International Journal of Research
Available at https://edupediapublications.org/journals
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 04 Issue 10
September 2017

Experimental Studies On Strengthening Of Rcc Continious Beams Using Frp Sheets

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ABSTRACT

Strengthening of structures via external bonding of advanced fibre reinforced polymer (FRP) composite is much less dense and therefore lighter than the equivalent volume of steel which provides a more economical and technically superior alternative to the traditional techniques in many situations as it offers high strength, low weight, corrosion resistance, high fatigue resistance, easy and rapid installation and minimal change in structural geometry. The manufacturing process for glass fibers sheets suitable for reinforcement uses large furnaces to gradually melt the silica sand, limestone, kaolin clay, fluorspar, colemanite, dolomite and other minerals to liquid form. Although many in-situ RC beams are continuous in construction, there has been very limited research work in the area of FRP strengthening of continuous beams.

In the present study an experimental investigation is carried out to study the behaviour of continuous RC beams under static loading. The beams are strengthened with externally bonded Glass fibre reinforced polymer (GFRP) sheets. Different scheme of strengthening have been employed. The program consists of continuous (two-span) beams with overall dimensions equal to (150×200×2300) mm. The beams are grouped into two series labelled S1 and S2 and each series have different percentage of steel reinforcement. One beam from each series (S1 and S2) was not strengthened and was considered as a control beam, whereas all other beams from both the series were strengthened in various patterns with externally bonded GFRP sheets. The present study examines the responses of RC continuous beams, in terms of failure modes, enhancement of load capacity and load deflection analysis. The results indicate that the flexural strength of RC beams can be significantly increased by gluing GFRP sheets to the tension face. In addition, the epoxy bonded sheets improved the cracking behaviour of the beams by delaying the formation of visible cracks and reducing crack widths at higher load levels.

INTRODUCTION

GENERAL

A structure is designed for a specific period and depending on the nature of the structure, its design life varies. For a domestic building, this design life could be as low as twenty-five years, whereas for a public building, it could be fifty years. Deterioration in concrete structures is a major challenge faced by the infrastructure and bridge industries worldwide. The deterioration can be mainly due to environmental effects, which includes corrosion of steel, gradual loss of strength with ageing, repeated high intensity loading, variation in temperature, freeze-thaw cycles, contact with chemicals and saline water and exposure to ultra-violet radiations. As complete replacement or reconstruction of the structure will be cost effective, strengthening or retrofitting is an effective way to strengthen the same.

The most popular techniques for strengthening of RC beams have involved the use of external epoxy-bonded steel plates. It has been found experimentally that flexural strength of a structural member can increase by using this technique. Although steel bonding technique is simple, cost-effective and efficient, it suffers from a serious problem of deterioration of bond at the steel and concrete inter-phase due to corrosion of steel. Other common strengthening technique involves construction of steel jackets which is quite effective from strength, stiffness and ductility considerations. However, it increases overall cross-sectional dimensions, leading to increase in selfweight of structures and is labour intensive. To eliminate these problems, steel plate was replaced by corrosion resistant and light-weight FRP Composite plates. FRPCs help to increase strength and ductility without excessive increase in stiffness. Further, such material could be designed to meet specific requirements by adjusting placement of fibres. So concrete members can now be easily and effectively strengthened using externally bonded FRP composites.

By wrapping FRP sheets, retrofitting of concrete structures provide a more economical and technically superior alternative to the traditional techniques in many situations because it offers high strength, low weight, corrosion resistance, high fatigue resistance, easy and rapid installation and minimal change in structural geometry. FRP systems can also be used in areas with limited access where traditional techniques would be impractical. However, due to lack of the proper knowledge on structural behaviour of concrete structures, the use of these materials for retrofitting the existing concrete structures cannot reach up to the expectation. Successful retrofitting of concrete structures with FRP needs a thorough knowledge on the subject and available user-friendly technologies/ unique guidelines.

