Investigation on Flexural Behavior of Pre-cracked RC Beams Strengthened using CFRP

S. M. Z. Islam[1*], B. Ahmed[2], J. Deb[3], S. S. Shamim[4], O. F. Himel[5], M. N. H. Nisat[6] M. M. Rahman[7]

[1]*Professor, Department of Civil Engineering, RUET, Bangladesh (zahurul90@gmail.com)*
[2]*Assistant Professor, Department of Civil Engineering, RUET, Bangladesh*
[3,4,5,6]*Student, Department of Civil Engineering, RUET, Bangladesh*
[7]*Chairman and CEO, Nutech Construction Chemicals Company Limited, BUET, Dhaka, Bangladesh*

Abstract

Carbon Fiber Reinforced Polymer (CFRP) is one of the most promising composite materials for strengthening of reinforced concrete structures. Flexure failure is a common phenomena in Reinforced Concrete (RC) beam due to seismic action, design and construction faults, change in application and implementation, damage for over loading and corrosion. The objective of this research is to investigate the flexural behavior of pre-cracked RC beams strengthened using CFRP. A series of tests have been conducted to strengthen the RC beam by CFRP. Nine RC beam including one reference beam and another eight initially cracked beam were tested in this study with varying (i) CFRP plate and sheet (ii) types of strengthening including CFRP U-strips applied and (iii) different FRP length. Hydraulic controlled universal testing machine was used for four-point loading system. The failure loads, failure modes and the load-deformation behavior of reference beam and CFRP strengthen beam were also presented in this paper. Reference RC beams was failed by common flexural pattern while initially cracked CFRP strengthened RC beams were failed at end plate and interfacial debonding. Based on test results, it was found that the structural performance of CFRP strengthening pre-cracked RC beam is significant than reference RC beam. The load carrying capacity improved significantly and varied 18.61%-75.29% for different strengthening technique. Therefore, it can be concluded that the better performance can be attained by strengthening in flexural region damaged RC beam with appropriate method.

Keywords: *CFRP, Flexural Behavior, Pre- crack, RC Beam, Strengthening*

1. Introduction

Fibre reinforced polymer (FRP) is increasingly being used for strengthening and repair of existing Reinforced Concrete (RC) beams due to its excellent performance. It is pleasing technique of the strengthening for new construction and retrofitting of RC beams by CFRP. Flexural strengthening and retrofitting of RC beams is needed due to earthquake, design and construction faults, change in application and implementation, damage for over loading and corrosion, ageing and improvements to design code. In Bangabandhu multipurpose bridge over Jamuna river, some cracks were developed at the surface of deck, bottom face of soffit, pier and girder connections. The cracks developed in Bangabandhu Jamuna multipurpose bridge were repaired by CFRP retrofitting technique (Khan et al. 2010). Research on structural strengthening and retrofitting on concrete structure and RC beam was performed by Islam et al. 2019. Byrne and Tikka (2008) conducted a research on repair and strengthening of severely damaged concrete beams with externally bonded CFRP. Failure in flexure region occurs when some additional loads has been introduced in the existing structure or deterioration of the structure. In literature reviews, last two decades, different researchers performed researches on this field. Flexural capacity of RC beams was increased using CFRP composite by Brena (2003).

Over the years, numerous researches of FRP strengthening system have been conducted on virgin RC beams. Only a few researches are performed on pre-cracked RC beams. Flexural behaviour of pre-cracked RC beams strengthened by CFRP sheet and plate were conducted by (Arduini and Nanni 1997; Buyukozturk and Hearing 1998; Islam et al. 2018, Mamun et al. 2019). They evaluated the efficiency of external strengthening of concrete members using CFRP strand sheets and compare this with the performance of continuous fibre sheets. They found that the flexural capacity improvement of CFRP strengthened beams varied from different range with respect to unstrengthened beams depending on strengthening methods. CFRP strengthened RC beam were investigated by Esfahani et al. (2007). This research results indicated that use of externally bonded uni-directional CFRP composite system significantly increases flexural strength. Hasnat et al. (2016) investigated the debonding strain, and consequently the ultimate moment capacity, gradually raised with increasing U-clamp width and stiffness. Wide-ranging experimental and analytical investigations on FRP strengthening RC beam were conducted by Hassan and Sami (2002), Choi et al. (2008). However, a little research had been conducted on strengthening and retrofitting of pre-crack RC beam at flexural region by CFRP. Therefore, it is novel approach to study on flexural behavior of pre-cracked RC beams strengthened using CFRP.

