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Study on RC Beams Strengthed With Overlay Madeup of Advanced Composite Materials

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Abstract: Fiber reinforced polymer materials are continuing to show great promise for using strengthening reinforced concrete structures. These materials are an excellent option for use as external reinforcing, because of their light weight, resistant to corrosion and high strength.
The main aim of this study is to investigate the flexural characteristic of RC beams using GFRP sheets and CFRP sheets.

This paper presents experimental results of the RC beams strengthened in flexure with externally bonded GFRP at the constant bending moment, here in order to delay the GFRP debonding. Similarly apply the CFRP sheets. Experimental data on load, deflection and failure modes of each of the beams were obtained. The detail procedure and application of GFRP sheets and CFRP sheets for strengthening of RC beams are also included. The effect of GFRP layers and CFRP layers on ultimate load carrying capacity and failure mode of the beams are investigated.
Keywords: GFRP, CFRP

I. Introduction

There are considerable number of existing concrete structures in India that do not meet current design standards because of inadequate design and construction or need structural up gradation to meet new seismic design requirements because of new design standards, deterioration due to corrosion in the steel caused by exposure to an aggressive environment and accident events such as earthquakes. Inadequate performance of this type of structures is a major concern from public safety standpoint. That is why reinforced concrete structures often have to face modification and improvement of their performance during their service life. In such circumstances there are two possible solutions: replacement or retrofitting. Full structural 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. When possible, it is often better to repair or upgrade the structure by retrofitting.

The strengthening of concrete structures with externally bonded reinforcement is generally done by using either steel plates or Fibre Reinforced Polymer (FRP) laminates. Each material has its specific advantages and disadvantages. The plate bonding technique is now established as a simple and convenient repair method of enhancing the flexural, shear and compressive performance of concrete structures. Fibre reinforced polymers offer numerous beneficial characteristics over steel including excellent corrosion resistance, non magnetic, non conductive, generally resistant to chemicals, good fatigue resistance, low coefficient of thermal expansion, and high strength to weight ratio as well as being lightweight. FRPs also possess a high specific stiffness and an equally high specific strength in the direction of fibre alignment. Use of FRPs provides a high structural efficiency and their low density makes physical implementation much easier. Unfortunately, FRPs are also expensive, but the higher costs of FRP materials are often offset by savings in reduced periodic maintenance, longer life spans and of reduced labour costs.

II. Previous Research Works on Beams

Investigation on the behaviour of FRP retrofitted reinforced concrete structures has in the last decade become a very important research field. In terms of experimental application several studies were performed to study the behaviour of retrofitted beams and analyzed the various parameters influencing their behaviour.

Almusallam *et al.,* 2001. They cast eighteen specimens and were divided into three series. The first series consisting of three groups was employed as a control group without any strengthening. The second series consisting of three groups, first group were strengthened with one layer of GFRP laminate, second group were strengthened with two layer of GFRP laminate and third group were strengthened with four layer of GFRP laminate. The third series consisting of two groups, first group were strengthened with one layer of CFRP laminate and second group were strengthened with two layer of CFRP laminate. The thickness of GFRP and CFRP is 1.3 and 1 mm. They found that beam strengthened with CFRP laminate require less number of layers than those strengthened with glass FRP laminate for the same load capacity. The computational analysis to determine the nominal capacity of RC beams strengthened with external FRP laminate proved to be good and efficient in the prediction of experimental values and indicates that a significant gain in flexural strength can be achieved by bonding FRP laminate to the tension face of RC beams.

Brena *et al*., 2003 experimentally carried out tests on twenty rectangular beams. Two beams were used as reference beams and eighteen beams were strengthening using carbon fibre reinforced polymer. Four composite material systems used such as two unidirectional carbon fibres, woven fabric and pultruded plates were applied to the surface of the beams with four different layouts. In the first layout the CFRP composites were attached to the soffit of beams. Second layout straps were wrapped around the bottom of the cross section and extended vertically to within 75 mm of the compression face. Third layout the longitudinal composites were positioned on the sides of the beams rather than on the bottom surface. Fourth layout the longitudinal composites were positioned on the sides of the beams rather than on the bottom surface in addition with that transverse straps were used with the side application of the composites. The author concluded that the debonding is prevented by adding transverse straps alone the shear span and debonding of the longitudinal composites was delayed. The flexural capacity of reinforced concrete beams can be increased by attaching CFRP laminate than control beams.