Beams are the critical structural members subjected to bending, torsion and shear in all type of structures. Similarly, columns are also used as various important elements subjected to axial load combined with/without bending and are used in all type of structures.

Therefore, extensive research works are being carried out throughout world on retrofitting of concrete beams and columns with externally bonded FRP composites. Several investigators took up concrete beams and columns retrofitted with carbon fibre reinforced polymer (CFRP)/ glass fibre reinforced polymer (GFRP) composites in order to study the enhancement of strength and ductility, durability, effect of confinement, preparation of design guidelines and experimental investigations of these members.

Current Research on FRP

A serious matter relating to the use of FRPs in civil applications is the lack of design codes and specifications. For nearly a decade now, researchers from Canada, Europe, and Japan have been collaborating their efforts in hope of developing such documents to provide guidance for engineers designing FRP structures.

EXPERIMENTAL STUDY:-

The experimental study consists of casting of large scale continuous (two-span) rectangular reinforced concrete beams. All the beams weak in flexure are casted and tested to failure. The beams were grouped into two series labeled S1 and S2. Each series had different longitudinal and transverse steel reinforcement ratios which are mentioned in Table 3.6 and Table 3.7 for S1 and S2 respectively. All beams had the same geometrical dimensions: 150 mm wide × 200 mm deep × 2300 mm long.

One beam from each series (S1 and S2) was not strengthened and was considered as a control beam, whereas all other beams from both the series were strengthened with externally bonded GFRP sheets. Experimental data on load, deflection and failure modes of each of the beams are obtained. The change in load carrying capacity and failure mode of the beams are investigated for different types of strengthening pattern.

Casting of Specimen

For conducting experiment, the proportion of 1: 1.67: 3.33 by weight for W/C = 0.50 is taken for cement, fine aggregate and course aggregate. The mixing is done by using concrete mixture. The beams are cured for 28 days. For each beam six concrete cube specimens were made at the time of casting and were kept for curing. The uniaxial compressive tests on produced concrete (150 × 150 × 150 mm concrete cube) were performed and the average concrete compressive strength (fcu) after 28 days for each beam is shown in Table 3.6 and Table 3.7.

Table 3.1 Design Mix Proportions

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e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 04 Issue 10
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Description	Cement	Sand (Fine Aggregate)	Course Aggregate	Water
Mix Proportion (by weight)	1	1.67	3.33	0.55
Quantities of materials (Kg/m^3)	368.42	533.98	1231.147	191.58

Materials for Casting

Cement

Pozzolana Portland Cement (PPC) is used for the experiment. It is tested for its physical properties in accordance with Indian Standard specifications. It is having a specific gravity of 2.96.

(i) Specific gravity: 2.96
(ii) Normal Consistency: 32%
(iii)Setting Times: Initial: 105 minutes Final: 535 minutes.
(iv) Soundness: 2 mm expansion
(v) Fineness: 1 gm retained in 90 micron sieve

Fine aggregate

The fine aggregate passing through 4.75 mm sieve and having a specific gravity of 2.67 are used. The grading zone of fine aggregate is zone III as per Indian Standard specifications.

Coarse aggregate

The coarse aggregates of two grades are used one retained on 10 mm size sieve and another grade contained aggregates retained on 20 mm sieve. It is having a specific gravity of 2.72.

Water

Ordinary tap water is used for concrete mixing in all the mix.

Reinforcing Steel

All the beams were grouped into two series labelled S1 and S2. Each series had different longitudinal and transverse steel reinforcement ratios which are mentioned in Table 3.6 and Table 3.7. Series S1 beams are reinforced with two 12 mm diameter at the bottom, two 8 mm diameter bars as top reinforcement throughout the length and two 10 mm diameter bars at top tension zone. To strengthen the beam in shear, two different diameter bars is used for stirrups, 10 mm diameter is used in the shear zone of intermediate support and 8mm diameter is used in the zone of end support. The diameter variation is given due to higher shear force in intermediate or continuous support than end support. Series S2 beams were reinforced with two high-yield Strength Deformed bars of 10 mm diameter at the bottom and two 10 mm diameter bars at top tension zone, 6 mm bars were used as hanger bars, closed stirrups of 8 mm diameter high-yield Strength Deformed bars at 100 mm centres were provided to prevent shear failure.

