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Behaviour of concentrically and eccentrically loaded short concrete columns confined with CFRP wraps

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ABSTRACT: Significant increase in both the compressive strength and ultimate strain of concrete has been achieved by confining concrete using fibre reinforced polymer (FRP) composites. Focus of most of the studies was on normal strength concretes with strengths ranging from 35 to 60 MPa. Very limited research on effectiveness of confinement provided by FRP on low strength has been reported. Results of an experimental study are presented in this paper on the behaviour of low unconfined concrete strength short concrete columns confined with CFRP wraps subjected to eccentric loading. A total of twenty four (24) concrete columns were tested. Three unconfined and three reinforced concrete columns were used as control specimens. CFRP wraps of different heights and spacing were used to provide confinement. Effect of different confinement schemes on the load carrying capacities of eccentrically loaded columns was determined by testing the columns in uniaxial compression. Load was applied at an eccentricity from centre of the column, to determine the load carrying capacities of the confined and unconfined columns. Enhancement in load carrying capacities of CFRP-confined concrete columns was found in all confinement schemes used during the study indicating effectiveness of CFRP wraps in improved performance of eccentrically loaded concrete columns.

1 INTRODUCTION

Reinforced concrete (RC) structures deteriorates due to a myriad of causes including ageing, faulty initial design and/or construction, improper maintenance, change of space utilization, and more strict design criteria. Columns play a major role in resisting vertical and lateral loads and deterioration of RC columns might lead to failure of the structure. Repair and retrofitting of deteriorated RC columns is, therefore, one of the major issues that needs to be addressed properly. In recent years deteriorated RC columns have been successfully strengthened / retrofitted using different techniques like external pre-stressing, concrete jacketing and steel jacketing but all these techniques are labour intensive. Research over the last few decades reveals that the application of non-metallic FRP materials for strengthening and retrofitting of reinforced concrete structures has proved to be of economic and engineering advantage. FRP composites as a structural reinforcing material have higher strength-to-weight ratio, ease of handling and high corrosion resistance (Haedir & Zhao (2011)). FRP composites are available in various sizes, geometry and dimensions. Different researchers have used FRP composites in various ways to retrofit deteriorated RC members, either by bonding FRP sheets externally to concrete members or by constructing new RC structural members by using various available forms of FRP [Isaa et al. (2009), Park et al. (2008), Fam et al. (2003), Youssef et al. (2003), Shahawy et al. (2000), Khan and Zafar (2010), Quiertant & Clement (2011)]. It has been found that reinforced concrete short columns show little deformation when failure occurs (Punurai et al. (2013)). Similar behavior was observed in a previous study (Khan & Fareed (2012)) of short concrete rectangular columns, in which most of the specimen failed by crushing of concrete.

This study is the continuation of initiative taken by the Department of Civil Engineering, NED University of Engineering and Technology to explore possibility of using new materials for repair of deteriorated RC structures as major distresses have been observed in RC structures located near the coast lines of Pakistan very early in their service life requiring repair and sometimes even replacement of such structures. Use of FRP materials is one of possible alternatives but needs to be explored before it can be used with confidence in Pakistan.

This paper presents results of experimental study, carried out in parallel at the Department of Civil Engineering, NED University of Engineering and Technology to the work presented by Khan & Fareed (2012). Twenty four (24) short circular columns, 100 mm in diameter and 600 mm in height, were tested with unconfined compressive strength up to 21 MPa. Low strength concrete was selected keeping in mind the limited literature available on low strength FRP-confined concrete and the fact that concrete used in local construction is of low strength, usually of the order of 21 MPa. In the present study CFRP wraps of different heights and spacing were used to provide confinement. Effect of different confinement schemes on the load carrying capacities of eccentrically loaded columns was determined by testing the columns in uniaxial compression. Load was applied concentrically and eccentrically to determine the load carrying capacities of the confined and unconfined columns. Enhancement in load carrying capacities of CFRP-confined concrete columns was found in all confinement schemes used during the study indicating effectiveness of CFRP wraps in improved performance of eccentrically loaded concrete columns.

