An Analytical, Numerical and Experimental Investigation of Glass Fibre Sheet Wrapped Reinforced Concrete Beams

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Abstract - *In construction field maintenance, rehabilitation and strengthening of structural members are the major issue. The wrapping of RC beams with Glass Fibre Reinforced Polymer sheet increases the strength. A finite element reinforced concrete model has been analysed by using ANSYS finite element program for both unstrengthen and RC beams. In analytical investigation six beams were analysed using theoretical formulae. In experimental investigation six beams were casted and analysed under two point loading system in a loading frame. The retrofitting is attained with the adhesion of GFRP sheet to the total volume of the beams. In this thesis totally six beams of size 150 x 200mm2 with a span of 1200mm are modelled on the basis of three parameter such as under reinforced, balanced and over reinforced beams. The ultimate failure load, deflection, crack pattern, percentage of increase in strength of GFRP strengthened RC beams are compared with those of their counterpart specimen of control group to evaluate the effectiveness of strengthening. From the numerical analytical and experimental investigation it is concluded that the ultimate load carrying capacity of RC beam wrapped with GFRP sheet is higher when compared to the unwrapped beams.*

*Key Words***:** GFRP sheet-Glass fibre reinforced polymer sheet, URB-Under Reinforced Section, WURS -Wrapped under Reinforced Section, BRS-Balanced Reinforced Section, WBRS- Wrapped Balanced Reinforced Section, ORS-Over Reinforced Section, WORS-Wrapped over Reinforced Section

1. INTRODUCTION

FRP can be applied to strengthen the beams, columns, and slabs of buildings and bridges. It is possible to increase the strength of structural members even after they have been severely damaged due to loading conditions. In the case of damaged reinforced concrete members, this would first require the repair of the member by removing loose debris and filling in cavities and cracks with mortar or epoxy resin. Once the member is repaired, strengthening can be achieved through wet, hand lay-up of impregnating the fibre sheets with epoxy resin then applying them to the cleaned and prepared surfaces of the member. Two techniques are typically adopted for the strengthening of beams, relating to the strength enhancement it may be flexural strengthening .In many cases it may be necessary to provide both strength enhancements. Principal tensile fibres are oriented in the beam longitudinal axis, similar to its internal flexural steel reinforcement.

In order to avoid the problems created by the corrosion of steel reinforcement in concrete structures, research has demonstrated that one could replace the steel reinforcement by fibre reinforced polymer (FRP) reinforcement. Corrosion of the steel reinforcement in reinforced concrete (RC) structures affects the strength of both the steel and the concrete. The strength of a corroding steel reinforcing bar is reduced because of a reduction in the cross-sectional area of the steel bar.

1.1 Objective

   1. To study the behaviour of reinforced concrete beam.

   2. To study the effect of GFRP sheet in improving the strength of the reinforced concrete beam.

   3. To study the effect of RC beam and GFRP sheet wrapped RC beams on deflection, crack pattern.

   4. To analyse the percentage of increase in load carrying capacity of GFRP wrapped RC beams under two pint loading system.

2. GLASS FIBRE REINFORCED POLYMER SHEET

Glass fibres are also available as thin sheets, called mats. A mat may be made of both long continuous and short fibres. To enhance the bond between fibres and matrix, as well as to protect the fibres itself against alkaline agents and moisture, fibres undergo sizing treatments acting as coupling agents. Such treatments are useful to enhance durability performance of the composite material. Glass fibres are the fibres commonly used in the naval and industrial fields to produce composites of medium-high performance. It possesses high strength. Glass is mainly made of silicon (SiO_2) with a tetrahedral structure (SiO_4).
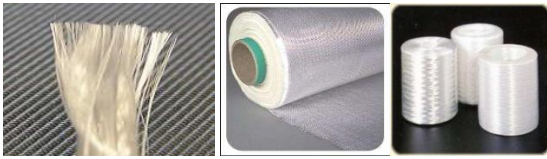
FRP composites based on fiberglass are usually denoted as GFRP. The glass fibres available in the form of sheets called glass fibre reinforced polymer (GFRP) sheet. The fibres and matrix combine to form a GFRP sheet.

2.1 Applications

GFRP can be used for both interior and exterior fissures in a variety of shapes, styles and textures in new building or in retrofitting projects and also in domes, foundation, columns, balustrade, planters, panels, sculpture, entryways, modelling, facades, cornice, porticos, cupolas, signs, roofs.

I. NUMERICAL INVESTIGATION:

3. FINITE ELEMENT METHOD

The finite element analysis (FEA) is a numerical method for solving various problems in engineering field. The RC beams reinforced concrete beams reinforced concrete beams are analysed by using finite element model in ANSYS.

