Effects of CFRP composites on strength and ductility of slender concrete columns

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ABSTRACT: In recent years, retrofitting of concrete structures is the major problem of existing civil structures. Concrete columns are essential structural components in concrete structures. Most researches have mainly concentrated on the stress-strain model, the compressive strength, and the shape of cross section of short columns. The fact is commonly accepted that FRP composites increase the strength and ductility of short columns. But, with increasing slenderness, slenderness effects can prohibit the column from attaining its maximum performance and the column may become susceptible to instability. Because the FRP composites have a higher strength and lower stiffness than steel, the FRP wrapped columns tend to be more susceptible to slenderness effects. This paper presents the results of experimental studies about mechanical properties of retrofitted slender concrete columns with CFRP composites. In this study, 30 unreinforced concrete cylinders 100 mm diameter with variable height of 200, 400, 600, 800, and 1000 mm were prepared and retrofitted. In every group, a plain specimen (unwrapped) and five wrapped specimens with different fiber orientations (0, 0/0, 90/0, 45, and 45/0) were tested under pure compressive axial force up to failure. The results of testing the columns have shown that the CFRP composites are most effective in increasing the strength and ductility of slender columns.

1 INTRODUCTION

There is an obligation to strengthen weak structures due to failure of many construction and bridges in recent would earthquakes. Reinforced concrete structures have had most effect on failures of earthquakes. So, their strengthening is main strategy for seismic strengthening. With attention to recent researches, there are many strengthening projects on bridges and buildings using FRP (fiber reinforced polymers) composites in whole world. Wrapping concrete columns with FRP composites has made increasing strength and ductility. But this performance improvement was depended to several parameters such as columns geometry and wrapping fiber orientation. Importance of researching about behavior of columns wrapped with FRP composites was clear, because design codes were not indicated design specification for elements wrapped with FRP composites. Just design equations for short columns under axial forces were indicated by advanced standards such as ACI 440 and Canada ISIS, and important subject such as buckling and slenderness were not attended, because of absence of enough studies.

2 LITERATURE REVIEW

Since first of 1990, FRP composites were used for strengthening of bridges and buildings. There were many researches about strengthening of concrete columns with FRP composites. These researches were focused on small scale specimens under axial loading or large scale specimens under cyclic loading. There were few researches about buckling of concrete columns wrapped with FRP composites that are explained in continuance.

The FRP tubes filled by concrete with slenderness proportion (L/D) 2.1 to 18.6 were tested by Mirmiran et al. (1998) under axial compressive, and it was observed 20% decreasing of strength. Completely tests were performed on FRP tubes filled with concrete by Mirmiran et al. (2001) and it was observed that effect of slenderness was more on ductility. Some equations were presented for slenderness limit of columns.

The Compressive tests on cylindrical specimens with height of 300 to 750 mm and diameter of 150 to 250 mm were performed by Silva and Rodriguez (2006). This specimens were wrapped with GFRP composites, obviously was not seen in their tests result, contrary of Mirmiran et al. (1998 and 2001) tests result. Of course, there was no focus on slenderness and effect of specimens dimension on compressive strength was measured generally.

The Compressive tests were performed on reinforced concrete rectangle specimens (6 specimens) with slenderness of 4.5 to 17.5 and were strengthened with CFRP composites by Pan et al. (2007). They were presented equations for strength degradation of slender columns.

It is obvious that the studies were little and there were different ideas between researches about effect of slenderness. So, with attention to studies and unknown subjects, there were two basic questions about behavior of slender column: How is slenderness effect on compressive strength and ductility of columns wrapped with FRP composites? What is fiber orientation effect on strength and ductility of slender columns wrapped with FRP composites?

To answer those questions, thirty unreinforced cylindrical specimen were prepared and after wrapping with different orientation of FRP composites, were tested under compressive axial loading. Main purpose of these experimental studies was indicating the effect of slenderness in columns wrapped with FRP composites on their strength and ductility under pure axial loading. Experimental studies have been explained in the below section.

