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RESEARCH ARTICLE

RETROFITTING OF REINFORCED CONCRETE BEAMS WITH GLASS FIBER REINFORCED COMPOSITE

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ABSTRACT

This work is a study of the behaviour of concrete beams retrofitted with Glass Fibre Reinforced Composites (GFRC), using experiments and Finite element analysis. Experiments are conducted on normal Reinforced Concrete (RC) beams and GFPC retrofitted RC beams. These are tested for Ultimate loads. Further analysis were performed on normal RC beams and GFRC retrofitted RC beams using ANSYS. Comparison of the same was also conducted.

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INTRODUCTION

Reinforced concrete structures often have to face modification and improvement of their performance during their service life. The main contribution factors are change in their use, new design standards, deterioration due to corrosion in the steel caused by exposure to an aggressive environment and accident events such as earthquakes. In such circumstances there are two possible solution: replacement or retrofitting. Full structure replacement might have determinate disadvantages such as high costs for material and labour, a stronger environmental impact and inconvenience due to interruption of the function of the structure e.g., traffic problems. When it is possible it is often better to repair and upgrade the structure by retrofitting. In the last decade, the development of strong epoxy glue has led to a technique which has great potential in the field of upgrading structures. Basically the technique involves gluing steel plates or Fibre Reinforced Polymer (FRP) to the surface of the concrete. The plates then act compositely with the concrete and help to carry the loads. FRP can be convenient compared to steel for a number of reasons.

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These materials have higher Ultimate strength and lower density than steel. The installation is easier and temporary support is not required until the adhesive gains its strength, due to low weight. They can be formed on site into complicated shapes and also can be easily cut to length in site. Many options for retrofitting are possible; the ones which are used traditionally for long time now such as Addition of new shear walls, Addition of infill walls, Addition of wing walls. Addition buttresses, Jacketing of RC members, Propping up, Sleeving, Steel collars, Casing, Bonding Steel plates. However, with increase in research and introduction of new materials and technology there are new ways of retrofitting the structure with many added advantages. Introduction of fibre Reinforced Composites being one of them. It has proven to be a promising material and technology in repairs and retrofitting's.

The following are some reasons that any need retrofitting:

- Building which are designed for gravity loads only.
- Development activities in the field of Earthquake Resistant Design (EQRD) of buildings and other structures result into change in the design concepts.
- Lack of timely revisions of codes of practice and standards.

- Lack of revision of the seismic zone map of our country.
- The quality of construction actually achieved may be lower than what was originally planned.
- Lack of understanding by the designer.
- Improper planning and mass distribution on floors.

Ashour, Refaie and Garrity (2004) have presented a review on Flexural strengthening of RC continuous beams using CFRP laminates. They mentioned the use retrofitting of Carbon Fibre Reinforced Composite for enhancing the mechanical properties of RC slab on highway in China. Camata, Spacone (2007) have conducted experiments and non-linear finite element analysis of RC beams strengthened with FRP plates. They have concluded that the confinement is generally applied to members in compression, in order to enhance load bearing capacity. Esphangi, Kianoush, (2007) have studied the flexural behaviour of reinforced concrete beams strengthened by CFRP sheets. Garden, (1998) have conducted experimental studies on the influence of Plate End Anchorages of Carbon Fibre Composite Plates. They have concluded that retrofitting of RC structures with CFCPs strengthened the structural elements like columns, beams, slabs and walls. Hillerborg, Modeer and Peterson (1976) have analysed the crack formation and crack growth in concrete using tools like fracture mechanics and finite elements. They have based their results on the observations drawn from the demonstrations that have applied to the bending of an unreinforced beam with varying depth, by conducting tension tests.

Hu, Lin and Jan (2006) have based their studies on Non-linear Finite Element analysis of reinforced concrete beams strengthened by FRPs. They have concluded that the behaviour of the beams with high reinforcement ratio and strengthened with FRP at the bottom are not influenced by length of beam. Karbhari (2004) has reviewed the use of FRP in construction and has concluded that FRP retrofitting technique for strengthening the buildings will be a preferred choice for many repair and rehabilitation structures. Khalifa, Tumilian, Nanni and Belarbi (1999) have explored various techniques of shear strengthening of continuous RC beams using externally bonded CRPF Sheet. Lim (2008) have reviewed the effect of externally bonded composite plate concrete interface. The have made studies on the technique of gluing the fibre composites to the tensile region of the RC structure. Lundquist, Nordin, Taljsten and Olofsson (2005) have presented the Numerical analysis of concrete beams strengthened with CFRP and also studied about the anchorage lengths.