The purpose of this research is to study the flexural behavior of pre-cracked RC beams strengthened using CFRP. A series of tests have been carried out to CFRP-strengthen the RC beam by CFRP four points loading by universal testing machine. Nine RC beams including one reference beam and another eight initially cracked beam were tested in this study with varying (i) CFRP plate and sheet (ii) types of strengthening including CFRP U-strips applied (iii) different FRP length. Hydraulic contorted universal testing machine were used for four-point loading system. The flexure regions of RC beam has been strengthened and retrofitted by CFRP materials to observe the failure mode, deflection, extra load carrying capacity. CFRP materials can be apply for strengthening and retrofitting of Pre-crack RC beam effectively for better performance against flexure.

2. Matrial Properties

External bonded strengthening highly depends on the properties of adhesive and CFRP (Chuanxi et al. 2019). The main mechanical properties of adhesive for strengthening structures are effective bond strength, elastic modulus, and elongation. CFRP materials are composite materials that typically consist of fibres embedded in a resin matrix. Epoxy resin is the most widely used resin. CFRP could be more than 85 times higher strength than concrete (Amran et al. 2020). Five materials have been used to prepare the specimens. These are primer & saturant, CFRP fabric, CFRP plate, adhesive and concrete beam as shown in Figure 1. In this experiment, carbon FRP fabrics Kor-CFW450 is used. Kor-CFW450 having fiber strength 4900 MPa, fiber stiffness 230 GPa, areal weight, 450 g/m^2, fabric thickness, 0.255 mm. CFRP plate Kor-CLS0214 is used in this research having tensile strength 3000 (MPa), E-Modulus 165 GPa width 20 mm, thickness 1.4 mm. Primer and saturant were used having density 1.14 gm/cm^3 1.8 gm/cm^3; pot life 30 min,1hr 30 min; tensile strength 1350 MPa, 4875 MPa; Modulus of elasticity, 99.37 GPa, 238.00 GPa, respectively. Adhesive Kor-CPA 10 Base Resin and hardener used in this research have tensile strength 49.8 MPa, shear strength of adhesive 29 MPa, pot life 70 min. Concrete beam was cast targeted 25 MPa concrete.

Figure1. Primer & Saturant, CFRP Fabric, CFRP plate, adhesive and concrete beam

3. Experimental Program

A series of test on RC beam is conducted on FRP to steel, stainless steel, aluminum, and concrete interface. Total 9 RC beam specimens were casted, and then CFRP strengthen and tested in this research. Schematic view of beam dimension in longitudinal and cross section and three points loading is shown in Figure 2. Reinforced concrete beam was 1066 mm long 152.4 × 203.2 mm of cross sections. Figure 3. present's reinforcement placement in the mould and pre-cracked RC beam specimen. Surface is treated by grinding machine. Application of primer-saturaent, attaching CFRP sheet, CFRP attached specimen is shown in Figure 4. Figure 5, shows test setup for 3 point loading of unstrengthen and CFRP strengthen RC beam.

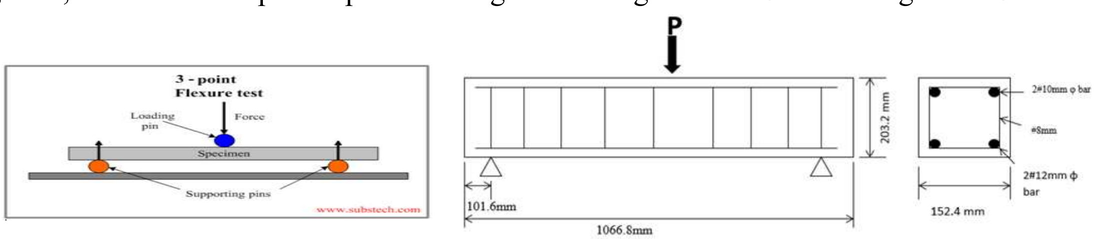

Figure 2. Schematic view of beam dimension in longitudinal and cross section and three points loading

