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Studies on carbon fiber polymer confined slender plain and steel fiber reinforced concrete columns

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ABSTRACT

This paper presents an experimental research to examine the behavior of carbon fiber reinforced polymer (CFRP) confined plain and steel fiber reinforced concrete columns. In this study, plain and steel fiber reinforced concrete columns were wrapped with CFRP material and experimentally tested to determine the effects of sheets on column behavior. It is revealed that the CFRP material is significantly effective on reinforced concrete columns with respect to strength, ductility and confinement. In addition, a numerical procedure is presented for the analysis of slender reinforced concrete columns confined with CFRP sheets subjected to combined axial load and biaxial bending. The CFRP confined slender reinforced concrete columns have been analyzed using geometric features and experimental parameters of concrete compressive strength, steel yield strength and CFRP material properties to predict the column structural behavior. The analysis and experimental results of CFRP confined slender plain and steel fiber reinforced concrete columns have been achieved in good accuracy in this study.

1. Introduction

Confinement effect and strength capacity are critical issues for reinforced concrete column members. Reinforced concrete columns behave more brittle with increasing concrete strength. Thus, columns require additional retrofit to improve the confinement and deformability features. Retrofitting of reinforced concrete columns by wrapping and bonding with CFRP has been increasingly used recently. The effectiveness of the use of CFRP sheet materials is seen especially in the seismic areas. The CFRP sheet can be easily applied on reinforced concrete columns and it provides cost economy and rapid construction. The mechanical properties of CFRP material is effective on reinforced concrete column behavior. The most effective parameters on the structural behavior of CFRP columns are the type of carbon fiber polymer, modulus and strength of the material, thickness of the fiber polymer, the number of CFRP layers, fiber orientation and also implementation of fiber polymer material.

The use of CFRP material improves confinement of the concrete core of plain and steel fiber slender reinforced concrete columns. In addition, CFRP jacketing is significantly effective to achieve strength capacity, ductility and stiffness of the structural members. Therefore, 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 structural behavior of plain and steel fiber reinforced concrete columns confined with carbon fiber reinforced polymer.

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 [1], Toutanji and Balaguru [2], Teng and Lam [3] and Sheikh [4] researched the structural behavior of columns confined with fiber composites. Samaan et al. [5] proposed a confinement model to predict the response of fiber reinforced polymer confined concrete in both the axial and lateral directions. Parvin and Wang [6] described the behavior of CFRP jacketed concrete columns subject to eccentric loading. Hadi [7] reported test results of fiber reinforced polymer wrapped normal strength concrete columns under eccentric loading. The results showed that wrapping a column with fiber reinforced polymer provided higher strength, ductility and energy absorption capacity. Barros et al. [8] presented a strengthening technique method by using CFRP material to improve the flexural capacity of columns subjected to bending and compression. Hadi [9] researched the behavior of eccentrically loaded reinforced concrete columns and steel fiber concrete columns wrapped with CFRP material. Malik and Foster [10] conducted experimental investigation to research the behavior of ultra-high strength

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concrete columns confined by carbon fiber reinforced polymer subjected to concentric and eccentric loading. Quiertant and Clement [11] examined the performance of eccentrically loaded columns externally strengthened with different carbon fiber reinforced polymer systems. Zaki [12,13] presented analysis and design techniques for retrofitting of reinforced concrete columns using CFRP under eccentrically applied axial load. Ozbakkaloglu et al. [14] studied on the comprehensive assessment of stress–strain relations of fiber reinforced polymer confined concrete available in the literature. Vincent and Ozbakkaloglu [15] studied on the effect of concrete compressive strength and confinement of fiber reinforced polymer confined concrete. Vincent and Ozbakkaloglu [16] reported the experimental results of the influence of fiber orientation of fiber reinforced polymer jacket and specimen end condition on the compressive behavior of fiber reinforced confined concrete. Ozbakkaloglu and Lim [17] presented a comprehensive test database constructed from the results of a large number of tests on fiber reinforced polymer confined concrete and a new design-oriented model was developed in the study. Punurai et al. [18] examined experimental and theoretical behavior of biaxially loaded slender reinforced concrete columns confined with carbon fiber reinforced polymer jackets. Alecci et al. [19] and Hu and Barbato [20] studied on the determination of the behavior of concrete columns confined with CFRP wraps. Hadi and Le [21] worked on the effect of fiber orientation on hollow core square reinforced concrete columns confined with CFRP tested under concentric and eccentric conditions. Rahai and Akbarpour [22] presented experimental study on rectangular reinforced concrete columns strengthened with carbon fiber reinforced polymer composites under axial load and biaxial bending. There is a lack of information particularly on steel fiber reinforced concrete columns wrapped with CFRP material. Thus, further research studies are necessary to better describe the structural behavior of CFRP confined plain and steel fiber reinforced concrete columns under combined axial load and biaxial bending including slenderness effect.

