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Behaviour of Reinforced Concrete Beam Strengthened With GFRP

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ABSTRACT

To carry out studies some experimental investigations were done on behaviour of RC beams strengthened in flexural and shear by means of GFRP laminates. Outwardly epoxy-bonded GFRP sheets reinforced concrete beams were tested to failure using a two point concentrated static loading system. For this experimental investigation three sets of beams were casted test program. In first set of three beams were casted which were weak in flexure, among them one was controlled beam and rest two beams were strengthened by means of continuous glass fiber reinforced polymer (GFRP) sheets in flexure. For second set, three beams were casted but they were weak in shear, and again among them one was the control beam and left over two beams were strengthened by means of continuous glass fibre reinforced polymer (GFRP) sheets in shear. For third set, three T beams were casted, having one controlled beam along with two beams which were strengthened with GFRP Different amount and configuration was to strengthen the beams with the help of GFRP sheets. For each of the beams experimental data for load and their corresponding deflection were recorded. Also the detailed procedure and their application for strengthening RC beams are included. The orientation of GFRP layers and its effect of number on ultimate load carrying capacity is studied along with this failure mode of the beams are investigated

INTRODUCTION

Basically there are two types of techniques used i.e. seismic resistance based design and Seismic response control design. In former we use Concrete jacketing, Steel jacketing and GFRP wrapping whereas in latter we uses Elastic-plastic, dampers Base isolators and Tuned liquid dampers and many other options are possible. For long time we have been using methods such as addition of shear walls, infill walls, buttresses, etc but with the advancement of technology and research of new material retrofitting of structures can be done with many advantages and FIBRE reinforced composite is one among them.

OBJECTIVE OF WORK

The main objectives of this work are:

To develop new technique for strengthening of concrete structure.

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1. To study the effect of using GFRP sheets on shear behavior of beam
2. To study the behaviour of reinforced concrete (RC) beams under normal loading condition.
3. To determine the effect of various condition of GFRP on different sample for the enhancement of the structure.
4. To obtain the feasibility of this method in present technology.
5. To obtain various negative and positive points regarding this methodology.

SCOPE OF THIS WORK

Over the past three four decades GFRP have came forward as an eye-catching construction material for civil structures, their strengthening and restoration. These highly developed materials have been profitably in use for new structures reinforcement and the rehabilitation or strengthening of existing structure. Their use, analysis, design and method for installation are frequently being explored and it is estimated that their use will continue to meet the demand of the construction industry.

CASTING OF BEAMS

For these experiment three beams sets were casted. In first set of three beams i.e. FB1, FB2 and FB3 which were weak in flexure having same grade of concrete and reinforcement were casted. In same way in second set of three beams i.e. SB1, SB2 and SB3 which were weak in shear same grade of concrete and reinforcement were casted. In third set of three beams we used T-Beams i.e. TB1, TB2, and TB3. The specimens are identical in dimensions. The c/s dimensions of the first two set of beams is 300 mm by 200 mm along with length of 2400 mm. In first set 2, 12 mm φ bars were used as the main longitudinal reinforcement as well as 6 mm φ bars as stirrups with spacing of 75 mm c/c where as in second set, 3, 12 mm φ bars were used as the main longitudinal reinforcement but without any stirrups. In third set beams have Length of 2m, flange width of 0.35m, web of width of 0.15 m, flange depth was .10m, and overall depth was .35m.20 mm φ HYSD bars were used as major reinforcement along with 8 mm φ HYSD steel bars for shear reinforcement

MATERIALS FOR CASTING

Cement

For the investigation Portland slag cement (PSC) – 43 grades was used. For its physical properties it was tested in harmony with IS provision.

Fine aggregate

From river bed of Koel the fine aggregate were obtained, which were free from all sorts of organic impurities and was then used in this experimental program. The fine aggregate was passed through 4.75 mm sieve along with specific gravity of 2.68. The fine aggregate was of grading zone III as stated by Indian Standard specifications.

Coarse aggregate

Two grades of the coarse aggregates were used, which were non-reactive as well as available in local quarry. First grade include aggregates passing through 4.75 mm sieve as well as hold on 10 mm size sieve. an additional grade have aggregates passing through 10 mm sieve however retained on 20 mm sieve.

Water

Ordinary tap water used for concrete mix in all mix.

Reinforcing steel

HYSD bars of 12 mm φ were used as main reinforcement. 6 mm φ mild steel bars were used for shear reinforcement.

EXPERIMENTAL SETUP

The testing method for the whole specimen was same. Subsequent to the curing period of 28 days was complete; the beam was washed along with its surface and was dirt free for clear visibility of cracks.Two-point loading can suitably be provided by the arrangement shown in Figure.