2 EXPERIMENTAL PROGRAM

Behaviour of twenty four (24) short concrete circular CFRP wrapped and unwrapped columns were studied by testing them in concentric and eccentric loading conditions. Out of twenty four, six (6) columns, three (3) with plain concrete and three (3) with reinforced concrete served as control specimen, having no CFRP confinement. All wrapped and unwrapped columns were of 100 mm diameter and 600 mm height. The material properties of concrete and CFRP wraps used to cast columns and for confinement of columns respectively are shown in Table1.

Table 1.Material properties of unconfined concrete and CFRP wraps

	Concrete	CFRP wraps
Unconfined Compressive strength	21MPa	-
ultimate tensile strength	-	4100 MPa
Tensile modulus of elasticity	-	231000 MPa
Fibre density	-	1.78 gms. /cm^3

Six different confinement patterns of CFRP wraps were used as shown in Figure 1. Nomenclatures used to designate specimens are shown in Table 2. For each of the six different confinement pattern used in the current study, two specimen of each pattern were tested under eccentric loading and one specimen of each pattern was tested under concentric loading. Similar approach was also used for control specimens. Load was applied to the columns either at no eccentricity or an eccentricity of 19 mm for the determination of load carrying capacities of confined and unconfined columns under concentric and eccentric load respectively. ACI-318-05minimum requirement of eccentricity for design of columns was used to define an eccentricity of 19 mm.

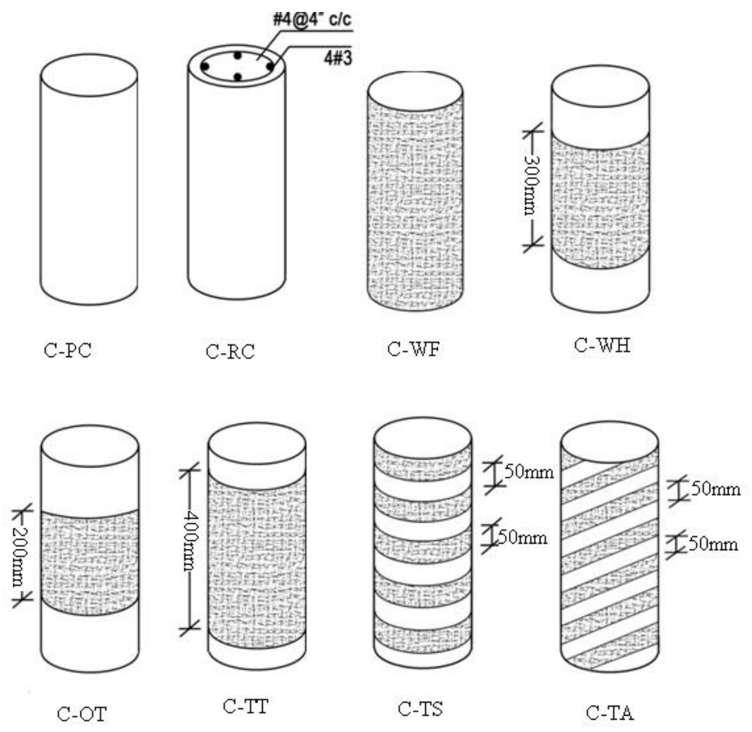

Figure 1. Confinement schemes of wrapped and unwrapped columns.

Table 2. Nomenclature of unconfined and confined columns

Specimen	Description
C-PC	Plain concrete control column
C-RC	Reinforced concrete control column.
C-WF	Fully wrapped circular concrete column
C-TT	Two third wrapped circular concrete columns.
C-WH	Half wrapped circular concrete column.
C-OT	One third wrapped circular concrete column.
C-TS	Plain concrete column with 50 mm wide strip wrapped at 100 mm c/c spacing.
C-TA	Plain concrete column with 50 mm wide continuous strip wrapped angularly at 100 mm c/c spacing.

Steel caps were used at both ends of short concrete column specimens, Figure 2, to restrain the lateral movement of specimens. In order to ensure application of point load, square steel cube of 25mm × 25mm were placed at both ends in addition to these steel caps as shown in Figure 2.

