EXPERIMENTAL INVESTIGATION ON PRE-CRACK RC SHORT COLUMN RETROFITTED BY CFRP UNDER ECCENTRIC LOADING

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ABSTRACT

Reinforced Concrete (RC) column is an essential member of structures that transmit load from upper levels to the lower levels and then to the soil through the foundation. RC column failure is more critical than beam or tension member failure. In practical application, most of the RC short column is experienced eccentric loading. The load bearing capacity as well as structural performance is reduced due to the eccentricity of the columns. Moreover, eccentrically loaded RC short Column oftenly may found deficient due to seismic action, design and construction faults, change in application and implementation and corrosion. Carbon Fiber Reinforced Polymer (CFRP) is one of the most important, effective, potential, and advanced composite materials for retrofitting and retrofitting RC structures. CFRP retrofitting can be considered to resolve this problematic issue. The objective of this research is to investigate on pre-crack RC short column retrofitted by CFRP under eccentric loading. A series of tests have been conducted to strengthen the T, L and C shape RC short column by CFRP subjected to eccentrically loading. Eighteen RC column including reference and initially pre-cracked short column were tested in this research with varying the influence parameters such as retrofitting technique, deep and light deficient, cross-sectional shape of column, the dimension of eccentricity and the no. of CFRP layers. Load – deflection behavior, the failure loads, the failure modes have been presented due to eccentric loading. The load carrying capacity improved significantly and varied 211.95%-271.31% for different retrofitting technique. Hence, it was found that the improved performance can be achieved by CFRP retrofitting in damaged RC short column with appropriate technique under eccentric loading.

Keywords:*Carbon Fiber Reinforced Polymer (CFRP), Concrete columns, Eccentric loading, Pre-crack, Retrofitting*

1. INTRODUCTION

Now a day, reinforced concrete (RC) columns are one of the important structural elements in building, bridges, and other structures. The failure of RC column may lead to collapse of the whole structure. In construction, most of the RC column is subjected to axial compression and uniaxial or biaxial bending due to eccentricity. Eccentric loading generates extra moment which may occur due to vertical misalignment,faulty workmanship, erroneous design, beam flashing error and non-uniform settlement etc. The eccentricity of the column is the main causes to reduce the structural performance and load carrying capacity of RC column (Abed et al., 2018). Furthermore, RC column may find structurally deficient and accelerate damage of structure due to wind and seismic stroke, corrosion and design and construction errors subjected to eccentric loading. The effect of extra moment other than the design moment can be mitigated by incorporating strengthening techniques (Chotickai et al., 2020).In few years FRP sheets has become very significant and popular for retrofitting reinforced concrete structures by externally wrapping (Yang et al., 2018). Fiber Reinforced Polymer (FRP) to RC column and other structural members. Common process of wrapping FRP is fully wrapping, partially wrapping and spirally wrapping. Retrofitting and strengthening by CFRP has become vital and significant day by day in construction for many years causes of crack or weakening of the concrete structures (Hadi et al., 2012).FRP composite are generally used for warping RC structural members. CFRP retrofitting can be considered to carry the extra moment due to eccentricity(Hadi &Widiarsa, 2012).Application of CFRP warp for retrofitting to RC column is a comparatively a new and smart retrofitting technique over the conventional strengthening method and, also has a great potential to meet such challenges. In Bangladesh, the crack was developed in Bangabandhu Multipurpose bridge and Kanchpur Bridge which is retrofitted by CFRP (Khanet al., 2010; Rahmanet al., 2020).

Lab testing investigation on concrete columns strengthening by using CFRP was conducted by Olivova &Bilcik, (2009). This case study was based on the results of experimental research and analytical modeling for performance of CFRP sheet and CFRP laminating strips under a static axial compression load and cyclic horizontal load.The use of FRP composites were externally applied on different types of reinforced concrete (RC) structural member such as beam, column, slab to increase the strengthening for those structures (Rodrigues et al., 2015).It showed that CFRP wrapped specimens are stronger than unwrapped specimens. (Raza et al., 2021) also showed that the strengthened structure can withstand double load compared to that of unstraightened structure. An experimental investigation on performance of RC column specimen strengthening with CFRP composites under axial load capacity of short column at different cross section was done by Abed et al. (2018).Experimental research on behaviour of RC column specimen strengthening with CFRP composites under axial load at different slenderness ratio was performed by Narule & Bambole, (2021).

