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Flexural Behaviour of FRC Beams Wrapped With FRP

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***Abstract:** Structural elements such as beams, slabs and columns may require strengthening during their service life period. A concrete structure may need strengthening for many reasons such as to increase live load capacity, to add reinforcement to a member that has been unsigned or wrongly constructed. The FRPs have various advantages like, high strength to weight ratio, corrosion resistance and ease of installation and flexibility in its use. FRP material which are available in the form of sheet are being used to strengthen a variety of RC elements to enhance the flexural, shear and axial load carrying capacity of these elements. The objective of this experiment is to strengthen the RC beams using fibres and FRP sheets in flexure. In this experimental program CFRP and GFRP sheets were applied to the bottom surface and sides of the concrete beam with different configuration and their performance in flexure were studied. In this experimental program eight RC beams of size 1500 x 150 x 200mm were casted with two 10mm dia. bars as tension zone, two 8mm dia. bars as compression zone and 8mm dia. bars @ 200mm c/c spacing as shear reinforcement. The experimental result shows that the flexural strength of FRP wrapped beams were increased in the range of 23.49% to 67.9% in comparison with the flexural strength of the control beam (unwrapped). The flexural strength of the beam wrapped with the single layer CFRP at the soffit and around the sides (for full depth of the beam) and beam wrapped with the single layer GFRP at the soffit and around the sides (for full depth of the beam) exhibits better performance compared with other FRP beams and increase in flexure was 67.9% in comparison with the capacity of the control beam.*

***Keywords:** FRP, GFRP, CFRP, RC beams etc*

I. INTRODUCTION

As construction technology develops and the world population increases, the safety of infrastructure increasingly becomes a focus of public interest. With the development of new construction materials such as Carbon Fiber Composite (CFC), Aramid Fiber Composite (AFC) and glass fiber composites (GFC), the strengthening of concrete structures has been increasingly studied in recent years. In the last decade, the effect of external application of fiber reinforced polymers (FRP) plates and wraps to a reinforced concrete beam to increase their performance has been investigated.

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The use of FRP offers several advantages, related to its high strength to weight ratio, resistance to corrosion, fast and relatively simple application. FRP technology has developed very quickly over the last few years and now more and more FRPs have been produced such as GFRP (glass FRP), CFRP (carbon FRP), AFRP (Aramid FRP), BFRP (basalt FRP). However experiments focus mainly on the behavior of CFRP or GFRP- confined concrete. Therefore, a systematic assessment of the effectiveness of concrete confined with various FRP is necessary. The selection of the most suitable method for strengthening requires careful consideration of many factors including the following engineering issues: [1]

- Magnitude of strength increase;
- Effect of changes in relative member stiffness;
- Size of project (methods involving special materials and methods may be less cost effective on small projects);
- Environmental conditions (methods using adhesives might be unsuitable for applications in high-temperature environments, external steel methods may not be suitable in corrosive environments);
- In-place concrete strength and substrate integrity (the effectiveness of methods relying on bond to the existing concrete can be significantly limited by low concrete strength).
- Dimensional/clearance constraints (section enlargement might be limited by the degree to which the enlargement can encroach on surrounding clear space).
- Availability of materials, equipment's and qualified contractors.
- Construction costs. Maintenance cost and life cycle costs.

The rehabilitation of infrastructures is not new and various projects have been carried out around the world over the past two decades. One of the techniques of strengthening of the RC structural members is through confinement with a composite enclosure. This external confinement of concrete by high strength fiber reinforced polymer (FRP) composite can significantly enhance the strength and ductility and will result in large energy absorption capacity of structural members. FRP material, which are available in the form of sheet, are being used to strengthen a variety of RC elements to enhance the flexural, shear, and axial load carrying capacity of these elements[2]. Only a few years ago, the construction market started to use FRP for structural reinforcement, generally in combination with other construction materials such as wood, steel and concrete. FRPs exhibit several improved properties such as, high strength-weight ratio, high stiffness-weight ratio, flexibility in design, non-corrosiveness, high fatigue strength, and ease of application.

Therefore now a days FRP sheets are using for strengthening beams etc. The objective of this experiment is to strengthen the RC beams using fibres and FRP sheets in flexure. In this experimental program CFRP and GFRP sheets were applied to the bottom surface and sides of the concrete beam with different configuration and their performance in flexure were studied.

