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The Effect of CFRP Laminate Length for Strengthening the Tension Zone of the Reinforced Concrete T-Beam.

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ABSTRACT:

Most of the researches on strengthening so far had been focused on rectangular reinforced concrete (RC) beams. Researches on strengthening of RC T-beams are rather limited. This study focuses on the application of carbon fibre reinforced polymer (CFRP) laminate for strengthening the tension zone of RC T-beam constrained by the presence of a stump (representative of a column) and the effect of varying the length of the strengthening laminates. To evaluate the effectiveness of the proposed strengthening method, a total of three RC T-beams were fabricated and tested. The beams were tested using the three point bending test set-up. The results showed that the load carrying capacities of the tension zone strengthened beams were increased by about 50% compared to un-strengthened beams. The length of the CFRP laminate recommended in the Technical Report 55 did not prevent end peeling but it did increase the load bearing capacity of the RC T-beam.

KEY WORDS: Tension zone, Strengthening, Continuous beam, Carbon fiber, structure, Negative moment.

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INTRODUCTION

While many methods of strengthening structures are available, strengthening by applying CFRP laminate has become popular. For strengthening purposes, application of CFRP laminate is more advantageous than other materials. Teng et al. (2002) pointed out that, there is increased demand for extensive research work to improve the characteristic behaviour of FRP materials to establish their application acceptability in RC structures, beams, slabs and columns[1]. In particular, their practical implementations for strengthening civil structures are numerous.

Several researchers pointed out that most of the pragmatic works consist mainly of the rectangular beams[2-5]. Furthermore, the design methodologies as well as guidelines are evolved mainly for the simply supported rectangular beams. Generally, the research works were conducted on RC rectangular sections which are not truly representative for the fact that most RC beams would have a T-Section due to the presence of a top slab.

Although many research studies had been conducted on the strengthening and repairing of simply supported RC beams using external plates, there is little reported work on the behavior of strengthened RC-T beams[6-9]. Especially, works relating to the application of CFRP laminate for strengthening the tension zone of RC T- beams in the presence of column are very few. In addition, there are few difficulties arise due to the presence of columns and other components such as electric and plumbing lines or HVAC ducts. These columns and components hinder the process of applying CFRP laminate in this region using conventional techniques. Another important point is that, the use of thick steel plates for strengthening will raise the floor level, which might be undesirable.

An exhaustive literature review has revealed that, a little amount of research works had been done to address the possibility of strengthening the tension zone of RC T- beam in presence of column using FRP materials .The constraints caused by columns in the application of the strengthening system were not considered in the existing researches.

PREVIOUS RESEARCH WORKS RELATED TO THIS TOPIC

Jumaat et al. (2010) pointed out that, although several research studies have been conducted on the strengthening and repair of simply supported reinforced concrete beams using external plates, there are few reported works on the behavior of strengthened T-beams in the presence of column[10]. Furthermore, almost all the available design instructions to strengthen the structures by the external laminates of FRP are demonstrating the simply supported beams[11-13]. The literature review revealed that a meager amount of research works had been explored to address the potential of applying CFRP laminate for strengthening the tension zone of RC 'T'– beam in the presence of column .On the field of strengthening continuous beam, Grace et al. (1999) tested five continuous beams[14]. They found that the use of FRP laminates to strengthen continuous beams is effective for reducing deflections and for increasing their load carrying capacity. They also concluded that beams strengthened with FRP laminates exhibit smaller and better distributed cracks. Later, Grace et al. (2001) investigated the experimental performance of CFRP strips used for flexural strengthening in the hogging region of a full-scale reinforced concrete beam[15]. Grace et al. (2005) also worked on another research where three continuous beams were tested[16]. They noted that CFRP strips were not stressed to their maximum capacity when the beams failed, which led to ductile failures in all the beams. On the other hand, El-Refaie et al. (2003a) examined eleven reinforced concrete (RC) two-span beams strengthened in flexure with external bonded CFRP sheets[17]. In another research, El-Refaie et al. (2003b) tested five reinforced concrete continuous beams strengthened in flexure with external CFRP laminates [18]. They investigated that extending the CFRP sheet length to cover the entire hogging or sagging zones did not prevent peeling failure of the CFRP sheets**.** They also found that, strengthened beams at both sagging and hogging zone produced the highest load capacity**.** Ashour et al. (2004) tested 16 reinforced concrete (RC) continuous beams with different arrangements of internal steel bars and external CFRP laminates. As in previous studies, they observed that increasing the CFRP sheet length in order to cover the entire negative or positive moment zones did not prevent peeling failure of the CFRP laminates[19]. Aiello et al. (2007) compared the behavior between continuous RC beams strengthened with of CFRP sheets at hogging or sagging regions and RC beams strengthened at both sagging and hogging regions [20]. Recently, Maghsoudi and Bengar (2008) have examined the flexural behavior and moment redistribution of reinforced high strength concrete (RHSC) continuous beams strengthened with CFRP [21]. Finally, Akbarzadeh and Maghsoudi (2010) have conducted an experimental program to study the flexural behavior and moment redistribution of reinforced high strength concrete (RHSC) continuous beams strengthened with CFRP and GFRP sheets [22].