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The sample was positioned above the two steel rollers bearing parting 150 mm from the ends of the beam. The residual 2000 mm was alienated as shown in the figure into three equal parts of 667 mm. as shown in the figure Two point loading arrangement was done. Loading was made by hydraulic jack of capability 100 KN. Three dial gauges were used for recording the deflection of the beams. One of the dial gauges was placed immediately beneath the center of the beam also the left over two dial gauges were placed immediately beneath the point loads to measure deflections.

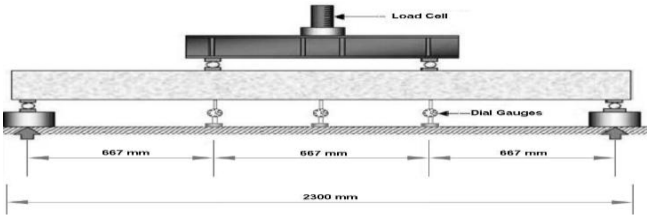

Figure 1: Two point loading experimental set up

PROCEDURE

The members were checked dimensionally before testing, as well as a detailed check was made with carefully recording all the information. After locating and reading all gauges, the load was enlarged incrementally up to the designed working load, by recording loads and deflections at each stage. Loads will then usually be increased yet again in like increments up to failure, by replacing deflection gauges by a properly mounted scale as failure come near. It is essential to keep away from damage to gauges, and even though accuracy is decreased, the deflections at this stage will more often than not be large and can be effortlessly measured from a distance. in the same way, cracking and manual strain annotations must be balanced as failure approaches if not special safety measures are taken. If it is necessary that exact deflection readings are taken up to failure. Cracking and failure mode was ensured visually, as well as a load-deflection plot was arranged.

RESULTS AND DISCUSSION

FIRST SET OF BEAM

CONTROL BEAM OR FB1

Table 1: Load and deflection analysis of beam FB1

LOAD APPLIED IN KN	DEFLECTION		
	AT LEFT L/3	AT CENTER	AT RIGHT L/3
0	0	0	0
5	0.5	0.7	0.54
10	1.03	1.44	1.09
15	1.5	1.68	1.54
20	1.67	1.86	1.73
25	2.05	2.19	2.11
30	2.53	2.8	2.64
35	3.09	3.49	2.95
40	3.76	4.1	3.62
45	4.03	4.56	4.18
50	4.56	5.18	4.79
55	5.07	5.68	5.19

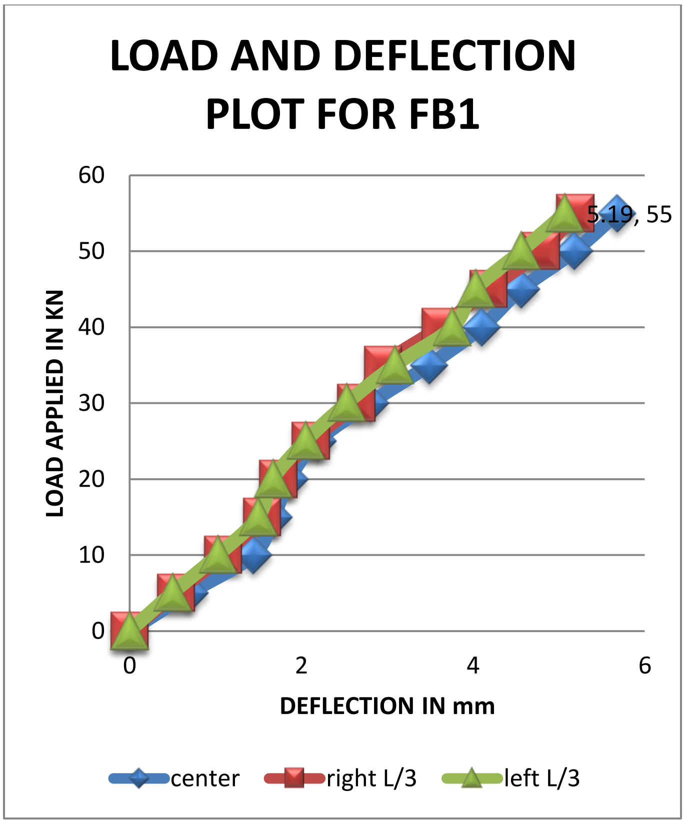

Figure 2: Graph showing load and deflection behaviour of FB1

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BEAM FB2

Table 2: Load and deflection analysis of beam FB2

LOAD APPLIED IN KN	DEFLECTION in mm		
	AT LEFT L/3	AT CENTER	AT RIGHT L/3
0	0	0	0
5	0.2	0.27	0.2
10	0.44	0.48	0.39
15	0.53	0.6	0.53
20	0.74	0.79	0.67
25	0.93	1	0.84
30	1.36	1.48	1.24
35	1.81	1.97	1.69
40	2.4	2.58	2.2
45	2.77	3.08	2.63
50	3.27	3.62	3.08
55	3.6	4	3.43
60	4.07	4.54	3.86
65	4.5	5.04	4.31
70	8.15	9.78	8.58

