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Experimental study on pre-cracked reinforced concrete beams strengthened with externally bonded GFRP composites

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Abstract
Cost of construction for demolishing and the reconstruction of old structures is always more than the cost of repairing and rehabilitation for those structures. Several systems are followed in the field of strengthening of existing structures. Many researchers have experimented plain Fibre Reinforced Polymer (FRP) sheets for strengthening existing structural members. This study extend to rectangular corrugated GFRP laminates used for strengthening of pre-cracked RC beams to enhance flexural strength and load carrying capacity. The updated minimum criteria of concrete grades in Indian Standard code of practice forced the structural engineers to concentrate more on the rehabilitation and strengthening of old structures to obtain the expected lifespan. Five beam specimens were cast and tested including a control specimen. This paper presents preliminary theoretical analysis and experimental study on RC beams externally strengthened with GFRP plain sheets and corrugated laminates and the same are compared. Test results reveals that the corrugated laminates used for repairs and rehabilitation work performed satisfactory.

Keywords: corrugated laminates, flexural strength, pre-cracked, repair and rehabilitation

1. Introduction

Life span of RC structural members of existing buildings may decrease because of code revisions, seismic zone up-gradation and environmental effects. In India, seismic code IS 1893 – 1984 [1] has been revised and new code was released on 2002 [2] Sudhir K Jain. According to the old code, seismic design on buildings is not required for some places and new code 1893 – 2002 [3] indicates that seismic load must be considered for the same zone. Hence strengthening is required for the buildings constructed based on old code.

Experimental Investigations
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1. Selection of profile by conducting preliminary theoretical analysis
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2. Fabrication process of GFRP corrugated laminates
↓
3. Tests on concrete ingredients and GFRP composites
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4. Casting of beam specimens, cubes, and workability tests
↓
5. Formation of crack on beams using pre-cracking technique
↓
6. Conducting the experiments and record of results

Fig 1: Flow chart showing the structure of the experimental work

Corrosion of steel rods embedded inside the reinforced concrete members is a great challenge for engineers Balasubramaniam, V., [4]. Water, moisture intrudes through the voids of the concrete and induces reinforcement corrosion and leads to concrete cover separation. To increase the life of existing buildings, external retrofitting using advance materials are common practice in strengthening techniques. Traditionally, steel plates were used for strengthening RC beams. Currently, FRP composites are used for retrofitting techniques. Researchers have tried plain sheets of Glass and Carbon fibre reinforced polymers for retrofitting RC flexural members. This paper proposes an experimental analysis on strengthening of RC beam using plain sheets and corrugated Glass Fibre Reinforced Polymer (GFRP) laminates because of its excellent properties. Experimental investigations involves six various works as shown in figure 1.

1.1 Finite Element Simulation

Preliminary theoretical analysis was conducted in ANSYS 2014 software and the results were compared. In general, the shape of the concrete folded plates are Rectangular, 'V' and trapezoidal in shape Ramachandran, J., 1993 [5] and Krishna Raju N., 2013 [6] Therefore those three profiles are considered for the preliminary analysis. Three various corrugated profiles are considered for finite element simulation such as rectangular, 'V' and trapezoidal as shown in figure 2.