Neale, Ebead, Abdel, Elsayed and Godat (2005) have based their studies on modelling phenomena in FRP- strengthened concrete beams and slabs. They have based their studies on the primary functions of the matrix in a composite to transfer stress between the fibres to provide a barrier against the environment and to prevent from mechanical abrasion. Piggott (2002) has studied the load bearing fibre composites. Load bearing elements such as walls and columns can be retrofitted either by jacketing or casing.

RETROFITTING METHODS

Retrofitting Techniques: There are relatively many new technologies developed for seismic retrofitting which are used on ‘Response Control”. These techniques include providing dampers, base isolation technique take over seismic control.

Retrofitting to increase the capacity of strength of the system (Seismic Based Design):

- Concrete Jacketing
- Steel Jacketing
- FRP Wrapping.

Retrofitting to reduce the demand on the system (Seismic Response Control Design):

- Elasto - plastic Dampers
- Base isolators
- Lead- Extrusion Dampers
- Tuned liquid Dampers
- Friction Dampers.

Base Isolation: The base isolation technique is aimed to attenuate the horizontal acceleration transmitted to the superstructure. The base isolators attempt to decouple the building or structure from the horizontal components of ground motion. Isolators have low horizontal stiffness and they are placed between the structure and foundation.

Fibre Warping: Involves the wrapping of RC columns by high strength –low weight fibre wraps to provide passive confinement, which increases both strength and ductility. FRP sheets are wrapped around the columns, perpendicular to the longitudinal axis of column and are fixed to the column using epoxy resin. The wrap not only provides passive confinement and increases the compressive strength but also provides significant strength against shear. Confinement is generally applied to members in compression, in order to enhance load bearing capacity. The confinement in seismically active regions has proven to be one of the early applications of FRP materials in infrastructure applications. Confinement may be beneficial in non-seismic zones too. In any case, confinement with FRP may be provided by wrapping RC columns with pre-fabricated jackets or in-situ cured sheets, in which the principle fibre direction will be circumferential. The direction of fibres is parallel to that of high tensile stresses. Both prefabricated FRP strips as well as sheets are applied. Shear strength is usually provided by bonding the external FRP reinforcement on the sides of the webs with the principle fibre direction perpendicular or with an angle of 45º to the member axis.

FIBRE REINFORCED COMPOSITES

FRC: These are commonly used in the form of FRC viz., Pre cured CFRC, GFRC, rebar, glass fibre roll, etc. Fibre reinforced polymer (FRP) composites consist of high strength fibres embedded in a matrix of polymeric resin. Fibres typically used in FRP are glass, carbon and aramid. These are either in the form of unidirectional fibres or they are woven. These fibres are all linear elastic up to failure, with no significant failure yielding compared to steel. The primary functions of the matrix in a composite are to transfer stress between fibres to, provide a barrier against the environment and the surface from mechanical abrasion. The mechanical properties of composites are dependent on the fibre properties, matrix properties, fibre-matrix bond properties, fibre amount and fibre orientation. A composite with all fibres in one direction is designated as unidirectional. If the fibres are woven or oriented in many directions, the composite is multidirectional.

Since it is mainly the fibres that provide stiffness and strength composites are often anisotropic with higher stiffness in fibre directions.

Applications in Retrofitting: For structural applications, FRP is mainly used in two areas. The first area involves the use of FRP bars instead of steel reinforcement bars and pre stressing strands in cement concrete structures. The other application, is to strengthen structurally deficient structural members with external applications of FRP. Retrofitting with adhesive bonded FRP has been established around the world as an effective method of applicable to many types of concrete structural elements. FRP structural elements can be reinforced to concrete structures using various techniques like external bonding, warping and near surface mounting. FRP plates may be glued to tension side of a structural member to provide flexural strength or glued to web side to provide shear strength. FRP sheets can also be wrapped around the column to provide confinement and thus increase the strength and ductility. Surface mounting consists of sawing a longitudinal groove inside the concrete member, applying a bonding material in the groove and inserting an FRP bar or strip.

