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Experimental and Numerical Study of Retrofitted RC Beams Using FRP

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ABSTRACT - This paper deals with Experimental and Numerical study of retrofitted reinforced concrete beams using Fibre Reinforced Polymer (FRP). Retrofitting means modifying the existing structures to increase the resistance of the structures against seismic activity. The objective of the current study is to investigate the improvements in the structural behaviour of RC beams, while retrofitting using various types of FRP. The fibres used for the study were Glass fibres and Coir Fibres. Experimental tests were conducted on RC beams and RC beams retrofitted with various FRP such as GFRP and Coir FRP. For numerical study RC beams and RC beams retrofitted with GFRP were considered and ANSYS software was used to build a 3D model of the beams and to analyse the beam structure. The result shows that the RC beams retrofitted with Glass reinforced Polymer makes the structure more resistant to seismic activity.

Keywords - Retrofitting, Strengthening, FEA, ANSYS, FRP, RC Beam, Structures.

1. INTRODUCTION

In the field of structural engineering, new contemporary researches were carried out using advanced materials in order to structures considering strength aspect. Due to new innovations the plain cement concrete was introduced with steel members and it gives quite satisfactory results but the problem is that the aggressive steel member introduced in the plain cement concrete may get corroded if it's affected by moisture content. To overcome this, new ideas emerged and such a one kind is retrofitting. Retrofitting can be applied on old structures, and structures in seismic zone to resist their structural collapse. Retrofitting means the further modification of anything after it has been manufactured. Retrofitting can be achieved by using composite materials. By effectively doing retrofitting process, we can improve the strength of existing structures against seismic activity.

Composite materials are materials made from two or more constituent materials with significantly different physical and chemical properties that when combined produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. Technologically the most important composite are those in which the dispersed phase is in the form of fibre. The fibers are either long or short. Long and continuous fibers are easy to orient and process, where as short fibers cannot be controlled fully for proper orientation. The principal fibres in commercial use are various types of glass, carbon, graphite and Kevlar. All these fibers are incorporated in matrix form either in continuous length or in discontinuous length. The polymer is most often epoxy, but other polymers, such as polyester, vinyl ester or nylon, are sometimes used. The properties of FRP depend on the layouts of the fiber, the proportion of the fibers relative to the polymer and the processing method.

Experimental study involves the determination of flexural load or ultimate load by subjecting the beams under loading condition. Three points loading is carried out. From the ultimate load obtained and providing suitable factor of safety the permissible load is calculated. The permissible load is then taken for numerical study. Numerical study can be achieved by using FEM (Finite Element Modelling) with the aid of ANSYS software. In Finite Element Modelling first the meshing process is carried out i.e. the structure is divided into finite number of elements, each element is considered for the analysis. Then the boundary conditions are applied. Boundary conditions are selected from the load and support. The load can be applied either as force, torque, weight etc and the support can be given as simply supported or as fixed. Here weight is applied as load and support is assumed to be fixed. The permissible load from the numerical study is applied as load and stresses are calculated.

2. MATERIALS

Ordinary Portland cement of grade 53 satisfying the requirements of IS12269-1987 was used for the investigation. The initial setting time was 30 minutes with a specific gravity of 3.1. The clear river sand passing through 4.75 mm sieve is used as fine aggregate. The coarse aggregate was machine crushed broken stone with angular shape. The maximum size of aggregate was 20mm. Ordinary clear potable water free from suspended particle and chemical substances was used for mixing and curing of concrete. Design concrete mix of 1:1.87:2.79 by weight is used. The water cement ratio of 0.5 is used. 3 cubic specimens were casted and tested to determine compressive strength. Mild steel bars of 8mm diameter ,Glass fibre fabric and coir fibre sheets were used.

