Effect of CFRP Confinement on Plain and Reinforced Concrete Square Columns

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Abstract: This paper describes an experimental study that evaluates the effectiveness of carbon fiber reinforced polymer (CFRP) confinement on the axial compressive strength of plain and reinforced concrete square columns. For this purpose eight concrete square columns were experimented under axial compression load. The tested specimens were divided into two groups. The first group contained four plain concrete square columns while the second group comprised four reinforced concrete square columns. In each group two columns were tested as control specimens without CFRP wrapping and the remaining two columns of each group were tested after wrapping with a single layer of CFRP jacketing. The results of the CFRP wrapped specimens for each group were compared with their control un-wrapped specimens in terms of gain in axial load strength. The results showed that the CFRP confinement is more effective for enhancing the axial load carrying capacity of the un-reinforced concrete square columns compared to the reinforced concrete square columns. Furthermore, the axial load carrying capacity of the plain concrete CFRP wrapped square columns was increased up to or even more than the level of un-wrapped reinforced concrete square columns.

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1. Introduction

The concrete column is the most critical structural member in the building because the failure of column can cause the failure of the whole structure. Square shape of concrete columns is commonly used in the construction of concrete structures and strengthening of concrete square columns is one of the most important issues relevant to strengthening, repairing and retrofitting of concrete structures. There are many reasons to strengthen the concrete columns such as overloading, aging, design or construction defects, accidental or earthquakes damages. Different strengthening techniques for columns have been used in the past such as section enlargement using concrete jacketing or steel jacketing. Nowadays, the use of fiber reinforced polymer has been considered the best strengthening material due to their excellent performance in the field of strengthening, repairing and retrofitting of concrete structures especially in columns. The use of FRP composites as a jacketing material around the square concrete columns can increase the strength and ductility of square columns. A large number of research studies have been reported in the literature to investigate the different aspects of FRP confinement on the reinforced concrete square columns and small scale plain concrete specimens [1-20]. Most of the studies mainly focused on the strengthening of reinforced concrete columns. However, according to the author's knowledge no research has been conducted to study the effect of carbon fiber reinforced polymer confinement on the medium scale un-reinforced and reinforced concrete square columns. In the present study, the performance of carbon fiber reinforced polymer (CFRP) on plain and reinforced concrete square columns was investigated in term of gain in axial load carrying capacity. The main objective of this study is to provide an insight into the effectiveness of CFRP confinement on the plain and reinforced concrete square columns.

2. Experimental Programme

In order to study the effectiveness of carbon fiber reinforced polymer on plain and reinforced concrete square columns, a total of eight concrete square columns were cast with siliceous aggregate concrete along with their strength controlling concrete cylinders in the Reinforced Concrete Laboratory, at the University of Engineering and

Technology, Taxila, Pakistan. The columns were categories into following four groups:

(1) Columns without reinforcement and without CFRP jackets (Test 1 & 2)
(2) Columns without reinforcement and wrapped with CFRP jacket (Test 3 & 4)
(3) Columns with reinforcement and without CFRP jackets (Test 5 & 6)
(4) Columns with reinforcement and wrapped with CFRP jackets (Test 7 & 8)

All the above four groups of columns have 200 mm square in cross section and 1000 mm in height. The square columns of group (3) and (4) were reinforced with four longitudinal deformed No.4 (12.5 mm Ø) bars at corners and with two No.3 (10mm Ø) deformed bars in the middle (intermediate) position. The total longitudinal reinforcement ratio used in the square columns was 1.6%. No.3 (10mm Ø) deformed bars were used as the tie (square shape) bars spaced at 100 mm centers throughout the length of columns. The measured yield strength of the main deformed reinforcing (No.4 and No.3) bars and tie reinforcing (No.3) bars was 414 MPa. In all square columns 25 mm concrete cover was provided to the main longitudinal reinforcing bars. The corners of the all eight square concrete columns were rounded using plastic pipe of radius 25mm placed inside the formwork of concrete column at the time of casting. All the geometry and reinforcement detail used in the reinforced concrete square columns is shown in Fig.1.