✓ **Element Properties**

SOLID 65 is used for the 3-D modelling of solids with or without reinforcing bars. The element is defined by eight nodes and having three degree of freedom at each node. The solid is capable of cracking in tension and crushing in compression. In concrete applications the solid capability of element may be used to model the concrete whereas rebar is used for modelling of reinforcement. This element is also applicable for composite material like glass fibre.

✓ **Reinforcement**

Beam 188 elements are used for modelling reinforcement bars. This type is a quadratic beam element and created in three dimensions. This element is also applicable for the linear analysis, nonlinear analysis and also for element having large rotation. These includes translation in the x, y and z directions and The bonding between the reinforcement and concrete and also the concrete, reinforcement, glass fibre sheet is obtained by using merge command.

✓ **Laminates**

To model the laminated composites like glass fibre reinforced polymer composites SOLID 186 element is used. It is created as laminate over the reinforced concrete beam

for a thickness of about 1.5mm. The bonding between epoxy and RC beam is obtained by using epoxy resin.

3.1 FEM Input Data

For concrete, ANSYS requires input data for material properties as follows:

- Elastic modulus (E_c).
- Ultimate uniaxial compressive strength (f'_c).
- Ultimate uniaxial tensile strength (modulus of rupture, f_r).
- Poisson's ratio (ν).
- Shear transfer coefficient (β_t).
- Compressive uniaxial stress-strain relationship for concrete.

3.2 Reinforcement Details

Table 3.2: *REINFORCEMENT DETAILS*

TYPE OF BEAM	BOTTOM BARS	TOP BARS
Under reinforced section	2 # 10mm	2 # 8mm
Balanced section	2 # 12mm	2 # 8mm
Over reinforced section	2# 16mm	2 # 8mm

4. ANSYS MODEL

- The six beams are modelled using a finite element program called **ANSYS**.
- The crack pattern, ultimate load deflection and the percentage of increase in load carrying capacity of the beams are determined.
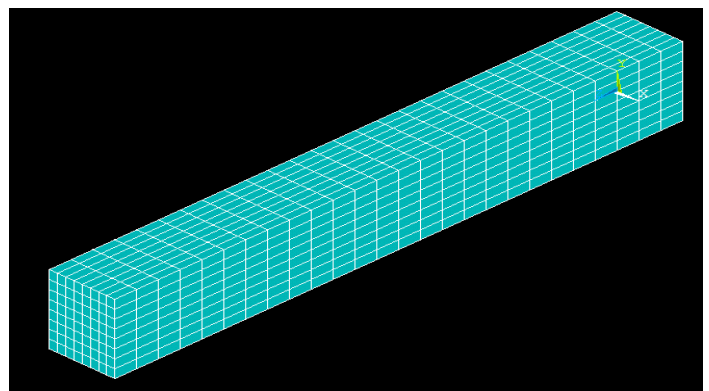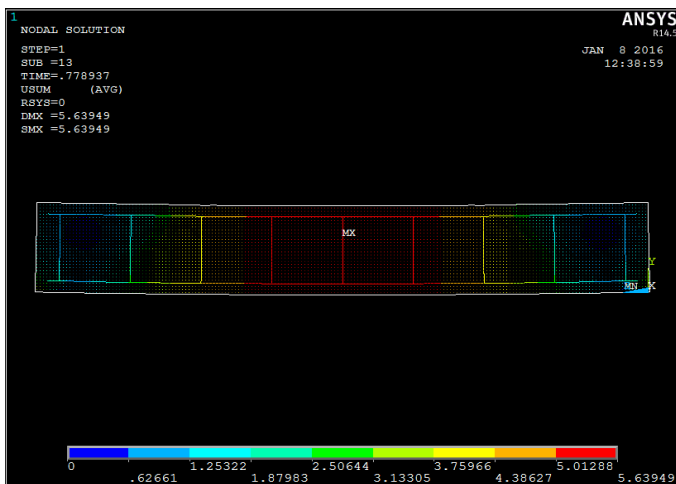

