COMPARISON EXPERIMENTAL BEHAVIOUR OF RC COLUMN WITH AND WITHOUT CARBON FIBER POLYMER (CFRP) LAYER UNDER ECCENTRIC LOADING

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ABSTRACT

This paper presents the results of experimental studies on reinforcement concrete (RC) column under eccentric loading. Large-scale specimen with 2700 mm length and rectangular cross section (200 mm x 300 mm) was prepared and tested under compressive eccentric loading up to failure. In this study, the RC column behavior with and without CFRP layer was compared. Stiffness, failure force and energy absorption of the RC columns was investigated. Results have shown that by increasing the axial load, deep cracks in the RC column without CFRP layer were expanded and bending hardness was decreases up to failure. This submission represents yield point of the tensile armature in the column. After the surrender, tensile force at longitudinal reinforcement was increases slightly. Also, behavior of the RC column without CFRP layer have shown that the maximum curve was in middle of the column and maximum transverse strains were recorded in the compression zone. Finally, by compared this experimental specimen with similar RC column that composited by CFRP layer, indicated that this layer can increases axial load bearing of RC column up to 108%

Keywords: RC column; Eccentric loading; Rectangular section; Energy Absorption, CFRP layer.

1. INTRODUCTION

The use of externally applied fiber-reinforced polymer (FRP) composites has gained significant popularity for the strengthening and repair of concrete structures. FRP composites have been used successfully for the strengthening of deficient reinforced concrete (RC) structures including bridges and buildings. Concrete columns in these structures are essential elements that may need to be strengthened. In recent years, several studies have been conducted about FRP-confined and

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strengthened columns under concentric loads. However, it is clear that most columns are loaded under the combination of the axial compression load and bending moment (i.e., eccentric compression loading). So there is a need for research on the behavior of FRP-strengthened columns under eccentric loading. The present paper is a step along this direction.

Some research has been conducted on FRP-confined columns under eccentric loading. In a study performed by Parvin and Wang (2001), small-scale square concrete columns (i.e., 108*108*305 mm) were strengthened with varying layers of carbon fiber reinforced polymer (CFRP) composites and tested subjected to an axial load at different eccentricities. The eccentric loading was achieved by placing a knife edge at a set distance from the center of the cross section of the column. The results showed that the increase in eccentricity resulted in a decrease in the strength capacity of the column and the use of the CFRP increased the load capacity of the column.

Yalçin and Kaya (2004): An experimental study was conducted on the determination of strengthening reinforced concrete columns using FRP material. Four reinforced concrete cantilever columns of 200x400x1610 mm dimensions, representing the old construction practice, were tested. One lap-spliced and one continuous longitudinally reinforced as build control columns, and their strengthened columns were tested under constant axial load and reversed cyclic lateral load. FRP sheets were wrapped around the potential hinging zones. Test results showed that lap-splicing dominates the behaviour where no difference in force-deformation relationship between control and strengthened columns were observed. However, the columns with continuous longitudinal reinforcement showed significant increase in ductility.

Lignola et al.(2007) have mainly focused their attention on square hollow columns wrapped with CFRP composites (height of 3020 mm, width of 360 mm, and wall thicknesses of 60 mm). A total of seven RC specimens with hunched solid heads were prepared, wrapped in the transverse direction, and tested under various eccentric loadings. The outcomes highlighted that composite wrapping can enhance the structural performance of concrete columns under eccentric loading in terms of strength and especially in terms of ductility. The strength improvement was more pronounced in the case of specimens loaded with smaller eccentricity, while the ductility improvement was more significant in the case of larger eccentricity.

Malik and Foster (2010): An experimental investigation was conducted to investigate the behavior of ultra-high-strength reactive powder concrete (RPC) columns confined by carbon fiber-reinforced polymers (CFRPs) and subjected to concentric and eccentric loadings. Seventeen columns were cast with the concrete mixture containing either no fibers, with a concrete strength of approximately 140 MPa (20.3 ksi), or 2% (by volume) of straight steel fibers, with a concrete strength of approximately 165 MPa (23.9 ksi). The column specimens contained no conventional steel reinforcement, either in the longitudinal or transverse direction with the tensile forces carried by the CFRP. Experimental data for strength lateral and axial deformation, and the failure mode were obtained for each test. For the concentrically loaded specimens, failure occurred at or close to the

peak loading with little or no residual capacity. The transverse strains measured at the fracture of the CFRP for confined columns were found to be significantly lower than the ultimate tensile strength reported by the manufacturer or obtained from the standard tensile coupon tests. For the eccentrically loaded columns, the final failure was sudden and explosive but only after the peak load was passed and at the point of tearing of the CFRP wrapping. There was no evidence, however, that the use of CFRP in the hoop direction significantly increased the strength for the eccentrically loaded columns.