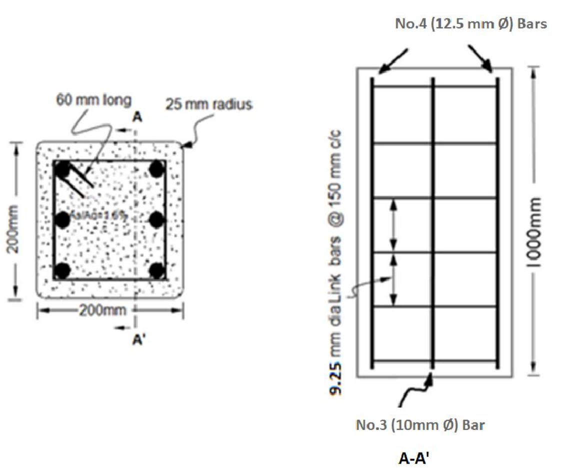

Fig. 1. Steel reinforcement bars arrangement in square concrete columns.

A single layer of commercially available unidirectional carbon fiber reinforced polymer (CFRP) was used for jacketing around the square columns. The properties of Sika Wrap Hex-230C, Sikadur-330 epoxy resin and their laminate properties provided by the manufacture are shown in Tables 1, 2 & 3 respectively.

Table 1. Typical dry fiber properties of Sika Wrap Hex-230C

Tensile Strength	3,450 MPa
Tensile Modulus	230,000 MPa
Tensile Elongation	1.5 %
Density	1.8 g/cc

Table 2. Epoxy Material Properties of Sikadur-330

Tensile Strength	30 MPa
Tensile Modulus	4,500 MPa
Elongation Percent	0.9 %
Density	1.3 Kg/Ltr

Table 3. Laminate Properties (after standard curing) of Sika Wrap Hex-230C with Sikadur-330 Epoxy

Tensile Strength	894 MPa
Tensile Modulus	65,402 MPa
Tensile Elongation	1.33 %
Ply thickness	0.381mm

All concrete square columns were cast in the vertical position as shown in Fig.2. The ingredients used in the concrete mix design were sand, coarse aggregate (siliceous aggregate with maximum size 20 mm) and Ordinary Portland Cement (OPC). The mix ratio 1:3:6 with water cement ratio 0.6 (w/c) was used in the preparation of concrete mix design. In order to remove air from the concrete during casting of the square columns; compaction was carried out using an internal vibrator as shown in Fig.3. For each test specimen, three cylinders of 150 mm x 300 mm size were cast from the same consignment of concrete in order to check the strength of tested columns. The four groups of concrete square columns and strength controlling cylinders were cast from the same consignment of concrete mix and cured under similar conditions in the laboratory environment.

The uniform concrete mixing was carried using concrete mixer as shown in Fig.4 and concrete was poured into the moulds of columns. The average of three strength controlling cylinders for each square column at the test date is shown in Tables 4. Four columns were cast from the same consignment of concrete along with three strength controlling cylinders for each column. After 24 hours of casting, the test specimens were removed from the moulds and cured with hessian that was kept continuously wet with water.

In order to retain the water content, a polythene panel was used to cover the surface of all the specimens. All the specimens were kept for curing up to fourteen days and then left in the laboratory conditions until the time of testing. All strength controlling cylinders were also kept with the specimens for curing until the day of testing.

Table 4. Certain Concrete Properties

Compressive Strength (fc')	24.51 MPa
Slump	75mm
Concrete Mix Ratio	1:3:6
pH of water Aggregate size	6.5-7.5 2-20mm
Water to Cement Ratio	0.6
Reinforcement ratio Yield Strength of steel (fy)	1.6% 414 MPa
Lab Temperature	27^{O} C