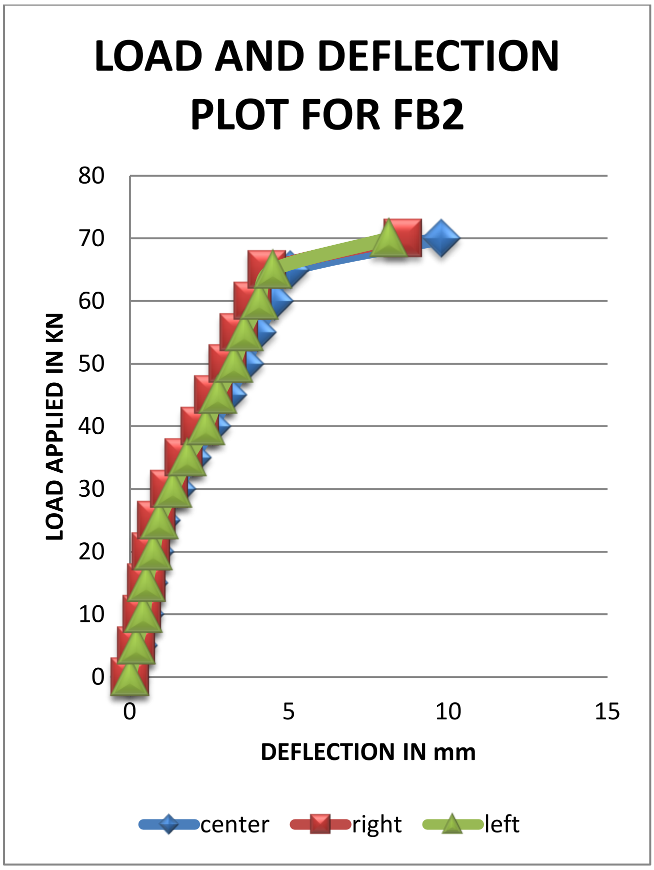

Figure 3: Graph showing load and deflection behaviour of FB2

BEAM FB3

Table 3: Load and deflection analysis of beam FB3

LOAD APPLIED IN KN	DEFLECTION in mm		
	AT LEFT L/3	AT CENTER	AT RIGHT L/3
0	0	0	0
5	0.23	0.26	0.29
10	0.4	0.56	0.53
15	0.53	0.62	0.56
20	0.6	0.81	0.7
25	0.76	1.03	0.89
30	1.14	1.42	1.22
35	1.55	1.86	1.66
40	2	2.35	2.16
45	2.41	2.826	2.49
50	2.8	3.34	2.99
55	3.2	3.735	3.32
60	3.68	4.203	3.79
65	3.98	4.56	4.09
70	4.69	5.41	4.8
75	5.99	6.79	6.13
80	10.12	12.02	11.14
85	12.79	13.27	12.52

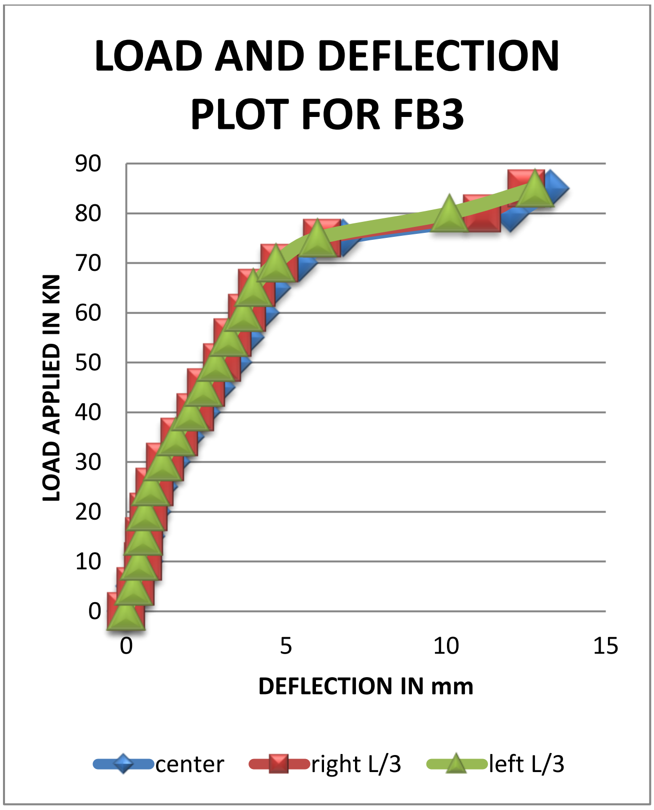

Figure 4: Graph showing load and deflection behaviour of FB3

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COMBINED BEHAVIOR FLEXURE BEAM