Three bars of each diameter rods were tested in tensile and the measured average yield strength is averaged and shown in Table 3.3. The modulus of elasticity of steel bars was 2 × 10^5 MPa.

Table 3.2 Tensile Strength of the bars

Diameter of the reinforcement(mm)	Tensile strength (MPa)
8	523
10	429
12	578

Strengthening of Beams

At the time of bonding of fiber, the concrete surface is made rough using a coarse sand paper texture and then cleaned with an air blower to remove all dirt and debris. The fabrics are cut according to the size and after that the epoxy resin is mixed in accordance with manufacturer's instructions. The mixing is carried out in a plastic container (100 parts by weight of Araldite LY 556 to 10 parts by weight of Hardener HY 951). After the uniform mixing, the epoxy resin is applied to the concrete surface. Then the GFRP sheet is placed on top of epoxy resin coating and the resin is squeezed through the roving of the fabric with the roller. Air bubbles entrapped at the epoxy/concrete or epoxy/fabric interface are eliminated. This operation is carried out at room temperature. Concrete beams strengthened with glass fiber fabric are cured for at least 3 days at room temperature before

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Available at https://edupediapublications.org/journals
e-ISSN: 2348-6848
p-ISSN: 2348-795X
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testing.

Figure 3.4 Application of epoxy and hardener on the beam

Figure 3.5 Roller used for the removal of air bubble

Fabrication of GFRP Plate

There are two basic processes for moulding: hand lay-up and spray-up. The handS lay-up process is the oldest and simplest fabrication method. The process is most common in FRP marine construction. In hand lay-up process, liquid resin is placed along with FRP against finished surface. Chemical reaction of the resin hardens the material to a strong light weight product. The resin serves as the matrix for glass fiber as concrete acts for the steel reinforcing rods.

The following constituent materials were used for fabricating plates:

1. Glass Fiber
2. Epoxy as resin
3. Diamine as hardener as (catalyst)
4. Polyvinyl alcohol as a releasing agent

A plastic sheet was kept on the plywood platform and a thin film of polyvinyl alcohol was applied as a releasing agent by the use of spray gun. Laminating starts with the application of a gel coat (epoxy and hardener) deposited in the mould by brush, whose main purpose was to provide a smooth external surface and to protect fibers from direct exposure from the environment. Steel roller was applied to remove the air bubbles. Layers of reinforcement were applied and gel coat was applied by brush. Process of hand lay-up is the continuation of the above process before gel coat is hardened. Again a plastic sheet was applied by applying polyvinyl alcohol inside the sheet as releasing agent. Then a heavy flat metal rigid platform was kept top of the plate for compressing purpose. The plates were left for minimum 48 hours before transported and cut to exact shape for testing.

Plates of 2 layers, 4 layers, 6 layers and 8 layers were casted and six specimens from each thickness were tested.

Figure 3.8 Specimens for tensile testing

Table 3.3 Size of the specimens for tensile test

No. of layers	Length (cm)	Width (cm)	Thickness (cm)
2	15	2.3	0.1
4	15	2.3	0.25
6	15	2.3	0.3
8	15	2.3	0.45

3.5 Determination of Ultimate Stress, Ultimate Load and Young's Modulus

The ultimate stress, ultimate load and young's modulus was determined experimentally by performing unidirectional tensile test on the specimens cut in longitudinal and transverse direction. The dimensions of the specimens are shown in Table 3.4. The specimens were cut from the plates by diamond cutter or by hex saw. After cutting by hex saw, it was polished in the polishing machine.