Pannirselvam, *et al*., 2008 analyzed fifteen rectangular beams experimentally of 3 m length. Three rectangular beams were used as control beam and the remaining were strengthened with GFRP laminates on the soffit of the rectangular beam. Three different steel ratios with two different GFRP types such as chopped strand mat and woven roving and two different thicknesses in each type of GFRP were used. The authors carried out the flexural test with two-point loading to study the performance of FRP plated beams in terms flexural strength, deflection, ductility and compared with the unplated beams. The test results show that the beams strengthened with GFRP laminates exhibit better performance. The increase in first crack loads were 88.89% and 100% for 3 mm and 5 mm of woven rovings GFRP plated. The increase in ductility in terms of energy and deflection was found to be 56.01% and 64.69% for 3 mm and 5 mm thick.

III. Concrete

For concrete the maximum aggregate size used was 20 mm. The concrete mix proportion designed by IS method to achieve the strength of 20 N/mm^2 .

Water	Cement	Fine Aggregate	Coarse Aggregate
186 lit	413 Kg	617.34 Kg	1189.15 Kg
	1	1.49	2.88

The design water cement ratio was 0.45. Three cube specimens were cast and tested at the time of beam test (at the age of 28 days) to determine the compressive strength of concrete. The average compressive strength of the concrete was 20 N/mm^2.

IV. Reinforcing Steel

The main Reinforcement bars of four numbers of 8 mm diameter bars are used. The vertical stirrups of 6 mm diameter of 150 mm centre to centre to spacing.

V. Casting of Samples

Cube mould, cylinder mould and beam mould were used to prepare the concrete specimens for the determination of various strength characteristics. Care was taken during casting and vibrator was used for proper compaction. All the moulds were cleaned and oiled properly. These were securely tightened to correct dimensions before casting. Care was taken that there is no gaps left from where there is any possibility of leakage out of slurry.

a) Beam specimen

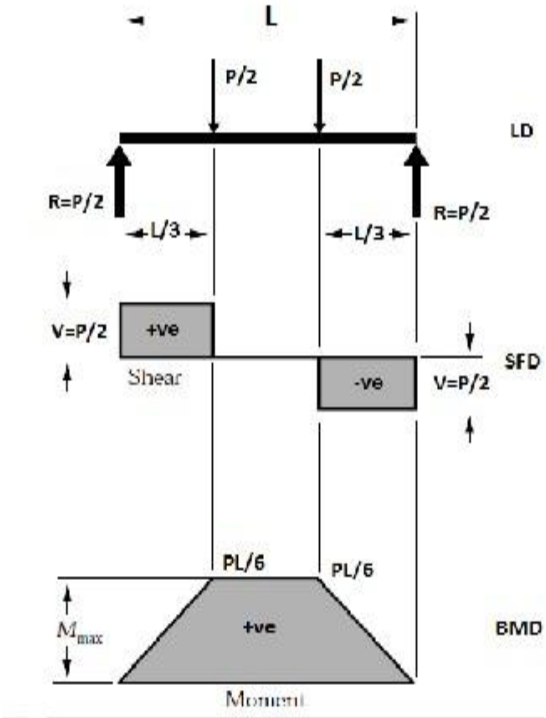
The size of beam was100 mm x 200 mm and the length of beam was1500 mm long.

b) Curing:

The concrete is made to prevent or replenish the loss of water which is essential for the process of hydration and hence for hardening Concrete is usually cured by water although scaling compounds are also used. It makes the concrete stronger, more durable, more impermeable and more resistant to abrasion and to frost. Curing is done by spraying water or by spending wet hessian cloth over the surface. Usually, curing start as soon as the concrete is sufficiently hard. Normally 28 days of curing is done.