In all the above cases it is seen that the researches were conducted on RC rectangular sections which are not representative of the fact that most RC beams would have a T- Section due to the presence of top slab. In all the above cases, the restraint caused by the columns in the application of the strengthening system was not considered.

EXPERIMENTAL PROGRAM

In this section three beams are presented as shown in Table 1. Beam B5 is control and without stump. The other two beams (B6, B7) are with stump and strengthened both in the tension and compression zones with the same orientation of CFRP laminate.For the beam B6 and B7, the length of CFRP in the compression zone is provided up to full span while the length of CFRP in the tension zone are varied. According to Technical Report 55, to avoid end peeling, strengthening plate should be extended up to the length where the interfacial shear stress should be ≤0.8 MPa. For the beam B6, the CFRP length is provided up to the length where the shear stress is 0.8MPa.This length is calculated as 2500 mm. On the other hand, the length of CFRP in the tension zone of the beam B7 is provided up to the full span. The detailed test matrix is shown in Table 1.

Table 1: Test Matrix

Beam name	Concrete strength (MPa)	Size (mm)	Length	Applying zone
B5	26	Control beam		
B 6	26	100 x1.4	Compression zone 3000 mm, Tension zone 2500mm	Tension + compression zone
B 7	26	100 x1.4	3000 mm	Tension + compression zone

After 28 days of curing, the beams are strengthened with CFRP laminate. 1.4 mm x 100 mm CFRP laminate (SikaCarboDur S1014/180) has been used for all the strengthened beams. Oil, dirt and other foreign particles removed from the surface in order to expose the texture of aggregate with the help of a diamond cutter (Figure 1.a).The dust particles were removed by high pressure air jet (Figure 1.b). Colma cleaner is used to remove the carbon dust from the bonding face of CFRP laminate.

CFRP laminate was bonded to concrete surface by using Sikadur-30 as a bonding agent. The process of mixing the adhesive and applying it to the surfaces are shown in Figure 2.The well –mixed adhesive is pasted to the bonding surface of concrete up to 2-3 mm thickness.

Figure 1: Preparation of surface

(a) Mixing of adhesive

(b) Placing of adhesive on CFRP laminate

(c) Pressing CFRP with the help of Rubber Roller

Figure 2 : Installing CFRP

Ready mixed concrete has been used for this research. Concrete compression testing has been carried out at 7thday, 28thday and the day of testing. Three cubes are tested each time and the average strength is calculated. The average compressive strength is 26 MPa for beams B4, B5,and B7. The flexural tensile strength of concrete is estimated using the equation of, $f = 0.53\sqrt{fc'}(kg/cm^2)$.The average yield strength and ultimate strength were 560 MPa and 645 MPa respectively. Modulus of elasticity of the bar is 200GPa.CFRP laminates of type SikaCarboDur S1014/180 ;(1.4mm x 100 mm) has been used. The maximum design and ultimate strain of CFRP laminates are 0.85% and 1.7% according to the manufacturer's guideline. The tensile strength is 2800MPa. Modulus of elasticity is 165Gpa.