II. MATERIALS USED

A. Composite Materials:

Composite materials are engineered materials made from two or more constitute materials with significant different physical or chemical properties and which remains separate and distinct on a macroscopic level within the finished structure. Fiber Reinforced Polymer is an example for composite materials. Composite materials made of fiber embedded in polymer resins are also known as Fiber Reinforced Polymer (FRP). The fiber is usually fiberglass, carbon or aramid, while the polymer is usually an epoxy, vinyl ester or polyester thermosetting plastic [8].

B. FRP Composites:

Fiber reinforced plastics are a category of composite plastics that specifically use fibrous materials to mechanically enhance the strength and elasticity of plastics. FRP composites can be manufactured in many shapes and forms. Applications of FRP composites in civil/infrastructure engineering are diverse and may include internal reinforcement, the most popular forms of FRP are smooth and deformed bars, pre-stressing tendons and pre-cured and cured-in place sheets/shells. FRP bars and tendons are currently produced with sizes and deformation patterns similar to those of steel bars and strands. FRP composites are light in weight, which means they are easier to transport and install. They are corrosion- resistant and therefore perform better in terms of long-term durability and maintenance cost. FRP pre-cured and cured-in-place sheets are used for external concrete reinforcement and FRP shells have been used as jackets for columns [9].

C. Type of Fibres

A large variety of fiber materials in various sizes, shape have been developed for use in FRC. They are commercially available for use in the construction industry. Currently steel, glass, polymeric and carbon fibres are commonly used. And natural fibres, such as bamboo, akwara, aramid, asbestos and cotton etc are of limited use. These fibres are classified into metallic fibres and non-metallic fibres.

D. Metallic Fibres

Some of the metallic fibres used in concrete are steel fiber, low carbon steel fiber, galvanized iron fiber and aluminum fiber. Among these fibres steel fiber is one of the most commonly used fibres. Other fiber such as, low carbon steel fiber having some disadvantages such as low strength, high cost and more corrosive compared to steel fiber and aluminium fiber is also having some disadvantage compared to steel fiber such as lightweight, high cost and low strength. Due to above said limitations these fibres are rarely used in construction with concrete.

E. Steel Fibres:

Steel fibres for use in concrete are available in a number of shapes, sizes and metal types. Many different types of fiber with round, rectangular and crescent shaped cross sections are commercially available. They range in ultimate strength from 345 to 2070 MPa. Corrosion of steel fibres in concrete with high water-to-cement ratio may cause deterioration. The free moisture in wet concrete provides a medium, which facilitates transport of chlorides towards the metal. It also increases the electrical conductivity of material, thus aiding tendency for electrochemical corrosion. However, in actual field cases, corrosion of carbon steel fibres has been found to be minimal. When fibres were exposed on a surface, they showed evidence of corrosion; however, internal fibres showed no corrosion. The crack-arrest and crack control mechanism of SFRC results in the improvement of all properties associated with cracking, such as strength, stiffness, ductility, energy absorption, and the resistance to impact, fatigue and thermal loading.

F. Application of SFRC

The uses of SFRC over the past thirty years have been so varied and so widespread, that it is difficult to categorize them. The most common applications are pavements, tunnel linings, pavements and slabs, shotcrete. There has also been some recent experimental work on roller-compacted concrete (RCC) reinforced with steel fibres. The list is endless, apparently limited only by the ingenuity of the engineers involved. The fibres themselves are unfortunately relatively expensive, 1% steel fibre addition will approximately double the material costs of the concrete, and this has tended to limit the use of SFRC to special applications.

G. Non-Metallic Fibres

In this classification we come across many fiber such as Asbestos, Glass, Carbon, Polypropylene, Recron, Nylon, Acrylic, Aramid, Kevlar, Coconut coir, Sisal, Sugar cane bagasse, Bamboo, Jute, Wood and Vegetables. In these fibres some are available naturally such as, coconut coir, sisal, bamboo, jute [10].

III. EXPERIMENTAL INVESTIGATION

The objective of the experimental work is to study the flexural behaviour of SFRC beam wrapped with FRP sheets (GFRP/CFRP) with different amount and configuration of sheets.