VI. Wrapping Of Samples

The experimental work consists of casting of nine reinforced concrete (RC) beams having grade M20, cross-sectional dimensions of 100 mm x 200 mm and 1500 mm length. We provided 2 numbers of 8mm Ø bottom reinforcement and 2 numbers of 8mm Ø top with 6mm Ø vertical stirrups @ 150mm c/c. The strengthening of the beams using GFRP sheet is done with wrapping at constant bending moment occurs in the beam. It means, for three beams to wrap the GFRP in between the loading point. Similarly CFRP wrapped in between loading point for another three beams.



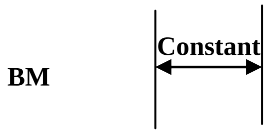


Figure 1 Constant Bending Moment occurs in between two equal point loading

VII. Wrapping Length

The exact length of wrapping is 400 mm at the centre of beam. To measure at the centre point of the beam to either side of 200 mm, wrap three beams with the bidirectional GFRP.

Similarly, done with same procedure, to wrap three beams of unidirectional CFRP. The experimental study consists of casting of totally nine of reinforced concrete (RC) beams, for three of control beams, another three beams for wrapping GFRP and remaining three beams for wrapping CFRP.To mark centre point, loading point and supporting point as clearly.

The length of the beam is 1500 mm.To mark the supporting point is 150 mm from each corner of the beam,then loading point is 400 mm from the each support.So wrap the materials of GFRP and CFRP in between the loading point of 400 mm.The figure 1 shows the constant bending moment occur in the simply supported with equal point load acting.The figure 2 shows the marking and wrapping distance.

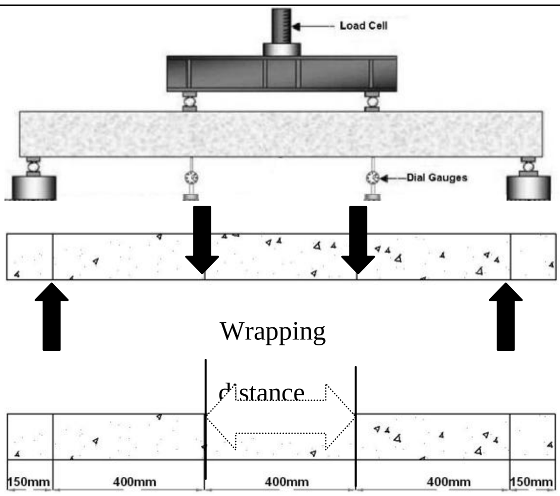


Figure 2 wrapping length

VIII. Epoxy Resin

The success of the strengthening technique critically depends on the performance of the epoxy resin used. NITOWRAP resin was used. It has various advantages including; Rigid connection of narrow joints, Bonding of concrete elements, bridge parts, columns, Patching vertical and overhead surfaces, Repair of joint corners etc.

IX. Number of beams

Total number reinforced concrete beams are nine. It is separated into each three beam,

A. First set of (3 numbers) RC beams designated as control RC beams (SET I).

B. Second set of (3 numbers) RC beams (SET II); all are strengthened using GFRP wrap.

C. Third set of (3 numbers) RC beams (SET III); all are strengthened using CFRP wrap

X. Testing for Beams

A two-point flexure bending system was adopted for the tests. All the beams were designed to fail flexure only, premature failure by shear was avoided by providing adequate number of stirrups at 2D distance from both ends, after mounting the test beams over two supporting pedestals kept at the two ends, the concentrated loads consisting the two point loading scheme was applied by means of SOT hydraulic jack, using distributor made of steel box section. For measurements of deflection.

Dial gauges were located at three places, one at mid span and other two under the load points. The deflection frame should be a metallic device that attaches to the concrete beam's neutral axis above the pin and roller on either side of the beam. It should contain a metallic stick at least on one side of the beam for which a LVDT can be held by. The LVDT should be placed at the beam's midspan and should be allowed to read deflections from the epoxied angle bracket. Attach the deflection frame by screwing it into the points marked on the beam with the LVDT holder just under the angle bracket. Make sure all screws and nuts are tightened on the frame against the beam.

