70	-0.343	0.554	0.01477	1338	1539	1615	2277.25	0.291488	17500000	35.71
75	-0.343	0.565	0.01554	1708	2049	2035	2984.75	0.382048	18750000	38.27



Load vs Deflection

Fig:5.16: Graphical representation of GFRP wrapped beam –case 3

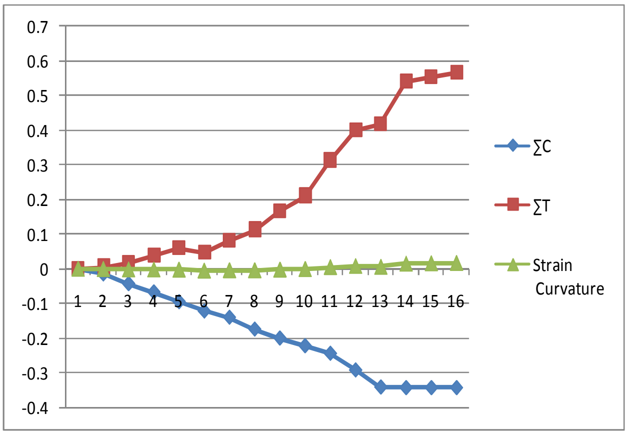


Fig:5.17: Graphical representation of Strain deviation in comp and tension of GFRP wrapped beam–case 3

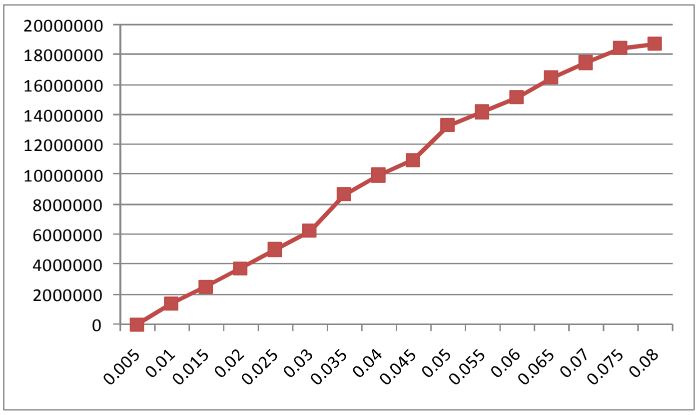


Fig:5.18: Graphical representation Moment vs Deflection curvature of GFRP wrapped beam – case 3

5.2.4.5 BEAM 5 - Flexural Test Results of beams strengthened with GFRP on both tensile and compressive zone along with 'U' type wrap near the support to resist shear as Case 4.

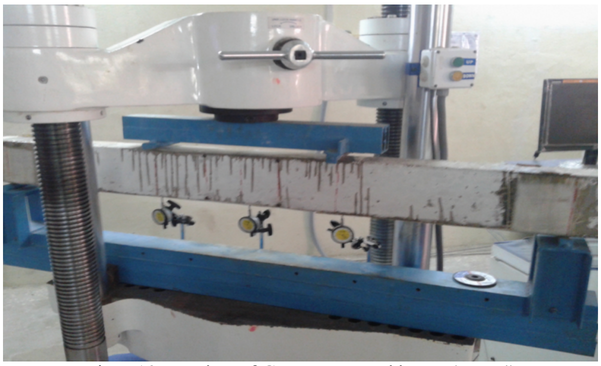
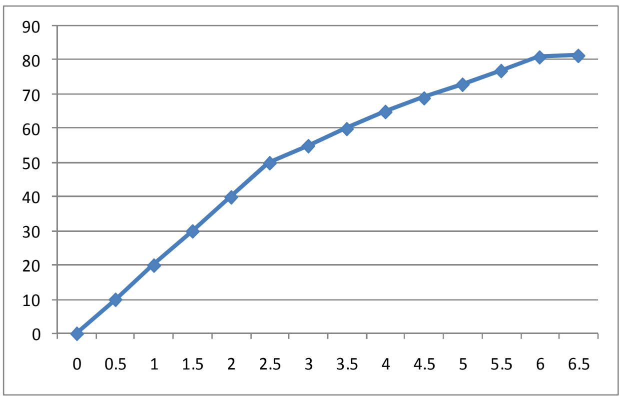