In this investigation eight beams of size 1500mmx150mmx200mm were casted in the following manner,

- One beam of RC, which served as a control beam (unwrapped) without steel fibers.
- One beam of FRC with 1% of fiber content by volume
- Three beams of FRC beam wrapped with GFRP sheet
- Three beams of FRC beam wrapped with CFRP sheet

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The beams were wrapped with different amount and configuration of glass fiber composite sheets (GFCS) and carbon fiber composite sheets (CFCS). These wrapped beams were tested in flexure till failure and results were compared with control beam.

- The flexural behaviours of FRC beams wrapped with FRP under static loading were investigated.
- The load deflection behaviours were studied.
- The comparison between FRC beams wrapped with FRP sheets and the plain concrete beam were studied under this experimental program.

IV. SPECIMEN DETAILS

Cubes Specimens: Six cubes of size 150mm × 150mm × 150mm were casted by using M20 mix concrete and were cured through accelerated curing for 20 hrs at 61˚C.

A. Beam Specimens:

Total eight beams of size 1500mmx150mmx200mm were casted and were of the following,

- One beam of RCC, which served as a control beam (unwrapped).
- One beam of SFRC with 1% of fiber content by volume.
- Three beams of SFRC wrapped with GFRP sheets named Set I.
- Three beams of SFRC wrapped with CFRP sheets named Set II.
- The beams were loaded up to the ultimate load. The beams were wrapped with different amount and configuration of glass fiber glass sheets (GFRP) and carbon fiber sheets (CFRP). These wrapped beams were tested in flexure till failure and results were compared with control beam.

B. Each Beam has A Different Strengthening Scheme as Described below:

B1 : Control RC beam without steel fibres and FRP wrapping.

B2 : Steel fibres RC beam (SFRC).

Set I:

B3: SFRC beam with single layer of GFRP sheets attached to soffit of the beam.

B4: SFRC beam with single layer of GFRP sheets wrapped around the sides (for half depth of beam) and soffit of beam.

B5: SFRC beam with single layer of GFRP sheets wrapped around the sides (for full depth of beam) and soffit of beam.

Set II:

B6: SFRC beam with single layer of CFRP sheets attached to soffit of the beam.

B7: SFRC beam with single layer of CFRP sheets wrapped around the sides (for half depth of beam) and soffit of beam.

B8: SFRC beam with single layer of CFRP sheets wrapped around the sides (for full depth of beam) and soffit of beam.

V. STRENGTHENING SCHEME OF BEAMS

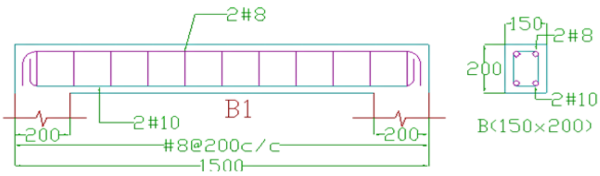

Fig.1: Control Beam (B1)

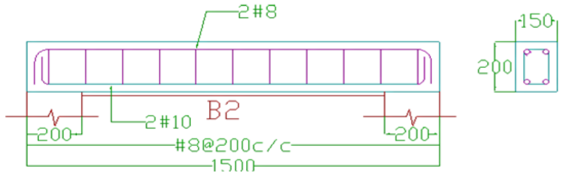

Fig.2: Steel Fiber Reinforced Concrete (SFRC) Beam (B2)

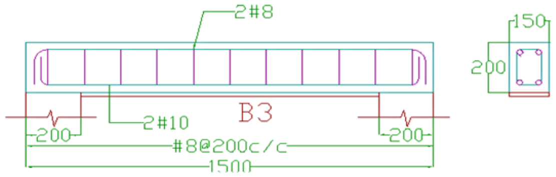

Fig.3: SFRC beam wrapped with GFRP at soffit (B3)

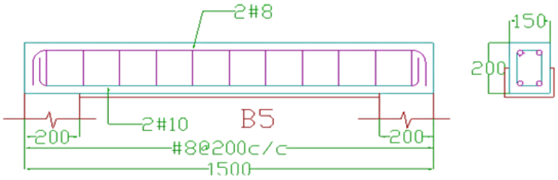

Fig.4: SFRC beam wrapped with GFRP upto half depth (B4)