The main objective of this study is to determine the behavior of biaxially loaded CFRP confined slender plain and steel fiber reinforced concrete columns. A total of 16 both plain and steel fiber reinforced concrete column specimens were constructed with concrete strength in the range between 53.13 and 76.76 MPa. The column specimens were strengthened by CFRP sheets 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 nonlinear behavior of the stress–strain relations of the materials is used in the analysis procedure. In the study, the theoretical results have been compared with the test results and found to be in good agreement.

2. Experimental study

The purpose of this experimental research was to investigate the effects of CFRP material on the behavior of plain and steel fiber reinforced concrete columns. The test parameters were concrete compressive strength, load eccentricity, yield strength of reinforcing steel, CFRP sheet property, steel fiber and slenderness effect. The column strength capacity, load–deflection behavior and the effects of carbon fiber reinforced polymer material on the structural behavior of plain and steel fiber reinforced concrete columns were observed in the study.

2.1. Column specimens

The experimental work comprised sixteen square plain and steel fiber reinforced concrete columns. All the columns were 1300 mm in length. The cross section dimensions of the column specimens were 125×125 mm. The slenderness ratio (effective length to the radius of gyration of cross section) of the column specimens was 34.67 determined according to ACI Standard 318-08 [23]. In order to provide biaxial loading application, two $200 \times 200 \times 200$ mm heavily reinforced concrete brackets were designed at column both ends. Fig. 1 illustrates the details and the reinforcement configuration of the test columns. Deformed bars were used for longitudinal and lateral reinforcement arrangements of test columns. The longitudinal reinforcements were 8 mm-diameter deformed bars located at each corner of the section. The lateral reinforcements were designed with 6 mm-diameter deformed bars were bent into 135° hooks at the ends. The lateral tie spacing was 100 mm and 50 mm on column section and on brackets, respectively. The yield strengths of longitudinal and lateral reinforcements were 550 MPa and 630 MPa, respectively.

2.2. Materials

The column specimens were constructed using CEM I 42.5 R type Portland cement, well dry and clean natural gravel aggregate. The maximum coarse aggregate size was 20 mm. Tap water and also super plasticizer were used in concrete mixtures. Steel fiber concrete was prepared with using RC 65/35 BN-type hooked steel fibers. The fiber length and diameter were 35 mm and 0.55 mm, respectively. The aspect ratio of steel fiber was 64, and the density of fibers was 7850 kg/m^3. The amounts of concrete mixture compositions of the column specimens are given in Table 1. Steel fibers were contained in concrete batches at the dosages of 0, 50 and 60 kg/m^3. In the experimental study, bi-directional carbon fiber reinforced polymer material namely SikaWrap Hex 300C 0/90 was used for strengthening of column specimens. For this type of sheet, the fibers were designed in two directions as longitudinal and transverse. The carbon fiber reinforced polymer material applied on column surface with Sikadur-330 adhesive.

2.3. Specimen preparation

The plain and steel fiber reinforced concrete column specimens were cast horizontally in a steel mold in the Structural Laboratory at Cukurova University in Adana. The specimens were compacted by using mechanical vibrator. For the determination of the concrete compressive strength and properties of plain and steel fiber concrete, at least three concrete cylinder specimens (150 mm in diameter and 300 mm in length) were cast from each concrete batches. The cylinders were subjected to the same curing conditions with the prepared column specimens.

In order to determine the effects of carbon fiber reinforced polymer material on reinforced concrete column behavior, the plain and steel fiber reinforced concrete column specimens were designed with no sheet, one layer and two layers wrapping configurations. 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. The other columns were strengthened by one layer and two layers of sheets applied on four sides of column surface (Table 2). In order to eliminate the stress concentration, the sharp corner of the column specimens was rounded before applying the CFRP sheets.

The cylinder specimens were tested in axial compression after two months on the day of column test. It was seen that the inclusion of steel fibers has significantly effect on concrete deformability ([24]). The cylinder compressive strength of unconfined concrete (f_c), the eccentricity (e_x,e_y) of column specimens, CFRP material design details are presented in Table 2. The average