Previous investigation identified that the ductility and strength of concentrically loaded RC columns can be effectively improved by FRP wrapping (Wu et al., 2008; Olivova & Bilcik, 2009; Siddiqui, et al.,2014; Rahai & Akbarpour, 2014; Mehdi & Rasheed, 2018).The effect of eccentrically loaded FRP-strengthened RC columns has been investigated by a few researchers (Parvin & Wang, 2001; Li & Hadi, 2003; Chaiwino & Sirimaha, 2021). Experimental and analytical investigation on square and rectangular shape of RC column strengthen with FRP under eccentric loading had conducted by previous researchers (Hadi &Widiarsa,2012; Widiarsa& Hadi, 2013; Yang et al., 2018; Chotickai et al., 2020). But very few investigations were conducted on pre-cracked RC columns under eccentric loading. Therefore, extensive research is needed to enhance performance of pre-crack RC column retrofitting by CFRP under eccentric loading.

The purpose of this research is to investigate on pre-crack RC short column retrofitted by CFRP under eccentric loading. A series of tests have been conducted to strengthen the RC column by CFRP subjected to eccentrically loading. Eighteen RC column including reference and initially pre-cracked column were tested in this research with varying the influence parameters such as retrofitting technique, height of column, cross sectional shape of column, the dimension of eccentricity and the no. of CFRP layers. CFRP wrapping can be applied for strengthening and retrofitting of Pre-crack RC column effectively for better performance against eccentric loading.

2. MATERIAL PROPERTIES

Externally bonded strengthening highly depends on the properties of adhesive and CFRP materials. The effective bond strength, elastic modulus, and elongation are the key mechanical properties of adhesive for strengthening of structures. CFRP material is a composite material that typically consists of fibers embedded in a resin matrix. Epoxy resin is the most widely used resin for the CFRP. Four materials have been used to prepare the specimens such as primer and saturant, CFRP fabric, adhesive and RC column as shown in Fig. 1. In this research, carbon CFRP fabrics Kor-CFW450 is used having fiber strength of 4900 MPa, fiber stiffness of 230 GPa, areal weight 450 g/m^2, and fabric thickness 0.255 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 of 49.8 MPa, shear strength of adhesive 29 MPa, pot life 70 min. Properties stated above are from manufacturer's specification.

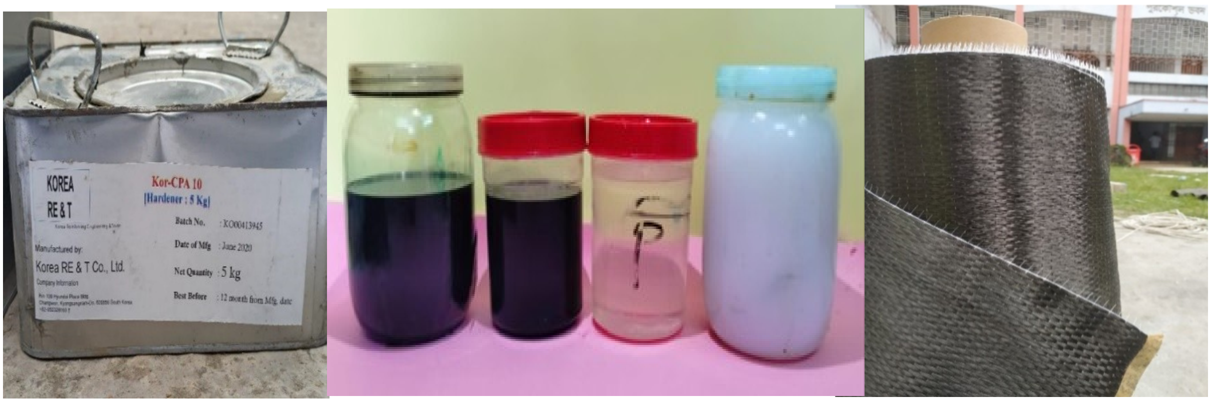

Figure 1: Primer, adhesive and CFRP fabric.