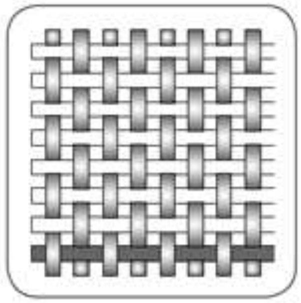


Figure 1: $0/90^0$ PW Style

Figure 2: Glass fibre sheet

Figure 3: Coir sheet

3. PREPARATION OF COMPOSITE

Materials used for the preparation of composite were Plain weave (PW) glass fibre fabric, Epoxy resin and hardener. Fibre fabric are sheet of layers of fibre made by mechanical interlocking of fibre themselves or with a secondary material to bind these fibers together and hold them in place, giving the assembly sufficient integrity to be handled. Fabric types are categorized by the orientation of the fibres: Unidirectional, 0/90°, Multiaxial, and Other/random. The orientation and weave style of the fibre fabric is chosen to optimize the strength and stiffness properties of the resulting material. Most commonly used weave style of $0/90^0$ fabric is plain weave (PW) which gives much strength.

4. CASTING

The design mix ratio was adopted for designing the beams. 9 under reinforced beams were casted, 3 as control specimens and 6 beams for retrofitting. The dimensions of all the beams are identical. The length of the beams was 500 mm and cross sectional dimensions were 100x100mm. Mild steel bars of 8 mm diameter were used for longitudinal reinforcement.

5. RETROFITTING OF BEAMS

Hand layup method was used for retrofitting of beams. The surface of the beam after curing was made rough and then cleaned with water to remove all dirt's for the proper bonding with fibre. Then the beam was allowed to dry for 24 hours. The fibre sheets were cut according to the size. After that the epoxy resin primers was mixed in a plastic container to produce a uniform mix. Then it was coated on the surface of beam for the effective bonding of fibre sheets with the concrete surface. Then fibre sheets were placed on the top of epoxy resin and another coating of resin was applied on the top of fibre sheets. This operation carried out at room temperature and is allowed to set under sunlight for 6 Hrs.

5.1. RETROFITTING BY GLASS FIBRE REINFORCED EPOXY

Initially the required PW glass fibre fabric is cut from the fabric sheet to make a U – wrap around the lateral faces of the RC beam. (500 X 300) fibre fabrics of three numbers are chooses for retrofitting a specimen. Epoxy resin is mixed with hardener and the solution is applied on the selected surface of the RC beam by Brushes. Glass fibre (fabric) is placed over the reinforced concrete beam (specimen) making a U- wrap. By brushes again the solution is impregnated on the fabric .The process repeats by layering fabric one by one. Finally three layered retrofitted RC beam is left to cure under standard atmospheric conditions. Three such specimens are prepared for the test

Figure 4: RC Beam Retrofitted with Glass Fibre sheet

5.2. RETROFITTING BY COIR FIBRE REINFORCED EPOXY

Initially the required coir fibre is cut from the fabric sheet to make retroffiting on one side of the RC beam. (500x100) one fibre fabric is chooses for retrofitting a specimen. Epoxy resin is mixed with hardener and a solution is applied on the surface of the RC beams by brushes. One coating of epoxy is done and then the coir fibre is placed on the surface of the beams. Finally one layered retrofitted RC beam is left to cure under standard atmospheric conditions. Three such specimens are prepared for the test.

Figure 5: RC Beam Retrofitted with Coir Fibre sheet

6. EXPERIMENTAL STUDY

All the specimens are tested in the Universal Testing Machine. The test procedures of all the specimens are same. After the curing period of 28 days is over control beams are washed and its surface is cleaned for clear visibility of cracks where other sets of beams are strengthened by GFRP. The load arrangements for testing of all sets of beam is consist of central point loading as shown in figure.

Figure 6: Test on RC beam

Fig. 7: Test on RC beam Retrofitted with GFRP

Figure 8: Test on RC beam Retrofitted with coir FRP

From the experimental work the rupture load is obtained. From that ultimate bending stress can be find out by using the following equation.

$\sigma_b = 3PL/2bt^2$

where, P is the rupture load,
L is the gauge length,
b is the width of the beam, and
t is the thickness of the beam.

