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# Using Carbon Fibre Reinforced Polymer Strips for Recuperation of Originally Fissured Concrete Beams

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***Abstract*— Carbon fiber reinforced polymer (CFRP) strips are widely used all over the globe as a repair and strengthening material for concrete elements. This paper looks at comparison of numerous methods to rehabilitate concrete beams with the use of CFRP sheet strips. This research work consists of 4 under-reinforced, properly cured RCC beams under two point loading test. One beam was loaded till failure which was considered the control beam for comparison. Other 3 beams were load till the appearance of initial crack which normally occurred at third-quarters of failure load and then repaired with different ratios and design of CFRP sheet strips. Afterwards, the repaired beams were loaded again till failure and the results were compared with control beam. Deflections and ultimate load were noted for all concrete beams. It was found out the use of CFRP sheet strips did increase the maximum load bearing capacity of cracked beams although their behavior was more brittle as compared with control beam.**

***Index Terms*— CFRP, rehabilitation, deflection, brittleness, cracked sections Concrete bonding, Mechanical, Chemical, bonding agent, mix ratio**

## I. Introduction

A staggering seismic tremor, estimating 7.6 on the Richter scale, hit the upper area of Pakistan on eighth October, 2005. With the loss of life of around 90 thousands and wounds in a similar range, it is a fiasco on a scale at no other time found in this district. The seismic tremor likewise brought about annihilation of a wide range of structures and other framework. The structures which survived are likewise experiencing serious significant breaks. The recovery and repair of breaks to make the structure alright for human utilize is a noteworthy issue. To reestablish their basic limit, retrofitting or potentially fortifying are severely required. There are distinctive systems accessible for retrofitting and fortifying of at first split strengthened solid pillars detailed in literature. In this exploration, lab examination with respect to utilization of carbon fiber fortified polymers to fortify a given structure or part of it to reestablish its serviceability and quality is talked about.

From the past research, it is prominent that FRP (Fiber reinforced plates) tend to increase the strength of concrete members in flexure considerably. Carbon fiber reinforced polymer tends to have a satisfactory fatigue performance, extraordinary strength to weight proportion and outstanding confrontation to electrochemical oxidization which makes it essentially aimed at structural solicitation [1]. A study conducted by Alfarabi presented that despite the fact that application of FRP does elevate the maximum load taken by concrete specimens, almost all the beams started to fail at the curtailment zone of the plate [2]. The epoxy that was used to conceal the plate at the soffit of flexural individuals just fizzled at loads considerably higher than the required level [3]. Some studies have also shown that the mode of failure of beams changed from ductile to brittle after the application of Fiber reinforced polymer plates [4]. The likelihood of this change depends to a great extent on the level of FRP being utilized, the area of FRP and the nearness of shear support in the current structures [5]. Researches have also shown that despite this change in behavior of concrete elements from ductile to brittle, an increase in flexural strength ranging from 65%-135% has been seen [6].

In this research work CFRP plates were applied at the soffits of initially cracked RCC beams in different proportions in order to observe their strengthening effect as compared to control beam which was loaded up to its failure load. Besides this investigation centers around the serviceability, quality and flexibility execution for each of the CFRP proportion used to find out their potential application in at first split fortified beams.

## II. Experimental Setup

For investigation of the consequence of repair by using various patterns of CFRP, on the structural response of initially cracked RCC beams, four Reinforced cement concrete beams were cast, cured and tested. All beams were designed by ultimate strength method as under-reinforced and having dimensions 3000 x 200 x 275 mm and singly strengthened by 3 # 4 bars, without using shear reinforcement. All specimens were tested under two pint loading. One beam, designated by A1, was named as Control Beam and was loaded till failure. During loading of A1 specimen, deflection gauges were used to measure the deflection in the beam which were installed at middle and quarter points and finally in the end its failure load was also noted. Other three specimens were loaded till they had reached three-quarters of maximum load taken by A1 specimen. Subsequently, the load was removed and specimens removed from the testing frame, so that repairs may be carried out.

