Interaction between Theory and Practice in Civil Engineering and Construction
Edited by Komurlu, R., Gurgun, A. P., Singh, A., and Yazdani, S.

ISBN: 978-0-9960437-2-4

BEHAVIOR OF PLAIN AND STEEL FIBER HIGH STRENGTH REINFORCED CONCRETE COLUMNS CONFINED WITH CFRP

DUYGU ERTURKMEN[1], CENGIZ DUNDAR[1], and SERKAN TOKGOZ[2]

[1]*Civil Engineering Dept, Cukurova University, Adana, Turkey*
[2]*Civil Engineering Dept, Mersin University, Mersin, Turkey*

High strength reinforced concrete columns have been increasingly used in structural applications. It is known that high strength reinforced concrete columns exhibit brittle behavior under applied loads. Therefore, steel fibers can be added into the core concrete to improve the ductility and deformability of high strength reinforced concrete columns. In addition, reinforced concrete columns can be wrapped with carbon fiber reinforced polymer (CFRP) materials for strengthening the columns. In this work, experimental and analytical studies on plain and steel fiber reinforced concrete columns and CFRP confined columns have been presented. The experimental strength capacities, load-deflection relations and failure modes of the column specimens have been observed. The effects of the parameters of concrete compressive strength, load eccentricity, steel fibers, and carbon fiber polymer material on the structural behavior of high strength reinforced concrete columns have been examined. It is concluded that the inclusion of steel fibers has considerable effect on column ductility and deformability, but has insignificant effect on column strength capacity. The experimental study exposed that wrapping CFRP material on plain and steel fiber high strength reinforced concrete columns has provided significant improvement on the column strength capacity and confinement. The tested columns have been analyzed with a theoretical method considering the experimental stress-strain relations of CFRP confined concrete; and the analysis shows good agreement with the experimental results.

Keywords: Carbon fiber polymer, Confinement, Deflection, Ductility, Strength capacity, Deformability.

1 INTRODUCTION

Carbon fiber polymer (CFRP) sheet wrapping to the reinforced concrete columns presents significant advantages in the field of civil engineering applications and constructions. Hence it is important to understand the behavior of plain and steel fiber reinforced concrete columns confined with CFRP.

A number of research studies were conducted to determine the behavior of CFRP confined eccentrically loaded slender reinforced concrete columns and mechanical behavior of fiber reinforced polymer confined concrete (Mirmiran and Shahawy 1997, Samaan *et al*. 1998, Sheikh 2002, Hadi 2009, Punurai *et al.* 2013). But there is lack information about steel fiber reinforced concrete columns confined with CFRP sheets.

So in this research a total of 16 both plain and steel fiber reinforced concrete column specimens were wrapped with CFRP material and experimentally tested to determine the column structural behavior. In addition, the tested column specimens have been analyzed to predict the ultimate strength capacity and load–deformation behavior of CFRP confined slender reinforced concrete columns. The experimental stress–strain relation of the CFRP confined concrete is used in the analysis procedure. To obtain the concrete stress-strain relations of the each CFRP wrapped column specimens, one layer and two layers of CFRP wrapped standard cylinder specimens tested under uniaxial compressive loading. In conclusion, the analysis and experimental results of tested columns have been achieved in good accuracy in this study.

2 EXPERIMENTAL STUDY

The experimental study was focused on the determination of the behavior of CFRP confined plain and steel fiber reinforced concrete columns. For this purpose, a total of 16 column specimens were prepared and experimentally tested under biaxial bending and axial load.

The yield strength of the longitudinal bars and lateral reinforcement was 550 MPa and 630 MPa, respectively. Steel fiber concrete was prepared with using RC 65/35 BN-type hooked steel fibers. The steel fiber column specimens were constructed at dosages of 50 and 60 kg/m^3 steel fiber composites. For strengthening of the columns, bi-directional CFRP material namely SikaWrap Hex 300C 0/90 was used. This material applied on the columns surface with Sikadur-330 adhesive. All the details of the specimens are shown in Figure 1.