Furthermore, the results of a parametric analytical study, performed by the authors (2012), using finite element method for old-type existing columns with optional steel bars' buckling under compression are utilized in order to propose an upgraded empirical strength model. The parametric study involved column models constructed with three-dimensional finite elements for concrete and steel incorporating plasticity theory and laminas for FRP jacket elastic response. After elaboration of the parametric finite element analyses of characteristic RC columns, the effect of the existing bars' yield strength on the behaviour of FRP strengthened columns is evaluated covering all qualities of steel met in existing columns. Finally a strength model sensitive to bars' quality is proposed for the design of RC columns confined by FRP jackets that requires no estimation of the effective failure strain of the FRP jacket, as it was found strongly related to the axial rigidity of the confining FRP device and the strength enhancement of the concrete core. The model is compared against an extensive database of experimental results. The proposed model provides remarkably accurate strength prediction results for the abovementioned strengthening applications.

2. EXPERIMENTAL PROGRAM

2.1. Specimen Layout

In this research, a total of tow RC specimens were designed with a rectangular section (200 mm*300 mm). The test portion of each specimen had a height of 1,500 mm and each hunched head had a height of 600 mm. The specimens were tested under compression eccentric loading up to failure. The corners of the cross section were chamfered to a radius of 15 mm. Figure 1 shows the geometry of the specimens.

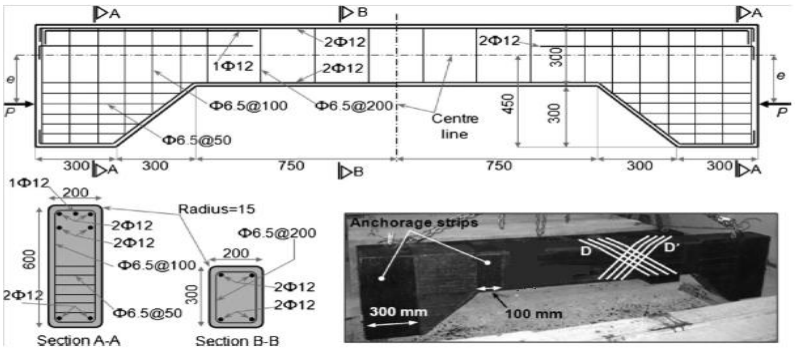

Figure 1: Geometry and reinforcement detailing of specimens (Sadeghian et al. 2009)

One of the RC columns was unstrengthened (U300); and the other one was strengthened with two diagonal layers of CFRP (S300-DD'). In the composited specimen, FRP thicknesses was 1.8 mm (two layers); fiber orientations were +45° and -45° respects with an axis perpendicular of the column axis. The test program and specimen properties are summarized in Table 1, where D is the diagonal direction (+45°); and D' is the inversed diagonal direction (+135° which is the same as -45°).

Table 1: Specimen Design Details

Specimen	Strengthening	Number of CFRP layers	Fiber orientation	Eccentricity (mm)
U300	-	-	-	300
S300-DD'	*	2	±45	300

The specimens were divided into two groups. The first group labeled "S" consisted of strengthened specimens, and the second group labeled "U" were unstrengthened and served as control specimens. Specimen of each group was tested under an eccentricity of 300 mm.

2.2. Material Properties

The specimens were cast from one batch of concrete with a 28-day compressive strength of $f_c' = 30\,MPa$ and a slump of 80 mm. Also this specimens were reinforced with $4\Phi 12$ mm longitudinal ribbed bars ($f_y = 350\,MPa$) symmetrically placed. Transverse reinforcement was provided with rectangular ties $\Phi 6.5 @ 200$ mm that made of smooth bars ($f_y = 325\,MPa$).

The clear concrete cover for the ties was 20 mm. The reinforcement details for the specimens were shown in Figure 1. Extra longitudinal and transverse reinforcement were provided in hunched heads in order to prevent premature failures. Unidirectional carbon fiber sheets were adopted. The mechanical properties of CFRP through tension testing on these layers in the longitudinal and transverse directions are shown in Table 2.