3 EXPERIMENTAL STUDIES

3.1 *Specimens layout*

Six series of unreinforced cylindrical specimens were prepared with diameter of 100 mm and height of 200, 400, 600, 800, 1000 mm (all specimens were 30). Research variables were contained column slenderness (2 to 10), wrap thickness, and fiber orientation (orientations of 0, 0/0, 0/90, 45, and 45/0). Concrete strength, specimen diameter and wrap types were constant. Five plain specimens, five specimen wrapped with one hoop layer (0), five specimens wrapped withy two hoop layers (0/0), five specimens wrapped with one angle layer (45), five specimens wrapped with two longitudinal-hoop layers (90/0), and five specimens wrapped with two angle-hoop layers (45/0) were tested. Properties of specimens are shown in Table 1.

Table 1. Properties of specimens

Height (mm)	Fiber orientation					
	A Plain	B (0)	C (0/0)	D (90/0)	E (45)	F (45/0)
200	C20A	C20B	C20C	C20D	C20E	C20F
400	C40A	C40B	C40C	C40D	C40E	C40F
600	C60A	C60B	C60C	C60D	C60E	C60F
800	C80A	C80B	C80C	C80D	C80E	C80F
1000	C100A	C100B	C100C	C100D	C100E	C100F

3.2 *Material property*

The concrete was mixed by constant mix design in all specimens. 28 days compressive strength of the concrete was 25 MPa. The fibers were unidirectional carbon fibers and the resin was epoxy in order preparation of CFRP composites.

3.3 *Specimens preparation*

PVC pipes with length of specimens' height were used to prepare every specimen. For concreting, pipes were positioned vertically and were fixed with lab floor. To prevent voiding of concrete extract from mold floor, it was insulated by nylon. Electric vibrator was used compact concrete and their free surface was flattened carefully. 24 hours after concreting, the PVC molds were cut in longitudinal direction (Figure 1) and specimens were put in curing container for 28 days.

After curing, specimens were dried and cleaned for wrapping with CFRP (Figure 2). Wrapping was performed based on Table 1. Fibers were cut to necessary dimension that they were overlapped 50 mm together. Then surface of specimens was the wrapped with epoxy resin and after fiber saturated by resin, the composites was attached and vacuumed with predefined orientation and layers.

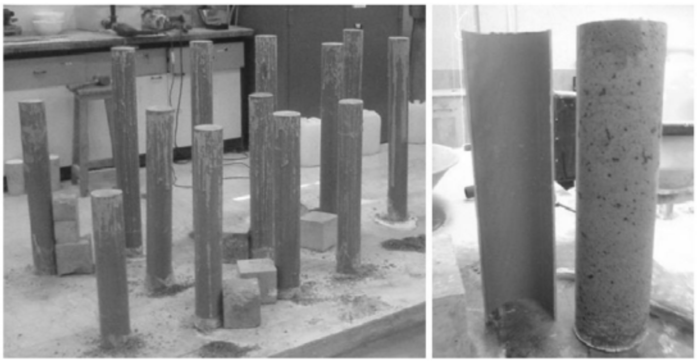

Figure 1. Concreting and remolding of specimens.

Figure 2. Specimens after curing and wrapping

3.4 *Test setup and loading*

Specimens were tested by 2500 KN test machine under axial compressive loading up to failure. Test was performed is displacement control condition and with rate of 0.1 mm/min. During the test of every specimen, axial forces, axial displacement, specimen's diameter variation and specimen's lateral displacement in middle of height were measured. Axial force and displacement by test machine, diameter variation by chain gauge, and middle lateral displacement by four orthogonal potentiometers were digitally recorded. Figure 3 has shown test setup and tested specimens.

4 EXPERIMENTAL RESULTS AND DISCUSSION

After data processing, the stress-strain curves were drawn to consider what slenderness effects on strengthening were and what fiber orientation effects on strength and ductility were.