Table 4: Load and deflection analysis of beam FB1, FB2, AND FB3

LOAD APPLIED IN KN	DEFLECTION in mm		
	FB1	FB2	FB3
0	0	0	0
5	0.72	0.19	0.3
10	1.4	0.38	0.58
15	1.64	0.49	0.63
20	1.81	0.63	0.74
25	2.17	1.02	0.9
30	2.79	1.49	1.32
35	3.46	1.94	1.77
40	4.02	2.53	2.3
45	4.55	3	2.72
50	5.14	3.5	3.25
55	5.64	3.92	3.64
60		4.48	4.12
65		5.01	4.48
70		9.71	5.32
75			6.67
80			12.02
85			13.27

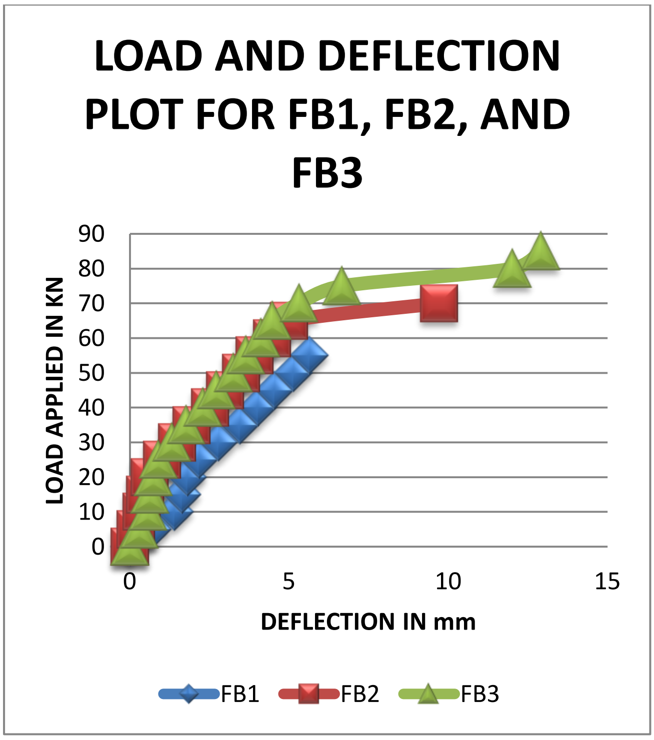

Figure 5: Graph showing combined behaviour of FB1, FB2, AND FB3

SECOND SET OF BEAM

BEAM SB1 AS CONTROL BEAM

Table 5: Load and deflection analysis of beam SB1

LOAD APPLIED IN KN	DEFLECTION in mm		
	AT LEFT L/3	AT CENTER	AT RIGHT L/3
0	0	0	0
5	0.42	0.48	0.43
10	0.83	0.87	0.78
15	0.9	0.95	0.84
20	0.95	1.01	0.89
25	1.233	1.3	1.08
30	1.6	1.8	1.51
35	1.98	2.15	1.86
40	2.36	2.59	2.23
45	2.74	2.99	2.56
50	3.07	3.36	2.9
55	3.39	3.72	3.19
60	3.92	4.2	3.67
65	4.18	4.53	3.91
70	4.56	4.95	4.29
75	5.04	5.49	4.74

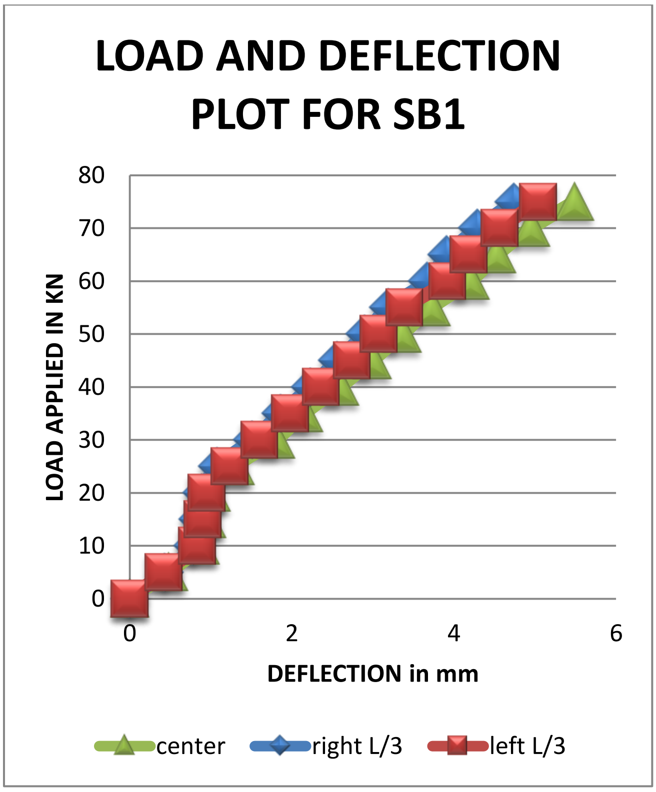

Figure 6: Graph showing load and deflection behaviour of SB1

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BEAM SB2

Table 6: Load and deflection analysis of beam SB2

LOAD APPLIED IN KN	DEFLECTION in mm		
	AT LEFT L/3	AT CENTER	AT RIGHT L/3
0	0	0	0
5	0.23	0.26	0.23
10	0.43	0.51	0.406
15	0.49	0.62	0.51
20	0.52	0.74	0.63
25	0.71	0.9	0.79
30	0.82	1.07	0.9
35	1.24	1.43	1.18
40	1.57	1.76	1.409
45	1.9	2.18	1.76
50	2.26	2.48	2.07
55	2.62	2.93	2.48
60	2.93	3.29	2.76
65	3.26	3.67	3.07
70	3.57	4.01	3.37
75	7.51	8.8	5.41
80	12	13.07	7.67