Figure.3 Testing set up of loading frame with data logger

The LVDT 1was installed in the middle of the beam to record the data of a vertical deflection. The LVDT 2 was installed in the any side of the beam (away from middle) to record the data of a deflection.

Static load is applied by using the load cell. The two supports were placed at the end of the beam and the actual location of the support is 150 mm from both ends as shown in Figure.

The load applied for this test was controlled manually and all the data appeared on the computer that are connected to the machine, The cracks that developed on the beam are marked using permanent marker at all load level applied on the beam.

The beam was tested until it reaches the ultimate load. However, for the beam with the CFRP plate it was tested until the plate debonded and the load was recorded and the test was continued until the beam reached the ultimate load.

At the end of each load increment, observations were recorded for under load deflection, midpoint deflection, crack development and its propagation on the beam surfaces. The load at first crack, ultimate load, type of failure etc., were carefully
Observed and recorded.

a) Testing of control beam

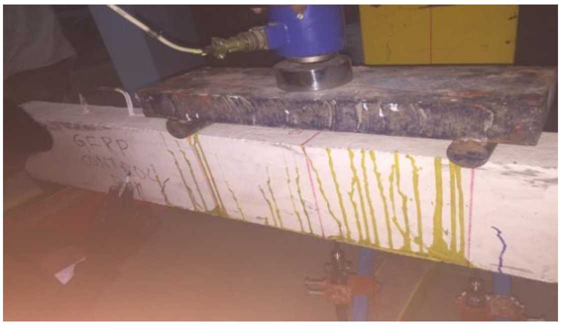
A. First set of (3 numbers) RC beams designated as control RC beams (SET I).

The above figure shows the testing of control beam and crack pattern of control beam. The values of load and corresponding deflection are noted.

b) Testing of GFRP wrapped beam

Second set of (3 numbers) RC beams (SET II); all are strengthened using GFRP wrap

Applying the load from load cell to GFRP wrapped beam and noted the crack pattern, ultimate load and deflection.

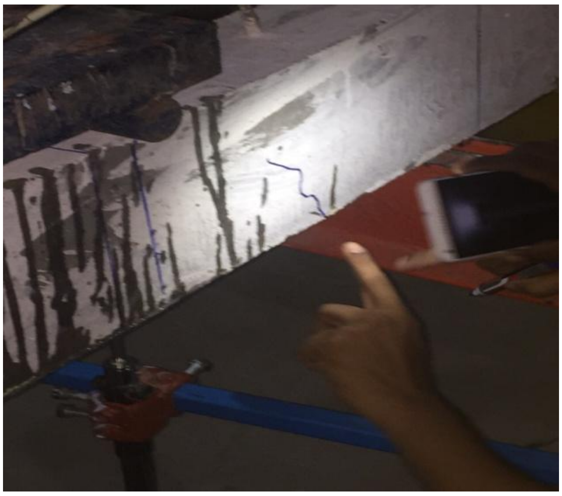


The above figure shows crack pattern of GFRP beam.

c) Testing CFRP beam

A. Third set of (3 numbers) RC beams designated as CFRP wrapped RC beams (SET III).

Note the load and corresponding deflection values of CFRP wrapped beam. The following figure shows the crack pattern of the CFRP beam.



XI. Experimental Results

From the testing we get the following values of deflection from corresponding load applied. The LVDT 1 shows the deflection of middle portion and LVDT 2 shows the deflection of away from middle portion

Table.1 Load and corresponding deflection values for control beam

LOAD (kN)	LVDT 1 (mm)	LVDT 2 (mm)
0	0	0
5	0.2	0.3
10	0.5	0.4
15	0.7	0.6
20	1.1	1.0
25	1.7	1.6
30	2.3	2.2
35	2.8	2.7
40	3.2	3.1

From the table 1 the deflection of 0.5 mm at the middle and 0.4 mm for away from middle for the load of 5kN applied. At maximum of deflection 3.2 mm for middle and 3.1 mm for away from middle portion at the load of 40 kN applied in the control beam.