Table 2: Mechanical Properties of CFRP (Sadeghian et al. 2009)

Test direction	Ultimate strength (MPa)	Initial modulus (MPa)	Ultimate strain (mm/m)	FRP thickness (mm/layer)	Dry thickness (mm/layer)
Fiber direction	303	41000	7.4	0.9	0.25
Matrix direction	29	2400	7.2	0.9	0.25

2.3. Specimen Preparation

The concrete was placed in one batch and cast in a special steel formwork. After curing in a humid condition for 28 days, the surface of specimens was cleaned and one of them prepared for strengthening. In order to prevent anchorage rupture in diagonal layers were applied on the full

length of the S300-DD' specimen and anchored by extra transverse strips at both ends of the prismatic part and hunched heads, as shown in a photograph of a strengthened specimen in Figure 1.

The carbon fiber layers were applied on all faces of the specimens and the layers with transverse fibers were the last layers. The epoxy resin cured at laboratory temperature (i.e., 22°C) for a minimum of 7 days.

2.4. Test Setup

A hydraulic actuator was used to apply the axial load to the columns. The upper ends of the specimens were attached to the actuator, while the lower ends were supported on the steel reaction frame. Both end supports were designed as hinged connections with predefined eccentricity. The lateral stability of each specimen in and out of plane was maintained by appropriate steel supports.

A total of six linear variable displacement transducers (LVDTs) and 24 strain gauges were used for every specimen. Figure 2 shows the arrangement of LVDTs and strain gauges. The specimens were tested using a 600 kN capacity compression actuator under displacement control and the data were monitored using an automatic data collecting system. Displacements and strains were monitored by a digital data logger system. The tests were performed up to failure of the specimens. Force, displacements, and strains were obtained during the test and were filed by computer software. The test was stopped when the FRP failed on the tension face (i.e., for the strengthened specimens) or the concrete crushed on the compression face (i.e., for the unstrengthened specimens), because the test setup and actuator situation were very sensitive and were not able to manage large postpeak deformations.

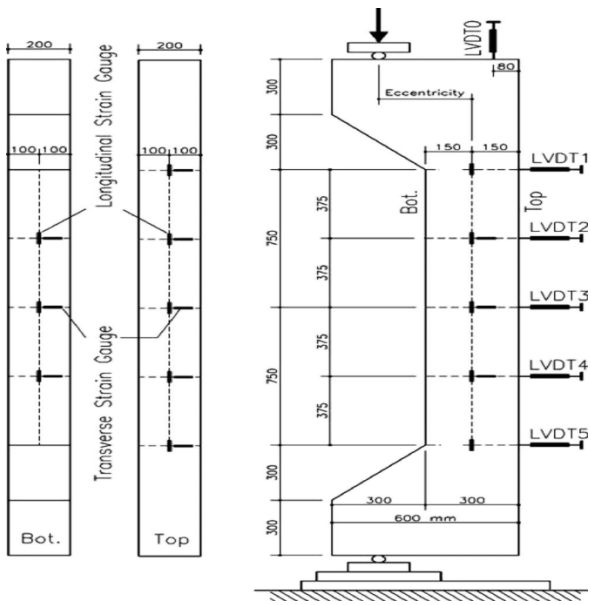

Figure 2: Arrangement of strain gauges and LVDTs (Sadeghian et al. 2009)

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1. Overall Behavior

At the early stages of loading of the strengthened specimen, the noise related to the micro cracking of concrete and stretch of the FRP was obvious indicating the start of stress transfer from the concrete to the FRP. Prior to the failure, the noises of the stretched FRP were extremely heard and the curvature of the specimen was visible. The maximum lateral deflection was almost seen at middle height of the specimen. The lateral deflection was gradual and no other bonding took place between the FRP and the concrete during the tests. This behavior would end with a sudden rupture of the diagonal in DD' layers on the tension face of the specimen.

The rupture of the FRP was almost initiated at middle height of the specimen. At this time an impact was induced in the specimen with a sudden increase of lateral deflection and decrease of load. The strength of all strengthened specimen increased significantly, but the post peak behavior showed a sudden drop in both strength and stiffness. After the rupture of the FRP, concrete cracking progressed to both ends of the specimen. The sudden failure indicates the release of an extra ordinary amount of energy as a result of the tensile stress provided by the FRP. Inspection of the failed specimen showed yielding of the longitudinal steel bar in the tension face and buckling of the longitudinal steel bar in the compression face of the column.

The overall behavior of the unstrengthened specimen was typical. Tensile cracks were produced on the tension face at the early stages of loading and propagated with increasing of loading. The cracks on middle height of the specimen were opened extensively when the tensile steel bars were yielded. The load dropped when the concrete on the compression face crushed and the compressive steel bars buckled. Figure 3 shows the failure region of the strengthened and unstrengthened specimens.