3. EXPERIMENTAL PROGRAM

A series of RC short column was casted for testing to meet the main aim of this research to find the effectiveness of CFRP retrofitting as well as improving structural behavior and performance of pre-crack RC short column subjected to eccentric loading.Eighteen RC short column including reference and initially pre-cracked column were tested in this research with varying the influence four parameters such as strengthening technique, cross sectional shape of column, the dimension of eccentricity and the no. of CFRP layers. Six (6) T shape, six (6) L shape and six (6) C shape specimens were casted in this research. Detailing dimensions of L, T and C type short column is shown in Figure 2. Schematic view of pre-cracking position of L, T and C type short column is shown in Figure 3. The specimens were labelled as CC1F0, CC1F1, CC1F2 TC2F0, TC2F1, TC2F2, LC3F0, LC3F1, LC3F2 etc. where, C indicates C shape of Column, C1 indicates Column no. 1, C2 and C3 same as indicated column No. 2 and 3. Same as T and L indicate T and L shaped Column. F0 indicate no CFRP, F1 indicate one-layer CFRP; F2 indicate two layer CFRP. F1, F2, indicate one layer, two layer of CFRP warping retrofitting respectively.

The materials for short column casting such as brick chips, sand, cement, reinforcement steel was collected from the local market. Wooden forma for T, L and C shape short column was made for casting specific dimension. Cement, sand, brick chips were mixed at the ratio 1:1.5:3 with fixed water cement ratio for high strength concrete. After mixing of concrete the column was casted by three-layer temping. For high strength concrete column were cured for 28 days. The targeted concrete was compressive strength was 25 MPa.Then marking the area for application of CFRP on the column. Surface area was cleaned by electric sander machine. All components of primer were weighted first and then mixed in a clean mixing container as per required ratio 2:1 (Base: Hardener). The primer was applied for dust free surface of the column for well bonded adhesive with column surface. After drying primer, adhesive (Saturant) was applied on the column. Application carbon fibre fabrics with Saturant in the surface area of column.Retrofitting of the considered specimen was carried out by applying primer then adhesive and followed by wrapping the specimen with CFRP sheets. Specific targetedwas retrofitted by CFRP warping in this research as shown in Figure 4.