Table.2 Load and corresponding deflection values for GFRP wrapped beam

LOAD (kN)	LVDT 1 (mm)	LVDT 2 (mm)
5	0.1	0.1
10	0.4	0.3
15	0.7	0.5
20	1.1	0.9
25	1.6	1.5
30	2.0	1.9
35	2.6	2.5
40	3.1	2.9

From the table2 the deflection of 0.1 mm at the middle and 0.1 mm for away from middle for the load of 5 kN applied. At maximum of deflection 3.1 mm for middle and 2.9 mm for away from middle portion at the load of 40 kN applied in the GFRP Wrapped beam.

Compare the results from control beam to GFRP beam, the deflection of GFRP Wrapped beam as less compare to deflection of control beam from initial stage to end.

At the middle deflection for the control beam has 0.2 mm but GFRP wrapped beam has 0.1 mm for the load of 5 kN.Similarly at 40 kN load applied in the control beam we get the deflection of away from middle portion is 3.1 mm, and GFRP beam has 2.9 mm.

Table.3 Load and corresponding deflection values for CFRP wrapped beam

LOAD (kN)	LVDT 1 (mm)	LVDT 2 (mm)
5	0.2	0.1
10	0.4	0.3
15	0.6	0.5
20	0.9	0.8
25	1.4	1.2
30	1.8	1.7
35	2.2	2.1
40	2.5	2.4

Compare the results from control beam to CFRP Wrapped beam, the deflection of CFRP Wrapped beam as less compare to deflection of control beam from initial stage to end.

At the middle deflection for the control beam has 0.5 mm but CFRP wrapped beam has 0.2 mm for the load of 5 kN.Similarly at 40 kN load applied in the control beam we get the deflection of away from middle portion is 3.1 mm, and CFRP beam has 2.4 mm.

Compare the results from GFRP Wrapped beam to CFRP Wrapped beam, the deflection of CFRP Wrapped beam as less compare to deflection of GFRP beam from initial stage to end.

At the middle deflection for the GFRP beam has 0.3 mm but CFRP wrapped beam has 0.2 mm for the load of 5 kN. Similarly at 40 kN load applied in the GFRP beam we get the deflection of away from middle portion is 2.9 mm, and CFRP beam has 2.4 mm.
The table 4 shows the ultimate load for the control beam, GFRP wrapped beam and CFRP wrapped one layer at constant bending moment occur in the beam.

Table.4 Ultimate Load and corresponding deflection values

TYPE OF BEAM	WRAPPING	LAYERS	ULTIMATE LOAD (kN)
Control Beam	–	–	71.8
GFRP Beam	Constant Bending Moment	1 Layer	74.0
CFRP Beam	Constant Bending Moment	1 Layer	79.0

Compare the values Ultimate load of control beam to GFRP wrapped beam, we get ultimate load slightly higher in GFRP wrapped beam. The value of ultimate load for control beam has 71.8 kN, GFRP beam has 74 kN.

At the same time CFRP beam has 78 kN. It is much more than control beam. Also ultimate load value is more as compare to GFRP wrapped beam.

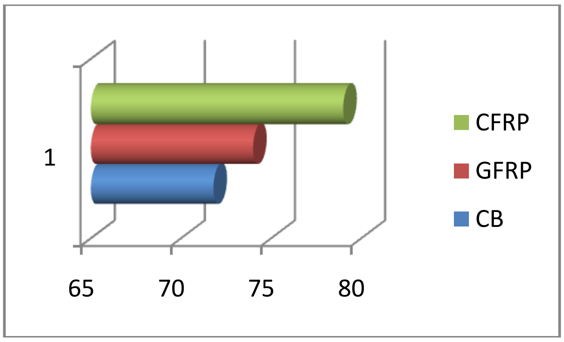


Chart.1 ultimate load of control beam, GFRP and CFRP beam

By plotting the chart we get clear idea about ultimate load of control beam, GFRP wrapped beam and CFRP wrapped beam.