Strain gages (30 mm) are attached to main reinforcing bars, CFRP laminates and on to the concrete surface to measure their strain .The reinforcing bars are smoothed by grinding machine, CFRP laminates are cleaned with acetone and concrete surface are also smoothed before fixing strain gauges. All strain gauges were connected with data logger to record the strain values during the test.LVDT (50mm capacity) has been used to measure the mid-span deflection of the beam .The LVDT was connected to Data Logger to record the readings during test. Data Logger TDS-530, manufactured by Tokyo Sokki Kenkyujo Co, Ltd. has been employed to record data from various connections. Strains at the sides of the beams were measured from the demec points using digital extensometer. The crack width of the beams during test was measured by using Dino-lite this instrument (Figure 3).

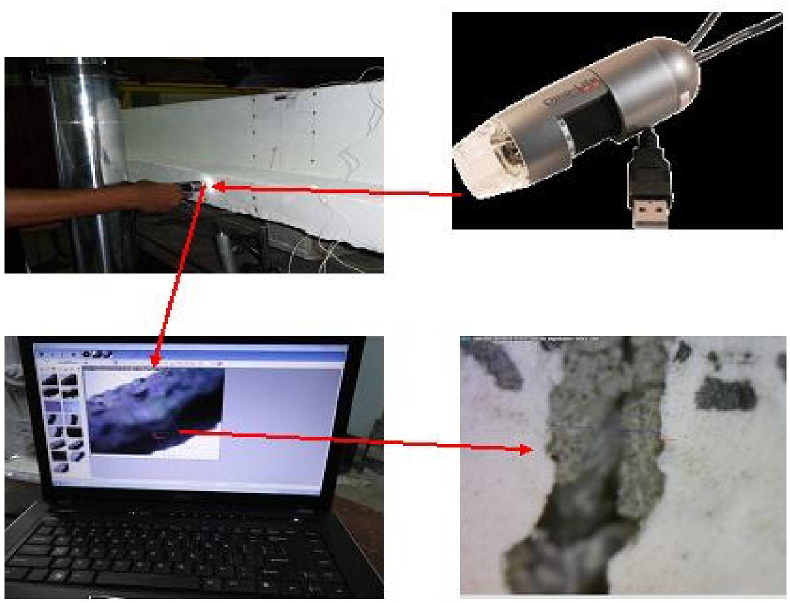

Figure 3: Measuring crack width by using Dino-lite

Three point bending was applied, where the supports represented the points of inflection of a continuous beam where the bending moment is zero. The position of the load as well as the setting of the machine is shown in Figure 4. After the beam has been lifted and positioned on the supports, the LVDT was placed and after that all the strain gages as well as the LVDT were connected to data logger properly. The load was applied with the help of INSTRON SATEC Testing Machine. This machine can apply up to 600 kN load and this machine can be controlled automatically by computer. The loading rate was controlled by **Blue Hill software**. The loading rate was controlled by 6 kN /min up to 60 kN. At every 10 kN the loading was hold for 2 minutes so that the manual readings from demec and manual readings of deflection can easily be taken. All other readings were recorded by Data Logger at every 10 second. The cracking width was measured with the help of 'Dino-lite'.