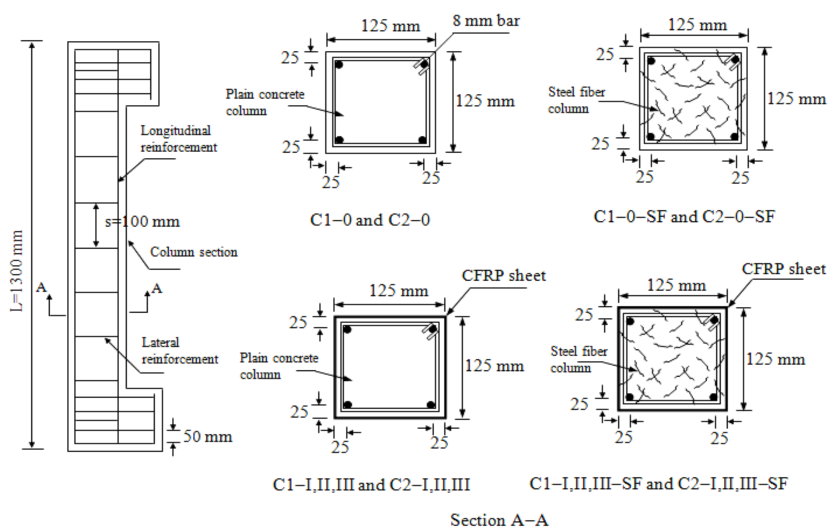


Figure 1. Details of test specimens and reinforcement configuration.

Eight specimens were plain high strength reinforced concrete columns (C1-0,I,II,III and C2-0,I,II,III) and other specimens were steel fiber high strength columns (C1-0,I,II,III-SF and C2-0,I,II,III-SF). The control plain and steel fiber column specimens of C1-0, C2-0, C1-0-SF and C2-0-SF were not wrapped with CFRP material. But the other columns were strengthened by one layer and two layers of sheets, respectively. The column specimens of C1-III, C1-III-SF, C2-III and C2-III-SF were strengthened by two layers of CFRP sheets similarly.

In the tests, a data acquisition system was established to record the digital measurements during the tests. Four linear variable displacement transducers were applied horizontally on each face of mid-height of the column specimens. A load cell was used to measure the load values. The column specimens were vertically tested using a universal testing machine with pinned conditions at both ends in the Structural Laboratory, at Cukurova University in Turkey. More details for the experimental work can be obtained from the study reported by Dundar *et al.* (2015).

3 ANALYTICAL RESEARCH

A theoretical method to analyze the reinforced concrete columns under combined axial compression and biaxial bending have been previously presented in Dundar *et al.* (2007) and Tokgoz (2009). The method has been modified by Dundar *et al.* (2015) to determine the behavior of CFRP confined plain and steel fiber slender reinforced concrete columns. In this study, the experimental stress-strain relations have been used to analyze the plain and steel fiber high strength CFRP confined slender columns.

The fundamental equilibrium equations for the axial load N, and the bending moments M_x and M_y of CFRP confined reinforced concrete columns are described as follows:

$$N = \sum A_c \sigma_c + \sum A_s \sigma_s + \sum A_{fp} \sigma_{fp} \tag{1}$$

$$M_x = \sum A_c \sigma_c y_c + \sum A_s \sigma_s y_s + \sum A_{fp} \sigma_{fp} y_{fp} \tag{2}$$

$$M_y = \sum A_c \sigma_c x_c + \sum A_s \sigma_s x_s + \sum A_{fp} \sigma_{fp} x_{fp} \tag{3}$$

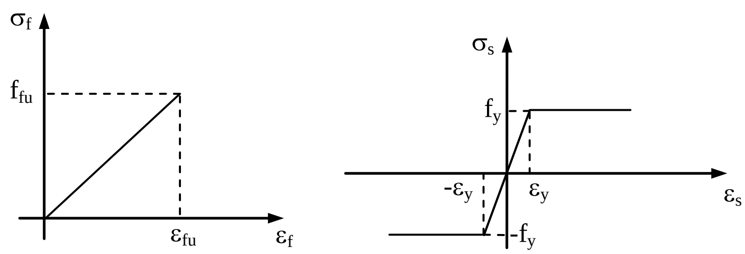
where A_c, A_s and A_{fp} are the elemental area of concrete segment, area of reinforcing steel bar and elemental area of CFRP sheet, respectively; σ_c, σ_s and σ_{fp} are the concrete, reinforcing steel and CFRP material stresses, respectively; (x_c, y_c), (x_s, y_s) and (x_{fp}, y_{fp}) indicate the distance between, respectively, the center of elemental area of concrete, reinforcing steel bar and the center of the elemental area of CFRP element, and the geometric center in x–y plane.