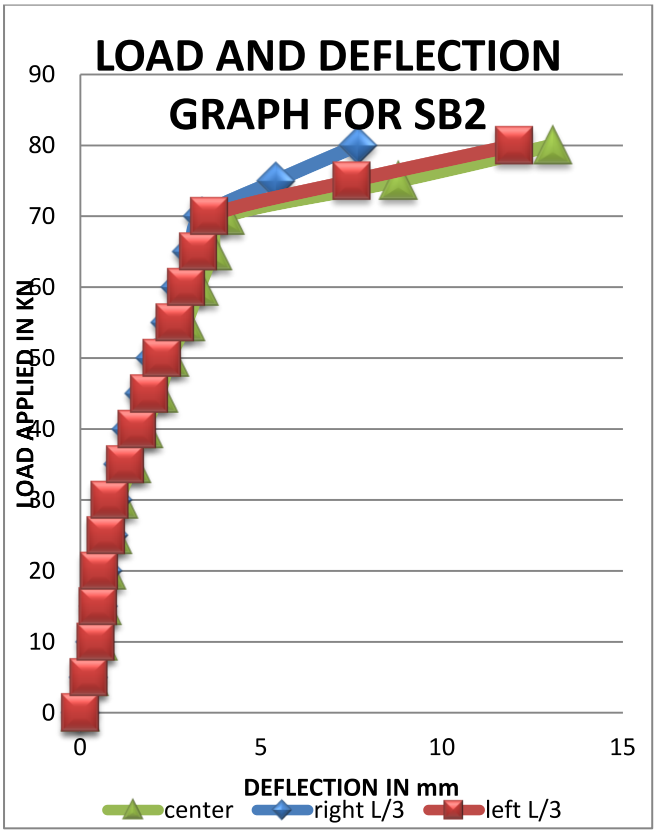

Figure 7: Graph showing load and deflection behaviour of SB2

BEAM SB3

Table 7: Load and deflection analysis of beam SB3

LOAD APPLIED IN KN	DEFLECTION in mm		
	AT LEFT L/3	AT CENTER	AT RIGHT L/3
0	0	0	0
5	0.16	0.23	0.34
10	0.3	0.48	0.63
15	0.48	0.66	0.81
20	0.59	0.81	0.99
25	0.81	1.06	1.24
30	0.99	1.35	1.42
35	1.35	1.78	1.74
40	1.64	2.14	2.03
45	2.03	2.46	2.35
50	2.32	2.89	2.68
55	2.71	3.25	3
60	3	3.58	3.25
65	3.29	3.9	3.61
70	3.58	4.23	3.87
75	6.21	6.96	5.67
80	8.51	8.98	7.57
85	11.06	12.58	10.2
90	13.15	15.67	12.94