For measuring the young's modulus, the specimen is loaded in universal tensile test machine to failure with a recommended rate of extension. Specimens were gripped in the upper jaw first and then gripped in the movable lower jaw. Gripping of the specimen should be proper to prevent slippage. Here, it is taken as 50 mm from each side. Initially, the strain is kept zero. The load as well as extension was recorded digitally with the help of the load cell and an extensometer respectively. From these data, stress versus stain graph was plotted, the initial slope of which gives the Young's modulus. The ultimate stress and the ultimate load were obtained at the failure of the specimen. The average value of each layer of the specimens is given in the Table 3.5.

Table 3.4 Result of the specimens

Thickness of the specimen	Ultimate stress (MPa)	Ultimate Load (N)	Young's modulus(MPa)
2 Layers	172.79	6200	6829.9
4 Layers	209.09	9200	7788.5
6 Layers	236.23	12900	7207.4
8 Layers	253.14	26200	7333.14

3.6 Testing of Beams

All the beams are tested one by one. All of them are tested in the above arrangement. The gradual increase in load and the deformation in the dial gauge reading are taken throughout the test. The load at which the first visible crack is developed is recorded as cracking load. Then the load is applied till the ultimate failure of the beam. The deflections at midpoint of each span are taken for all beams with and without GFRP and are recorded with respect to increase of load. The data furnished in this chapter have been interpreted and discussed in the next chapter to obtain a conclusion.

Table 3.5 Details of the Test Specimens for Series S1

Designation of Beams	f_{cu} (MPa)	Main Longitudinal steel		Positive moment strengthening		Negative moment strengthening	
		Top	*Bottom*	*No. of lay*	*Strengthened length(*	*No. of lay*	*Strengthened lengt*
CB1	22.67	2-8 2-*	2-12	-	-	-	-
SB1	23.85	2-8 2-*	2-12	2		6	
SB2	24.68	2-8 2-*	2-12	4		4	
SB3	25.13	2-12	2-12	3		6	

*provided at top tension zone

Table 3.6 Details of the Test Specimens for Series S2

Designation of Beams	f_{cu} (MPa)	Main Longitudinal steel		Positive moment strengthening		Negative moment strengthening	
		Top	*Bottom*	*No. of lay*	*Strengthened length(*	*No. of lay*	*Strengthened length(*
CB2	25.34	2-6,	2-10	0	-	0	-
TB1	24.5	2-6,	2-10	2	0.88m	6	0.88m
TB2	23.51	2-6,	2-10	2			
TB3	25.61	2-6,	2-10	4			

*provided at top tension zone

TEST RESULTS AND DISCUSSIONS

The beams were loaded with a concentrated load at the middle of each span and the obtained experimental results are presented and discussed subsequently in terms of the observed mode of failure and load-deflection curve. The crack patterns and the

Designation of Beams	Failure Mode	P_u (KN)	λ= Pu(strengthened beam) / Pu(Control beam)
CB1	Flexural failure	260	1
SB1	Debonding failure	334	1.28
SB2	Tensile rupture	380	1.46
SB3	Debonding failure without concrete	345	1.32

mode of failure of each beam are also described in this chapter. All the beams are tested for their ultimate strengths and it is observed that the control beam had less load carrying capacity than the strengthened beam. Two sets of beams i.e. S1 and S2 were examined and one beam from each series was tested as un-strengthened control beam and rest beams were strengthened with various patterns of FRP sheets. The different failure modes of the beams were observed for both the series S1 and S2 as shown in Table 4.1 and Table 4.2.

4.1 Experimental Results

The Beams from two series were tested under flexure loads for different SB's and TB's with different reinforcement details and compared with Control Beams.

4.1.1 Failure Modes

Strengthened Beams and Tested Beams fails due to flexure or de-bonding failure without concrete cover **or** tensile rupture.

4.1.1.1 Control Beam

The control beam CB1 and CB2 failed completely in flexure. The failure started first at the tension zone and then propagated towards the compression zone and finally failed in flexure.