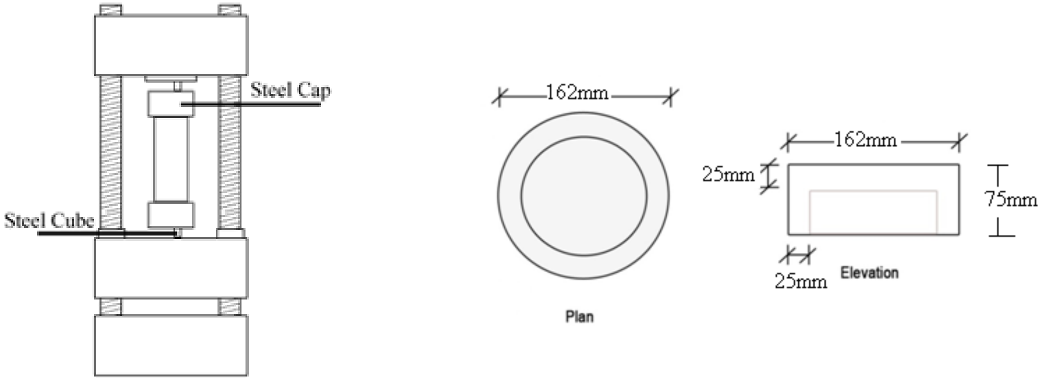

Figure 2. Testing arrangement for applying eccentric load on the specimens.

3 RESULTS AND DISCUSSIONS

3.1 *Concentrically Loaded Columns*

Failure loads, enhancement in strength along with modes of failure of concentrically loaded specimens is shown in Table 3. Control specimens (C-PC and C-RC) tested under concentric load failed at 183 kN and 310 kN respectively. Maximum load carrying capacity of columns tested under concentric loading was found to be of fully wrapped column (C-WF) i.e. 430 kN, showing an increase of 136% and 38% in comparison to control columns (C-PC and C-RC). Figure 3 presents the comparison of failure loads of concentrically loaded columns.

It can be seen from both Table 3 and Figure 3 that enhancement in load carrying capacities of concentrically loaded confined columns when compared to C-PC shows an increase of 126%, 80%, 76% , 75% and 5% respectively in following order C-TT, C-TS, C-WH, C-TA and C-OT, whereas the enhancement in load carrying capacities of these columns shows an increase of 33%, 6%, 3.5%, 3% and no enhancement respectively when compared with C-RC. It can be observed from the experimental results of concentrically loaded confined columns tested in the study that confinement provided by the CFRP wraps was beneficial irrespective of CFRP wrapping pattern used for confinement. Enhancement in load carrying capacities of confined specimens when compared to RC control specimen C-RC indicates that CFRP wraps can be used effectively to provide confinement comparable or even better than the confinement provided by internal steel stirrups, except for the specimen C-OT which was wrapped only at one-third of its length.

Almost identical enhancement in strength was achieved in columns that were wrapped with CFRP wraps along full length (C-WF) and at two third of its length (C-TT), Table 3, leading to the conclusion that in order to attain maximum strength wraps must be provided at least along two-third length of the columns. It can be also seen from Figure 3 that when wraps are applied at 100 mm c/c spacing (C-TS & C-TA) the strength enhancement is almost identical irrespective of their orientation, indicating that orientation of wraps used with identical spacing has no influence on strength enhancement.

Table 3. Failure loads and modes of failure of concentrically loaded columns

Specimen	Load (kN)	Strength enhancement (%) with respect		Failure mode
		Plain concrete	Reinforced concrete	
C-PC	182	-	-	Crushing of concrete
C-RC	310	-	-	Crushing of concrete and yielding of reinforcement
C-WF	430	136	38	CFRP rupture
C-TT	412	126	33	CFRP rupture
C-WH	321	76	3.5	CFRP rupture
C-OT	191	5	No enhancement	Crushing of concrete
C-TS	328	80	6	CFRP rupture
C-TA	318	75	3	CFRP rupture