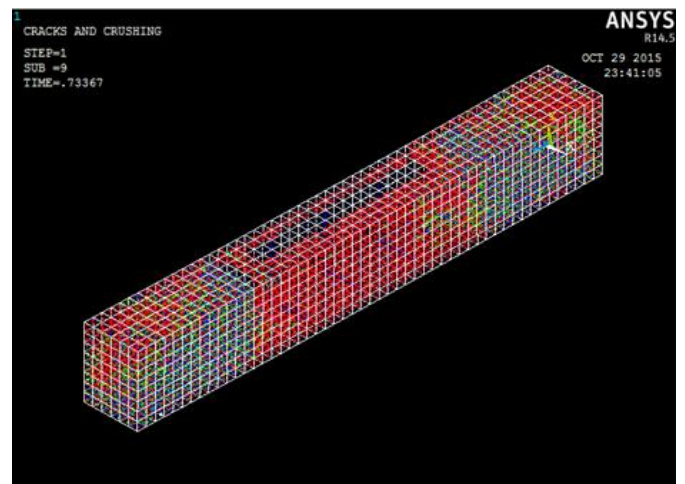**Fig 4.0:** *Meshing of Beam*

Fig 4.1: *Deflection of URB*

Fig 4.2: *Crack Pattern of URB*

Fig 4.3: *Deflection of* WURB

Fig 4.4: *Crack Pattern of WURB*

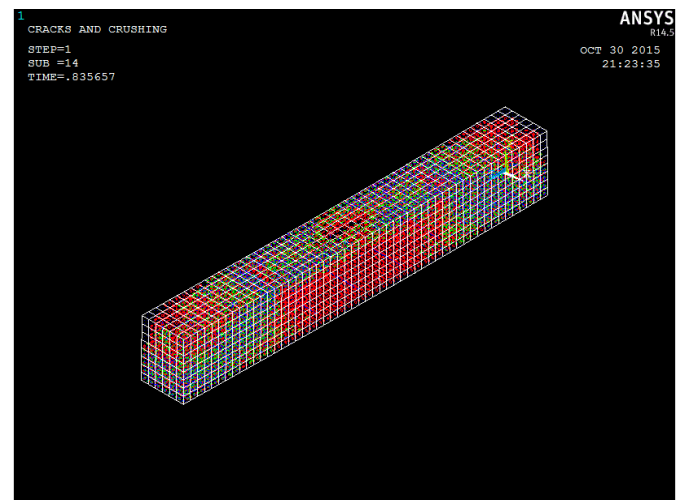

Fig 4.5: *Deflection of CRB*

Fig 4.6: *Crack Pattern of CRB*
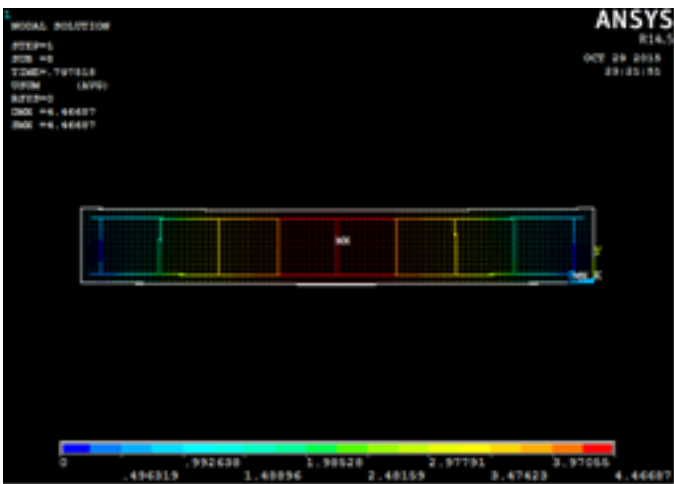
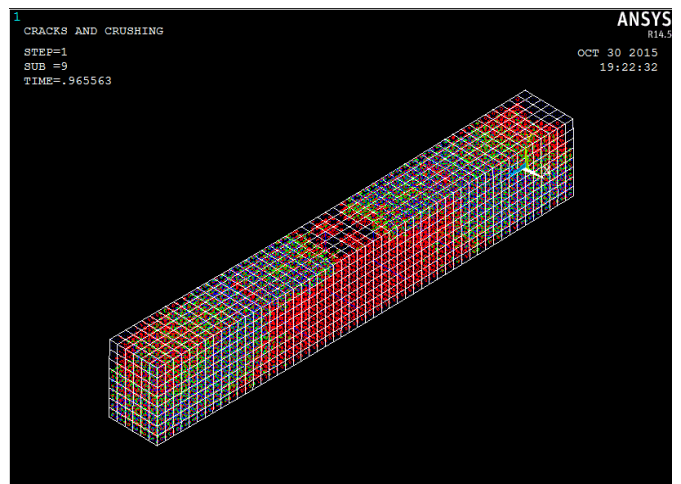**Fig 4.7:** *Deflection of* WCRB