7. DENSITY MEASUREMENT

Mass of GFRP sheet of (40X40X1) mm^3 was found out. The density was found out by the relation

Density = $\frac{\text{Mass}}{\text{Volume}}$

Observed reading: Mass = 3.46 gm

8. MATERIAL MODEL

The following assumptions have been made for modeling

1. Material is assumed to behave as linear elastic.
2. Heat generation and thermal stresses are ignored.
3. Material is isotropic and homogeneous in nature.

The Young's modulus and poisson's ratio of the E-Glass fibre composite was found out by laminar theory.

$E = E_f V_f + E_m (1-V_f)$ [Mixtures Equation]

$\gamma = \gamma_f V_f + \gamma_m (1-V_f)$

Where, E = Young's modulus of the composite shaft
E_f = Young's modulus of the Fibre.

E_m = Young's modulus of Mixture (Epoxy).
V_f = Volume of Fibres.
The composition of the composite is 60% fibre by volume. i.e, $V_f = 0.60$

Table 1

PROPERTIES	E – Glass Fibre	Epoxy
Density, ρ (kg/m^3)	2540	1360
Youngs Modulus, E (GPa)	72.5	3.792
Poissons ratio, γ	0.21	0.4
Ultimate tensile strength, σ_u (MPa)	2450	82.75

The materials used for finite element analysis and their properties are tabulated in table 2:
Table 2

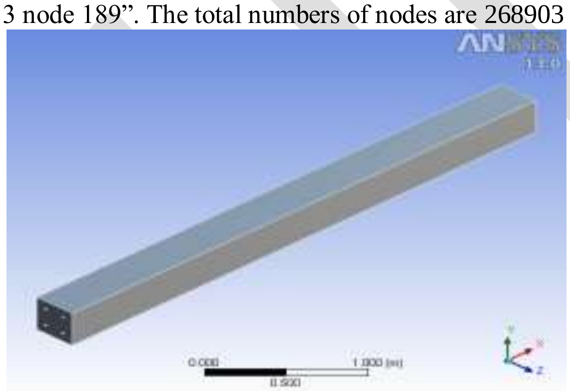
PROPERTIES	STRUCTURAL STEEL	CONCRETE	GFRP
Density (kg/m^3)	7850	2300	2162.5
Youngs Modulus (Gpa)	200	30	45
Poissons ratio	0.3	0.18	0.28
Ultimate tensile strength (Mpa)	460	5	1080

9. THREE DIMENSIONAL MODELLING OF FULL SCALE BEAM

A 3D model of the specimen was generated using ANSYS 13. RC beam of cross-section (300X300) mm^2 and span of 4000mm, reinforced with 4 structural steel rod of diameter 16mm each was modelled. The RC beam and the RC beam retrofitted with U wrap GFRP of 2mm thickness was considered for the study.

10. MESH GENERATION

After 3D Modelling, meshing of the model is necessary for the analysis. Mesh generation is done by selecting the element type "Beam 3 node 189". The total numbers of nodes are 268903 and the total numbers of elements are 98471.



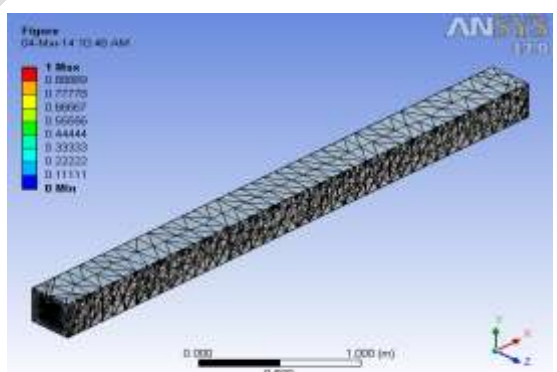


Figure 9: 3D Model

Figure 10: Mesh generation

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11. BOUNDARY CONDITION

Boundary condition is a very important step for the analysis of the structures in FEM. Here the load applied is in the form of uniformly distributed load with a total magnitude of 5,000N and the beam is supported by fixed support at its ends.