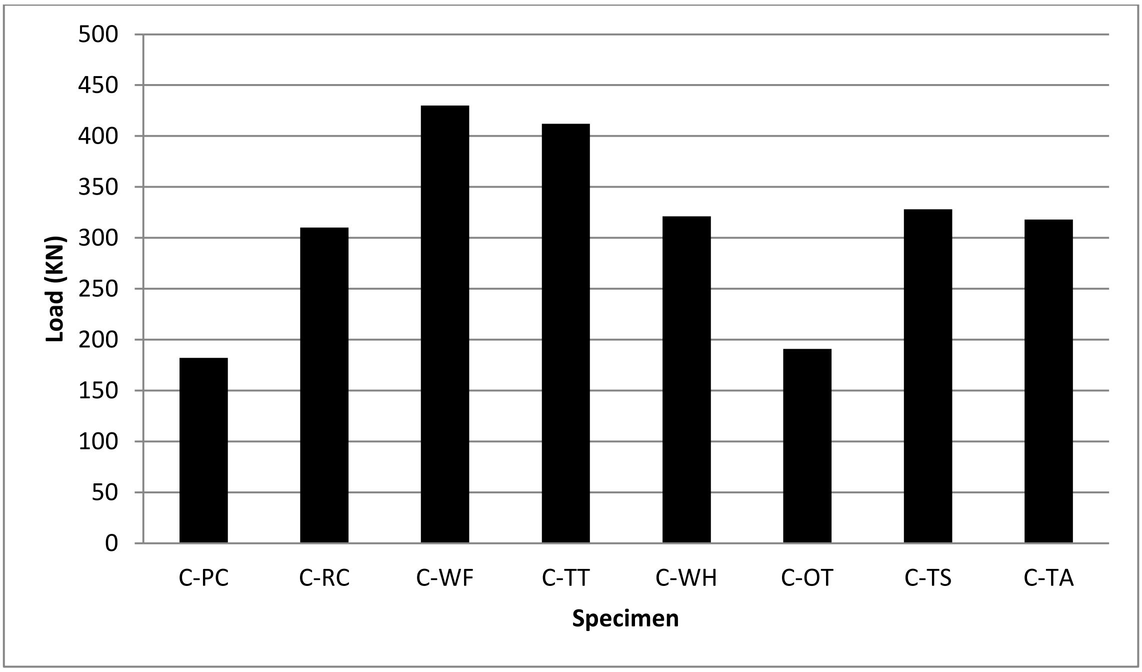

Figure 3. Failure load comparison of concentrically loaded columns

3.2 *Eccentrically Loaded Columns*

Load carrying capacities and enhancement in strength along with modes of failure of eccentrically loaded specimens is shown in Table 4. Control specimens (C-PC-E and C-RC-E) tested under eccentric load failed at 149 kN and 187 kN respectively. Maximum load carrying capacity of columns tested under eccentric loading was found to be of fully wrapped column (C-

WF-E) i.e. 241 kN, showing an increase of 62% and 29% in comparison to control columns (C-PC-E and C-RC-E). Figure 4 presents the comparison of failure loads of eccentrically loaded columns.

It can be seen from both Table 4 and Figure 4 that enhancement in load carrying capacities of confined columns when compared to C-PC-E and C-RC-E were in following order: C-TT-E, C-TS-E, C-TA-E, C-WH-E and C-OT-E, showing an increase of 30% and 3%, 12% and no enhancement, 4% and no enhancement, 3% and no enhancement and no enhancement respectively. It can be observed from the experimental results of eccentrically loaded confined columns tested in the study that the beneficial effects of confinement by using CFRP wraps on strength were observed by providing wraps at or more than two third of its length as specimens wrapped less than two third of its length show no or very little enhancement in strength is observed as in case of C-WH-E and C-OT-E in comparison with control specimen C-PC-E. This was not the case when specimens were tested under concentric load, in which even providing wraps at half of length proved to be beneficial in increasing the load carrying capacity of column.

It can be seen in Table 4 that specimens subjected to eccentric loading give better confinement than reinforced concrete specimen only with specimens wrapped at full or two-third of its length which was not the case in specimens subjected to concentric loading where wraps at more than one-third of the length of the were found to be effective in providing better confinement as compare to reinforced concrete column.

The strength enhancement of specimens (C-TS-E and C-TA-E) wrapped with different orientation of CFRP wraps at 100 mm c/c spacing was found to be identical as was the case in concentrically loaded columns, thus showing that strength enhancement is not dependent on orientation of wraps provided with identical spacing.