4.1.1.2 Strengthened Beam

Generally, the rupture of FRP sheet was sudden and accompanied by a loud noise indicating a rapid release of energy and a total loss of load capacity. For all the strengthened beams, the failure modes for Series S1 and S2 are described in Table 4.1 and Table 4.2.

The following failure modes were examined for all the tested beams:

- Flexural failure
- Debonding failure (with or without concrete cover)
- Tensile rupture

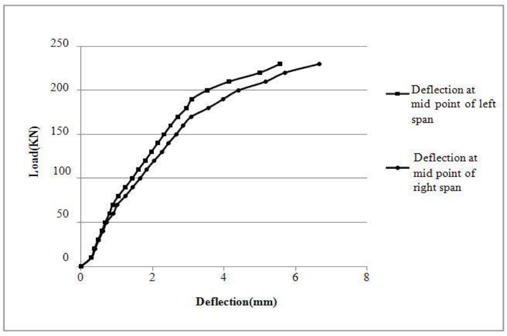
Rupture of the FRP laminate is assumed to occur if the strain in the FRP reaches its design rupture strain before the concrete reaches its maximum usable strain. GFRP debonding can occur if the force in the FRP cannot be sustained by the substrate. In order to prevent debonding of the GFRP laminate, a limitation should be placed on the strain level developed in the laminate.

Table 4.1 Experimental Results of the Tested Beams for Series S1

Table 4.2 Experimental Results of the Tested Beams for Series S2

Designation ofBeams	Failure Mode	P_u (KN)	λ = Pu(strengthened beam) / Pu(Control beam)
CB2	Flexural failure	200	1
TB1	Debonding failure	224	1.12
TB2	Tensile rupture	298	1.49
TB3	Debonding of FRP	326	1.68

4.1.2.1 Strengthened Beam of S1 Series



e-ISSN: 2348-6848
p-ISSN: 2348-795X
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4.1.2.2 Load versus Deflection curve for set series S1

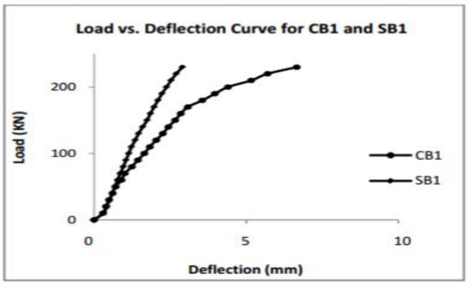
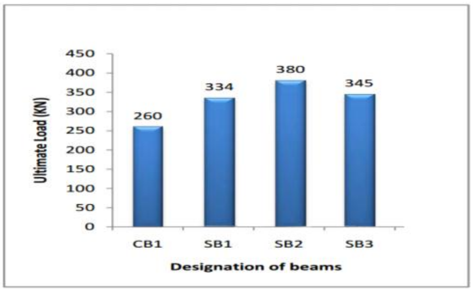


Figure 4.6 Ultimate Load Capacity of Series S1 beams



REFERENCES

[1] ACI Committee 440, "Starte-of-the-art report on fiber reinforced plastic reinforcement for concrete structures", Report ACI 440R-96, USA: *American Concrete Institute*, 1996.

[2] Aiello MA, and Ombres L, "Cracking and deformability analysis of reinforced concrete beams strengthened with externally bonded carbon fiber reinforced polymer sheet", *ASCE Journal of Materials in Civil Engineering*, vol. 16, No. 5, pp.292-399,2004.

[3] Akbarzadeh H, and Maghsoudi AA, "Experimental and analytical investigation of reinforced high strength concrete continuous beams strengthened with fiber reinforced polymer", *Materials and Design*, vol. 31, pp. 1130-1147, 2010.

[4] Arduini M, and Nanni A, "Behaviour of pre-cracked R. C. beams strengthened with carbon FRP sheets", *ASCE Journal of Composites for Construction*, vol. 1, No. 2, pp. 63- 70, 1997.