A total of three concrete beams were rehabilitated with use of altered amounts of Carbon fiber reinforced polymer plates and when repair process was over, they were again tested by the same loading arrangement till failure and deflections noted. The response of each of the three retrofitted specimens in terms of Stiffness, deflection, ultimate load, cracking load and also analyzed in the experiment were their failure patterns. Beam strengthened with one CFRP strip, are designated as B1. Similarly beam strengthened with one 1.5 meter length of strip is designated as B2 and beam strengthened by two CFRP strip is designated by B3.

*A. Materials used in the beam*

Cement that was used in this research was of type 1 ordinary Portland cement. Sand from Lawrencepur (Pakistan), free from deleterious substances was used. Gradation of sand was carried out in accordance with ASTM Standards. Fineness Modulus was found as 2.62. Coarse Aggregate consisted of hard, clear, sound, strong, and uncoated crushed stones quarried from Margalla hills, best source of aggregate in Pakistan near Islamabad. ASTM standard complied gradation was done for coarse aggregates. Water fit for drinking, as proved by water quality tests, was used for making of concrete elements. Beams were casted with the help of moulds of steel formwork.
1:2:4 mix design was used in making of concrete for beams with a water to cement ratio of 0.5. The average slump that was obtained from fresh concrete prepared was of 45 mm. Maximum cube crushing strength obtained from experimentation was 28 MPa. Surface of concrete was properly cleaned as the bond strength of epoxy greatly depends on the cleanliness of the surface of finished concrete

*B. Materials for retrofitting*

*1) <u>Sika Carbudur Laminates</u>*

Type used was S812, 1.2 mm in thickness and 80 mm in width having a cross sectional area of 96 $mm^2$, Black color, having base of carbon fiber reinforced with an epoxy matrix. Fiber volumetric content is greater than 68%. Main properties for this type as provided by manufacturer are as under:

| | |
|---|---|
| Unlimited (no exposure to direct sunshine) | Total life |
| > 165,000 $N/mm^2$ | **Young's modulus** |
| > 28,000 $N/mm^2$ | **Strength in tensile** |
| > 1.7 % | **Elongation at break** |
| 1.5 $g/cm^3$ | **Density** |

*2) <u>Sikadur-30 Adhesive</u>*

For bonding Sika Carbudur laminates on the prepared substrate of beams, Sikadur-30 adhesive was used. It has following properties as per manufacturer technical data:

| | |
|---|---|
| 0.04 % | **Shrinkage** |
| 12,800 $N/mm^2$ | **Static E-Modulus** |
| Failure of concrete (4.5 $N/mm^2$) | **Adhesive Strength** |
| Failure of concrete (15.5 $N/mm^2$) | **Shear Strength** |

*C. Strengthening of beams*

Three beams were retrofitted at their soffits as under:

- One S812 cover was attached along the length of beams right in the center as shown in Fig. 1.
- One 1.5 meter portion of S812 cover was attached over mid span right in the centre, shown in Fig. 2.
- Two S812 laminates were bonded along the length of beams right in the center. The schematic diagram is shown in Fig. 3.