Figuer 3. Reinforcement placed in the mould and pre-cracked RC beam specimen

Figure 4. Application of primer-saturaent, attaching CFRP sheet, CFRP attached specimen

Figure 5. Test setup for 3 point loading of unstrengthen and CFRP strengthen RC beam

4. Results and Discussion

Hydraulic controlled universal testing machine were used for three-point loading system. Failure mode of unstrengthen and CFRP strengthen RC beam is shown in Figure 6. Maximum load, maximum deflection, failure mode and improvement of load capacity with respect to reference beams is shown in Table 1. Unstrengthen RC beams was failed by common flexural pattern while initially cracked CFRP strengthened RC beams were failed shear failure and CFRP failure. The percentage of increase in load carrying capacity significantly varied 18.61%-75.29% for different strengthening technique. U type strengthening provides better performance than others. The load-deformation behavior of reference beam and CFRP strengthen beam are also presented in Figure 7. Flexural failure resist and deformation is increased due to CFRP strengthening. Moreover, progressive failures mode in U-strips beams allowing for larger deflections compared with other beams.

Figure 6. Failure mode of unstrengthen and CFRP strengthen RC beam

Table 1. Maximum load, maximum deflection, failure mode and improvement of load capacity with respect to reference beam

Beam designation		**Maximum Load (kN)**	**Deflection (mm)**	**Improvement load capacity (%)**	**Type of failure**
Ref. No CFRP beam	B_oF_o	48.23	2.24	00.00	Flexure Failure
CFRP sheet beam	B_1F-(1.5)	57.20	2.41	18.61	Shear Failure
CFRP sheet beam	B_2F-(2)	59.63	2.46	23.64	Shear Failure
CFRP U-stripes beam	B_3F-U-(1.5)	61.04	2.89	26.58	Shear Failure
CFRP U-stripes beam	B_4F-U-(1.5)	61.31	2.99	27.13	Shear Failure
CFRP Plate beam	B_5P-(1)	72.95	2.28	48.51	Shear Failure
CFRP Plate beam	B_6P-(1.5)	75.84	2. 31	57.26	Shear Failure
CFRP U-stripes beam	B_7F-U	83.35	3.16	72.83	Debonding & CFRP
CFRP U-stripes beam	B_8F-U	84.54	3.21	75.29	Debonding & CFRP

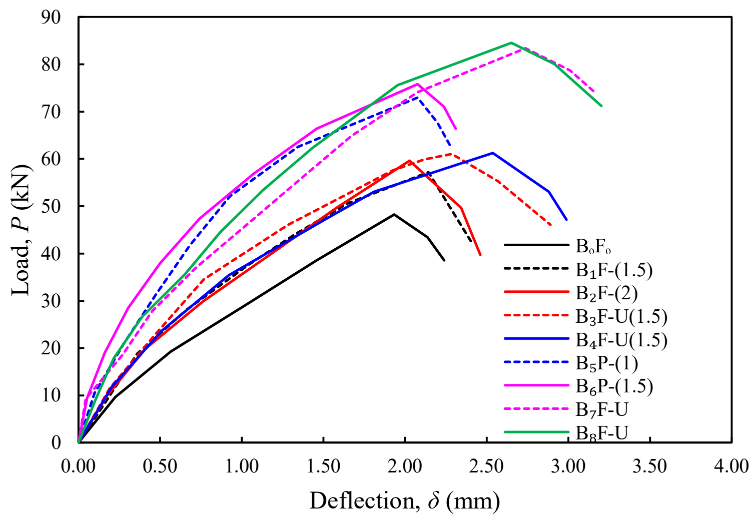

Figure 7. Load-deflection profile of beam specimens

5. Conclusions

In this paper, a series of tests on strengthening the RC beam by CFRP have been presented. Failure mode, maximum load, maximum deflection, load-deformation behavior improvement of load carrying capacity also presented in this research. CFRP plate provided better results and CFRP sheet. CFRP U-strips also provide better performance than other technique with effective length of strengthens. Unstrengthen RC beams was failed by common flexural pattern while pre-cracked CFRP strengthened RC beams failed by shear. Based on experimental results, it was found that CFRP strengthening pre-cracked RC beam provide better performance significantly than reference RC beam. The percentage of increase in load carrying capacity significantly varied 18.61%-75.29% for different strengthening technique Deformation is also increased due to CFRP strengthening U clamped beams. Therefore, it can be concluded that the flexural region damaged RC beam can be strengthen efficiently by CFRP with appropriate method.