Fig:5.19: Testing of GFRP wrapped beam (case 4)

Table 5.13 Flexural Test Results of GFRP wrapped beam (case 4)

Load	∑C	∑T	∑C	∑T	Strain Curvature	d1	d2	d3	Mean	Deflection Curvature	Moment	Stress
5	-0.066	-0.113	-0.015	0.013	-0.00014	29	128	332	218.25	0.0279	1250000	2.55
10	-0.094	-0.092	-0.043	0.021	-0.00154	71	129	369	239.00	0.0306	2500000	5.10
15	-0.118	0.034	-0.067	0.023	-0.00308	147	159	440	305.75	0.0391	3750000	7.65
20	-0.146	0.078	-0.095	0.025	-0.0049	213	231	504	410.25	0.0525	5000000	10.20
25	-0.173	0.14	-0.122	0.032	-0.0063	303	324	580	544.75	0.0697	6250000	12.76
30	-0.191	0.142	-0.14	0.0421	-0.006853	359	387	642	637.25	0.0816	7500000	15.31
35	-0.225	0.235	-0.174	0.051	-0.00861	444	479	716	769.00	0.0984	8750000	17.86
40	-0.251	0.277	-0.200	0.056	-0.01008	523	566	690	869.25	0.1113	10000000	20.41
45	-0.273	0.326	-0.222	0.059	-0.01141	578	629	850	986.00	0.1262	11250000	22.96
50	-0.295	0.374	-0.244	0.061	-0.01281	658	716	924	1111.50	0.1423	12500000	25.51
55	-0.343	0.421	-0.292	0.063	-0.01603	750	820	1010	1260.00	0.1613	13750000	28.06
60	-0.392	0.462	-0.341	0.065	-0.01932	881	969	1129	1471.50	0.1884	15000000	30.61
65	-0.4	0.544	-0.349	0.07	-0.01953	1068	1189	1325	1787.25	0.2288	16250000	33.16
70	-0.45	0.682	-0.399	0.075	-0.02268	1338	1539	1615	2277.25	0.2915	17500000	35.71
75	-0.563	0.916	-0.512	0.08	-0.03024	1708	2049	2035	2984.75	0.3820	18750000	38.27
80	-0.622	1.265	-0.571	0.09	-0.03367	1708	2049	2035	2984.75	0.3820	20000000	40.82



Load vs Deflection

Fig:5.20: Graphical representation of GFRP wrapped beam –case 4

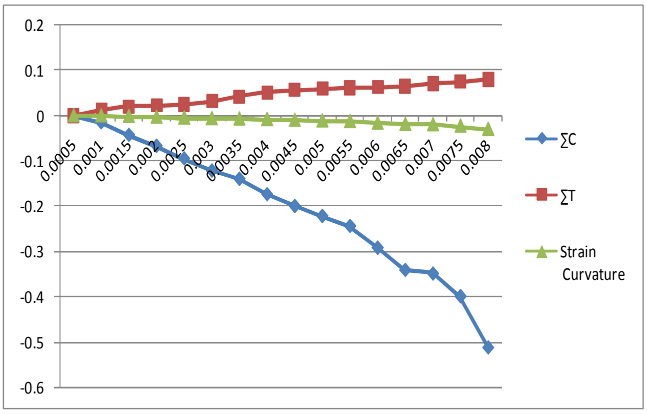


Fig:5.21 Graphical representation of Strain deviation in comp and tension of GFRP wrapped beam–case 4