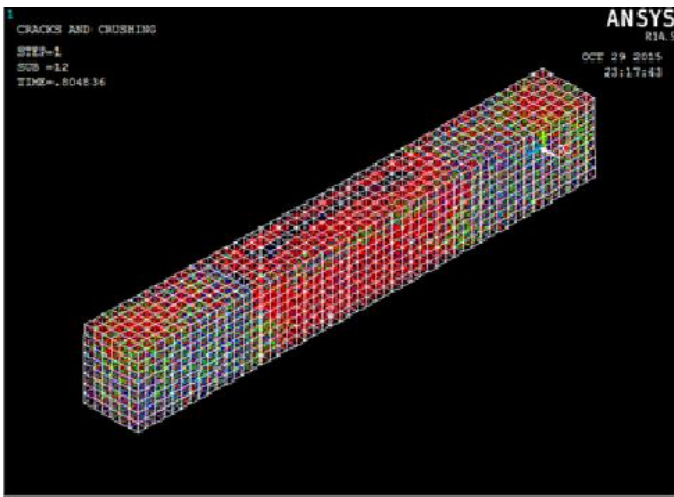**Fig 4.10:** *Crack Pattern of ORB*

Fig 4.8: *Crack Pattern of WCRB*
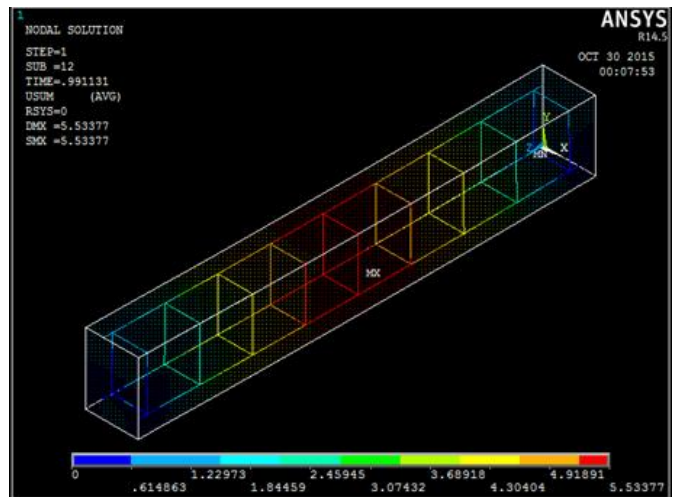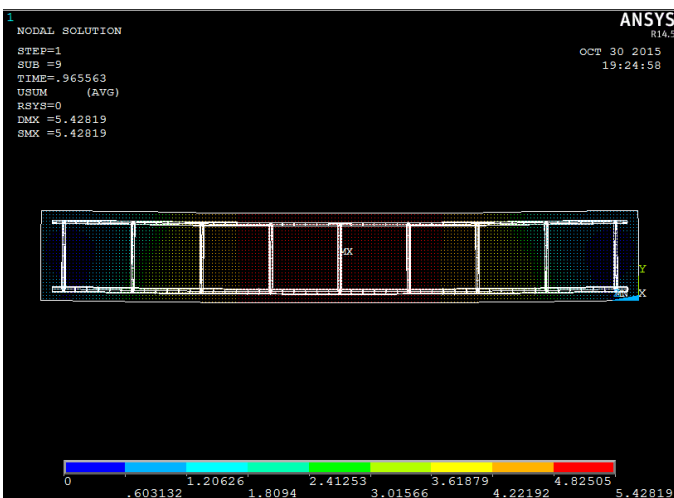

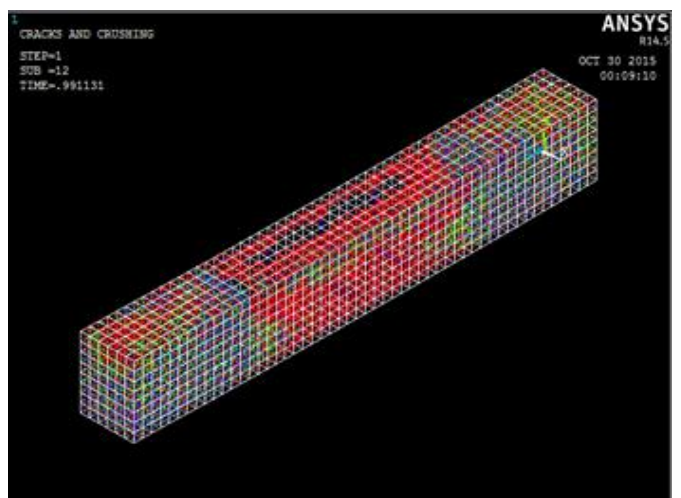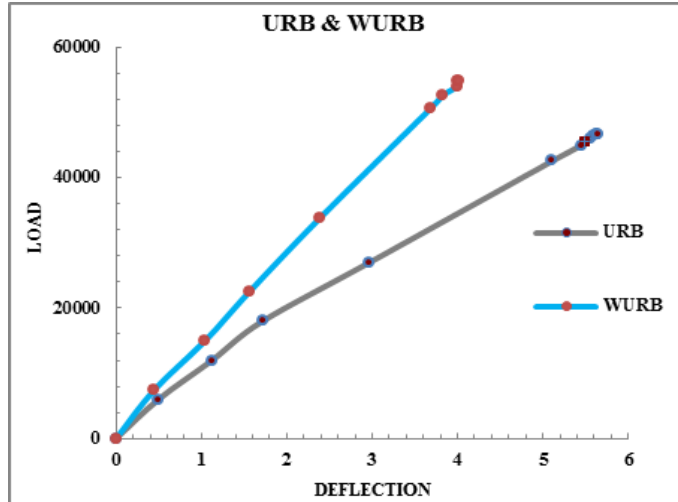**Fig 4.11:** *Deflection of WORB*