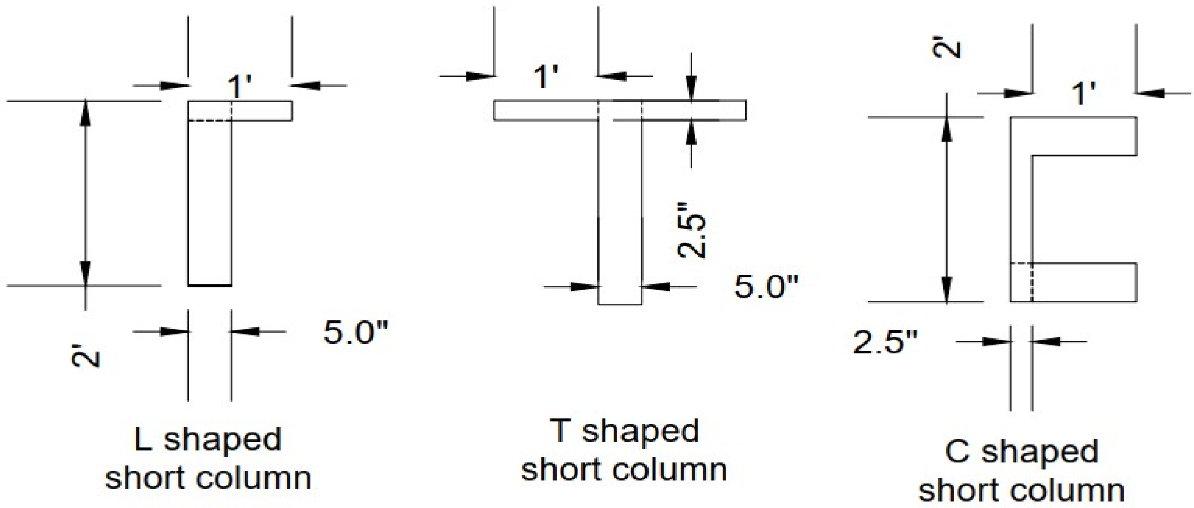

Figure 2: Detailing dimension of L, T and C type short column

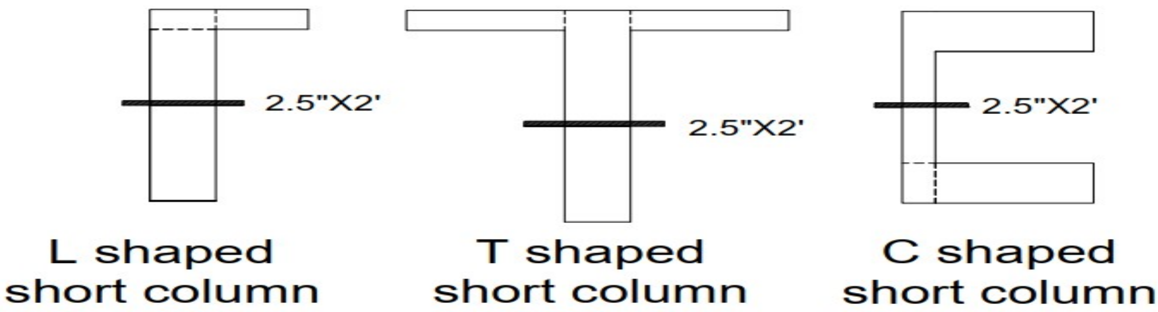

Figure 3: Schematic view of pre-cracking position of L, T and C type short column

The RC short column test were done by MATEST compressive testing machine. To perform test, the specimen placed between the two jaws and clamped firmly to conduct compression test. Four LVDT was placed properly to measure deflections of the specimen.Finally loading was started and the reading of load gauge and LVDT were recorded. In each cases deflection from LVDT was noted for corresponding load. The short specimens were placed into the machine with the help of plates.The loadings were obtained from the test machine as it is built with the help of computerized function. Test setup is shown in Figure 5.

Figure 3: Concrete mixing, T & Cwooden forma, column reinforcement and casted different type of specimens

(a) (b) (c)

Figure 4: (a) Cleaning of all Specimen (b) Applied adhesive (c) Wrapped of CFRP.

Figure 5: Experimental setup of the specimens

4. RESULTS& DISCUSSIONS

An extensive test program has been conducted on CFRP-retrofitting pre-crack RC short column subjected to eccentric loading. Eighteen RC short column including reference and initially pre-cracked column were tested in this research to verify the influence of five parameters such as retrofitting technique, cross section of column, eccentricity, and the no. of CFRP layers. The RCshortcolumn test were done by MATEST compressive testing machine. Long specimens were tested hydraulic controlled universal testing machine. The short specimens were placed into the machine with the help of plates. Four Linear variable differential transformer (LVDT) and two dial gauges was used for determining the deflection of the loading surface and deformation of the strut column. Two LVDT was touched at the strut surface and another at the base of the loading surface. The loadings were obtained from the test machine as it is built with the help of computerized function.The failure loads, failure modes and the load-deformation behavior of reference beam and CFRP strengthen slab are observed in this research. Load – deflection behavior, the failure loads, the failure modes have been presented due to eccentric loading.The failure modes of un-retrofitted and CFRP retrofitted RC short column are shown in Figure6. CFRP wrapping provided confinement effect on specimen which contributes to enhance the load carrying capacity of the short column under eccentric loading. Load carrying capacity enhancement by CFRP retrofitting C, T and L shape short column is presented in Figure Table1. Based on experimental results, it was found that CFRP retrofitting RC column provide better performance significantly than