Figure 3. Test setup and tested specimens

4.1 *Fiber orientation effects*

Axial stress-axial strain curve of specimens with height of 200 mm have drawn in Figure 4, to consider effect of fiber orientation. In this Figure, the plain specimen was broken as a brittle failure, when it achieved the maximum strength of 25 MPa, though the soft branch strain was about 0.5% as stress of 20 MPa. This strain was happened at stress of 85 percent of maximum strength that is called the ultimate strain of concrete. The behavior of the wrapped specimens is totally different. The behavior of wrapped and unwrapped specimens was not different until stress of 25 MPa, but after that, wrapped specimens were continuing their strength, with progressive second slope until the composites wrap rupture made specimen broken.

Generally, wrapped concrete performance depends to volume dilation in the concrete. Because concrete wrap works when concrete begins to expand. This volume dilation has a constant ratio in the linear region of concrete behavior, because the Poisson ratio is constant. So, there is no expectation of high performance of concrete wrap in the linear region. The behavior of wrapped and unwrapped concrete is similar during increasing stress up to unwrapped concrete compressive strength; and when stress increased further than limit, the wrap worked and with attention to wrap stiffness, the stress grouted with more second slope.

The second slope was constant in specimens with hoop orientation; because of that, the stress progressed. Maximum strength was increased from 25 to 40 MPa using a hoop layer as we can see in figure 6 and there was 60 percent strength increase. Maximum strength was increased 100 percent, from 25 to 50 MPa, in two hoop layer condition.

In those two conditions, sudden strength deuce was happened and it breaks as brittle failure, when the wrap was disjointed. The wrap rupture strain was 1.4 and 2.2 percentage in one and two layer hoop condition; it was shown strain ductility increase to 2.8 and 4.4 times comparing with unwrapped concrete. There was no difference between maximum strength of specimens with axial-hoop (90/0) and angle-hoop (45/0) orientation comparing to just hoop orientation, but sudden failure was not happened and there was a ductile behavior. Ductility was increased in that ductile behavior and it was more obvious in specimen's content diagonal orientation. Specimen's behavior made with angle orientation was different comparing other specimens. As it shown in Figure 4, their maximum strength was not different with unwrapped specimens, but their failure has indicated that column energy depreciation ability was got many times larger, with out increasing strength and making brittle failure condition. This ability is important for strengthening columns when earthquake happens. Some variations were happened in mentioned advantages with slenderness increase that we explained them in next topic.

4.2 *Slenderness effects*

The behavior of different specimens with different condition of strengthening has studied in this part. Effect of slenderness on unwrapped specimens has shown in Figure 5-a. Maximum strength was same for specimens with height of 200 and 400 mm, but maximum strength was decreased when slenderness increased. Strength was decreased to 16 MPa with deuce of 35 percentage in height of 100mm. unwrapped specimen with height of 800mm was crashed during transportation and it was tested. Effect of slenderness on ductility of specimens was more than strength. As it was shown in Figure 5-a, alternately strain in level of 5 MPa was decreased from 85 percent to 25 percent, with increasing specimen's height from 200 mm to 1000 mm. on the other hand, ductility was decreased when slenderness became 5 time larger that it was shown brittle failure of unwrapped specimens.

The effect of slenderness in specimens were wrapped one and two layer hoops has investigate in Figure 5-b and 5-c. Maximum strength was not different with increase of slenderness. On the other hand, effect of slenderness on strength was counter balanced by hoop orientation. In view of ductility, ultimately strain had decreasingly process more slowly than unwrapped specimens, with increase of slenderness. Slender specimen's failure was improved and energy deprecation ability was increased using hoop orientation.

The effect of slenderness on specimen's behavior wrapped by axial-hoop and angle-hoop orientation was studied in Figure 5-d and 5-e. It has observed that mentioned orientations, like hoop orientation, was made that ultimately strength of slender column was on level of short columns and energy depreciation ability was had a little decrease.

