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Study on Flexural Strength Enhancement of T-Beams through GFRP Wrapping

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Abstract: ***This paper presents experimental study conducted to investigate the behavior of flexurally damaged RC T beams retrofitted with Glass fiber-reinforced polymer GFRP laminates. Four RC beams were fabricated. Two of the beams were having neutral axis (NA) inside the flange –I1 & I2 and other two with neutral axis outside the flangeI1 & I2. The two set of beams which were designed strong in shear and weak in flexure were loaded to ultimate yield failure of steel reinforcement and retrofitted with GFRP with single and double layer. The retrofitted beams were named IR1, IR2 for beams with NA inside the flange and OR1, OR2 with NA outside the flange. Testing of Percentage of strength enhancement of retrofitted beam (IR1) showed 68.5. For Beam (IR2) percentage of strength enhancement was 88. For Beam (OR1) percentage of strength enhancement was 83. For Beam (OR2) indicates strength enhancement of retrofitted Beams in ultimate load carrying capacity.***

Keywords: Retrofitting, Neutral axis, flexure**.**

1. Introduction

In real life maintenance, rehabilitation and upgrading of structural members, is perhaps one of the most crucial problems in civil engineering applications. Moreover, a large number of structures constructed in the past using the older design codes are structurally unsafe according to the new design codes. Since replacement of such deficient elements of structures demand a huge amount of public money, time, strengthening has become the acceptable way of improving their load carrying capacity and extending their service lives.

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 From the past studies conducted it has been shown that externally bonded glass fiber-reinforced polymers (GFRP) can be used to enhance the flexural, shear and torsion capacity of RC beams. Due to the flexible nature and ease of handling and application, combined with high tensile strength-weight ratio and stiffness, the flexible glass fiber sheets are found to be highly effective for strengthening of RC beams. Due to the flexible nature and ease of handling and application, combined with high tensile strength-weight ratio and stiffness, the flexible glass fiber sheets are found to be highly effective for strengthening of RC beams. The use of fiber reinforced polymers (FRPs) for the rehabilitation of existing concrete structures has grown very rapidly over the last few years. Research has shown that FRP can be used very efficiently in strengthening the concrete beams weak in flexure, shear and torsion. Reinforcing steel), and is also another sought after retrofitting material, in demand. The most widely used fibers, which are used as reinforcements in FRP, for the strengthening of concrete structures are artificial fibers which are carbon, glass, and Aramid, etc.

Carbon fiber is one of the costliest of all the fibers, followed by Aramid fibers, and although it comes with an advantage of increasing the structural potential by many folds, it also comes at an overhead of huge price and cost, and hence cannot be easily considered as a good outcome based market product. (Tara Sen et al., 2013).

Table 1: Properties of different fibers and its laminates

Fiber	*Laminate Strength (Gpa)*	*Density of Laminate (g/cm3)*	*Strength-to-Weight Ratio*	*Young's Modulus (Gpa)*	*Cost /M2 (₹)*
E Glass	1.50	2.66	564	30-40	600
Carbon Fiber	1.60	1.58	1013	125-181	3500
Kevlar	1.43	1.44	993	70.5-112.4	2700

Wrapping schemes also play a critical role in strength enhancement. The influence of increase in number of layers of GFRP is an open area yet to be investigated in detail.

Although numerous studies on the strengthening of RC beams with FRP materials have been conducted in recent years, the retrofitting of GFRP woven sheet in T beam weak in flexure has not been experimentally studied yet. The significance of this study is derived from its analysis of the behavior of RC T beams, which is used in all constructions where beam and slabs are casted monolithically. Also all the possible conditions involved in T beam design