Figure 4: Test setup

FAILURE MODE

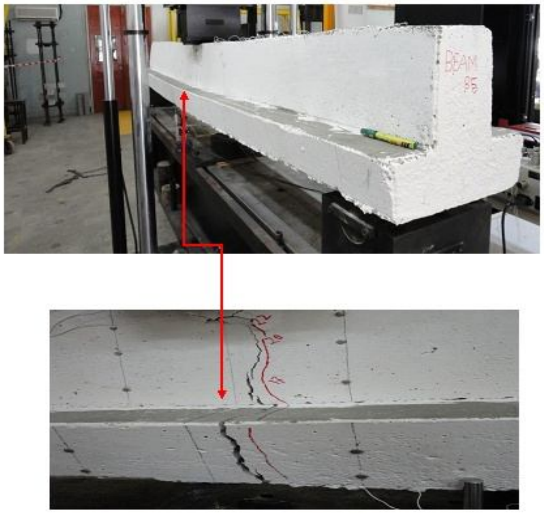

Figure 5: Failure mode of beam B5

Figure 6: Failure mode of beam B6

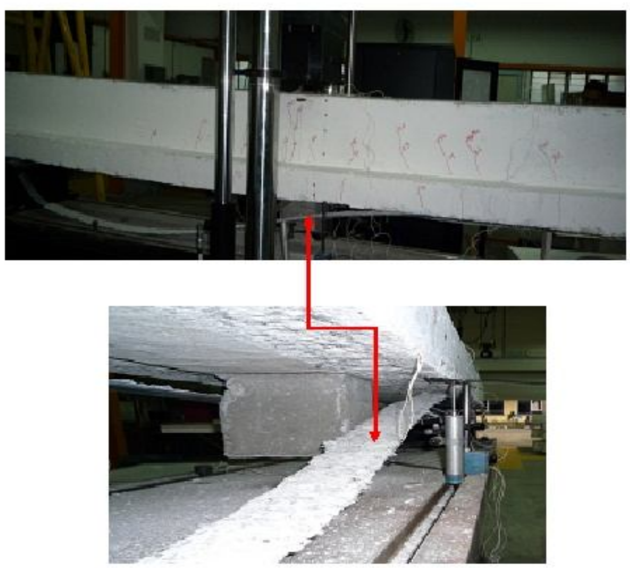

Figure 7: Failure mode of beam B7

EFFECT OF CFRP LENGTH IN THE TENSION ZONE

Test results are shown in table-2 and the failure modes are shown on Figure 5-8.The failure load of the beams B5, B6 and B7 are 69 kN, 104 kN and 120 kN respectively. Beam B5 depicted a conventional flexural mode (Figure 5) while beam B6 and B7 showed end peeling (Figure 6-7) but the difference in the failure load is remarkable. It is seen that, providing the length of CFRP upto a point where the longitudinal shear stress is 0.8 MPa could not prevent end peeling, even providing the length up to full span of the beam could not prevent end peeling.

The bar strains of the beams B5, B6 and B7 at different loadings are shown in Figure 8. It is seen that the bar strain of the control beam is more than that of others. From the figure it is noticed that there is a sudden strain increasing rate of beams at 15-25 kN loadings .This is due to the occurrence of 1st crack in the beam. Due to crack, concrete released stresses to steel. Since it is a sudden release of stress, it acted as an impact stress on the steel bar which led to sudden jump in the strain of the steel bar. It is seen that at failure the bar strain of the beam B7 is more than that of beam B6.

Figure 9 shows the load versus concrete compressive strain at the top of the beams B5, B6 and B7.It is seen that the strain of the control beam is more than that of strengthened beam. It is noticed that no beam has concrete compressive strain more than 0.0035, which indicates that the beams did not failed by concrete crushing.