Design of Fibre Reinforced strengthening: The design of FRP strengthening is performed on the well-established principles of mechanics. Most major codes like ACI, CEB-FIB, Euro Code, Japanese Code, Swedish Bridge Code, Chinese Standard, Turkish Code etc., give guidelines for the design of FRP system. For design of strengthening, a composite action is assumed between fibre and existing concrete.

The design is based on the following assumptions:

- No slip between fibre and concrete.
- Shear deformation within adhesive layer is neglected.
- Tensile strength concrete is neglected.
- FRP jacket has a linear elastic stress-strain relationship up to failure.

with high strength and high stiffness is embedded in and bonded together by the low modulus of continuous polymeric matrix. Each of the individual phases must perform certain functional requirements based on their mechanical properties so that a system containing them must perform satisfactorily as a composite. In case of FRP composites the reinforcing material form the backbone of the material and they determine its strength and stiffness in the direction of fibres. The polymeric matrix is required to fulfil the following functions:

- To bind together the fibres and protect their surfaces from damage during handling.
- Fabrication and service life of the composite.
- To disperse the fibres and separate them to transfer stresses to the fibres.

The matrix should be chemically and thermally compatible with the reinforcing fibres. The interface region is small but has an important role in controlling the overall stress-strain behaviour of the composites. It exhibits a gradation of properties and it is a dominant factor in resistance of the composite to corrosive environments. It also has a decisive role in the failure mechanism and fracture toughness of the polymeric composites. Glass fibres reinforced composites provided the initial scientific and engineering understanding of FRP matrix composites. The main advantages that enabled the widespread of glass fibres in composites are competitive price, availability, good handle ability, ease of processing, high strength and other convenient properties Glass fibres are the most commonly used reinforcing fibres for polymeric matrix composites. The most common glass fibres used are S-glass and E-glass. Alakali-resisitant glass fibres contain an amount of zirconium which helps prevent corrosion by alkali attacks in cement matrices. E-glass is least expensive of all glass types and it has wide application in fibre reinforced plastic industry. S-glass has higher tensile strength and higher Young's modulus than E-glass. However, due to its higher cost it makes them less popular than E-glass. Glass fibre roving consist of up to 120 untwisted strands, usually supplied wound together on a spool and suitable for unidirectional (UD) fibre reinforcement of polymeric resins.

Table: Typical properties of various retrofitting materials

Material	Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Density (Kg/ m^3)	Modulus Of elasticity to density ratio (Mm^2/ s^2)
Carbon	2200-5600	240 - 840	1800 - 2200	130 - 380
Aramid	2400-3600	130 - 160	1400-1500	90 – 110
Glass	3400-4800	70 - 90	2200-2500	31 - 33
Epoxy	60	2.5	1100-1400	1.8 – 2.3
CFRP	1500-3700	160 - 540	1400-1700	110 - 320
Steel	280- 1900	190 - 210	7900	24 - 27

Table: Typical properties of epoxy glasses

Fibre / Characteristic	E-glass	S-glass
Density (Kg/m^3)	2500	2500
Tensile Strength (MPa)	3450	4580
Young's Modulus (GPa)	72.4	85.5
Ultimate Tensile Strain (%)	2.4	3.3
Thermal expansion coefficient (10^{-6}/ºC)	5	2.9
Poisson's ratio	0.22	0.22

GLASS FIBRE REINFORCED COMPOSITE (GFRC)

GFRC as a reinforcing material: Composites are materials consisting of two or more chemically distinct constituents on a macro-scale, having a distinct interface separating them with properties which cannot be obtained by any constituent working individually. In fibrous polymeric composites, fibres

TEST PROCEDURE

Materials

- Primary binding materials – Cement

- Fine aggregate
- Coarse aggregate
- Steel (Fe 415)
- Water
- Moulds

Binder: The primary binding material ordinary Portland cement used in the work is ULTRA TECH 53 grade, the specifications of cement are as follows:

- **Physical properties**

Table: Physical properties of cement

Particulars	Value (%)	Requirement
Lime saturation factor	0.9	0.8-1.2
Alumina Iron ratio	0.95	0.66 (minimum)
Insoluble residue	0.38	2 (maximum)
Magnesia	0.96	6 (maximum)
Sulphuric anhydride	1.81	2.5 (C_3A <=5) 3 (C_3A >5)
Loss in ignition	0.9	4 (max)