2. Methodology

The experimental program consists of four (4) simply supported RC T-beams of length1800mm. RC T-beams are initially tested as un strengthen models. These beams were labeled as I1, I2 for undamaged beams with neutral axis inside flange and O1, O2 for un damaged beams with neutral axis outside flange. Once damaged and retrofitted, the beams I1, I2 are labeled as IR1, IR2 and O1 and O2 as OR1 and OR2. Fig. 3.5.1 to Fig. 3.5.4 shows the dimensions and details of reinforcement of the beams. RCC beam is designed using M25 grade concrete and Fe500 steel. The length of the beam was limited by the conditions of the available testing setup up to 1800mm. Then the dimensions in the section of the beams are determined based on the standard design procedure. The beam is designed using limit state method considering it to be an under-reinforced section with neutral axis inside and outside flange. 295 x 70 mm flange and 140 x120 mm web for beam with neutral axis inside flange with reinforcement details as shown in Fig. 1 and Fig. 2. For beam with neutral axis outside flange, flange is of size 295 x 40 mm and web is of size 150 x120 mm. Reinforcement details are as shown in Fig. 3 and Fig. 4. Strengthening is done by using GFRP bidirectional woven sheet 200GSM.GFRP sheet is bonded to tensile area of concrete surface by using high quality epoxy with hardener of Lapox Duratite. Wrapping scheme include single and double U wrapping of bi directional GFRP sheet on flexural area of RCC beam.

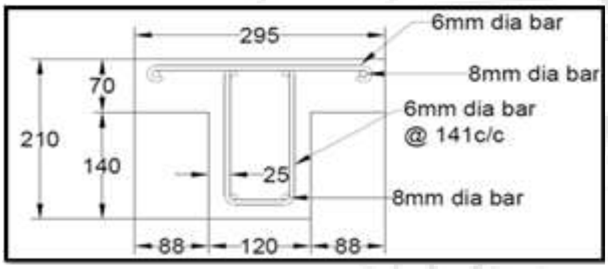

Figure 1: Beam cross section with NA inside flange

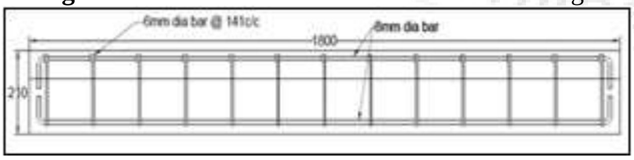

Figure 2: Beam longitudinal view with NA inside flange

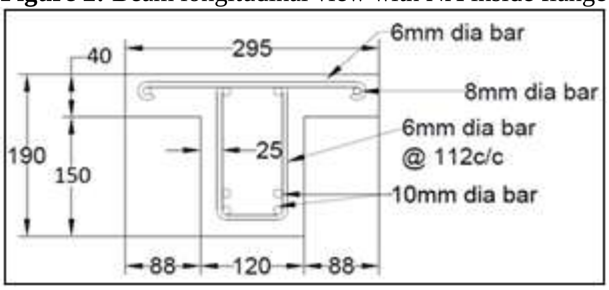

Figure 3: Beam cross section with NA outside flange

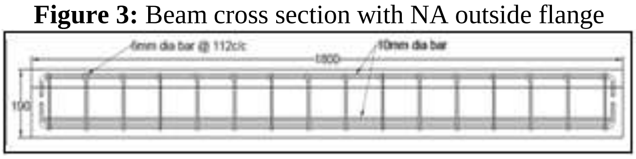

Figure 1: Beam longitudinal view with NA outside flange

Two-point loading can be conveniently applied by arrangement shown in Fig 5 Load is applied through a load cell and circular seater to spreader beam. Beam is placed on roller support on loading frame with an outstanding support length of 150mm. Available 1500mm available was equally divided into three equal parts as shown in figure. Beam specimen is kept on the loading frame supports and load is applied manually by hydraulic jack strain and deflection is checked at every 0.5ton. For this purpose, three deflection gauges were placed below mid points and loading points. Strain gauge ports were provided at pre-determined points on flexural area. Figure 6 shows pictorial view of Two point loading experimental setup and Figure 7. Figure 8 shows pictorial view of bending moment and shear force region developed as a result of two points loading experimental setup. Figure 9 shows actual two points loading experimental setup