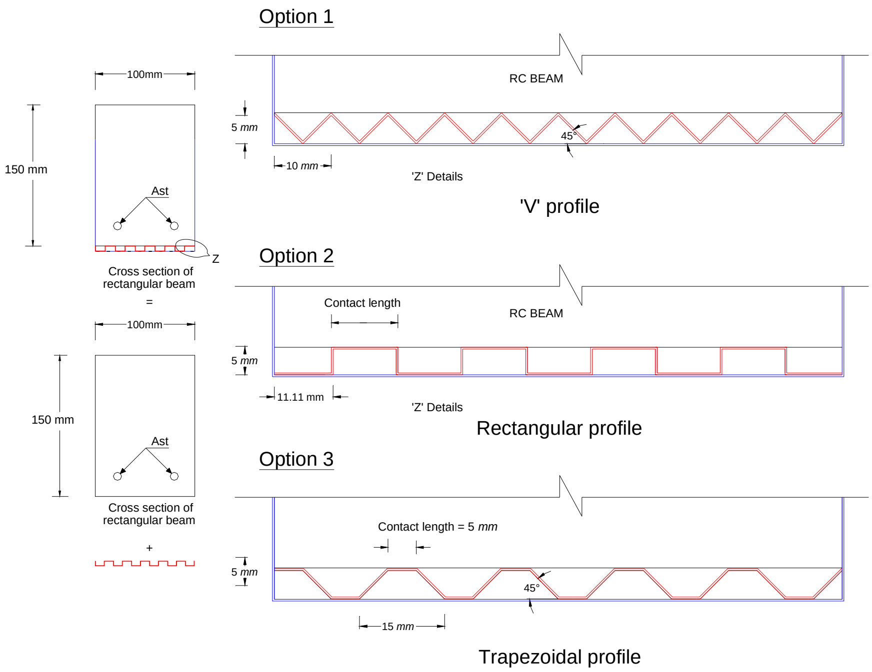

Fig 2: Cross section of beam with various profiles

Theoretical analysis for fixing the dimensions has been done based on finite element technique using the platform of ANSYS 14 software [7]. Beam model is developed with dimensions of 100 mm width, 150 mm overall depth and 1200 mm long. Beams are reinforced with two bars of 10 mm diameter HYSD (High Yield Strength Deformed) bars at tension zone. Characteristic compressive strength of concrete, yield strength of steel and clear cover for the beams are considered as 20 MPa, 415 MPa and 15 mm, respectively. Beam with reinforcements, steel plates and corrugated GFRP profiles model were developed using AutoCAD and analysed by ANSYS software and mesh has been generated for the imported model as shown in figure 3

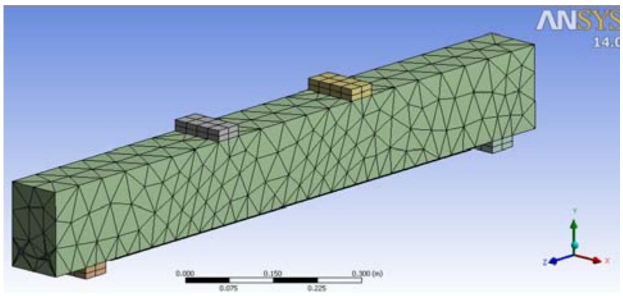

Fig 3: Mesh generated for a beam model

Loads were applied and static structural analysis was done for the developed model and the stress failure pattern was obtained as shown in figure 4.