- **Chemical properties**

Table: Chemical properties of cement

Characteristic properties	Value
Fineness (m^2/Kg)	220 (minimum)
Soundness by Le Chatlier (mm)	10 (maximum)
Soundness by Autoclave (%)	0.8 (maximum)
Initial Setting Time (minimum)(minutes)	30
Final Setting Time (maximum)(minutes)	600
Compressive strength after 7 days (minimum)(MPa)	27
Compressive strength after 14 days (minimum)(MPa)	37
Compressive strength after 28 days (minimum) (MPa)	53

- **Unit weight of cement: 1.43 g/cc**

Fine aggregate: The fine aggregate used was sand and they were sieved according to the requirements. Fine aggregate so selected was passing through 450 sieve was used.

Coarse aggregate: The coarse aggregate so used were angular aggregates and they were sieved to meet the requirements. Coarse aggregate so selected was passing through 20 mm sieve.

Water: Water to be used for the experiment is mineral water which is procured from our college premises.

Mould specifications: Standard beam mould of size 75cmx15cmx15cm.

Design mix:

M20 1:1.5:3
W/C: 0.47
M25 1:1.87:3.37
W/C: 0.5

Test Procedure

The test schedule spans over 28 days for graded beams, a brief summarizations of the schedule of events is as follows:

- Beam moulds were cleaned thoroughly and oil was applied.
- Amount of materials required according to proportions were calculated.
- The materials were mixed and care was taken to maintain the water cement ratio.
- Steel rods were bent to the required shape and placed in beam moulds properly.
- The materials were mixed thoroughly in definite proportion and beam moulds beam were filled with concrete.
- Concrete was tamped using tamping rods such that beam should be free from voids.
- A total of 25 beams for M20 grade were casted.
- A total of 25 beams for M25 grade were casted.
- After the casting, the moulds were left for a day for air curing and after approximately 24 hours, they were unbolted and put in the tank for water curing.
- After 14 days of curing the beams were removed and tested.
- 5 beams of each grade were tested.
- Loads were applied at a distance of 10cm from center of the beam on either side.
- For the remaining beams 70% of the ultimate loads were applied.
- Meshing is done for the beams and are tested.
- Ultimate loads for that beams were tested.

FINITE ELEMENT ANALYSIS – ANSYS

Almost all structures exhibit a certain degree of non-linearity at various load stages. This may be due to material non-linearity or geometric non-linearity. Geometric non-linearity is associated with certain structures where large deflection may alter the configuration of the structure and affect the behaviour of the structure after loading. The effect displacement of internal forces must be considered for the analysis of such structures. However, in the dimensions of the structure and hence the present study, geometric non-linearity is neglected. Since concrete is non homogeneous material and behaves linearly over a small percentage of its strength, material non-linearity is considered. Non-linear finite element analysis is a powerful tool in determining the internal stress-strain distribution in concrete structures. With the aid of non-linear finite element analysis it is possible to study the behaviour of composite layered concrete frames up to the ultimate load range, which leads to the optimum design of concrete frames. The load deformation relationships can be used to realistically predict the behaviour of the structures. Non-linear analysis gives better knowledge of the serviceability and ultimate strength. The computational time and solution costs of non-linear analysis are very high compared to linear analysis. Hence, the method should be as efficient as possible and the numerical technique adopted should reduce the computational requirements. The finite element analysis approach is adopted considering the various material non-linarites such as stress-strain behaviour of concrete, cracking of concrete, aggregate interlock at a crack, dowel action of reinforcing steel crossing a crack.

Steps involved in the analysis:

Step1: Pre-processing

- Define the element type, real constant and material models of the concrete model.
- Create the model.

- Concrete beam was mapped mesh.

Step 2: Solution

- Apply the boundary conditions and loads.
- Solve

Step 3: Post-processing

- Deflections at various locations were obtained.
- Stress contours were plotted.