The table 5 shows the values of initial cracking load for control beam, GFRP wrapped beam and CFRP Wrapped beam.

Table.5 Initial Cracking Load values for beams

TYPE OF BEAM	WRAPPING	LAYERS	INITIAL LOAD (kN)
Control Beam	–	–	37
GFRP	Constant Bending Moment	1 Layer	40
CFRP	Constant Bending Moment	1 Layer	44

Compare the values initial cracking load of control beam to GFRP wrapped beam, we get initial crack slightly later in GFRP wrapped beam. The value of initial crack load for control beam has 37 kN, GFRP beam has 40 kN.

At the same time CFRP beam has 44 kN. It is more than control beam. Also initial crack load value is more as compare to GFRP wrapped beam.

By plotting the chart we get clear idea about initial cracking load of control beam, GFRP wrapped beam and CFRP wrapped beam.

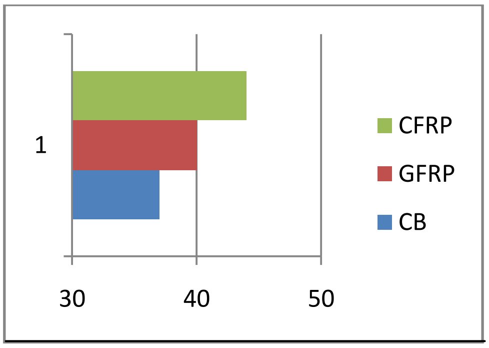


Chart.2 Initial load of control beam, GFRP and CFRP beam

Then to plot the graph to load (kN) in Y axis and corresponding deflection (mm) in X axis. The chart 3 shows the middle deflection of control beam and GFRP beam.

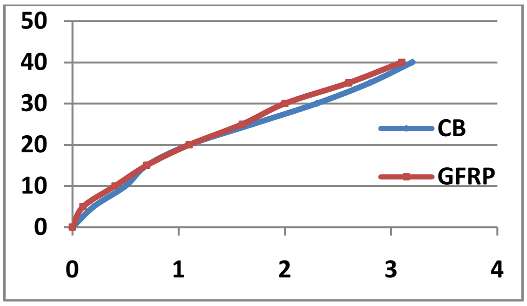


Chart.3 Load Vs deflection at middle portion of control beam and GFRP beam

The values of load and corresponding deflection of CFRP wrapped beam with control beam to be plotted. CFRP wrapped beam has less deflection values in middle portion as compare to control beam deflection.

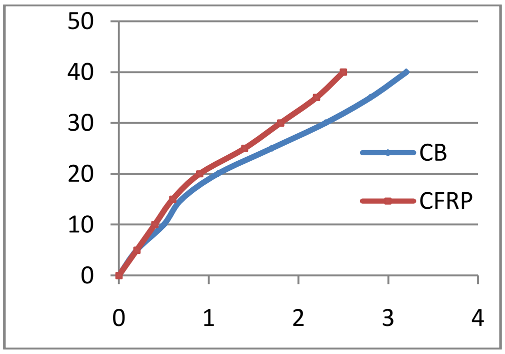


Chart.4 Load Vs deflection at middle portion of control beam and CFRP beam

Similarly, deflection away from the middle portion in GFRP wrapped beam has less values as compare to control beam deflection.

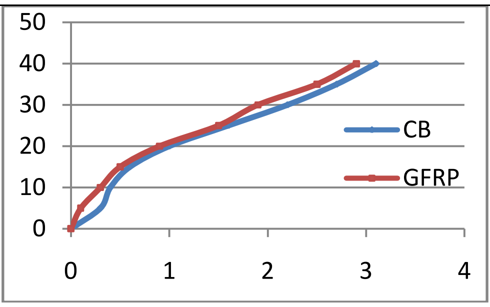


Chart.5 Load Vs deflection at away from middle portion of control beam and GFRP beam

Deflection away from the middle portion in CFRP wrapped beam has much less values as compare to control beam deflection. The chart 6 shows the deflection of control beam and CFRP beam. At the load 40 kN, the deflection of CFRP wrapped beam has less as compare to control beam.