The algorithm of the analysis procedure has been reported by Dundar et al. (2015). The stress-strain curves of the CFRP, steel and typical CFRP confined concrete are shown in Figure 2 (a-c).

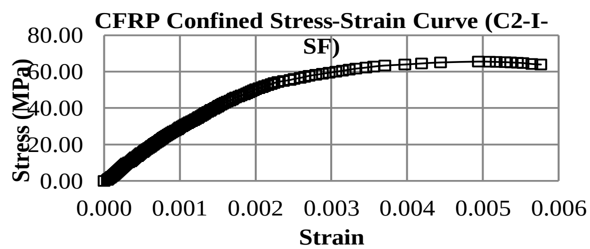
4 RESULTS AND DISCUSSION

The structural behavior of plain and steel fiber reinforced concrete columns strengthened by CFRP sheets were investigated in this study. It was observed that the unconfined plain high strength reinforced concrete columns (C1-0, C2-0) behaved more brittle under applied load. These specimens failed suddenly and in an explosively manner. On the other hand, the steel fiber column specimens (C1-0-SF, C2-0-SF) exhibited ductile behavior particularly after the peak load. It was concluded that, the inclusion of steel fibers considerably developed column ductility and deformability.

The failure was observed near the mid-height of the tested column specimens. For the CFRP confined columns, some of the longitudinal sheets were fractured in tension side at the time of failure. Lateral stiffness has been provided for the plain and steel fiber reinforced concrete columns strengthened with CFRP material owing to the transverse sheets (Dundar *et al.* 2015). The typical failure mechanism of the tested CFRP confined slender reinforced concrete column specimens is shown in Figure 3 and the typical comparative experimental axial load–lateral deflection diagrams of column specimens (C2-0-SF, C2-I-SF and C2-II-SF) are illustrated in Figure 4.



(a) CFRP (b) Steel



(c) CFRP confined concrete

Figure 2. (a-c) Typical stress-strain curves of CFRP, steel and confined concrete specimens.

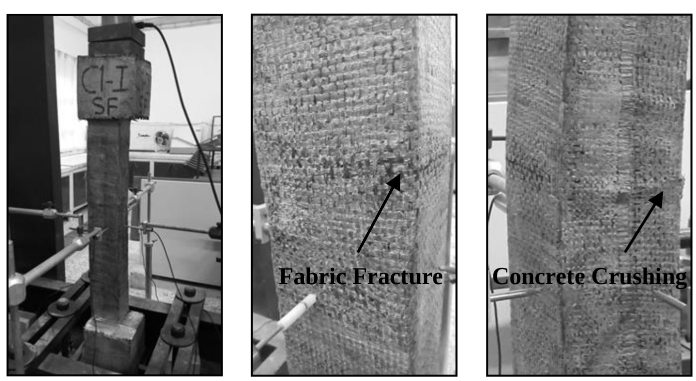


Figure 3. Experimental setup and typical failure mode of column specimens.

In this study, the plain and the CFRP confined slender reinforced concrete columns were analyzed by using the experimental stress–strain curves determined from plain and CFRP wrapped concrete standard cylinder specimens. The column specimen properties of the concrete compressive strengths and the load eccentricities are given in Table1. In addition, the experimental strength capacities (N_{test}), the analysis loads (N_u), and the comparative strength results of the column specimens are shown in Table 1.

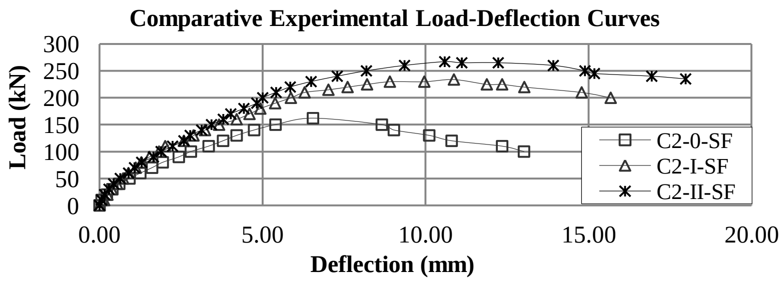


Figure 4. Comparative experimental axial load-lateral deflection diagrams.

Table 1. Test and ultimate strength results of column specimens.