RESULTS

Types of elements

Reinforced Concrete: An eight node-element, solid65, were used to model the concrete. The solid element has eight nodes with three degrees of freedom at each node-transactions in the nodal x, y, z directions. The element is capable of plastic deformation, cracking in the three orthogonal directions and crushing. A link8 element was used to model the steel reinforcement. Two nodes are required for this element. Each node has 3 degrees of freedom, translations in the nodal x, y and z directions. The element is also capable of plastic deformation.

- **Ultimate load for M20 grade beams**

Beam no.	Ultimate Load(KN), Experimentally	Ultimate Load(KN), Analytical (ANSYS)
1	82	85
2	83	86
3	81	83
4	85	88
5	80	84
Average	82.2	85.2

- **Ultimate load for M25 grade beam**

Beam no	Ultimate Load (KN), Experimentally	Ultimate Load(KN), Analytical (ANSYS)
1	89	93
2	86	95
3	87	90
4	90	92
5	87	91
Average	87.8	92.2

Properties of reinforced concrete to be entered into ANSYS software are as follows:

Table: Properties of reinforced cement

Material property	Value
Characteristic strength of concrete at 28 days	33.095N/mm^2
Modulus of elasticity of concrete	27227.9N/mm^2
Poissons ratio	0.3
Shear coefficient for open crack	0.3
Shear coefficient of closed crack	1.0
Uniaxial crushing stress	-1.0
Uniaxial tensile cracking stress	3.585N/mm^2

Glass Fibre Reinforced Composite

Similar type of mesh is created using a link8 element was used to model GFRC to retrofit the concrete structure so formed.

- **Ultimate load after retrofitting M20 grade**

70% ultimate load (KN)	Ultimate load after retrofitting (KN) Experiment	% change in load	Ultimate load after retrofitting (KN) (ANSYS)	% change in load
57.74	92	+11.9	95	+11.5
57.74	93	+13.1	96	+12.6
57.74	91	+10.7	94	+10.3
57.74	94	+14.3	98	+15.0
57.74	92	+11.9	95	+11.2
57.74	96	+16.7	99	+16.1
57.74	90	+9.48	94	+10.3
57.74	88	+7.05	91	+6.8
57.74	87	+5.83	90	+5.63
57.74	86	+4.62	89	+4.4
57.74	95	+15.5	98	+15.0
57.74	90	+9.48	94	+10.3
57.74	89	+8.27	95	+11.5
57.74	93	+13.1	98	+15.0
57.74	92	+11.9	95	+11.5
57.74	91	+10.7	96	+12.6
57.74	96	+16.7	99	+17.4
57.74	93	+13.1	95	+11.5
57.74	92	+11.9	96	+12.6
57.74	89	+8.27	94	+10.3

- **Ultimate load after retrofitting M25 grade**

70% ultimate load (KN)	Ultimate load after retrofitting (KN) Experiment	% change in load	Ultimate load after retrofitting (KN) (ANSYS)	% change in load
61.46	95	+8.2	102	+10.6
61.46	94	+7.06	104	+12.7
61.46	97	+10.4	107	+16.0
61.46	96	+9.33	109	+18.2
61.46	92	+4.7	105	+13.9
61.46	87	0	104	+12.7
61.46	86	-2.05	102	+10.6
61.46	93	+5.92	108	+17.1
61.46	99	+12.7	104	+12.7
61.46	93	+5.92	109	+18.2
61.46	96	+9.33	107	+16.1
61.46	92	+4.22	105	+13.8
61.46	94	+7.06	103	+10.8
61.46	97	+10.7	108	+17.1
61.46	98	+11.6	109	+18.2
61.46	99	+12.7	109	+18.2
61.46	97	+10.4	105	+13.8
61.46	96	+9.33	102	+10.6
61.46	94	+7.06	106	+15
61.46	93	+5.92	104	+12.7

Conclusion

The following conclusions have been drawn from the experimental results:

- A numerical study is carried out for retrofitted reinforced concrete shear beams using the finite elements adopted by ANSYS
- The measured deflection of beams and predicted deflections using ANSYS shows fair agreement.
- The total load is to be divided into a number of suitable load steps (load increment) by conducting a few trail analysis until a smooth load deflection curves obtained.
- The accuracy of the results depends upon meshing of Finite Element Model.
- In order to get more accurate behaviour, the tension reinforcements are to be precisely incorporated using discrete modelling techniques.
- After retrofitting the load capacities of beams were improved about 10-15% by analytically and experimentally

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