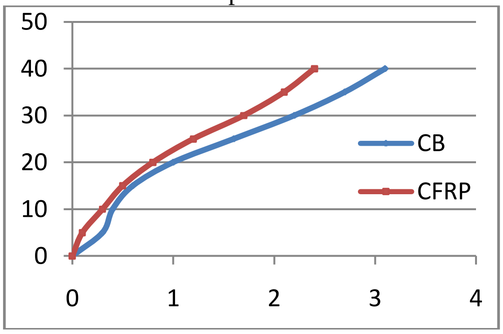


Chart.6 Load Vs deflection at away from middle portion of control beam and CFRP beam

Compare the GFRP wrapped beam and CFRP wrapped beam with control beam. The deflection at middle portion of the beam is plotted in chart 7.The GFRP beam has less deflection but CFRP beam has much less as compared to control beam and GFRP beam.

The deflection at away from middle also less in CFRP beams. The GFRP beams also lower to control beam. The chart 8 shows each values of deflection in control beam, GFRP beam and CFRP beam.

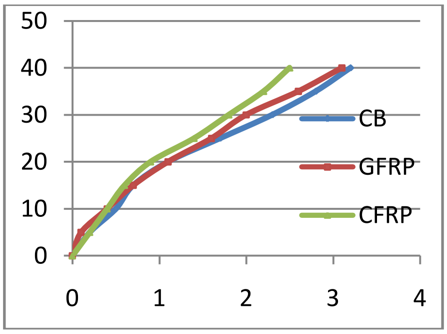


Chart.7 Load Vs deflection at middle portion of control beam ,GFRP and CFRP beam

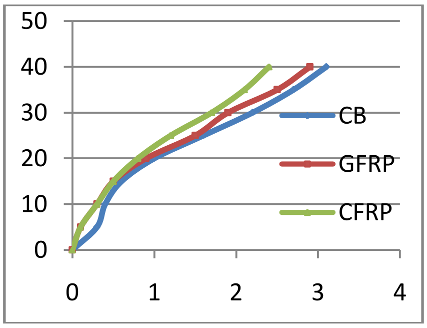


Chart.8 Load Vs deflection at away from middle portion of control beam, GFRP and CFRP beam

XII. Conclusion

Based on the outcome from the project, these differences were identified between Control beam, GFRP beam and CFRP beam.

GFRP vs Control Beam:

- There is a slight increase in strength of the GFRP Centre Wrapped beam when compared with Control Beam.
- The additional strength obtained with single layer of GFRP wrapping material is 10% compared to Control beam of Initial Cracking load.
- Similarly could notice ultimate breaking point load of the beam is also good when compared with Control beam.
- The additional strength obtained with single layer of GFRP wrapping material is 12% compared to Control beam of Ultimate breaking load.

CFRP vs Control Beam:

- For CFRP wrapping at constant bending moment beam has more strength as compared to control beam.
- The additional strength obtained with single layer of CFRP wrapping material is 20% compared to Control beam of Initial Cracking load.
- Similarly could notice ultimate breaking point load of the beam is also good when compared with Control beam.
- The additional strength obtained with single layer of CFRP wrapping material is 32% compared to Control beam of Ultimate breaking load.

CFRP vs GFRP:

- Additional strength obtained from CFRP Wrapped material is 10% higher than GFRP Wrapped material in the initial cracking load.
- Initial Crack in CFRP occurs later than GFRP.
- Ultimate breaking point load increased by 20% in CFRP when compared with GFRP.

As compared to wrapping materials of GFRP and CFRP, we get more strength obtained from CFRP material. But the initial cost is more for CFRP material and resins as compared to GFRP material.

In certain situation we might held up with cost constraints but at the same time we want the Beam strength to be higher than normal beam, in those circumstances we can go with CFRP Centre Wrapped beam instead of full Wrapped beam. Based on the required strength we can select GFRP or CFRP. Also we decide to increase the number of layers of wrapping materials.

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