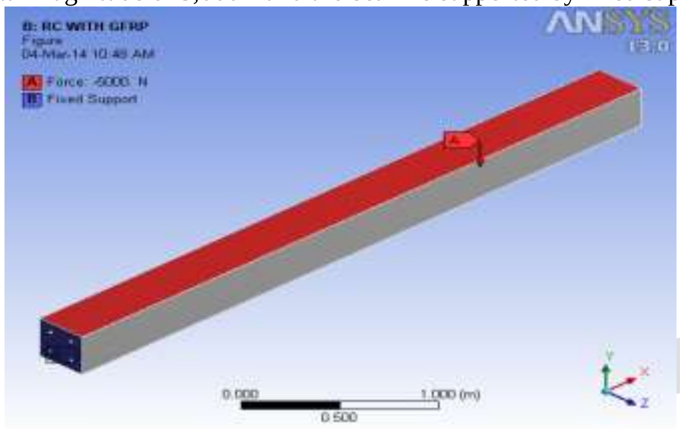

Figure 11: Boundary conditions

12. EXPERIMENTAL RESULT

Table 3

MATERIAL	ULTIMATE LOAD (KN)	ULTIMATE BENDING STRESS (MPa)
RC Beam without FRP	17	10.2
RC Beam with Coir FRP	24.66	14.8
RC Beam with GFRP	34.08	20.45