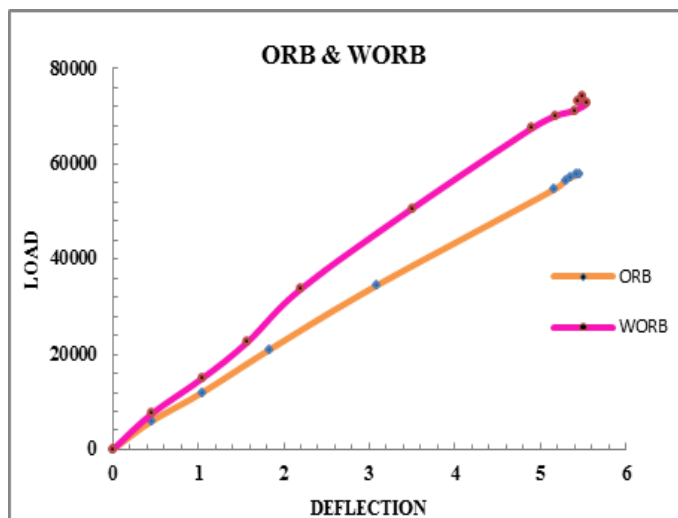**Fig 4.9:** *Deflection of* ORB
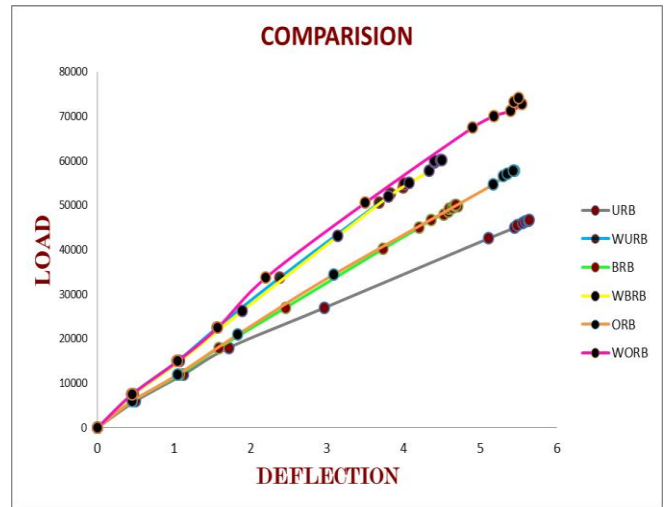

Fig 4.12: *Crack Pattern of WORB*

5.   LOAD-DEFLECTION CURVE

Graph 5.1: *URB & WURB*
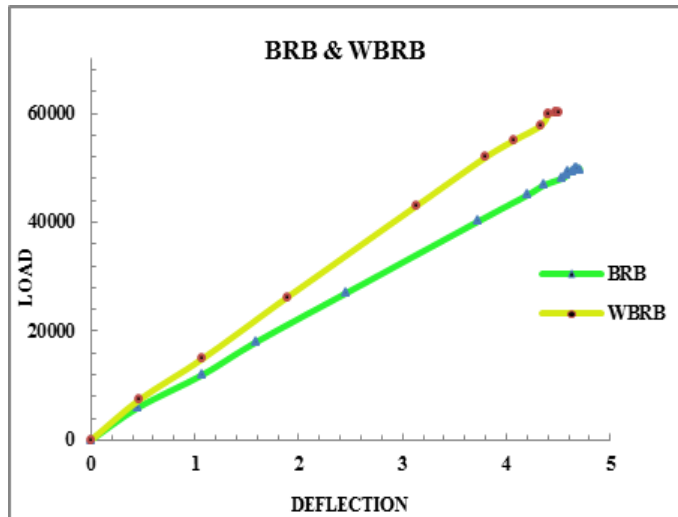
Graph 5.2: *BRB & WBRB*

Graph 5.3: *ORB & WORB*

Graph 5.4: *Total Comparisons*

6.   RESULT

Table: 6.1 *Numerical Results*

Beam Designation	Type of Beams	Ultimate Load at Failure in KN	% Increase in Load Carrying Capacity
B1	URB	46.73	-
B2	WURB	54.98	17.65
B3	CRB	50.10	-
B4	WCRB	60.3	20.35
B5	ORB	57.9	-
B6	WORB	74.2	28.15

II. ANALYTICAL INVESTIGATION:

The analytical investigation is done using some theoretical formulas. For the wrapped section the ultimate moment and ultimate load is determined using the following formula.