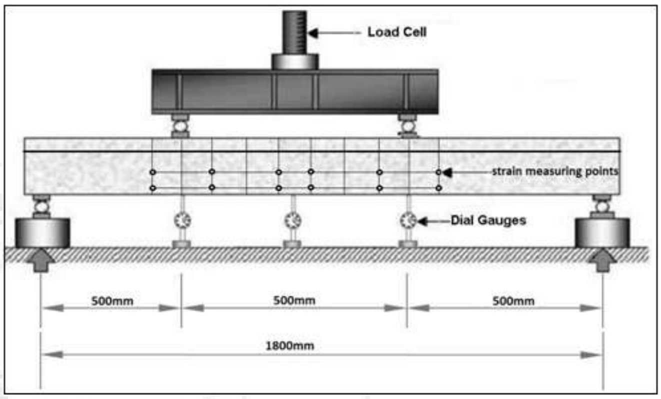

Figure 2: Two point loading experimental setup

Figure 3: Experimental set up

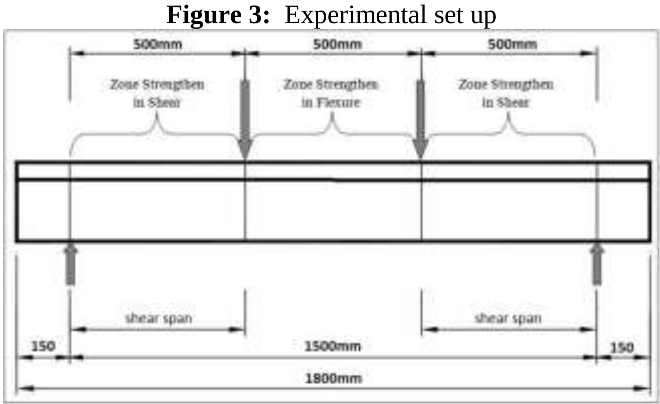

Figure 4: Shear and flexural strengthening zone of beam

Beam specimen is kept on the loading frame supports and load is applied manually by hydraulic jack strain and deflection is checked at every 0.98Kn. Loading is done until crack pattern appears at the flexural zone and load values are noted then loading is gradually increased until load ceases to increase and deflection increases steadily (yielding starts). The load value and deflection value are noted and load is released. The beams are then taken out for retrofitting. GFRP sheet are neatly cut to required size and kept for wrapping.

Strengthening is done by using Wrapping scheme include single and double U wrapping of bi directional GFRP sheet on flexural area of RCC beam. Retrofitting was done by the help of epoxy binders. GFRP bidirectional woven sheet 200gsm is used as retrofitting material. GFRP sheet is bonded to tensile area of concrete surface by using high quality epoxy with hardener of Lapox Duratite. First off, all beams are unloaded and made straight. Cracked beams are cleaned and loose concrete if any is removed. Then initial crack binder epoxy is applied on crack. The beam is then kept to cure as per instructions provided by data sheet of epoxy. After curing period epoxy for binding GFRP sheet is prepared. Epoxy and resin are blended together as per manufacturer instructions (1 parts of resin: 8parts of hardener). Mixing was done thoroughly in a plastic container until uniform color is obtained. This paste was to be applied on the prepared beam surface using a brush. To make the beam and sheet surfaces to have a better bond, their surface should not be smooth. So, surface was roughened using some sharp edge tool. The roughened surface is cleaned and washed well to remove the dust and oil particles from the surface. Then the surface is allowed to get dried. For beam with two layer of GFRP second layer is placed on top of first layer by using epoxy. Uniform pressure is applied on top of FRP to ensure sufficient bond between concrete and GFRP sheet. Concrete beam strengthened with GFRP is then kepot fr one full day curing as recommended in data sheet. Test setup is kept same and beam specimens are loaded to failure. All test responses like strain of GFRP, deflection of beam at mid-point of flexural zone and loading point, ultimate failure load, failure mode is noted.

3. Results and Discussion

In this chapter, detailed description of all the experimental results is compiled. The behaviors of beams with neutral axis inside the flange and other with neutral axis outside the flange are described in detail. Load verses deflection data, load verses strain data; ultimate load carrying capacity, crack patterns and mode of failure are also described in this chapter.

The undamaged beam and GFRP strengthened beams were tested to find their ultimate load carrying capacity. It was found that all the undamaged beams failed in flexure showing that all the beams were weak in flexure and strong in shear. The beams with single layer wrapping of GFRP failed in flexure while with double layer of GFRP failed in shear where the wrapping ends. The shear crack was inclined at an angle of 32degree with the horizontal. Even though GFRP was stressed no rupture of GFRP was noted in that case.

In the beams retrofitted with GFRP single layer failure occurred with rupture of GFRP at the middle of flexural region. Detailed experimental results of un damaged beams and retrofitted beams in terms of load at initial cracks, ultimate load and nature of failure are described in table 4.1 shown below.