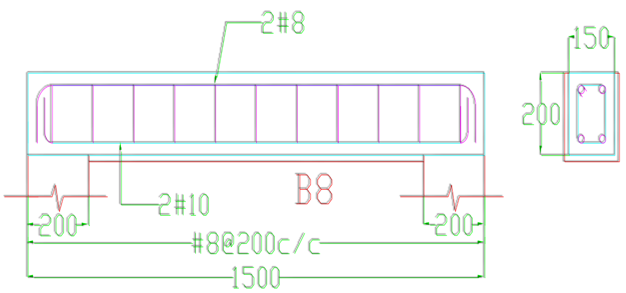

Fig.5: SFRC Beam Wrapped with GFRP upto Full Depth (B5)

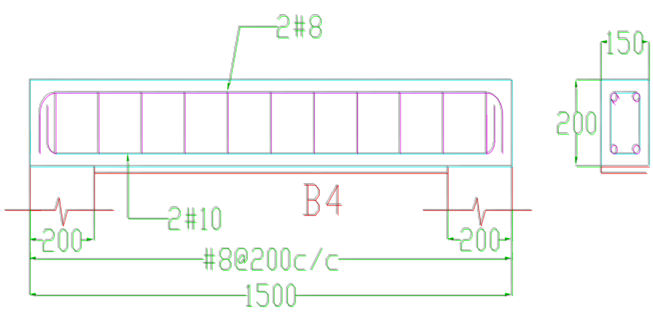

Fig.6: SFRC Beam Wrapped with CFRP at Soffit (B6)

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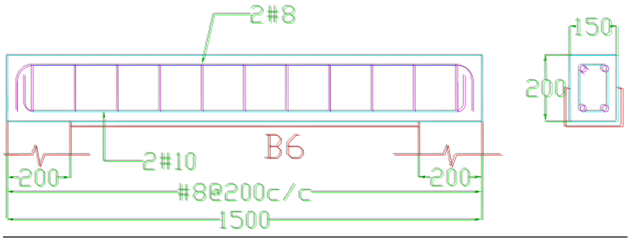

Fig.7: SFRC Beam Wrapped with CFRP upto Half Depth (B7)

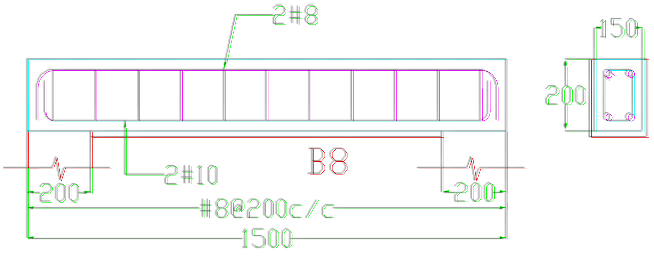

Fig.8: SFRC Wrapped with CFRP Upto Full Depth (B8)

Table 4.2: Load Versus Deflection Values of Beam B1

Sl. No.	LOAD in KN	Deflection in MM	Remarks & Crack Width	
1	0	0		
2	1.5696	0.06		
3	3.1392	0.11		
4	4.7088	0.16		
5	6.2784	0.2		
6	7.848	0.22		
7	9.024	0.26		
8	10.2	0.3		
9	11.5758	0.34		
10	13.1454	0.38		
11	14.715	0.41		
12	15.891	0.44		
13	17.067	0.48		
14	18.4428	0.54		
15	20.0124	0.58		
16	21.582	0.63		
17	22.758	0.75		
18	23.934	0.8		
19	25.113	0.85		
20	26.289	0.93		
21	27.468	1.04		
22	29.0376	1.17		
23	30.6072	1.28		
24	32.1768	1.4		
25	33.7464	1.54	1st crack	2.5mm
26	35.316	1.73		
27	36.8856	1.87	2nd crack	1.2mm
28	38.4552	2.12		
29	40.0248	2.3		
30	41.5944	2.45	3rd crack	0.8mm
31	43.164	2.66		
32	44.34	2.72		
33	45.516	2.87		
34	47.088	2.96		
35	49.05	3.14		
36	51.012	3.36	4th crack	0.5mm
37	52.188	3.46		
38	53.364	3.67		
39	54.347	3.82		
40	55.131	3.92		
41	55.917	4.2	5th crack	0.3mm
42	58.6638	4.92		
43	61.4106	5.28		
44	63.372	5.34		
45	64.50	5.58		