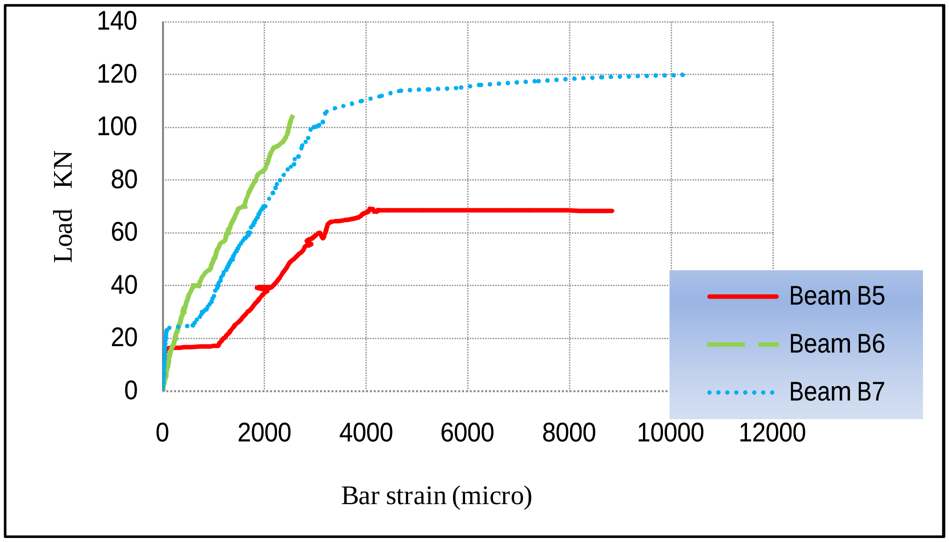

Figure 8: Load versus bar strain

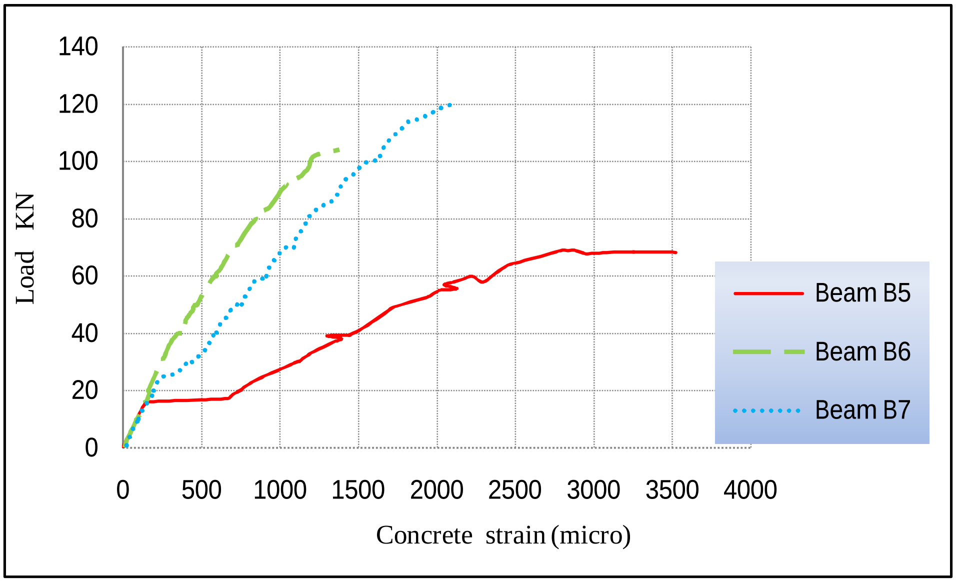

Figure 9: Load versus Concrete strain

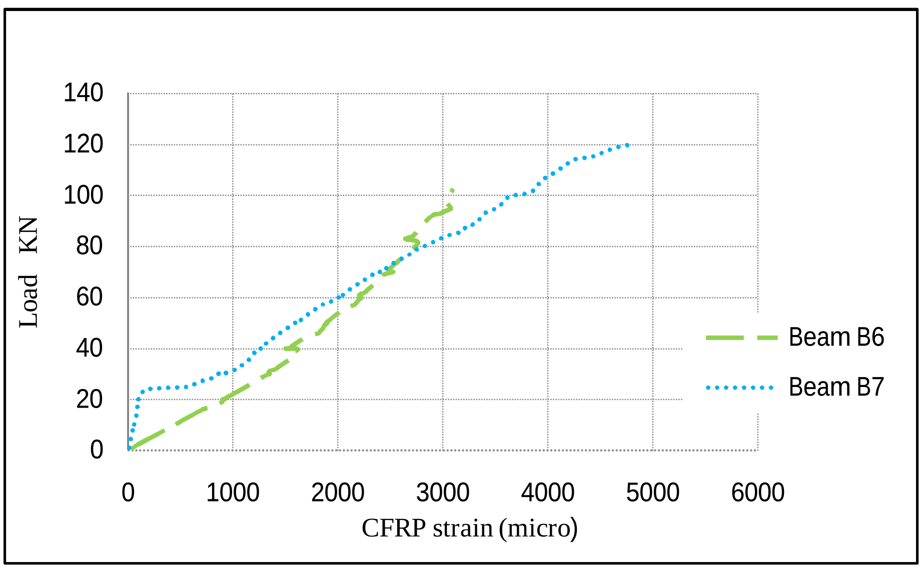

Figure 10: Load versus tension CFRP strain

The CFRP laminate strains of beams B6 and B7 are shown in Figure 10. From the figures it is found that, CFRP laminate did not have definite yield point and the CFRP strain of beam B7 and B6 have the same characteristics both in tension and compression zone.The load – deflection behavior of the beams B5, B6, B7 are shown in Figure 11. A linear increment of deflection is shown by the beam before failure. The strengthened beams (B6, B7) exhibited lower deflection than that of control beam because of having higher stiffness with compared to control beam. It is also seen that the deflection at failure load of control beam is more than that of strengthened beams. The reason is that, the beams strengthened both in the tension and compression zone, failed by plate debonding in the tension zone with brittle failure mode without any warning ,whereas, the control beam failed by flexure with ductile failure mode. It is also observed that the deflection of the beam B7 is more than that of B6 at failure.

Table 2: Test result

Beam name	**1st crack load** (kN)	**1st crack load increase over control beam (%)**	**Failure load** (kN)	**Failure load increase over control beam (%)**	**Strain (micro) at 63** kN **load**			**Concrete Compressive Strain (με)** at failure	**Mid-span deflection (mm) at 63** kN **load**	**Crack width(mm) at 63** kN **load**	**Mode of failure**
					Steel bar strain (με)	**Plate strain (με)**	**Concrete Compressive Strain (με)**				
B5	17	-	69	-	3289	-	2452	3389	14	1.305	Flexure
B6	24	41	104	51	1341	2143	933	1300	7	0.7	End peeling
B7	26	53	120	74	1776	2175	624	2056	9	0.21	End peeling