STEP-1: FRP design material properties

Due to the long-term exposure to various type of environment can reduce the tensile properties, creep-rupture and fatigue endurance of laminates. So the material property used should be reduced based on environmental conditions.

$$f_{fu} = C_E f_{fu}$$

f_{fu} - Design ultimate strength of FRP

C_E - Environmental Reduction Factor

$$\varepsilon_{fu} = C_E \varepsilon_{fu}^{*}$$

ε_{fu} - Design rupture strain of FRP

STEP-2: Existing Strain calculation

The only load acting on the beam at the time of GFRP installation is dead load. The existing strain value for the cracked section Is given as

$$\varepsilon_{bi} = \frac{M_{DL}(d_f - kd)}{I_{cr}\, E_c}$$

STEP-3: Design Strain of GFRP system

To prevent an intermediate debonding failiure mode, the effective strain for GFRP is calculated and it should be less than or equal to 0.9 times the design rupture strain of GFRP.

$$\varepsilon_{fd} = 0.41 \sqrt{\frac{fc'}{nE_f t_f}} \le 0.9\, \varepsilon_{fu}$$

STEP-4: The effective level of strain in GFRP reinforcement

The maximum strain level in GFRP is governed by the strain level developed In GFRP at the point at which the concrete crushes, GFRP rupture or debonding from the substrate.

$$\varepsilon_{fe} = 0.003 \left\{\frac{d_f - c}{c}\right\} - \varepsilon_{bi} \le \varepsilon_{fd}$$

$$\varepsilon_c = (\varepsilon_{fe} + \varepsilon_{bi}) \left\{\frac{c}{d_f - c}\right\}$$

STEP-5: Existing Strain in reinforcement

Based on strain level in GFRP sheet, the existing strain in reinforcement is determined using the relation,

$$\varepsilon_s = (\varepsilon_{fe} + \varepsilon_{bi}) \left\{\frac{d - c}{d_f - c}\right\}$$

STEP-6: Stress level in reinforcement and GFRP

The stress in steel is calculated

$$f_s = E_s \varepsilon_s \le f_y$$

The stress in GFRP sheet is calculated

$$f_{fe} = E_f \varepsilon_{fe}$$

Concrete stress block factors are calculated based on the parabolic stress-strain relationship for concrete.

$$\beta_1 = \frac{4\varepsilon_c{'} - \varepsilon_c}{6\varepsilon_c{'} - 2\varepsilon_c}$$

STEP-7: Calculate Flexural strength components

Steel contribution to bending

$$M_{ns} = A_s \left\{f_s d - \frac{\beta_1 c}{2}\right\}$$

FRP contribution to bending

$$M_{nf} = A_f \left\{f_{fe} d_f - \frac{\beta_1 c}{2}\right\}$$

STEP-8: Calculate Flexural strength of section

The design flexural strength of the beam is calculated and it should be greater than the moment calculated for the unwrapped beams.

$$\Phi M_n = \Phi (M_{ns} + \Psi M_{nf}) \ge M_u$$

7. RESULT:

Table 7.1: *Analytical Results*

Beam Designation	Type of Beams	Ultimate Load at Failure in KN	% Increase in Load Carrying Capacity
B7	URB	51.79	-
B8	WURB	61.34	20.2
B9	CRB	99.5	-
B10	WCRB	122.65	23.27
B11	ORB	112.88	-
B12	WORB	143.2	26.7

III. EXPERIMENTAL INVESTIGATION:

Totally six beams were casted in the structural engineering laboratory of "Dr.Mahalingam College of Engineering And Technology" at pollachi. The second set of three beams was wrapped with GFRP sheet of thickness 1.5mm. The bonding of GFRP laminate over the RC beam is obtained by coating epoxy resin over the beam by using wet lay-up method. All the beams are subjected under two point loading in a loading frame.
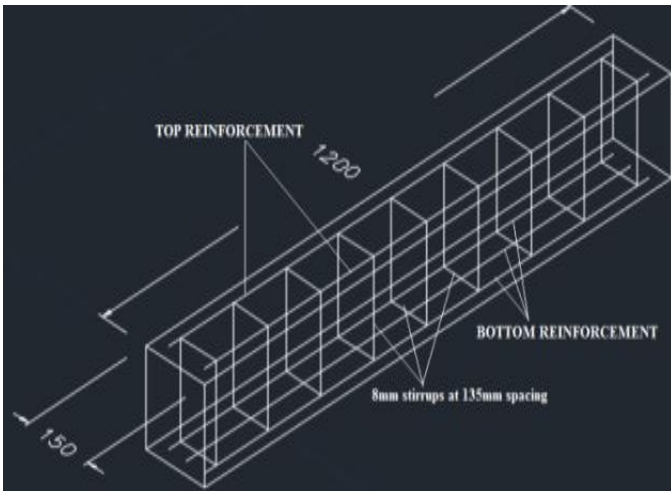
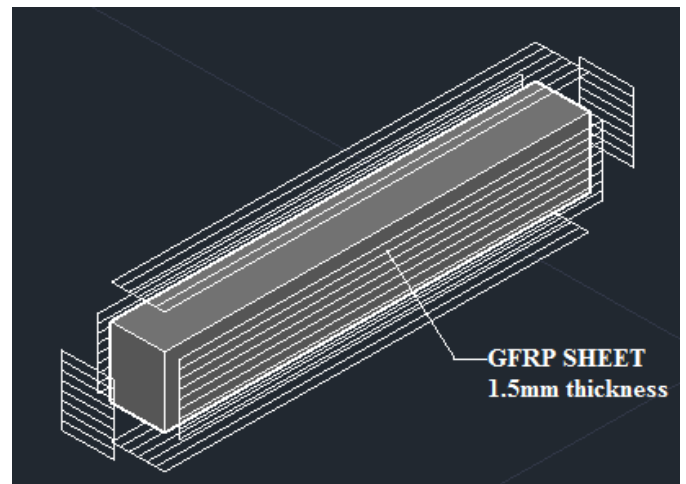**Fig 8.1:** *Beam dimensions*