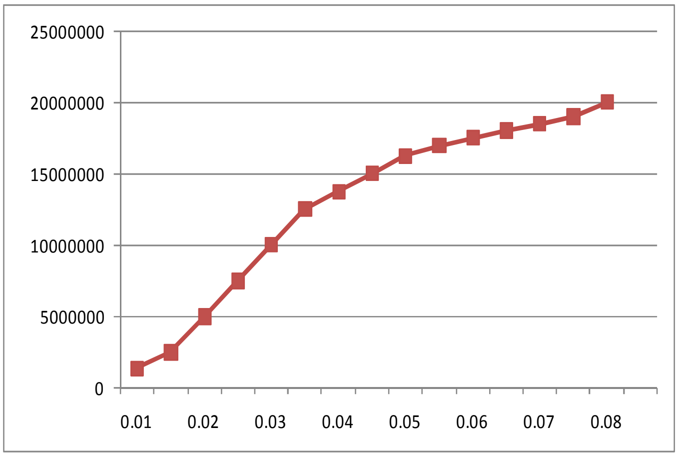


Fig:5.22: Graphical representation Moment vs Deflection curvature of GFRP wrapped beam – case 4

Fig:5.23: Testing of GFRP wrapped beam (case 4)

CHAPTER 6
CONCLUSIONSAND RECOMMENDATIONS FOR FURTHER RESEARCH

6.1 SUMMARY

In this experimental investigation the flexural and shear behaviour of reinforced concrete beams strengthened by GFRP sheets are studied. In this five beams were tested out of these one beam control one and the remaining four beams strengthened with GRFP. In this one beam with GFRP wrapped on bending zone along with 'U' type wrap near the support to resist shear as Case 1,the second one wrapping is done on bending zone at a distance of 2/3 rd of the span length along with ‘U’ type wrap near the support to resist shear as Case 2, third one strengthened fully on tensile zone along with ‘U’ type wrap near the support to resist shear as Case 3,the fourth one wrapped on GFRP strengthened on both tensile and compressive zone along with ‘U’ type wrap near the support to resist shear as Case 4.

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From the test results and calculated strength values, the following conclusions are drawn:

Table 6.1 results based on the formation of cracks

Types based on wrapping	Ultimate load in kN	inital crack load in kN	Crack propogation in mm
Control Beam	60.55	11.00	71.00
GFRP strengthened on bending zone	72.15	12.00	65.00
GFRP strengthened on Bending zone of the beam for (2/3)L distance	72.40	12.50	63.00
GFRP strengthened fully on tension zone	74.60	12.90	59.00
GFRP strengthened on both comp and tension zone	81.45	20.00	56.00

Types based on wrapping	failure pattern
Control Beam	First Flexural failure later comp failure
GFRP strengthened on bending zone	End peeling of GFRP laminates, Shear failure
GFRP strengthened on Bending zone of the beam for (2/3)L distance	Shear cum Compression failure
GFRP strengthened fully on tension zone	Shear failure
GFRP strengthened on both comp and tension zone	Shear cum Compression failure

6.2 CONCLUSION

Comparing to control beam GFRP wrapped beams are about 20% to 32% more strength and are based on the method wrapping done on different zones.

GFRP wrapping in flexural zone is more effective.

6.3 RECOMMENDATIONS FOR FURTHER RESEARCH

This thesis has dealt with the compressive and shear strength of the strengthened distress beams by wrapping with GFRP on different zones, in this same size beam was used and wrapping is done with GFRP alone and is not carried out for beams having different span-depth ratios due time constraints. Therefore future work should be undertaken for different span-depth ratios of beams such as 4.0, 5.0, 7.0 etc., and the method of loading can be done by static load which has to carry out up to the ultimate load to find the flexural behaviour. The percentage increase in strength in beams can be analysed.

The same type of wrapping can be done by different types of FRP such as Carbon Fibre Reinforced Polymer (CFRP) and Hybrid fibre reinforced polymer (combination of CFRP and GFRP).composites in damaged and undamaged condition. Test results can be analyse and curve be plot against load vs. curvature relationship. Ductility behaviours viz., deflection, ductility, energy ductility and curvature of all the beams can be presented.

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