Table 4.3 Load Versus Deflection Values of Beam B2

Sl. No.	LOAD in KN	Deflection in MM	Remarks &	Crack Width
1	0	0		
2	1.5696	0.06		
3	3.1392	0.12		
4	4.7088	0.18		
5	6.2784	0.24		
6	7.848	0.31		
7	9.024	0.36		
8	10.2	0.42		
9	11.5758	0.46		
10	13.1454	0.52		
11	14.715	0.59		
12	15.891	0.63		
13	17.067	0.7		
14	18.4428	0.77		
15	20.0124	0.81		
16	21.582	0.86		
17	22.758	0.99		
18	23.934	1.02		
19	25.113	1.15		
20	26.289	1.21		
21	27.468	1.32		
22	29.0376	1.38		
23	30.6072	1.5		
24	32.1768	1.63		
25	33.7464	1.8		
26	35.316	1.87		
27	36.8856	1.98	1st crack	2.2mm
28	38.4552	2.08		
29	40.0248	2.23		
30	41.5944	2.4		
31	43.164	2.44		
32	44.34	2.67		
33	45.516	2.76		
34	47.088	2.96		
35	49.05	3.02	2nd crack	1.0mm
36	51.012	3.1		
37	52.188	3.29		
38	53.364	3.38		
39	54.347	3.48		
40	55.131	3.58		
41	55.917	3.73		

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42	58.6638	3.84		
43	61.4106	3.98		
44	63.372	4.06		
45	64.548	4.15		
46	65.727	4.34	3rd crack	0.7mm
47	66.903	4.58		
48	68.079	4.68		
49	69.4518	4.77		
50	71.0214	4.9		
51	72.594	5		
52	73.77	5.09		
53	74.946	5.29		
54	76.125	5.56		
55	77.301	5.9		
56	78.48	6.51	4th crack	0.5mm
57	79.656	7.06		

Table 4.4 Load Versus Deflection Values of Beam B3

Sl. No.	LOAD in KN	Deflection In MM	Remarks	
1	0	0		
2	1.5696	0.05		
3	3.1392	0.08		
4	4.7088	0.11		
5	6.2784	0.15		
6	7.848	0.2		
7	9.024	0.24		
8	10.2	0.28		
9	11.5758	0.32		
10	13.1454	0.36		
11	14.715	0.4		
12	15.891	0.44		
13	17.067	0.46		
14	18.4428	0.51		
15	20.0124	0.57		
16	21.582	0.62	No cracks seen	
17	22.758	0.66		
18	23.934	0.75		
19	25.113	0.78		
20	26.289	0.82		
21	27.468	0.92		
22	29.0376	0.97		
23	30.6072	1.03		
24	32.1768	1.1		
25	33.7464	1.2		
26	35.316	1.25		
27	36.8856	1.39		
28	38.4552	1.44		
29	40.0248	1.52		
30	41.5944	1.76		
31	43.164	1.9		
32	44.34	2		
33	45.516	2.12	1st crack	0.8mm
34	47.088	2.29		
35	49.05	2.5		
36	51.012	2.58		
37	52.188	2.63		
38	53.364	2.76		
39	54.347	2.88		
40	55.131	3.05		
41	55.917	3.16		
42	58.6638	3.32	2nd crack	0.5mm
43	61.4106	3.45		
44	63.372	3.53		
45	64.548	3.62		
46	65.727	3.7		
47	66.903	3.79	3rd crack	1.3mm
48	68.079	4.04		
49	69.4518	4.23		
50	71.0214	4.37	4th crack	0.5mm
51	72.594	4.6		
52	73.77	4.82		
53	74.946	5.48		
54	76.125	5.58		
55	77.301	5.73	5th crack	2.2mm
56	78.48	5.84		
57	79.656	6.21		
58	80.832	6.58	6th crack	3.0mm
59	82.2078	6.78	7th crack	2.4mm
60	83.7774	7.5		
61	85.347	8.25	8th crack	0.8mm

Table 4.7 Load Versus Deflection Values of Beam B6

Sl. No.	LOAD in KN	Deflection in MM	Remarks	
1	0	0		
2	1.5696	0.03		
3	3.1392	0.06		
4	4.7088	0.1		
5	6.2784	0.13		
6	7.848	0.16		
7	9.024	0.19		
8	10.2	0.21		
9	11.5758	0.25		
10	13.1454	0.29		
11	14.715	0.32		
12	15.891	0.35		
13	17.067	0.36		
14	18.4428	0.46	No cracks were seen	
15	20.0124	0.5		
16	21.582	0.53		
17	22.758	0.58		
18	23.934	0.64		
19	25.113	0.7		
20	26.289	0.74		
21	27.468	0.81		
22	29.0376	0.88		
23	30.6072	0.95		
24	32.1768	1.02		
25	33.7464	1.08		
26	35.316	1.11		
27	36.8856	1.2		
28	38.4552	1.28		
29	40.0248	1.37		