Figure 6: Failure pattern of Column with & without CFRP (a) C-section (b) T-section (c) L-section.

square RC column. Test results shows that ultimate load carrying capacity of pre-crack cylindrical RC was increased 219.55%, 226.39%, 216.25% and 271.31% compared to reference for one layer, and two-layerCFRP strengthen C shape short column, in respectively. Ultimate load enhancement was found 211.95%, 231.34, 212.95 and 231.34% for T shape short column specimen CFRP strength by full one layer and two layer, respectively. For L shape short column, load carry capacity enhancement was found 245.83%, 267.11%, 245.83%, and 267.11% for pre-cracking CFRP retrofitting for one layer, and two respectively.A significant improvement in load carrying capacity of each type of specimen is clearly noticeable in this research. The load carrying capacity improved significantly and varied 211.95%-271.31% for different retrofitting technique. Hence, it can be revealed that the RC column sections can be strengthen efficiently by CFRP. The load-deformation behaviour of reference sections and CFRP strengthen section are also presented in Fig. 7.

Table 1: Load carrying capacity enhancement by CFRP retrofitting short column

Types of Columns	**Maximum Load (kN)**	**Maximum Deflection(mm)**	**Enhanced Load Carrying Capacity (%)**
CC1F0	5.123	2.752	-
CC1F1	11.248	3.257	219.55
CC1F2	11.598	3.564	226.39
CC2F0	4.221	2.752	-
CC2F1	9.128	3.128	216.25
CC2F2	11.452	3.257	271.31
TC1F0	5.292	2.754	-
TC1F1	11.092	3.256	211.95
TC1F2	12.243	3.592	231.34
TC2F0	4.283	2.758	-
TC2F1	8.924	3.823	212.95
TC2F2	9.574	3.572	231.34
LC1F0	6.024	2.756	-
LC1F1	12.978	3.257	245.83
LC1F2	13.562	4.242	267.11
LC2F0	5.212	2.751	-
LC2F1	11.027	3.251	245.83
LC2F2	11.529	3.519	267.11

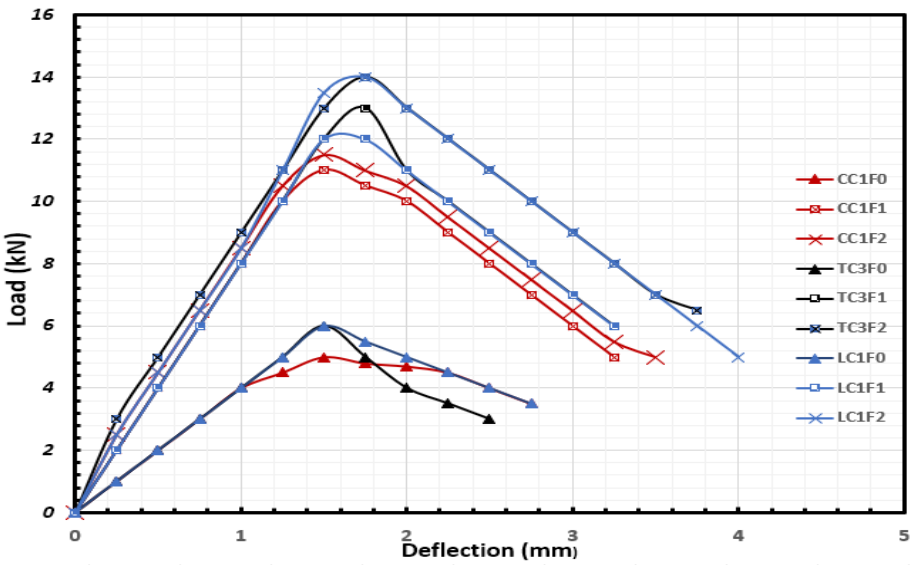

Figure 7: Load -deflection behaviour of deep layer cut section of L, T, C type column under eccentric loading.