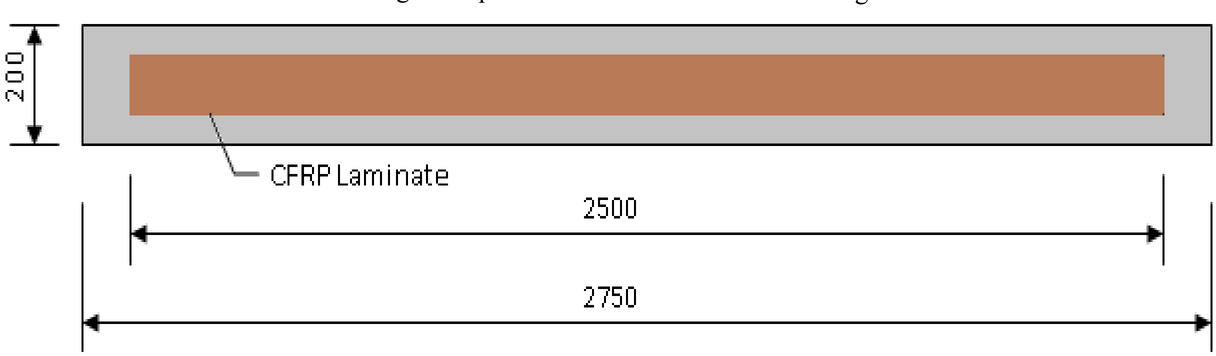


Fig. 1. Strengthening by one strip of full beam length

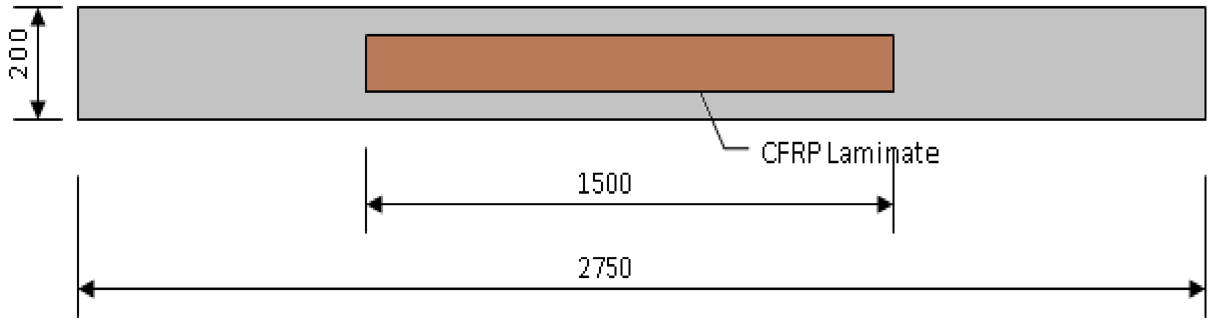


Fig. 2. Strengthening by one strip of 1.5 m length

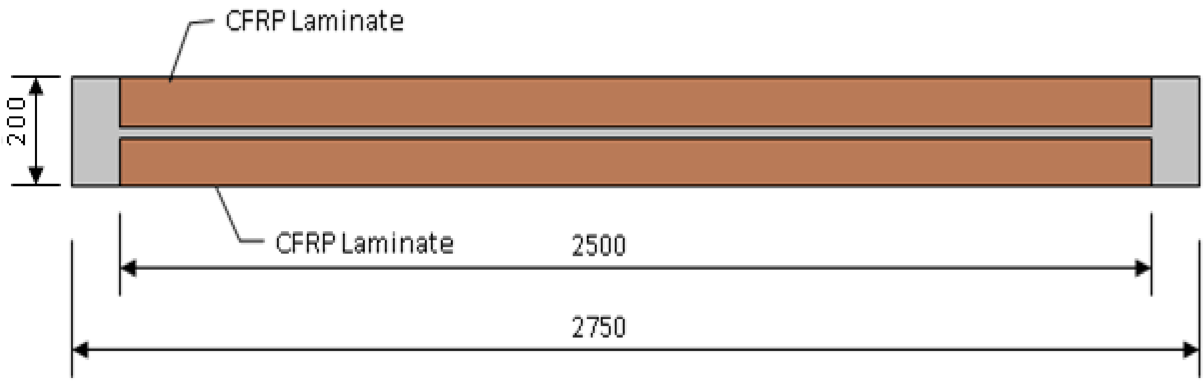


Fig. 3. Strengthening by two strips of full beam length

### III. Results and Discussion

Fig. 4, 5 and 6 show load-deflections curves of specimens B1, B2 and B3 before and after repair. For plotting these curves only, deflections measured at the midspan were used. It can be seen from the plotted graphs that specimens showed more of a brittle behavior after application of CFRP laminates as competed to ductile behavior before application of CFRP. The decrease in deflection is more prominent at advanced stages of loading. Beams strengthened with one 1500 mm CFRP plate show least deflection at the highest ultimate load i.e., 180 KN, which reveals that these beams are more brittle as compared to control as well as other repaired beams. A comparison of ultimate loads, taken by control and repaired beams, is shown in fiG. 8.