Table 2: Ultimate load and failure mode

No	Type of beam	Beam	Load at initial crack(kN)	Ultimate load	Nature of failure
1	Beam with NA inside the flange.	I1	31.38	60.5	Flexural failure
		I2	32.31	61.4	Flexural failure
	Retrofitted Beam with NA inside the flange.	IR1	Not visible	99.784	Rupture of GFRP at flexural region
		IR2	Not visible	121.65	Shear failure at shear region where GFRP wrapping ends
2	Beam with NA outside the flange.	O1	38.2	71	Flexural failure
		O2	37.4	69.9	Flexural failure
	Retrofitted Beam with NA inside the flange.	OR1	Not visible	138	Rupture of GFRP at flexural region
		OR2	Not visible	170	Shear failure at shear region where GFRP wrapping ends

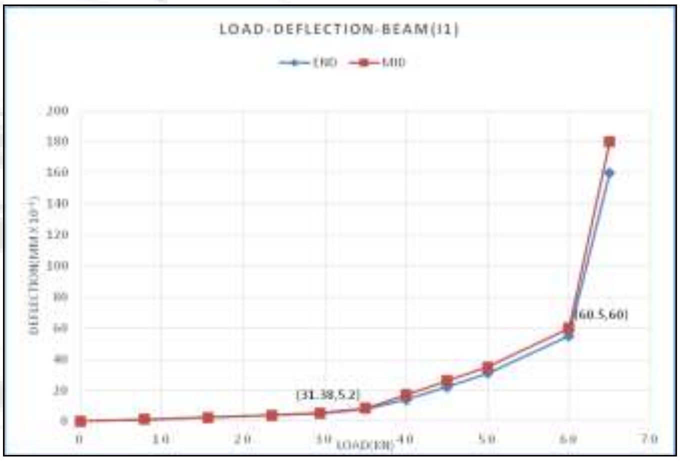

Figure 9: Beam (I1) Load vs Deflection curve

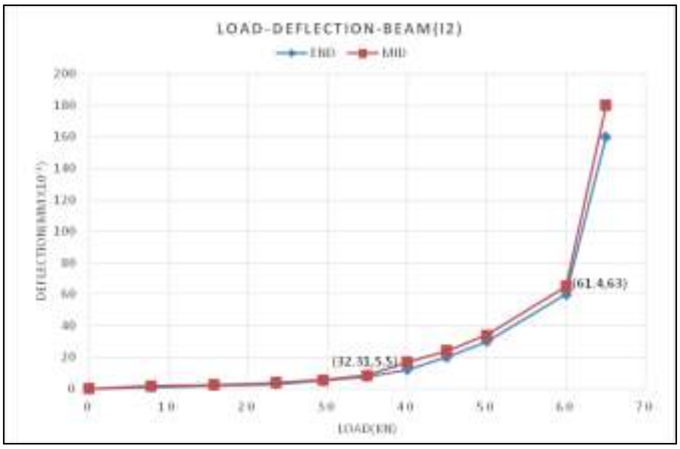

Figure 10: Beam (I2) Load vs Deflection curve

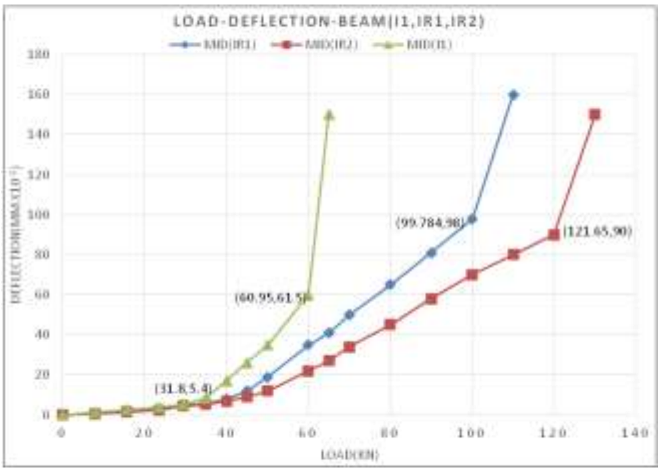

Figure 11: Beam (I1,IR1,IR2) Load vs Deflection curve