Table 4. Failure loads and modes of failure of eccentrically loaded columns

Specimen	Load (kN)	Strength enhancement (%) with respect		Failure mode
		Plain concrete	Reinforced concrete	
C-PC-E	149	-	-	Crushing of concrete
C-RC-E	187	-	-	Crushing of concrete and yielding of reinforcement
C-WF-E	241	62	29	CFRP rupture
C-TT-E	193	30	3	CFRP rupture
C-WH-E	153	3	No enhancement	Crushing of concrete
C-OT-E	114	No enhancement	No enhancement	Crushing of concrete
C-TS-E	167	12	No enhancement	CFRP rupture
C-TA-E	155	14	No enhancement	Crushing of concrete

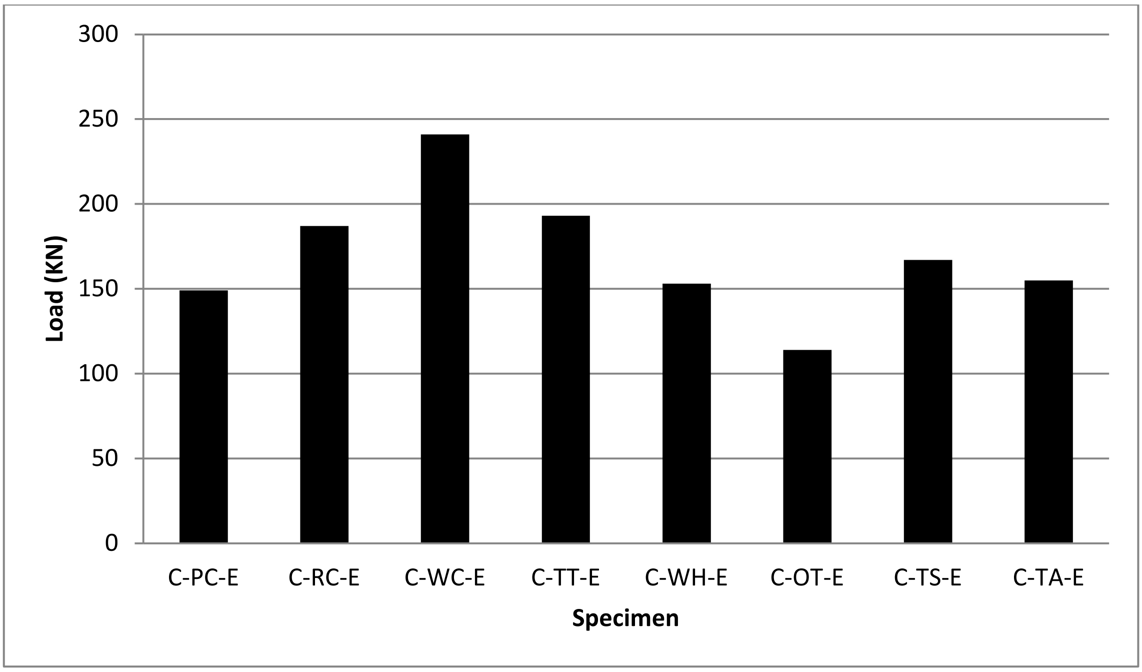

Figure 4. Failure load comparison of eccentrically loaded columns

4 CONCLUSIONS

Following are the main conclusions drawn from the study:

1. CFRP wraps can be used effectively to provide confinement comparable or even better than the confinement provided by internal steel stirrups. Almost all wrapped columns were able to carry more load than the reinforced concrete control specimen, except for C-OT which was wrapped along one-third of its length only.
2. In the case of columns subjected to eccentric loading appreciable increase in strength was observed only with C-WF-E and C-TT-E as compared to control specimen C-PC-E and C-RC-E. Use of full length wraps is, therefore, recommended for columns subjected to a combination of axial and flexural loading.
3. Maximum gain in strength was observed in columns that were fully wrapped along the length followed by the columns wrapped along two-third of the length irrespective of type of loading i.e. concentric or eccentric. In general it can be concluded that in order to attain maximum strength wraps must be provided at least along two-third length of the column irrespective of loading conditions.

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