Fig.2 Steel mould for casting of concrete columns

Fig.3 Application of vibration to concrete through internal poker vibrator

Fig.4 Concrete mixer for preparation of specimens

2.1 Application of Carbon Fiber Reinforced Polymer (CFRP) Jackets

The surface of concrete square columns to be strengthened with CFRP wrap was cleaned of any dust, laitance, grease, loose particles and other bond inhibiting materials with steel wire brush. In order to ensure the smooth faces of the columns to be wrapped with CFRP jacket, the surfaces of the columns were ground using electric grinder as shown in Fig.5. Sikadur 330 epoxy adhesive was used as primer coat on the substrate of all square columns to be strengthened with fiber reinforced polymers. The epoxy adhesive has two components (hardener and resin). The two components of epoxy adhesive were mixed together uniformly with a mixing ratio 4:1 by weight according to the supplier instructions. The carbon fiber sheets were cut according to the size of square columns by using a commercial quality heavy duty scissor. The CFRP sheets were saturated with the prepared standard epoxy adhesive before wrapping around the square columns. A thin layer of standard mixed primer (Sikadur 330 consisting of hardener and resin) was applied on the substrate of concrete square columns to be strengthened with CFRP with the help of brush as shown in Fig.6. Once the primer coat of Sikadur 330 had become sticky to the touch, the soaked sheets of carbon fiber reinforced polymer (CFRP) were wrapped around the square columns using wet layup technique as shown in Fig.7. An overlap of 200 mm and 100 mm was provided in the transverse and longitudinal direction respectively. The CFRP sheets were wrapped around square columns in such a way that the main fibers should remain in the lateral direction of longitudinal axis of columns. A specially trained contractor was hired for the installation of CFRP jackets around the

Fig.5 Preparation of columns for confinement of CFRP wrap

Fig.6 Application of epoxy on concrete column for CFRP confinement

square columns. A single layer of CFRP jacket was used in this study in order to investigate the effect of CFRP on the axial compressive strength of medium scale plain and reinforced concrete square columns. A small gap of 25 mm was left between the CFRP jacket and top or bottom ends of the columns in order to avoid direct axial loading on the CFRP jacket.

2.2 Instrumentation and Testing procedure

The frame of the test set up is presented in Fig.8. A total four dial gauges were used in the experiment in order to measure the deformations, two for the vertical and two for the transverse deformations as shown in Fig.9. The maximum capacity for both the vertical and transverse dial gauges was 30 mm to measure the vertical and transverse deformations. The top and bottom ends of

Fig.7 CFRP wrapping on concrete column

Fig.8 Arrangement of concrete column in axial load test up

the columns were capped with sulphur in order to apply the uniform axial loading on the top surface of columns. All the square concrete columns were experimented under axial compression using load control method. The load was applied using 3000 kN capacity hydraulic jack at an average rate of loading 1kN/minute until failure as shown in Fig.10 & 11. All the data was monitored and recorded through the testing of all specimens.

Fig.9 Arrangement of dial gauges to measure the deformation

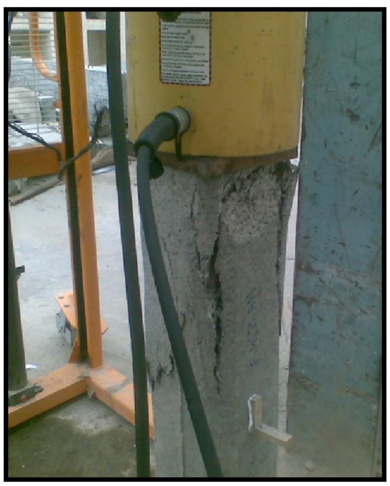

Fig.10 Failure mode of un-confined concrete column

Fig.11 Failure mode of CFRP confined column

3. Test Results and Discussions

3.1 Test observations and failure mode

All the columns were failed in a typical crushing failure mode at the top or bottom ends. It was observed that in columns without reinforcement (Test 1&2) vertical cracks were appeared at the top or bottom ends and extended towards the middle. Finally the extended cracks were converted into wider shear cracks. However, the vertical cracks in reinforced concrete square columns (Test 5&6) were initiated at the top or bottom ends and were smaller in width compared to the columns without reinforcement (Test 1&2). This could be due to the fact that the longitudinal bars may provide more restraining action against an inclined shear failure as compared to the plain concrete.

The failure mode of columns (Test 1&2) was brittle as compared to the columns (Test 5&6). The failure of CFRP wrapped columns (Test 3&4) and (Test 7&8) was took place at the corners by bursting the CFRP jackets close to the top or bottom ends with the explosive sound. The failure of CFRP confined columns (Tests 3, 4, 7 & 8) was more brittle and sudden compared to the un-wrapped columns.