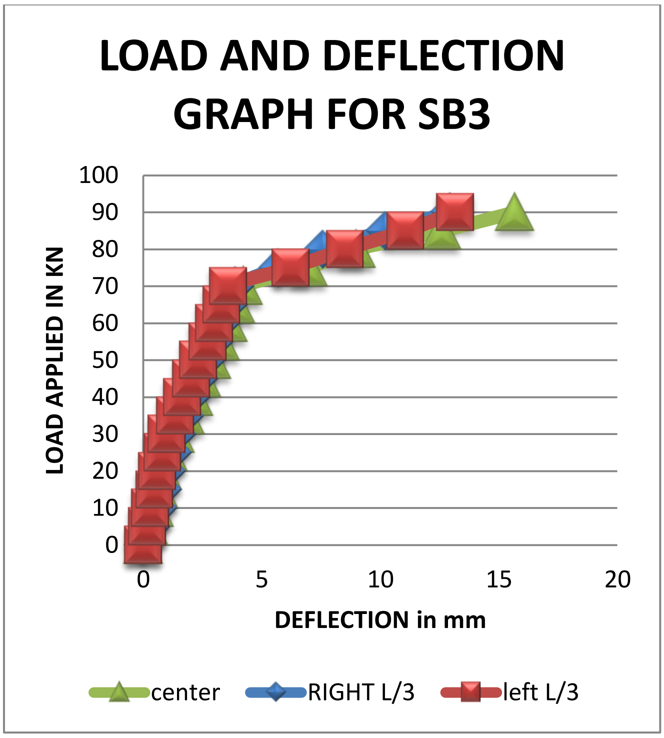

Figure 8: Graph showing load and deflection behaviour of SB3

COMBINED BEHAVIOR OF SECOND SET OF BEAM

Table 8: Load and deflection analysis of beam SB1, SB2, SB3

LOAD APPLIED IN KN	DEFLECTION in mm		
	SB1	SB2	SB3
0	0	0	0
5	0.53	0.34	0.27
10	0.8	0.56	0.49
15	0.97	0.5	0.67
20	1.08	0.67	0.89
25	1.33	0.86	1.11
30	1.77	1	1.3
35	2.18	1.37	1.7
40	2.55	1.66	2.07
45	3.02	2.07	2.44
50	3.35	2.44	2.84
55	3.72	2.88	3.17
60	4.27	3.21	3.5
65	4.53	3.54	3.83
70	4.93	3.87	4.2
75		8.09	6.59
80		12.95	8.98
85			12.25
90			15.7

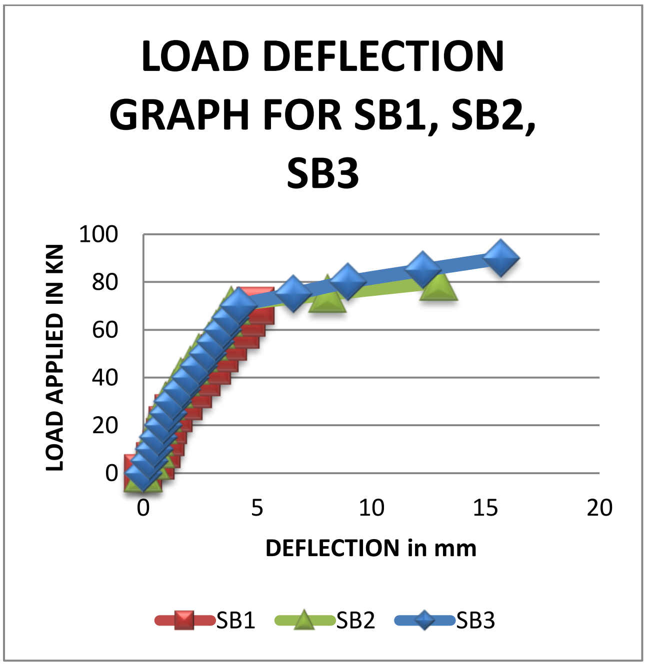

Figure 9: Graph showing load and deflection behaviour of SB1, SB2, SB3

THIRD SET OF BEAM

FIRST T-BEAM OR CONTROL BEAM TB1

Figure 10: Control Beam for third set

Table 9: Load and deflection analysis of beam TB1

LOAD APPLIED IN KN	DEFLECTION IN mm		
	LEFT L/3	CENTER	RIGHT L/3
0	0	0	0
10	.35	.29	.29
20	.54	.49	.49
30	.64	.71	.71
40	.75	.87	.80
50	.82	.93	.88
60	1	1.08	1.10
70	1.14	1.19	1.21
80	1.28	1.37	1.35
90	1.49	1.62	1.55
100	1.58	1.84	1.63
110	1.77	1.99	1.84
120	1.99	2.20	2.05
130	2.09	2.33	2.15
140	2.21	2.49	2.31
150	2.39	2.64	2.49
160	2.59	2.83	2.71
170	2.82	3.02	2.93
180	2.94	3.24	3.05
190	3.11	3.43	3.28
200	3.24	3.73	3.44
210	3.43	3.91	3.58
220	3.72	4.43	3.88

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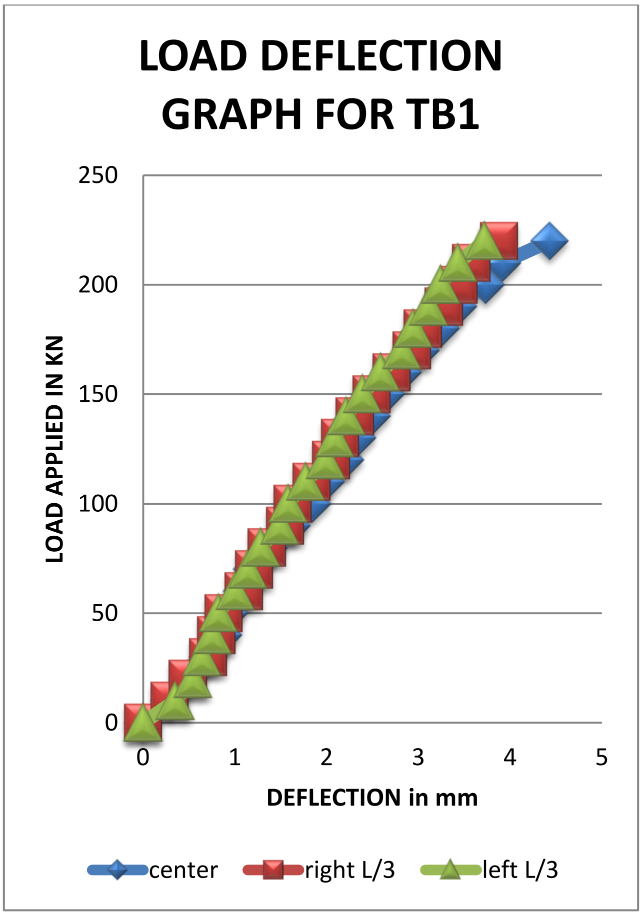