13. FEM RESULT OF FULL SCALE BEAM

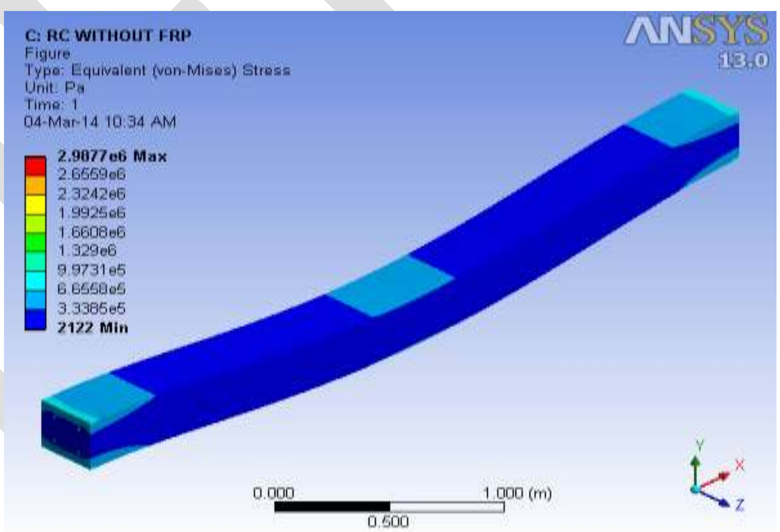

Figure 12: Equivalent stress of RC without FRP

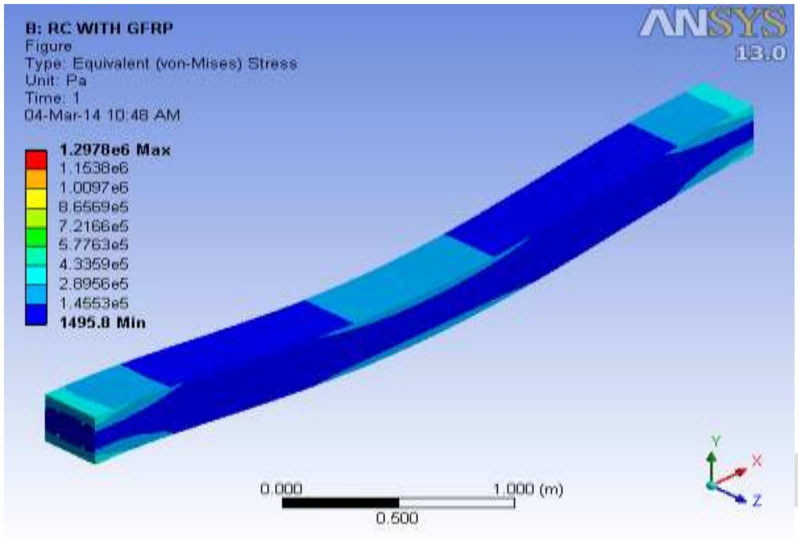

Figure 13: Equivalent stress of RC with GFRP

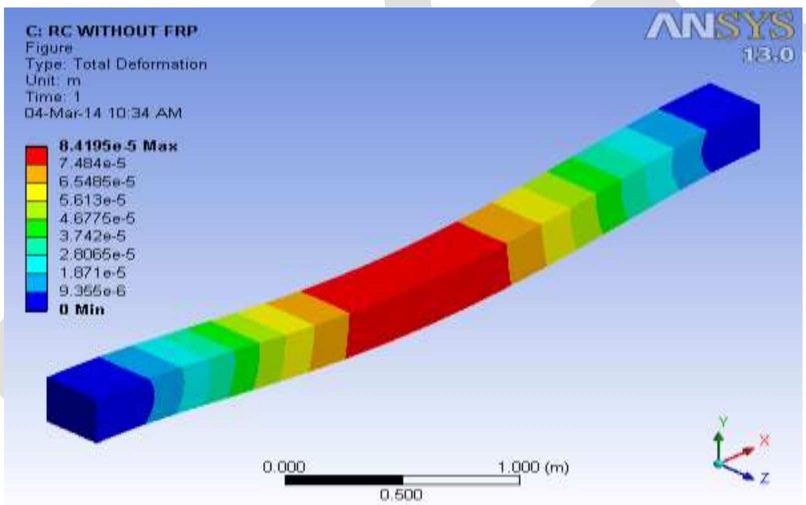

Figure 14: Total deformation of RC without FRP

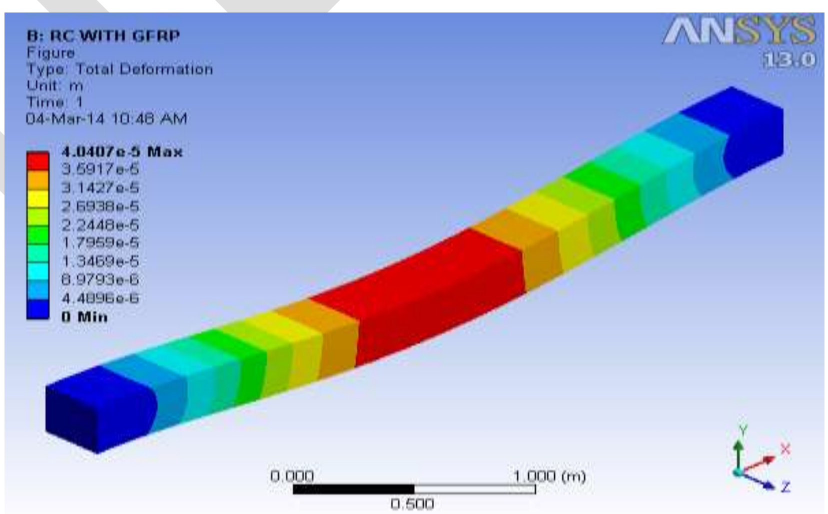

Figure 15: Total deformation of RC with GFRP

Table 4

FEM Result	Induced Equivalent stress (Von-Mises) (MPa)	Total Deformation(m)
RC beam without retrofitting	2.9877	8.4195×10^{-5}
RC beams retrofitted by GFRP	1.2978	4.0407×10^{-5}

5. CONCLUSION

From the results the following conclusions are obtained

- The flexural strength and ultimate load capacity of the beams can be improved by retrofitting.
- Retrofitting using E-Glass Fibre sheet gives more load carrying capacity than Coir sheets.
- Also GFRP sheets is economical since its cost is very less compared to carbon fibre sheets and the cost for GFRP sheet (E-Glass) is only Rs.75/m^2.

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