The Figure 5-f has shown the effect of slenderness on specimens wrapped by pure angle strengthening. With slenderness increase, strength was constant by angle orientation. But in view of ultimately strain, this orientation did not have ability of ductility increase, such as other orientations generally, positive effect of angle layer on short specimens was not seen in slender specimens. This matter was justified that big shape variation in low stress levels due angle orientation in tall specimens has made second moment increase and early failure for specimens. Even though in hoop orientations, big shape variations was happened in surfaces with high stress and space under stress-strain curve was increased in compare with other and also energy depreciation ability was increased by that.

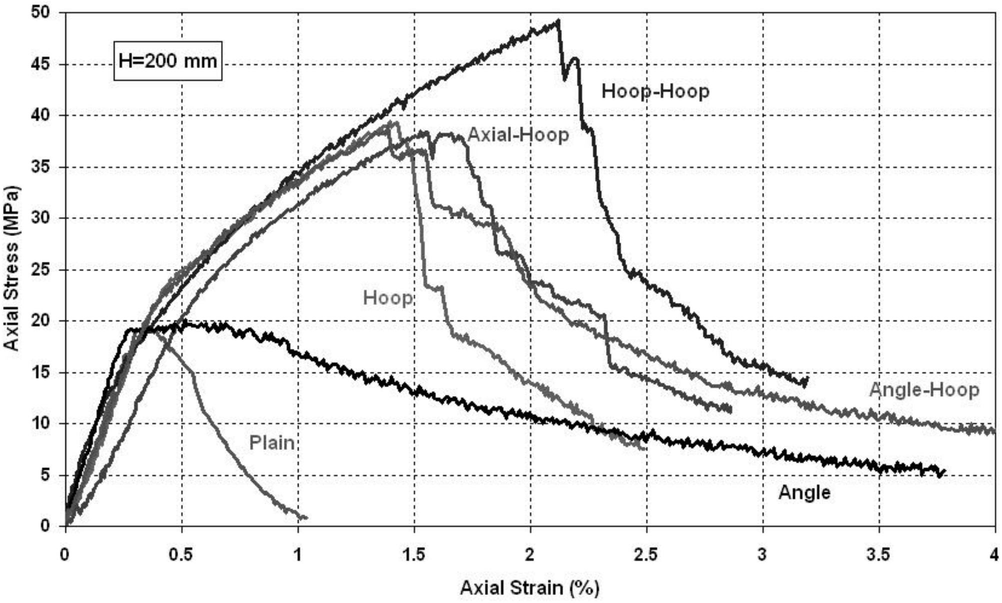

Figure 4. Stress-strain behavior of wrapped and unwrapped specimens

5 CONCLUSION

In this research with the purpose of investigation of slenderness effect on column wrapped with FRP composites, 30 unreinforced concrete columns with diameter of 100 mm and height of 200, 400, 600, 800, 1000 mm (slenderness of 1 to 10) were prepared and wrapped with unidirectional CFRP composites, In every slenderness, a plain specimen (unwrapped) and five specimens wrapped with different fiber orientation (0, 0/0, 90/0, 45/0, and 45) under the uniaxial compressive force was tested up to failure. Results were shown that strength and ductility were decreased 35 and 65 percent in turn when slenderness increased from 1 to 10, in plain specimens. Strength almost was maintained in level of short specimens and decrease ratio of ductility was decreased, by strengthening slender specimens with CFRP composites. Maintaining strength was observed in all strengthening fiber orientation, but strengthening consist hoop orientation were more effective than angle orientations in maintaining ductility. So using CFRP composites is so much effective approach to improve concrete slender columns performances of strength and ductility.