[5] Ashour AF, El-Refaie SA, and Garrity SW, "Flexural strengthening of RC continuous beams using CFRP laminates", *Cement and Concrete Composites*, vol. 26, pp. 765-775, 2003.

[6] Ceroni F, "Experimental performances of RC beams strengthened with FRP materials", *Construction and Building Materials*, vol. 24, pp. 1547-1559, 2010.

[7] El-Refaie SA, Ashour AF, and Garrity SW, "Sagging strengthening of continuous reinforced concrete beams using carbon fibre sheets", *The 11th BCA Annual Conference on Higher Education and the Concrete Industry*, Manchester, UK, pp. 281-292, 3-4 July 2001.

[8] El-Refaie SA, Ashour AF, and Garrity SW, "Strengthening of reinforced concrete continuous beams with CFRP composites", *The International Conference on Structural Engineering, Mechanics and Computation*, Cape Town, South Africa, 2-4. , pp.1591-1598, April 2001.

[9] Garden HN, and Hollaway LC, "An experimental study of the influence of plate end anchorage of carbon fibre composite plates used to strengthen reinforced concrete beams", *Composite Structures*, vol. 42, pp. 175-188, 1998.

[10] Grace NF, "Strengthening of negative moment region of reinforced concrete beams using carbon fiber- reinforced polymer strips", *ACI Structural Journal*, vol. 98, No. 3, pp. 347- 358, 2001.

[11] Grace NF, Sayed GA, and Saleh KR, "Strengthening of continuous beams using fibre reinforced polymer laminates", *American Concrete Institute*, Farmington Hills, Mich, pp. 647-657, 1999.

[12] Grace NF, Soliman AK, Abdel-Sayed G, and Saleh KR, "Strengthening of continuous beams using fibre reinforced polymer laminates", *Proceedings of 4th International Symposium on Fibre Reinforced Polymer Reinforcements for Reinforced Concrete Structures*, SP-188, American Concrete Institute, Farmington Hills, Michigan, USA, pp.647-657, 1999.

[13] Jumaat MZ, Rahman MM, and Rahman MA, "Review on bonding techniques of CFRP in strengthening concrete structures", *International Journal of the Physical Sciences*, vol. 6(15), pp. 3567-3575, 4 August. 2011.

[14] Khalifa A, Tumialan G, Nanni A, and

Belarbi A, “Shear Strengthening of Continuous Reinforced Beams Using Externally Bonded Carbon Fiber Reinforced Polymer Sheets”, *In: Fourth International Symposium on Fiber Reinforced Polymer Reinforcement for Reinforced Concrete Structures*, Baltimore, MD, American Concrete Institute, pp. 995-1008, November 1999.

[15] Lamanna AJ, Bank LC, and Scott DW, “Flexural strengthening of reinforced concrete beams using fasteners and fiber-reinforced polymer strips”, *ACI Structural Journal*, vol. 98(3), pp. 368-76, 2001.

[16] Oehlers DJ, Liu IST, and Seracino R, “Shear deformation debonding of adhesively bonded plates” *Proc. Institution of Civil Engineers*, vol. 158(1), pp. 77-84, 2005.

[17] Ross CA, Jerome DM, Tedesco JW, and Hughes ML, “Strengthening of reinforced concrete beams with externally bonded composite laminates”, *ACI Structural Journal,* vol. 96. No. 2, pp. 65-71, 1999.

[18] Spadea G, Bencardino F, and Swamy RN, “Structural behaviour of composite RC beams with externally bonded CFRP”, *Journal of Composites for Construction*, ASCE, pp. 132- 7, 1998.

[19] Yao J, Teng, JG, and Lam L, “Experimental study on intermediate crack debonding in FRP-strengthened RC flexural members”, *Advances in Structural Engineering*, vol. 8(4), pp. 365-396, 2005.