Specimen	**f_c (MPa)**	**$e_x = e_y$ (cm)**	**N_{test} (kN)**	**N_u (kN)**	**M_{ux}&M_{uy} (kN cm)**	**N_u / N_{test}**
C1-0	66.77	4	203	194.08	881.12	0.956
C1-I	59.86	4	258	251.13	1145.19	0.973
C1-II	61.62	4	350	311.87	1402.93	0.891
C1-III	69.00	5	254	249.74	1365.47	0.983
C1-0-SF	65.20	4	220	198.52	916.32	0.902
C1-I-SF	63.72	4	299	280.66	1288.97	0.939
C1-II-SF	67.03	4	365	322.56	1512.97	0.884
C1-III-SF	78.66	5	273	314.68	1812.20	1.153
C2-0	76.76	5	155	155.17	926.96	1.001
C2-I	77.88	5	255	237.80	1342.13	0.933
C2-II	73.65	5	283	282.82	1578.28	0.999
C2-III	78.27	6	222	235.33	1535.10	1.060
C2-0-SF	67.00	5	162	151.88	870.86	0.938
C2-I-SF	65.55	5	234	232.98	1350.11	0.996
C2-II-SF	65.30	5	267	300.59	1838.46	1.126
C2-III-SF	69.59	6	225	236.92	1581.28	1.053
Mean Ratio						**0.987**

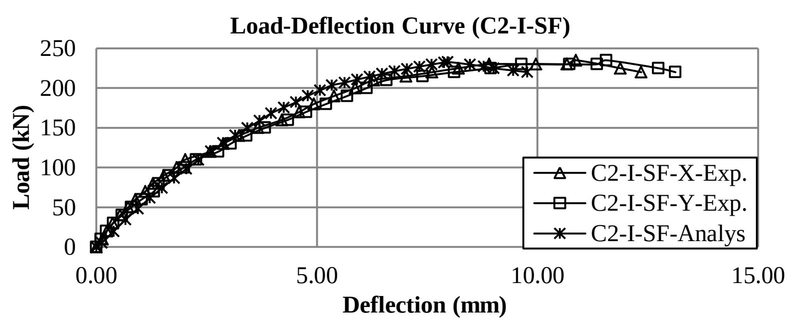


Figure 5. Typical experimental and analytical axial load-lateral deflection diagram.

5 CONCLUSIONS

The use of CFRP sheets have improved confinement, ductility, deformability and the ultimate strength capacity of plain and steel fiber reinforced concrete columns. In addition, the ultimate load and the deformation capacity of plain and steel fiber reinforced concrete columns have increased with increasing CFRP layers. The results show that the ultimate load capacities of reinforced concrete column specimens are significantly influenced by load eccentricity, concrete compressive strength, and slenderness effect. Finally, the comparisons between the test and the analysis results have indicated good accuracy in this study.

References

Dundar, C., Tokgoz, S., Tanrikulu, A. K., Baran, T, Behaviour of Reinforced and Concrete-Encased Composite Columns Subjected to Biaxial Bending and Axial Load, *Building and Environment*, 43(6):1109-20, 2007.

Dundar, C., Erturkmen, D., Tokgoz, S., Studies on Carbon Fiber Polymer Confined Slender Plain and Steel Fiber Reinforced Concrete Columns, *Engineering Structures*, 102:31-39, 2015.

Hadi, M. N. S., Behaviour of Eccentric Loading of FRP Confined Fibre Steel Reinforced Concrete Columns, *Construction and Building Materials*, 23(2):1102-8, 2009.

Mirmiran, A., Shahawy, M., Behavior of Concrete Columns Confined by Fiber Composite, *Journal of Structural Engineering*, ASCE, 123(5):583-590, 1997.

Punurai, W., Hsu, C. T. T., Punurai, S., Chen, J., Biaxially Loaded RC Slender Columns Strengthened by CFRP composite Fabrics, *Engineering Structures*, 46:311-321, 2013.

Samaan, M., Mirmiran, A., Shahawy, M., Model of Concrete Confined by Fiber Composites, *Journal of Structural Engineering*, ASCE, 124(9):1025-1031, 1998.

Sheikh, S. A., Performance of Concrete Structures Retrofitted with Fibre Reinforced Polymers, *Engineering Structures*, 24:869-79, 2002.

Tokgoz, S., Effects of Steel Fiber Addition on the Behaviour of Biaxially Loaded High Strength Concrete Columns, *Materials and Structures*, 42(8):1125-1138, 2009.