In case of control beam, failure load was 201 KN. First crack appeared at 136 i.e., 68 % of the ultimate load. Crack pattern showed that failure mode was tension failure.

In case of B1, failure load of repaired beams was 220 KN, which is greater than that of control beam. First crack appeared at an average load of 152 KN i.e., 69% of failure load. After strengthening, ultimate load bearing capacity increased by 10%. Failure mode was CFRP plates end interfacial de-bonding.

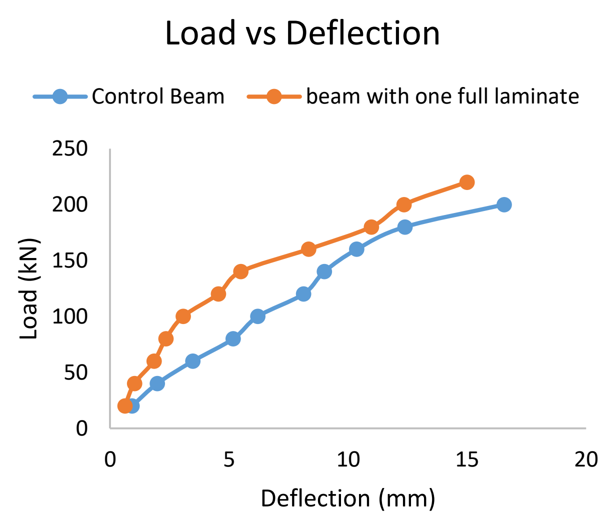


Fig. 4. Load vs Deflection graph for B1.

In case of B2, beams failed at a failure load of 180 KN. Ultimate load bearing ability for repaired beams decreased at a number of 10 % in comparison with the control beam. Failure was flexural tension failure near ends of CFRP laminates. Both tested beams failed in the same manner with CFRP plates intact with bottom.

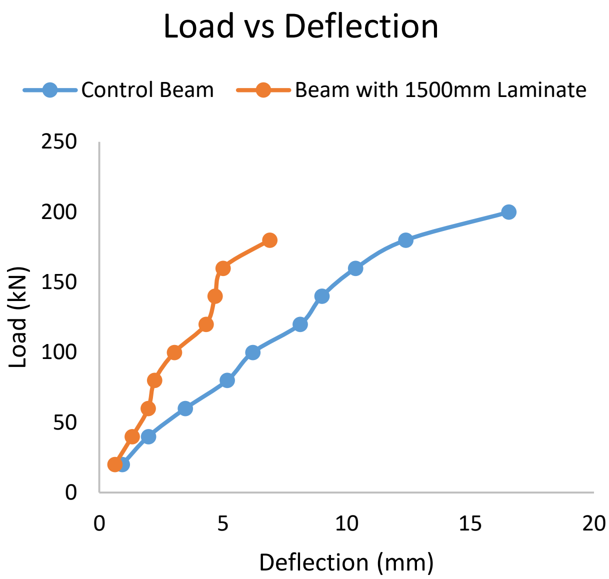


Fig. 5. Load vs Deflection graph for B2.