3.2 Effect of CFRP confinement on plain concrete (P.C) square columns

Fig.12 shows the effectiveness of a single layer of unidirectional carbon fiber reinforced polymer on the axial compressive strength of plain concrete (P.C) square columns. The numbers 1-6 on the x-axis in Fig.12 and 13 indicate the following

1) Plain concrete (P.C) square column without CFRP jacket (Test-1)
2) Plain concrete (P.C) square column without CFRP jacket (Test-2)
3) Plain concrete (P.C) square column with CFRP jacket (Test-3)
4) Plain concrete (P.C) square column with CFRF jacket (Test-4)
5) Reinforced concrete (R.C) square column without CFRP jacket (Test-5)
6) Reinforced concrete (R.C) square column without CFRP jacket (Test-6)

Fig.12 presents the results of un-confined (Test 1&2) and CFRP confined (Test 3&4) plain concrete (P.C) square columns without internal reinforcement in terms of ultimate axial failure load. It is evident from Fig.12 that CFRP confined plain concrete square columns have more axial load carrying capacity than un-confined plain concrete (P.C) square columns. This indicated that the external confinement of CFRP is very effective in enhancing the load carrying of the plain concrete (P.C) square columns. Fig.13 compares the results of CFRP confined plain concrete (P.C) square columns and reinforced concrete (R.C) square columns without CFRP confinement. It is also interesting to note that the performance of CFRP confined plain concrete (P.C) square columns was superior to reinforced concrete (R.C) columns without CFRP confinement in terms of enhancing the axial load carrying capacity of columns. This indicate that the application of external CFRP jacketing could be more effective for regaining the original strength of the structures in which defective or less reinforcement has been provided.

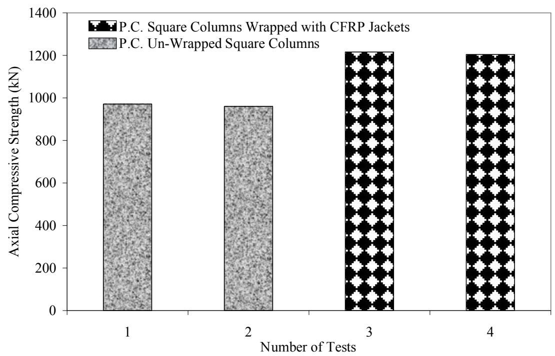

Fig.12 Strength Comparison of unconfined & confined P.C columns

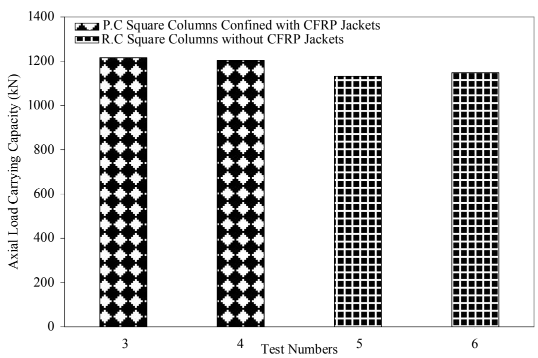

Fig.13 Strength comparison of confined P.C & un-confined R.C columns

3.3 Effect of CFRP confinement on reinforced concrete (R.C) square columns

Fig.14 shows the effectiveness of a single layer of CFRP jacket on the axial capacity of reinforced concrete (R.C) square columns. The numbers 5-8 on x-axis in Fig.14 refers to the following:

5) Reinforced concrete (R.C) square column without CFRP jacket (Test-5)

6) Reinforced concrete (R.C) square column without CFRP jacket (Test-6)

7) Reinforced concrete (R.C) square column with CFRP jacket (Test-7)

8) Reinforced concrete (R.C) square column with CFRP jacket (Test-8)

It is evident from Fig.14 that CFRP confinement is effective for enhancing the axial load carrying capacity for reinforced concrete (R.C) square columns. Fig.15 and Table.5 clearly shows that the external CFRP jacketing is more effective for enhancing the axial load carrying capacity of plain concrete (P.C) square columns compared to reinforced concrete (R.C) square columns. This could be due to the fact that the lateral expansion of un-confined plain concrete (P.C) is more than reinforced concrete (R.C).