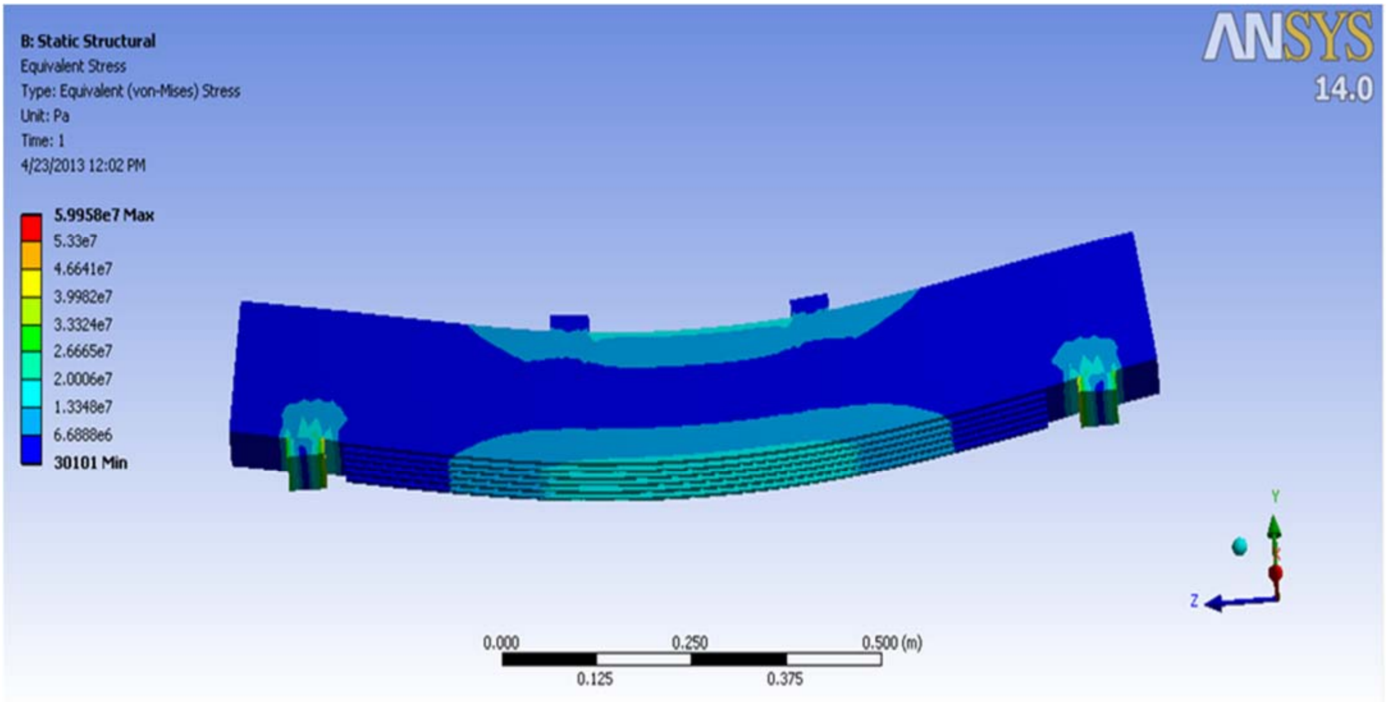

Fig 4: Failure pattern of RC beam with rectangular corrugated laminates

Load carrying capacity of control and strengthened beams are shown in table 1.

Table 1: Failure pattern of RC beam with rectangular corrugated laminates

Type of beam / Beam ID	Ultimate load (kN)
Control beam	39.20
Plain Sheet	45.25
CL – V Profile	48.80
CL – Rectangular profile	54.95
CL – Trapezoidal profile	50.50

Note: CL – Corrugated laminates; PS – Plain sheet

Based on the ANSYS results, the beam bonded with rectangular corrugated laminates carries an increased ultimate load of 21.43, 12.60 and 8.81 percent compared to plain mat, ‘V’, and trapezoidal corrugated laminates respectively. Hence for the experimental setup, rectangular profile is used.

1.2 Preparation of corrugated GFRP laminates

Corrugated laminates were fabricated at an industry with the help of grooved wooden dyes, GFRP sheets, GFRP chopped strands, mould release wax and epoxy resins. GFRP composites are used in the form of chopped strand mat and laminates for strengthening of structural components are as shown in figures 5 and 6 respectively.

Fig 5: GFRP chopped strand mat

Fig 6: GFRP corrugated laminates

2. Materials for RC Beams

Five beams were cast and classified into four categories such as control beam, beams retrofitted with plain sheets, corrugated laminates. The beams were cast using M15 grade concrete and Fe 415 grade steel. Portland Pozzalona Cement (PPC), natural river sand confirming to zone II and angular crushed granite with sizes of 12.5 and 6.3 mm were used. The beams were reinforced with 2-10 mm diameter bars at bottom, 2–8 mm diameter at top and 6mm diameter stirrups at 105 mm c/c. Cubes of size 150 mm were cast along with the beams and tested for each batch in compression to determine the 28-day compressive strength. The properties of fine and coarse aggregates were tested in accordance with Indian Standard codes specifications. Mix design for M15 concrete grade was done based on IS10262: 1982 [8]. Mix ratio and water cement ratio for M15 grade concrete is 1: 2.1: 4.66 and 0.59 respectively. Table 2 and 3 show the individual properties of adhesives and hardeners and properties of coating systems respectively which were supplied by the manufacturer. Aradur 140 was earlier called Hardener HY 840.