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30	41.5944	1.42		
31	43.164	1.49	1st crack	1.4mm
32	44.34	1.54		
33	45.516	1.6		
34	47.088	1.75		
35	49.05	1.79		
36	51.012	1.91		
37	52.188	2.12		
38	53.364	2.24	2nd crack	1.2mm
39	54.347	2.29		
40	55.131	2.43		
41	55.917	2.5		
42	58.6638	2.62	3rd crack	1.0mm
43	61.4106	2.75		
44	63.372	2.96		
45	64.548	3.03	4th crack	0.4mm
46	65.727	3.16		
47	66.903	3.2		
48	68.079	3.26		
49	69.4518	3.36		
50	71.0214	3.45		
51	72.594	3.56		
52	73.77	3.72		
53	74.946	3.8	5th crack	1.4mm
54	76.125	3.92		
55	77.301	4.01		
56	78.48	4.1	6th crack	1.6mm
57	79.656	4.12		
58	80.832	4.17		
59	82.2078	4.19		
60	83.7774	4.21	7th crack	1.0mm
61	85.347	4.28		
62	86.523	4.31		
63	87.699	4.34		
64	89.0748	4.36		
65	90.6444	4.53		
66	92.214	4.98		
67	93.39	5.28		
68	94.566	5.62	8th crack	1.0mm
69	96.138	5.92		

Table 4.10 Ultimate Load Carrying Capacity, Maximum Deflection of Control Beam and Sfrc and Frp Wrapped Beams and Their Failure.

Beam Description	Ultimate Load in KN	% of Increase in Ultimate Load In Comparison with Control Beam	Maximum Deflection (Mm)	% of Change in Deflection in Comparison with Control Beam Defection	Failure Mode of Beams
B1	64.50	-	5.58	-	Flexure failure at ultimate load
B2	79.656	23.49	7.06	26.52	Flexural cracking
B3	85.347	32.31	8.22	47.31	Flexural cracking and rupture
B4	94.566	46.61	5.65	1.25	Flexural cracking and rupture
B5	106.7328	65.55	8.17	46.41	By rupture of FRP
B6	96.138	49.05	5.92	6.09	Rupture and delamination of FRP
B7	104.769	62.43	5.72	2.51	Delamination & Rupture of FRP
B8	108.3024	67.9	9.61	72.2	Flexure failure

VI. CONCLUSIONS

From this experimental investigation following conclusions are drawn:

1) Initial flexural cracks appear at a higher load for the beam reinforced with steel fiber and still higher load when SFRC beams were wrapped with FRP sheets as compared to the control beam.
2) The ultimate load carrying capacity of the SFRC beams wrapped with different configuration and amount of GFRP sheet has increased in range from 32.31% to 65.55% as compared to the control beam. SFRC beam wrapped with GFRP sheet to the soffit and around the sides (for full depth of beam) has shown the max increase in the ultimate load carrying capacity of 65.55% as compared to the control beam.
3) The ultimate load carrying capacity of the SFRC beams wrapped with different configuration and amount of CFRP sheet has increased in range from 40.05% to 67.90% as compared to the control beam and 20.69% to 35.96% as compared to the SFRC beam. SFRC beam wrapped with CFRP sheet to the soffit and around the sides (for full depth of beam) has shown the max increase in the ultimate load carrying capacity of 67.90% as compared to the control beam and 35.96% when compared with the SFRC beam.
4) Overall from the experimental investigation we conclude that the ultimate load carrying capacity of FRC beam wrapped with CFRP sheet (for full depth of beam) is 67.9% more than the control beam and 31.52% as compared to SFRC beam. Also, the deflection for FRC beam wrapped with CFRP sheet (for full depth of beam) is 72.2% more than the control beam and showed better performance against flexure.
5) From the load deflection behaviour it can be concluded that ductility of the beams increases by wrapping of FRP sheets.

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