Fig 8.2: *Reinforcement*

Fig 8.3: *Compaction*

Fig 8.4: WRAPPING OF BEAMS

Fig 8.2: *GFRP Sheet*
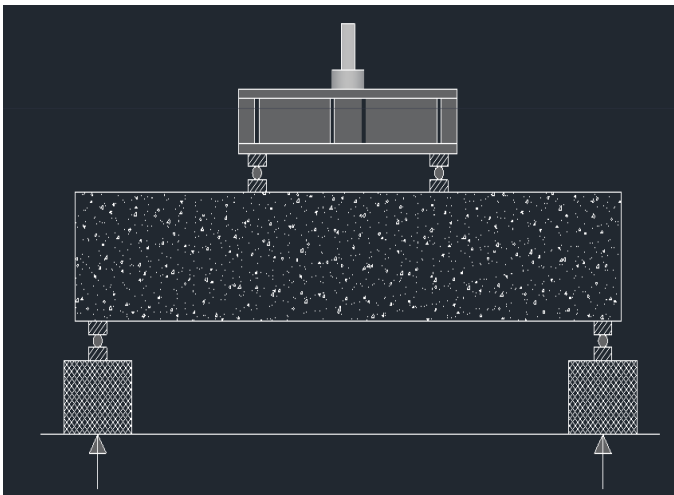
Fig 8.5: *Schematic Setup*

Fig 8.7: *Experimental Setup for Conventional RC beams*

**Fig 8.8:** *Experimental Setup for GFRP Wrapped RC Beams*

9.   RESULT
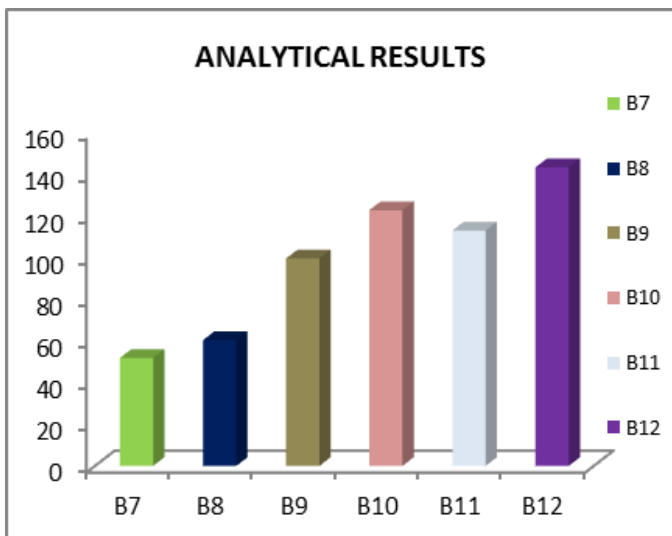
Table 9.1: *Experimental Results*

| Beam Designation	Type of Beams	Ultimate Load at Failure in KN	% Increase in Load Carrying Capacity
B13	URB	46.12	-
B14	WURB	54.72	17.87
B15	CRB	68.35	-
B16	WCRB	84.77	23.58
B17	ORB	79.92	-
B18	WORB	100.52	25.74