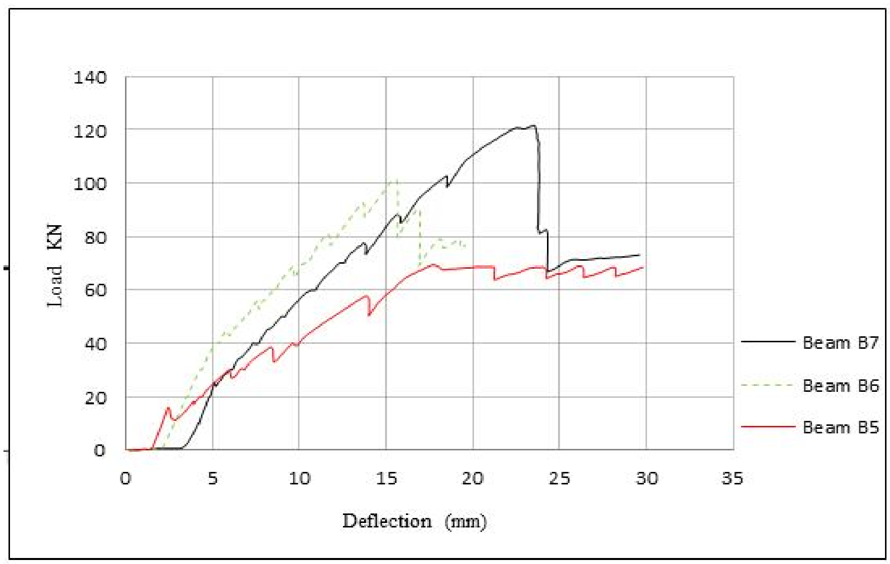

Figure 11: Load versus mid span deflection

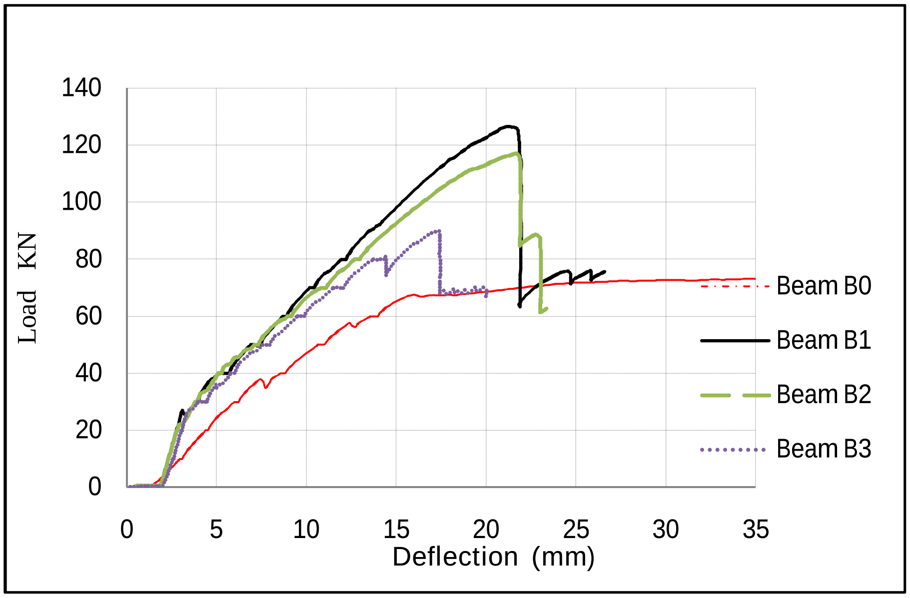

Figure 12: Load versus mid span Deflection

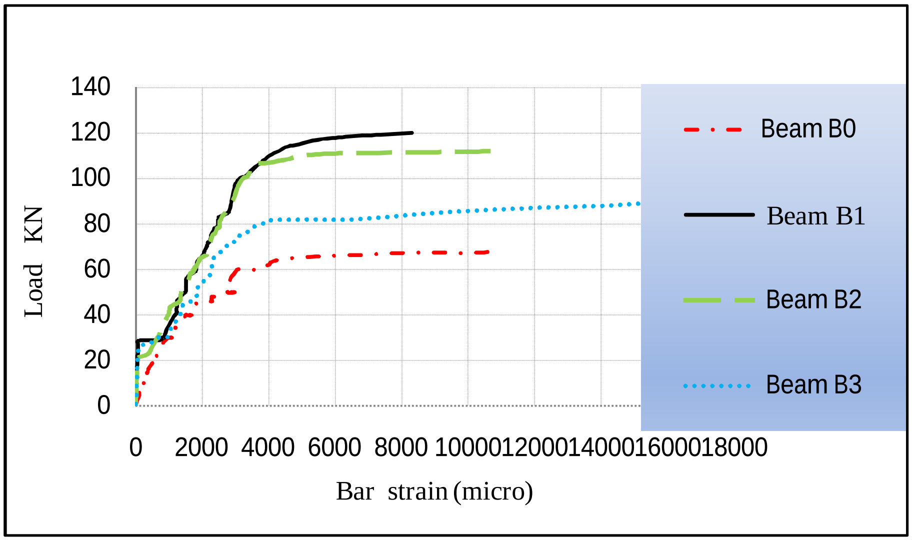

Figure 13: Load versus bar strain

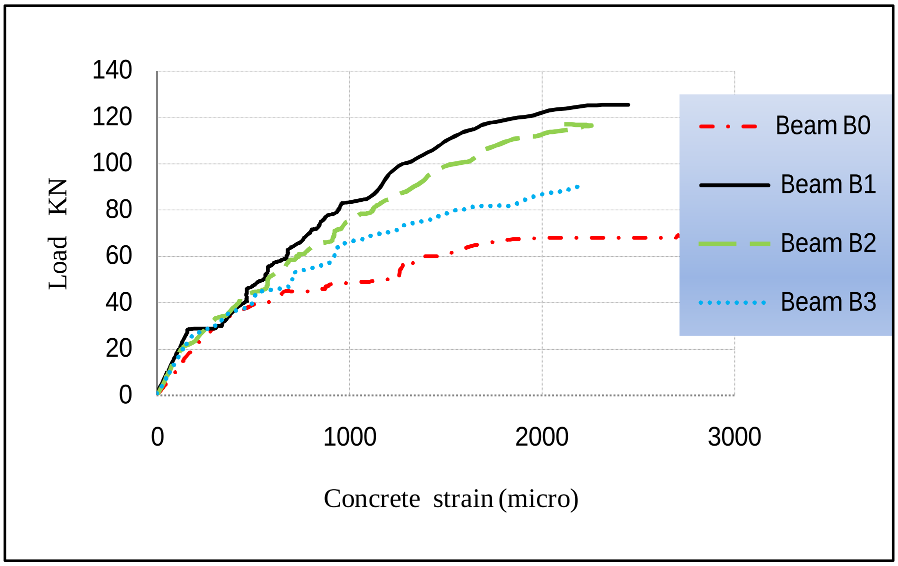

Figure 14: Load versus Concrete strain

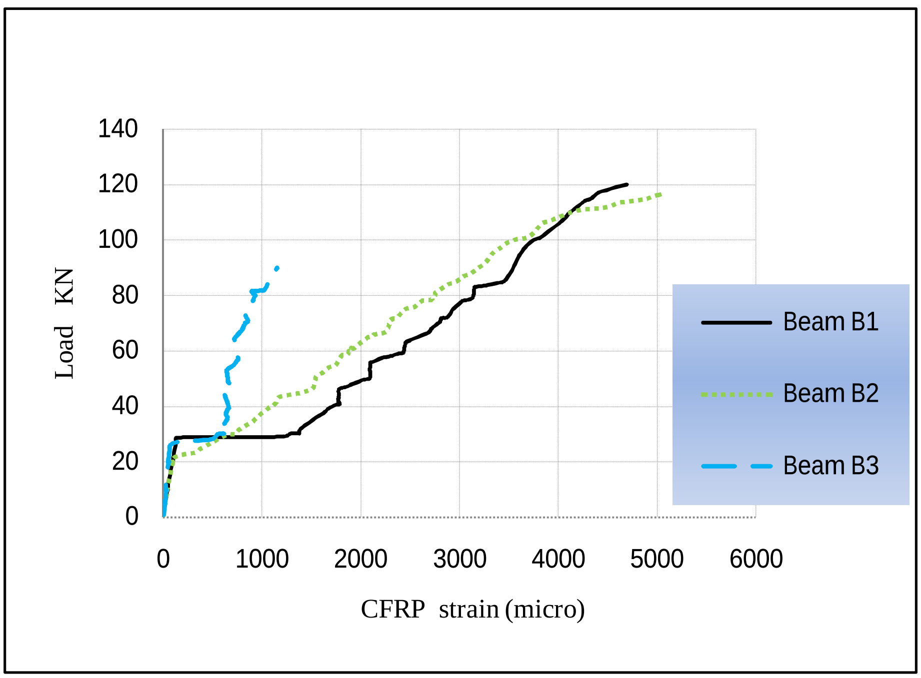

Figure 15: Load versus CFRP strain

CONCLUSIONS

The following outcomes were concluded from this study:

i. The recommended length for CFRP laminate specified in the Technical Report 55 seemed to be unsuitable for RC T-beams as end peeling was not prevented.
ii. About 70 % load carrying capacity was increased over un-strengthened beam by strengthening both the tension and compression zone. Therefore, CFRP strengthening at both compression and tension zone is able to increase strength significantly.
iii. The un-strengthened beam revealed the conventional flexural failure mode while end peeling of the CFRP laminate was the dominant mode of failure for all the strengthened beams tested.
iv. All strengthened beams had shown higher cracking and failure loads, less deflections, smaller crack widths and lower strain characteristics compared to that of un-strengthened control beams.

RECOMMENDATIONS

The following recommendations are presented in order to develop and improve current findings:

i. The strengthened beams failed by end peeling. Providing end anchors may prevent this type of failure and can further improve the strength of beam. So, the implementation of end anchors along with designing their appropriate dimensions are strongly recommended for further research for strengthening such kind of beams.
ii. The beams were tested under static loading condition only. More research is needed to determine the effect of repeated loading on strengthened beams.
iii. The experiments were conducted only for flexure. The combined effect of strengthening both for flexure and shear can be of further interest.
iv. Mechanical fastened system, Near Surface Mounted (NSM) method of strengthening of such types of beams may be of particular interest.

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