Table 2: Individual properties of Araldite GY 257 and Aradur 140

Properties	Units	Araldite GY 257	Aradur 140
Commercial form	-	Liquid	Liquid
Viscosity at 25° C	MPa.s	450-650	10000-25000
Epoxy equivalent	g/eq	182-192	-
Epoxy Content	Eq/kg	5.2-5.5	-
Amine Value	Eq/kg	-	6.6-7.5
Amine number	mg/KOH/g	-	370-410
Colour (Gardener)	-	<4	<12
Density at 25° C	g/cm3	1.15	0.98
Shelf life	-	12 months	12 months

Table 3: Properties of coating system

Mixture of Araldite GY 257 and Aradur 140		
Araldite GY 257		100 Parts by weight
Aradur 140		50 Parts by weight
Mix viscosity at 25 °C		1500-2700 MPa.s
Pot life at 25 °C		45-60 minutes
Touch dry time at 25 °C		4 hrs.
After hardening		
Compressive strength	kg/cm^2	600-700
Tensile strength	kg/cm^2	350-400
Modulus of elasticity in tension	kg/cm^2	2000-2200
Flexural strength	kg/cm^2	600-800
Bond strength	kg/cm^2	75-100

3. Experimental Work

Dimensions of all the beams were 100 mm (b) × 150 (D) mm and 1200 mm length. While casting, concrete compaction for beams were done using needle vibrator. Beam specimens were demoulded after 24 hours and cured in water. After 28 days, the specimens were taken out from the curing tank and kept in laboratory at ambient temperature. After drying, surfaces were prepared for strengthening works. The concrete projections and dust particles were removed from the beams using grinding machine and air blower respectively.

3.1 Pre-cracked Technique

The updated minimum criteria in codes forced the structural engineers to concentrate more on the rehabilitation and strengthening of old structures to obtain the expected lifespan. Practically, because of self-weight and external loads structural members subjected to crack followed by deflection. According to IS 456-2000 [9], clause no. 35.3.2, maximum width of crack at tensile zone should be equal to 0.3 mm. To bring out the reality in the experimental test beams, 0.3 mm cracks were developed at their tension zone of beams using torque wrench.

Beams were placed in such a way that the tension zone of bottom beam was placed facing to the ground and the tension zone of upper beam was kept in inverse direction. Spacer bars were placed in between the two beams and angle sections were kept at ends of the setup. The load was applied on these bolts using torque wrench as shown in figure 7. The load was applied on all the beams in the same manner until a crack was formed for a width of 0.3 mm.

Fig 7: Pre cracked technique

3.2 Retrofitted specimens preparation

The cracks in the tension zone of the beams were filled with epoxy filler mix. GFRP composites (TAISHAN Fiberglass) from Advanced Technical Services LLC, Oman available in roll of width 1m were used for strengthening work. GFRP composites and laminates were retrofitted with RC beams using epoxy resin (Araldite GY 257) and hardener (Aradur 140) mix with the ratio of 2:1 by weight.

GFRF Chopped Strand Mat (CSM) composites with three various types were used for beams strengthening works such as 300 and 450 GSM (Gram per square meter) with 0.4 and 0.6 mm thicknesses respectively.

The epoxy hardener mix has been applied on the bottom of the beam using hand roller. For beams strengthened with plain sheet, ickness 1, layer 1was cut into the size of 100 × 900 mm was placed at tension zone of the beam and pressure was applied uniformly using hand roller. After hardening, resin mix and second layer of GFRP sheet with the same thickness cut to the size of 325 x 900 mm was placed symmetrically at bottom of the beam and extended to the sides. In order to avoid debonding of GFRP plain sheets and laminates the second layer of plain sheets was extended upto 75% of the overall depth of beam. The beams retrofitted with plain sheets and corrugated laminates were tested after 24 hours. The same procedure was adopted for beams strengthened with corrugated GFRP laminates except the attachment of first layer. The contact area between corrugated laminates and RC beam was reduced and it may cause debonding of laminates. Hence the corrugated portions were filled with epoxy chalk powder mix. All the beams were over-designed for shear to avoid the shear failure. Slump tests were conducted for fresh concrete to measure workability.

3.3 Beam Testing Procedure

Three LVDTs were provided at bottom of the beam to measure displacements at mid span and under the loads corresponding to applied loads. All the specimens were tested as simply supported beam with a span of 900 mm and subjected under four point bending as shown in figure 8. The static load was applied using 300T UTM over the beams at constant interval and deflections at every interval, failure load and type of failure were noted.