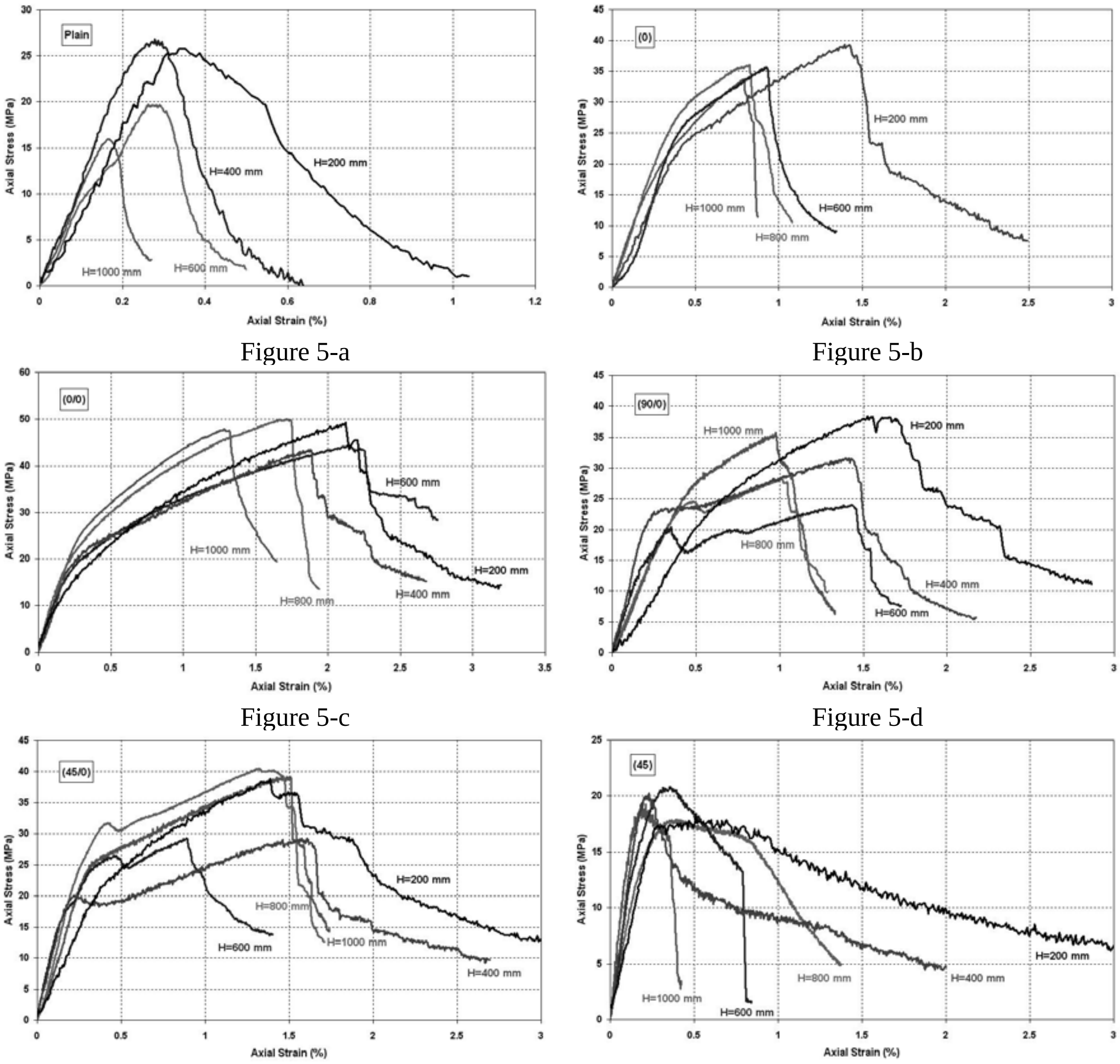

Figure 5-a

Figure 5-b

Figure 5-c

Figure 5-d

Figure 5-e

Figure 5-f

Figure 5. Slenderness effects on stress-strain behavior

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