Acknowledgments

The authors are grateful to RUET, University Grants Commission of Bangladesh, strength of Materials Laboratory, Department of Civil Engineering, Rajshahi University of Engineering & Technology (RUET). The financial support from the project (Project No.: DRE/7/RUET/489(31)/Pro/2020-2021/22) is highly acknowledge. Authors are greatfully acknowledge Nutech Construction Chemicals Company Limited, Dhaka, Bangladesh for supplying CFRP and adhesive materials and technical support.

References

Arduini, M., and Nanni, A. (1997). Behavior of pre-cracked RC beams strengthened with carbon FRP sheets. *Journal of Composites for Construction*, 1(2), 63-70.

Amran, Y. H. M., Alyousef, R., Alabduljabbar, H., Alaskar, A. and Alrshoudi, F. (2020). Properties and water penetration of structural concrete wrapped with CFRP. *Results in Engineering*, 5 (2020), 2-13.

Brena, S. F., Bramblett, R. M., Wood, S. L., and Kreger, M. E., (2003). Increasing flexural capacity of reinforced concrete beams using carbon fiber-reinforced polymers composites. *ACI Structural Journal*, 100(1), 36-46.

Buyukozturk, O., and Hearing, B. (1998). Failure behavior of precracked concrete beams retrofitted with FRP. *Journal of Composites for Construction*, 2(3), 138-144.

Byrne, D., and Tikka, T., (2008). Repair and strengthening of severely damaged concrete beams with externally bonded CFRP. *Advanced Composite Materials in Bridges and Structures*, Zurich, Switzerland, 80-85.

Choi, H. T., West, J. S., and Soudki, A. K. (2008). Analysis of the flexural behavior of partially bonded FRP strengthened concrete beams. *Journal of Composites for Construction*, ASCE, 12(4) 375-386.

Chuanxi, L., Lu, K., Jun, H., Zhuoyi, C., and Yang, J. (2019). Effects of mechanical properties of adhesive and CFRP on the bond behavior in CFRP-strengthened steel structures. *Composite Structures,* 211, 163-174.

Esfahani, M. R., Kianoush, M. R., and Tajari, A. R. (2007). Flexural behaviour of reinforced concrete beams strengthened by CFRP Sheets. *Engineering structures*, 29(10), 2428-44.

Hasnat, A., Islam, M. M., and Amin, A. F. M. S. (2016). Enhancing the debonding strain limit for CFRP-strengthened RC beams using U-clamps: identification of design parameters. *Journal of Composites for Construction, ASCE*, 20(1), 04015039-1-15.

Hassan, T., and Sami, R. (2002). Flexural strengthening of prestressed bridge slabs with FRP systems. *PCI Journal*, 47(1), 76–93.

Islam, G. M. S., Chowdhury, F. H. and Ismawi, A. D. (2018). Pre-Cracked RC Beam Strengthening with CFRP Materials. *IET Conference Publications,* CP, 750, 2-5.

Islam, S. M. Z., Ahmed, B., Islam, M. S., Ferdous, M. R. and Ali, M. W. (2019). FRP-adhesive materials for strengthening of RC beams at flexure and shear region. *Journal of Engineering and Applied Science, JEAS*, 3(1), 33-44.

Khan, M. A., Amin, F. M. S., Hossain, T. R., and Kabir, A. (2010). Cracks in the box girders of bongobondhu jamuna multipurpose bridge-Identification of causes based on FE analysis. *Proceedings of the IABSE-JSCE Joint Conference on Advances in Bridge Engineering-II*, at Dhaka, Bangladesh, 2, 451-460.

Mamun, N. M. Islam, G. M. S., and Alam, M. J. (2019). Flexural capacity assessment of brick aggregated pre-cracked RC beam strengthened with carbon fiber polymer. *Malaysian Journal of Civil Engineering*, 31(1), 1-8.