Fig 8: Pre cracked technique

4. Results & Discussion

Flexural tests for five beams were conducted in the laboratory and the main results of the experimental works are shown in Table 4.

Table 4: Experimental results

Beam code	Ultimate load (kN)	Maximum deflection (mm)	Type of failure
M15 Control	56.50	28.00	Flexure
M15 t1 Cr – PS	66.19	22.58	Compression
M15 t2 Cr – PS	66.90	22.00	Flexure
M15 t1 Cr - CL	73.90	21.17	Flexure
M15 t2 Cr - CL	76.90	19.86	Flexure

PS – Plain sheet; CL – Corrugated Laminates; Cr: Pre-cracked; t1, t2 – thickness of GFRP composites with 0.4 mm and 0.6 mm

Tensile test results for GFRP plain sheets and corrugated laminates were conducted in the laboratory and the tensile strength values for GFRP plain sheets with 300 GSM and 450 GSM were noted as 195 MPa and 137 MPa respectively. Similarly tensile strength of GFRP corrugated laminates with 300 GSM and 450 GSM were 168 MPa and 112 respectively.

4.1 Overall performance evaluation

The failure loads for the pre-cracked beams strengthened with GFRP plain sheets and corrugated laminates were found to be more than that of the control beams, therefore the externally bonded GFRP sheets and laminates were enhanced the flexural strength. Load verses deflection for M15 grade beams are plotted as shown in figure 9.

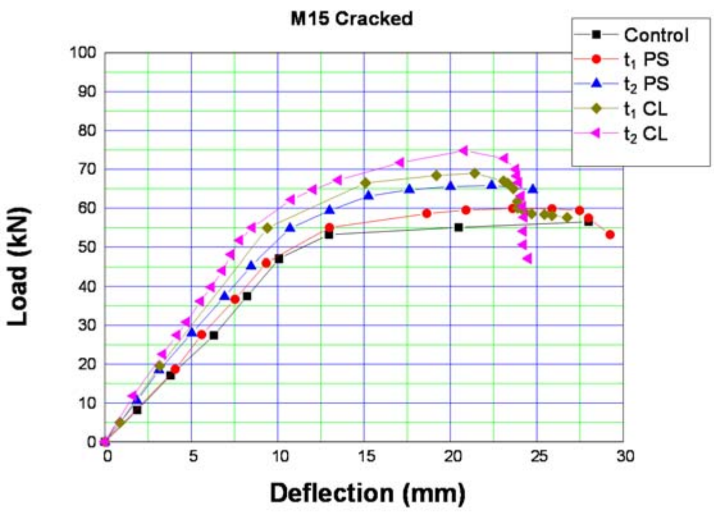

Fig 9: Load Verses Deflection for cracked beams

For 300 GSM GFRP composites pre-cracked beams, ultimate load for beams strengthened with plain sheet is increased by 17.15%, corrugated laminates is increased by 30.80% comparing control beam specimen. Similarly for beams strengthened with 450 GSM GFRP composites, load carrying capacities are increased by 18 and 36.11% for beams with plain sheet and corrugated laminate and laminate respectively.

5. Conclusions

Based on the experimental and theoretical analysis results the following conclusions were made:

1. The summary of experimental results shows that all the pre-cracked beams strengthened with GFRP plain sheets and corrugated laminates enhance the load carrying capacity and flexural strength. Hence the retrofitting technique can be adopted for flexural members of existing buildings.
2. Retrofitting of structural members can be done based on ACI guidelines and recommendations.
3. The failure load of pre-cracked beams retrofitted with GFRP laminates were greater than the beams retrofitted by GFRP plain sheets. This shows that the use of GFRP corrugated laminates is more effective in the case of repairs and rehabilitation.
4. The flexural strength of the strengthened beams increased depending on the thickness of GFRP sheets and laminates.
5. Adhesives, epoxy resin and hardener mix used for retrofitting work performed satisfactory.
6. None of the beam had failed by debonding of corrugated laminates. It reveals that the corrugated portions filled with epoxy filler mix, wrapping of laminates using second layer of plain sheets performed well in retrofitting works.

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