The experimental results showed that the column with fully wrapped CFRP, CC1F2 gains 226.39% of strength than the reference column, CC1F0. Similarly, the columns of TC1F2 achieve the load carrying capacity is 231.34% which also greater the reference column. In specimen of LC1F2, the graph shows that the ultimate load and deflection are 14 kN and 1.75 mm respectively. Enhancement of load carrying capacity for CFRP retrofitting of T, L and C type short column under eccentric loading is presented in Figure 8.Based on experimental results,TC3F2 column has the highest load carrying capacity is 14.289kN and LC3F0 column has the lowest load carrying capacity is 4.123kN among them. The results of the tests showed that CFRP could be used for both strengthening and retrofitting.Therefore, it can be concluded that the use of CFRP composite laminates for strengthening and repairing damaged reinforced concrete short column is an excellent and preferable option.

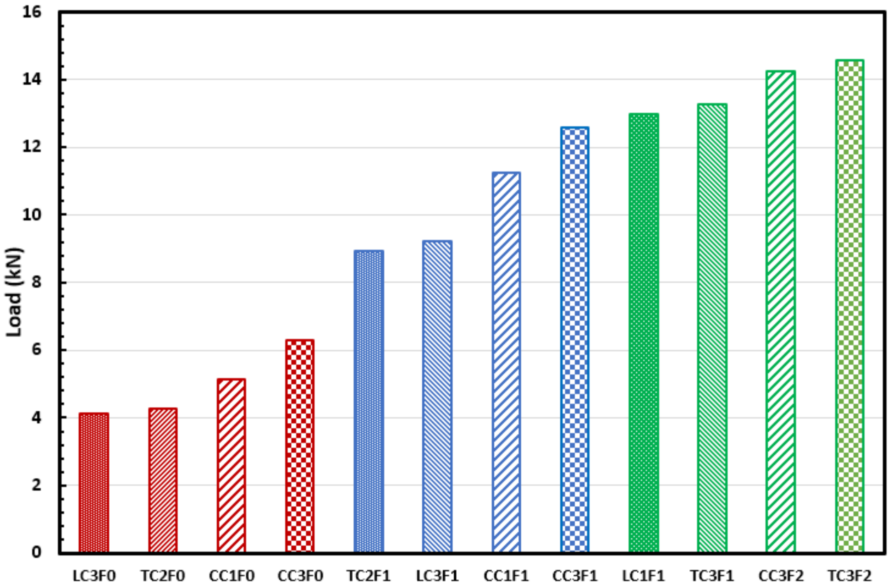

Figure 8: Enhancement of load carrying capacity for CFRP retrofitting of T, L and C type short column under eccentric loading

5. CONCLUSIONS

In this research, a series of tests on retrofitting of the pre-crack RC short column by CFRP have been presented. Failure mode, load-deformation behavior improvement of load carrying capacity also presented in this research. Ductility, stiffness, and ultimate load carrying capacity is enhancing significantly. CFRP wrapped sheet strengthening provided better results for L shape, deep cutting length warping and double layer strengthening. When eccentricity increased, load carrying capacity also decreases due to CFRP strengthening. CFRP wrapping provided confinement effect on specimen which contributes to enhance the load carrying capacity of the column under eccentric loading. Based on experimental results, it was found that CFRP retrofitting pre-cracked RC column provide significant performance compared to reference RC column. The percentage increase in load carrying capacity significantly. Based on experimental observation, it can be revealed that by increasing CFRP length, load carrying capacity enhancement also is increased. The value of load carrying capacity improved, and it varied from 211.95%-271.31% for different retrofitting techniques. Deformation is also increased due to CFRP strengthening. The test results revealed that externally bonded unidirectional CFRP strengthening increase, stiffness, ductility load carrying capacity and strength of the rectangular pre-cracked column. Hence, it was revealed that the improved performance can be achieved by CFRP retrofitting in damaged RC short column with appropriate technique under eccentric loading.

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