Figure 11: Graph showing load and deflection behaviour of TB1

SECOND BEAM OR TB2

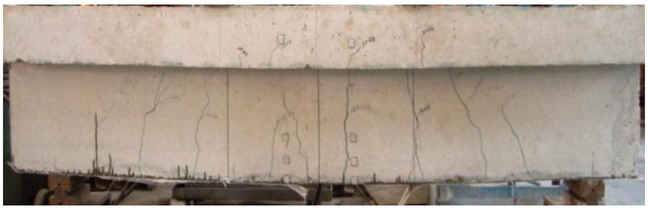

Figure 12: Picture of T-beam strengthened at the soffit

Figure 13: De-bonding of GFRP sheet from surface

Table 10: Load and deflection analysis of beam TB2

LOAD APPLIED IN KN	DEFLECTION IN mm		
	LEFT L/3	CENTER	RIGHT L/3
0	0	0	0
10	.12	19	.18
20	.28	39	.32
30	.39	51	.44
40	.47	61	.61
50	.61	.81	.69
60	.79	1.01	.83
70	.91	1.20	.97
80	1.01	1.31	1.10
90	1.20	1.49	1.24
100	1.38	1.71	1.44
110	1.49	1.88	1.55
120	1.71	2.03	1.78
130	1.81	2.18	1.89
140	1.97	2.34	2.04
150	2.11	2.51	2.17
160	2.29	2.73	2.34
170	2.44	2.89	2.49
180	2.59	3.05	2.63
190	2.77	3.33	2.91
200	2.91	3.51	3.01
210	3.09	3.73	3.20
220	3.21	3.89	3.34
230	3.31	4.10	3.49
240	3.45	4.31	3.62
250	3.58	4.53	3.72
260	3.70	4.82	3.84
270	3.92	5.05	4.08

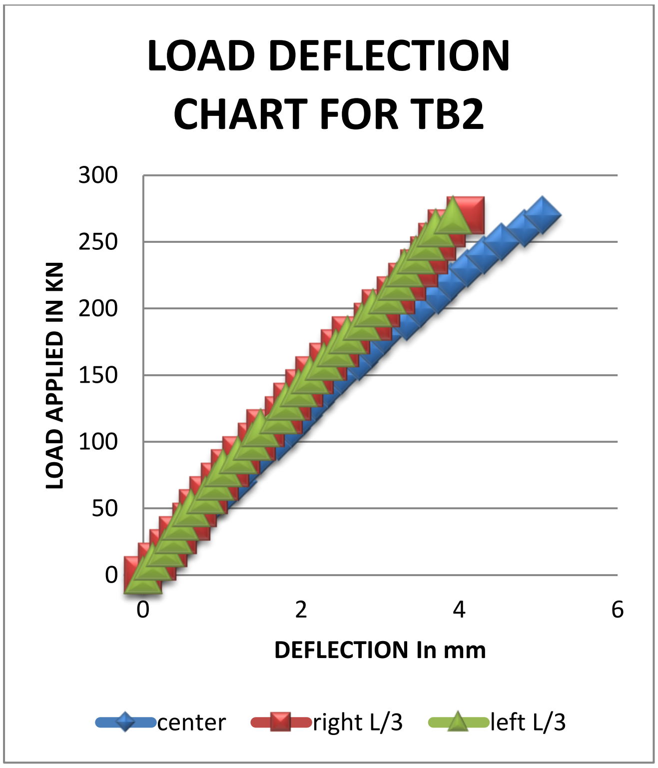

Figure 14: Graph showing load and deflection behaviour of TB2

THIRD BEAM OR TB3

Figure 15: De-bonding of GFRP from web of Beam

Table 11: Load and deflection analysis of beam TB3

LOAD APPLIED IN KN	DEFLECTION IN mm		
	LEFT L/3	CENTER	RIGHT L/3
0	0	0	0
10	.15	.12	.19
20	.31	.27	.37
30	.42	.42	.49
40	.51	.51	.55
50	.71	.77	.81
60	.88	.92	.98
70	1.01	1.10	1.15
80	1.19	1.27	1.31
90	1.31	1.61	1.45
100	1.49	1.85	1.61
110	1.63	1.99	1.77
120	1.81	2.12	1.95
130	1.99	2.31	2.10
140	2.18	2.59	2.32
150	2.31	2.88	2.49
160	2.55	3.11	2.73
170	2.75	3.42	2.89
180	2.89	3.72	3.05
190	3.11	3.94	3.29
200	3.33	4.14	3.52
210	3.51	4.39	3.73
220	3.81	4.49	3.97
230	4.17	4.87	4.42
240	4.38	5.03	4.62
250	4.64	5.30	4.79
260	4.82	5.72	4.99
270	5.51	6.40	5.82
280	6.62	7.52	6.90
290	7.19	8.12	7.30