Figure 3: Failure of the strengthened and the unstrengthened specimens

3.2. Load-Displacement Behavior

The load-displacement curves of the specimens with 300 mm eccentricity are shown in Figure 4. The longitudinal displacement U_{Lon} was measured from the actuator displacement gauge and the lateral displacement U_{Lat} was obtained from the middle height's LVDT. The unstrengthened

specimen U300 has an approximate linear load-longitudinal displacement behavior up to the yield point (i.e.,Y), that steel bars on the tension face are yielded at a force of 103.8 kN and longitudinal and lateral displacements was 9.53 and 5.00 mm, respectively. The yielding point was evaluated when the load-displacement curve slope changes. The longitudinal secant stiffness is equal to 14.83 kN/mm. After the yield point, the stiffness is enormously decreased and a plastic hinge is created. The plastic region has a small constant longitudinal tangent stiffness (i.e., 1.47 kN/m) due to the strain hardening of the steel bars. This bilinear behavior is continued up to the concrete crushed and steel bars buckled on the compression zone of the plastic hinge at a force of 114.4 kN and a longitudinal displacement of 16.74 mm. The strengthened specimen exhibited a similar bilinear behavior based on Figure 4. The first part of all curves roughly was linear up to the yield point, when the steel bars on the tension face yielded. The secant stiffness and yield strength were improved with increasing longitudinal stiffness of the FRP. Beyond the yield point, the FRPs were effectively activated, so the second part of all curves continues although at a stiffness that is lower than that for the elastic region. The tangent stiffness at the plastic region was improved with increasing longitudinal stiffness of the FRP. The maximum load carrying of each specimen was achieving at the FRP failure point, up to the FRP was broken. The failure force of S300-DD' sample was equal to 238 kN, which shown a 108% increase at compared with the unstrengthened specimen. Table 3 shows the longitudinal secant stiffness, yield point, longitudinal tangent stiffness, and failure point of all specimens.

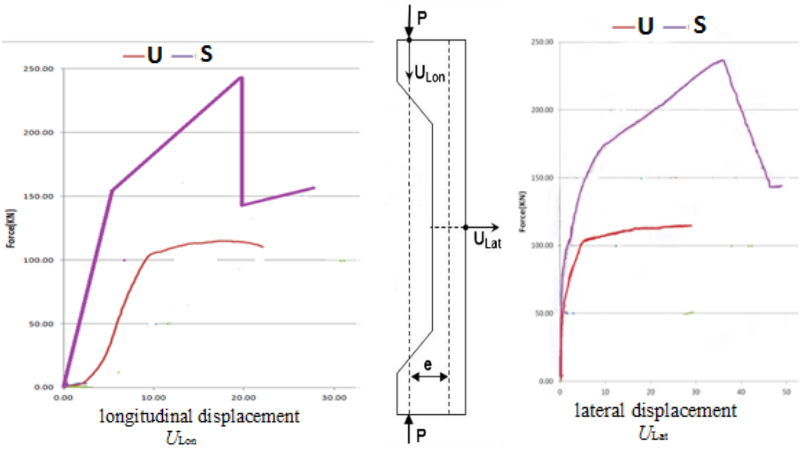

Figure 4: Load-displacement behavior of specimens: e=300 mm

Table 3: Experimental Results

Specimen	Longitudinal Secant stiffness (kN/mm)	Yield point		Longitudinal tangent stiffness (kN/mm)	FRP failure point	
		Load (KN)	U_{Lon} (mm)		Load (KN)	U_{Lon} (mm)
U300	14.83	103.8	9.53	1.47	114.4	16.74
S300-DD'	34.5	163	8.9	4.4	238	25.9

4. CONCLUSION

In this study, the RC column behavior with and without CFRP layer was compared. Load-displacement and moment - curvature graphs for the column were plotted and stiffness and energy absorption of the RC columns was investigated. The following conclusions were drawn:

- The failure force of the S300-DD' sample was equal to 238 kN and for the U300 sample was about 114.4kN, which shown a 108% increase at compared with the unstrengthened specimen.
- Longitudinal displacement of the U300 sample was 16.74 mm and for the S300-DD' sample was equal to 19 mm, which shown a 13% increase at compared with the unstrengthened specimen.
- The longitudinal secant stiffness of the U300 sample was equal to 14.83 kN/mm and for the S300-DD' sample was about 34.5 kN/mm, which shown a 132.64% increase at compared with the unstrengthened specimen.
- The relatively energy absorption of the U300 sample was equal to 1273 kN.mm and for the S300-DD' sample was about 2977 kN.mm, which shown a 133.9% increase at compared with the unstrengthened specimen.

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