Figure 12: Beam (O1) Load vs Deflection curve

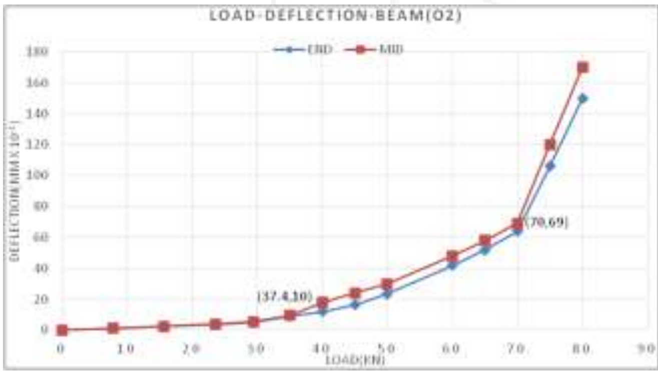

Figure 13: Beam (O2) Load vs Deflection curve

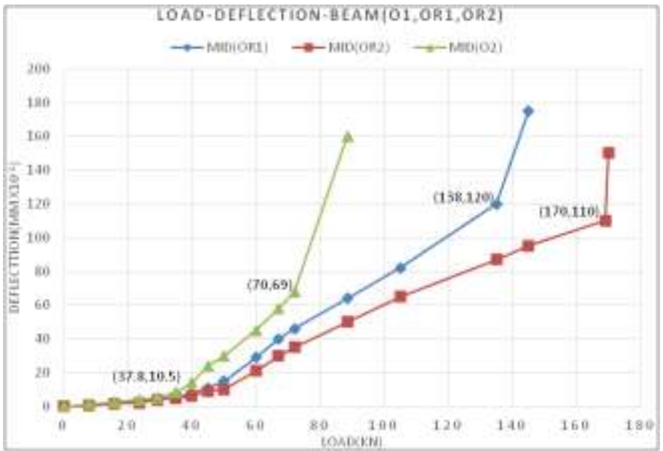

Figure 14: Beam (O1,O2,O3) Load vs Deflection curve

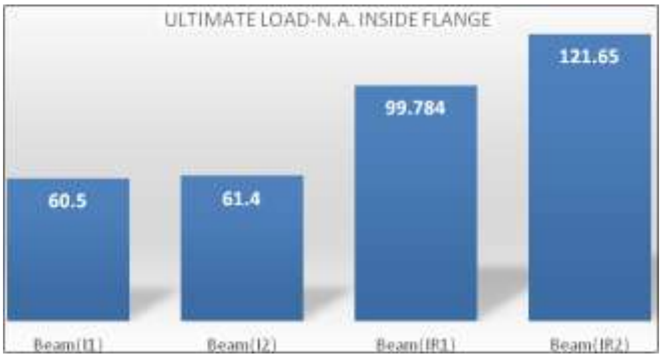

Figure 15: Ultimate load taking capacity(I1,I2,IR1,IR2)

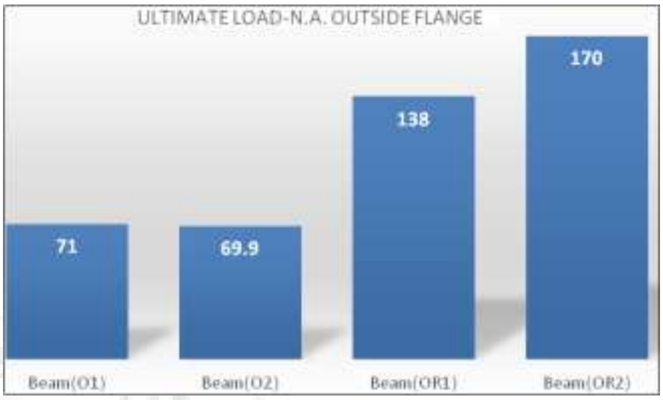

Figure 16: Ultimate load taking capacity (O1,O2,OR1,OR2)

From the above graphs it is clear that deflection values of retrofitted beam are less when compared to deflection values of un damaged beams.

From figure 15 & 16 we can see that GFRP wrapping is efficient in improving ultimate load taking capacity of T beams. Increasing the layers of GFRP wrapping shows increased ultimate load carrying capacity than that of beams with single layer of GFRP. Since Beams with neutral axis inside and outside flange differ in size and reinforcement percentage it is not preferable to compare both of them.