10.   RESULTS AND DISCUSSIONS:

From the numerical, analytical and experimental investigation it is noted that the ultimate load and percentage of load carrying capacity of wrapped RC beams are higher than the unwrapped beams. So the wrapping of RC beam with glass fibre polymer sheet is necessary to improve the flexural strength of the member.
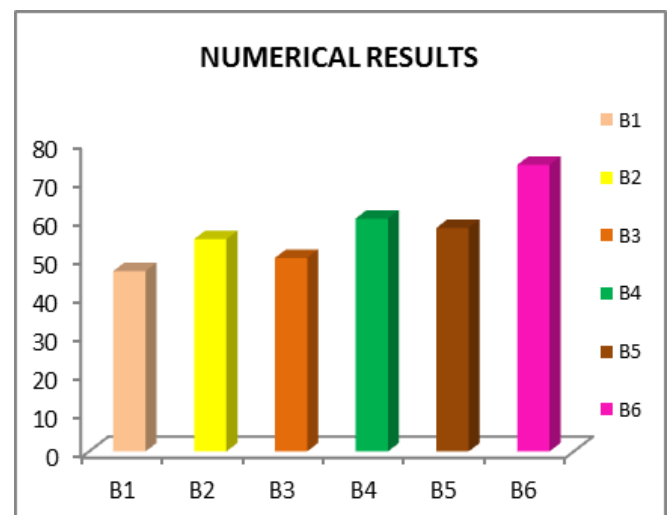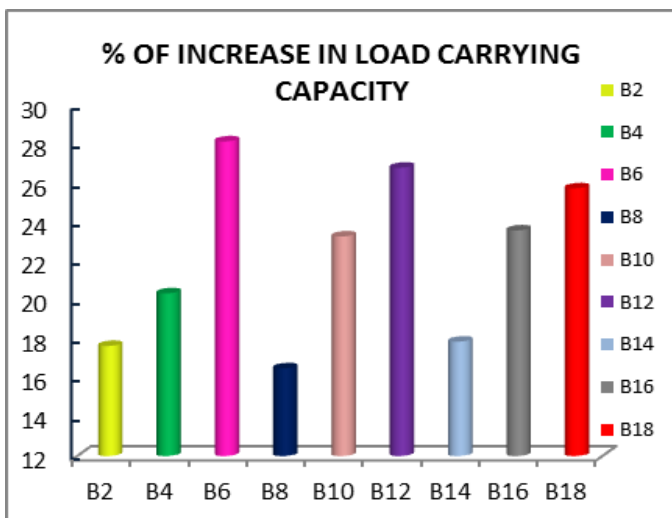

Graph 10.1: *Numerical Results*

Graph 10.2: *Analytical Results*
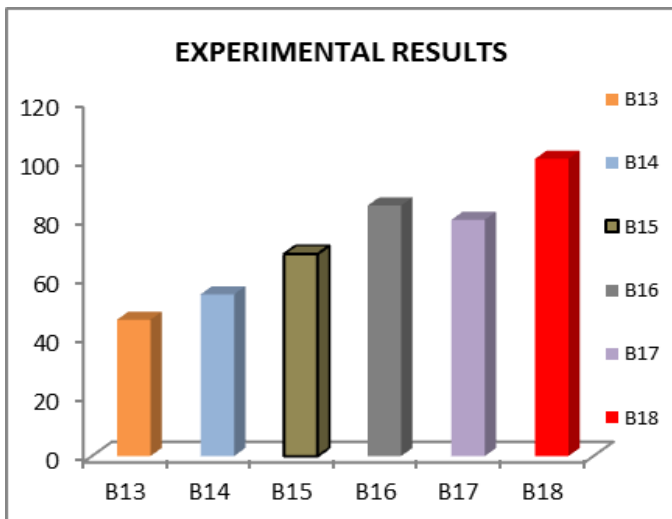
Graph 10.3: *Experimental Results*

Graph 10.4: *Comparison Results*

9.   CONCLUSION

The following observations and test results are obtained from the numerical investigation of wrapped and unwrapped RC beams

- The improvement in load carrying capacity of wrapped under reinforced beam is 17.65%, 20.2% and 17.87% when compared to unwrap under reinforced beam.
- The improvement in load carrying capacity of wrapped balanced reinforced beam is 20.35%, 23.27% and 23.58% when compared to unwrapped balanced reinforced beams.
- The improvement in load carrying capacity of wrapped over reinforced beam is 28.15%, 26.7% and 25.74% when compared to unwrap over reinforced beams.
- Instead of demolishing and also reconstruction of the structures it is economical to rehabilitate the structural element using GFRP.
- From the numerical results we can compare that the deflection in the strengthened specimen is comparatively lesser than that of the unstrengthen specimen.
- It is also observed that the ultimate load carrying capacity of all the strengthened beams is higher when compared to the controlled beams.

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11. BIOGRAPHIES

S.V.Hema Shangari currently doing my thesis on the topic "An Analytical, Numerical and Experimental Investigation of Glass Fibre Sheet wrapped Reinforced Concrete beams." I have compared the results obtained from the analytical, numerical and experimental results. The wrapping is done in the Structural Engineering Laboratory of Dr.Mahalingam College of Engineering and Technology at Pollachi.