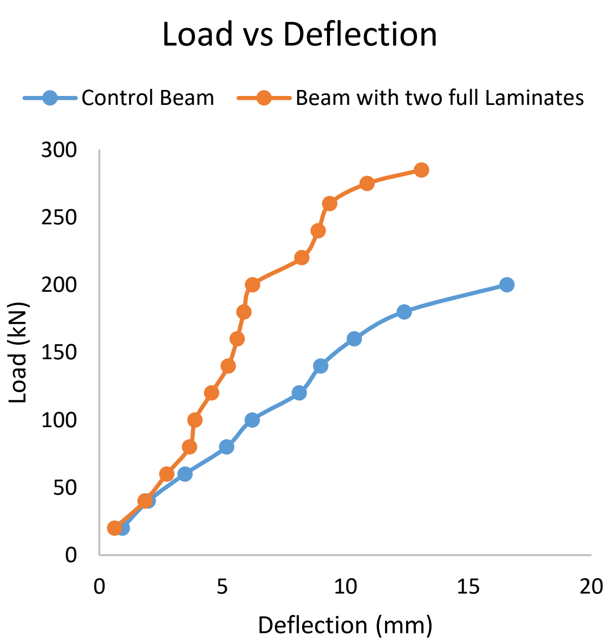


Fig. 6. Load vs Deflection graph for B3

When two CFRP laminates of full beam's length were used for repair of cracked beams, more favorable results were found. Both beams failed at 285 KN load. Ultimate load bearing capacity increased by 42% over the control beam. This ultimate bearing capacity is 29 % more than B1 and 58 % more than B2. Cracks started at load of 220 KN, which is 77 % of the ultimate failure load. Mode of failure involved the concrete cover separation (peeling off) along with laminate from one end.

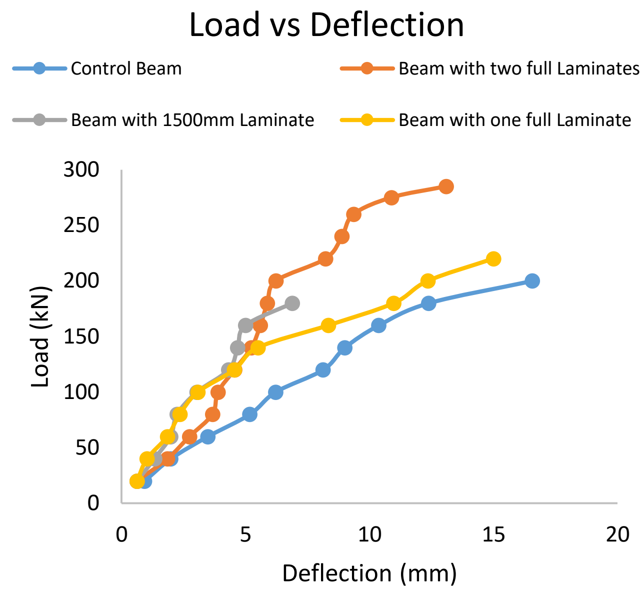


Fig. 7. Comparison for control beam and strengthened beams

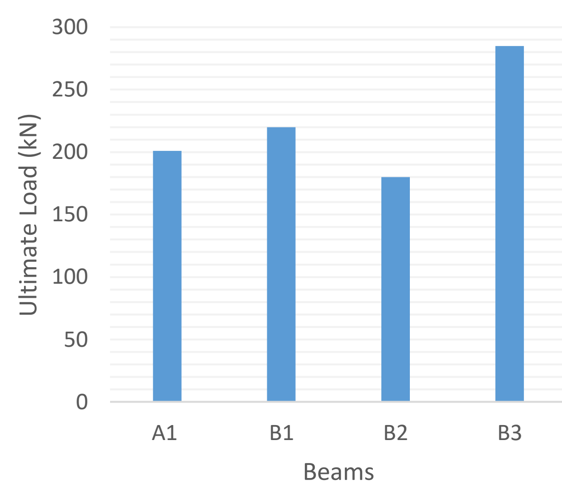


Fig. 8. Comparison of ultimate loads taken by all beams

## IV. Conclusions

Based on this study, the following conclusions can be made:

- Except one repair method, all other methods proved to be effective when it comes to ultimate flexural strength and an increase was noticed in ultimate bearing capacity of beams in flexure.
- Beams rehabilitated with CFRP laminates showed more of a brittle behavior as deflection for beams considerably reduced which resulted in shear tensile failure of concrete cover when two laminates were used in soffit.

- Best results regarding ultimate failure load were achieved in case of two CFRP strips having lengths equal to full beam's length. On the other hand, the same is associated with high cost of CFRP strips used. This factor should be kept in mind while finally selecting this mode of repair.

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