Figure 16: Failure of GFRP sheet

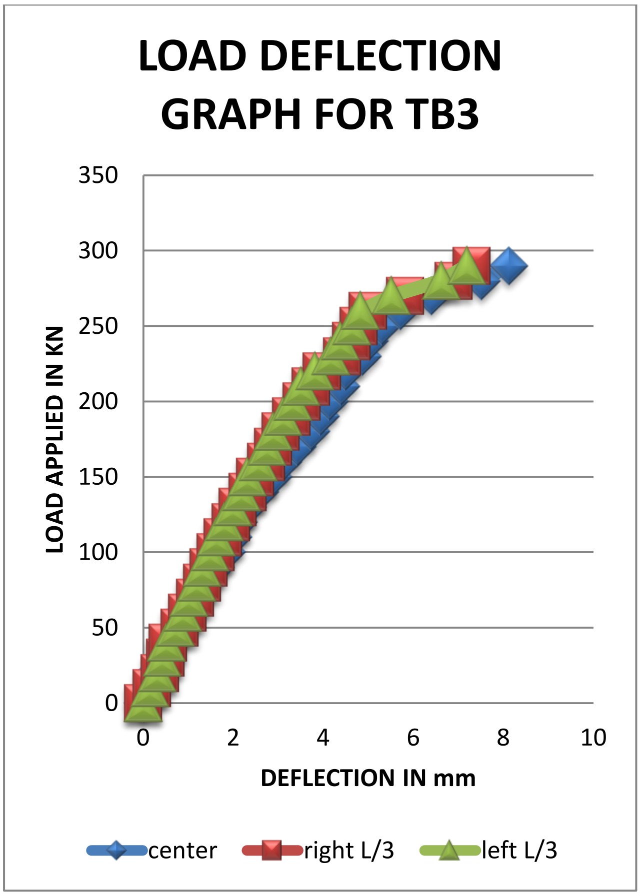

Figure 17: Graph showing load and deflection behaviour of TB3

CONCLUSIONS

In this study, experimental analysis of various beam which were strengthened with the use of GFRP laminates was carried out and after that the result were compared with the non strengthened beam called control beam. Three types of beam were casted, out of which two were rectangular beam and one was T-beam. Each type of beam has three specimens and among them one was un-strengthened and two were strengthened beam specimen. After the test results were obtained following conclusions can be made;

- In all the set of beam it was clear that the ultimate load carrying capacity of Control Beam was lesser than that of strengthened beams.
- In strengthened beams Initial flexural cracks were visible at much higher load as compared to control beam.
- The load carrying capacity of the U shape Jacket wrapping of beam with laminates was found to be maximum of all the beams. For third set of beam i.e. T-beams it enhances the load to about 40% greater than control beam TB1 and nearly 12% greater than beam strengthened with GFRP at the soffit only i.e. TB2.
- Thought the beam strengthened with U-Jacket wrapping of GFRP i.e. TB3 showed increased ultimate load carrying capacity, however it was relatively near to ultimate load carrying capacity of the TB2 beam which was strengthened at the soffit. so it will be economical efficient to use strengthening at soffit only. Also the cracks were not visible in TB3 due to side wrapping therefore it will not give warning prior to failure of the beam.
- In first set of beam when the beam was strengthened in flexure its load carrying capacity increased notably different for different strengthening. It was brought into notice that increase in capacity for FB2 was 40% and for FB3 it was more than 50%
- The difference in capacity of strengthened beam of first set was nearly 5 to 15%.
- Also theoretically it was obtained that the moment of resistance of a section increases after the use of GFRP laminated for strengthening purposes.
- When the first set of beam was not strengthened, its failure occurred in flexure. After the beam was strengthened flexure-shear failure occurred which does not give sufficient warning prior to failure. Hence during strengthening these conditions should be checked and kept in mind.
- In second set of beam that were strengthened in shear also the load carrying capacity of the member increases.

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- It was noticed that ultimate load carrying capacity can be increased upto 35% by the use of strengthening technique used for SB2. Furthermore this strength can be enhanced upto 50% by the use of U-wrapping in shear zone of the member.
- The difference in capacity of strengthened beam of second set was nearly 10 to 15%.
- The beam strengthened in shear, showed only flexural failure and thus giving adequate warning time as compared beam having brittle shear failure.
- Application of GFRP to retrofit and strengthen the beam in shear and flexure is found to be effective and its result can be used at a large scale.

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