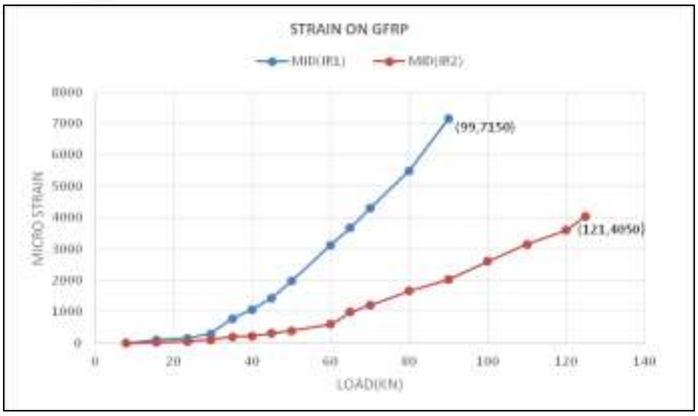

Figure 17: Beam (IR1,IR2) Load vs Micro strain

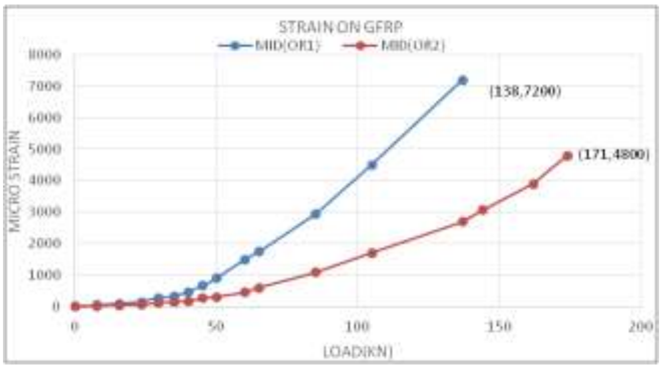

Figure 18: Beam (OR1, OR2) Load vs Micro strain

GFRP strain gives us an indication of involvement of GFRP laminate in enhancement of strength of retrofitted beam. It is noted that at a strain between 8000 to 9000 GFRP laminate will fail or tear off. Since initially beam was loaded to ultimate failure the contribution of tension steel in beam load taking is negligible. In this case GFRP is alone responsible for taking tensile load. Tension capacity of beam depends on tensile strength of GFRP laminate.

For beams with neutral axis inside flange the above load verses micro strain graph shows that beam with double layer of GFRP wrapping shows less strain when compared to beam with single layer of GFRP which means the contribution of GFRP in enhancing flexural strength decreases with increase in number of layers.

4. Conclusions

From the test results following conclusions were drawn

- Percentage of strength enhancement of Beam (IR1) showed 68.5. For Beam (IR2) percentage of strength enhancement was 88. For Beam (OR1) percentage of strength enhancement was 83. For Beam (OR2) percentage of strength enhancement was 131. This clearly indicates strength enhancement of retrofitted Beams in ultimate load carrying capacity.
- When beam is not strengthened, it failed in flexure. But when strengthened with single layer of GFRP, beam failed by tearing of GFRP at middle of beam which happened all of a sudden resulting in collapse of beam. No adequate warning symbols are provided before failure. This type of failure of beam is more dangerous than flexural failure.
- When beams are retrofitted with GFRP U wrapping up to neutral axis of beam initials cracks developed are not seen up to higher load. Due to invisibility of cracks no adequate warnings are provided before collapse of beam.
- When beams are strengthened with double layer of GFRP it failed in shear at the region where GFRP wrapping just ends. It shows that care should be taken while retrofitting using GFRP and other laminates. Loading on beam should never be allowed to increase beyond Shear capacity of beam.
- Deflection verses load curve shows low value of deflection corresponding to increasing load for beams retrofitted with GFRP when compared with Deflection verses load curve of un strengthened beams. With increase in number of layers of GFRP deflection verses load curve shows low value of deflection corresponding to increasing load. This means the beams become stiffer when retrofitted with more layers of GFRP.
- Micro strain verses load curve for GFRP bonded in double layer and single layer on beam shows that GFRP contribution in enhancing the strength of beam gets reduced with increase in number of layers of GFRP.

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