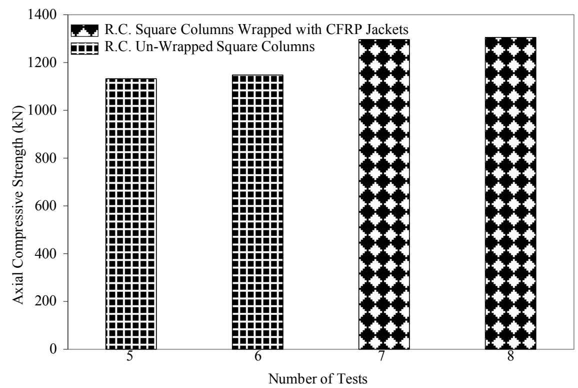

Fig.14 Strength Comparison of unconfined & confined R.C columns

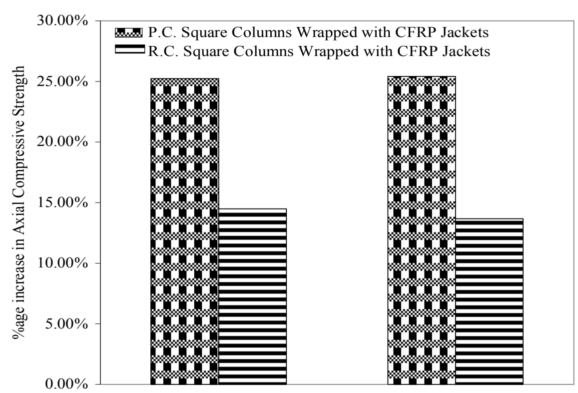

Fig.15 Strength comparison of confined P.C & R.C columns

It is evident from Fig.15 and Table.5 that the percent increase in axial load carrying capacity with respect to unwrapped specimens was more in plain concrete square columns compared to reinforced concrete square for the same single layer of CFRP jacket.

Table 5. Strength comparison of confined P.C & R.C columns

Type of Columns	No. of Tests	Un-Confined Axial Compressive Strength (kN) P_{uo}	Confined Axial Compressive Strength(kN) P_{ucc}	$\frac{P_{ucc}-P_{uo}}{P_{uo}}$ (%)
Plain Cement Concrete (P.C.C)	1	971	-	-
	2	960	-	-
	3	-	1216	25.231%
	4	-	1204	25.416%
Reinforced Cement Concrete (R.C.C)	5	1132	-	-
	6	1148	-	-
	7	-	1296	14.487%
	8	-	1305	13.675%

From Fig.15 and Table.5, it can be seen that 25% axial load carrying capacity was increased for CFRP confined plain concrete square column with respect to un-confined plain concrete square columns. However,14% axial load carrying capacity was increased for CFRP confined reinforced concrete square columns with respect un-confined reinforced concrete square columns. This is attributing to state that the presence of reinforcement could provide more restraining action against an inclined shear failure as compared to the plain concrete. The confining action of CFRP jacket depends on the lateral expansion of concrete. Due to more lateral expansion in plain concrete square columns under axial loading, the CFRP confinement effect was more pronounced in plain concrete square columns compared to reinforced concrete square columns.

4. Conclusion

The key focus of the this experimental study is to provide an insight into the behaviour of plain and reinforced concrete square columns confined with a single sheet of carbon fiber reinforced polymer in term of gain in axial load carrying capacity. The performance of CFRP confined plain and reinforced concrete square columns was studied with respect to axial load carrying capacity and the following conclusions were drawn from this experimental investigation:

1. The role of presence of internal main and link reinforcing bars becomes immaterial in enhancing the axial load carrying capacity of columns when external carbon fiber reinforced jacketing was applied to the concrete square columns
2. The axial load carrying capacity of the plain concrete square columns could be enhanced up to the level of axial load carrying capacity of the reinforced concrete square columns or even more when the plain concrete square columns were wrapped with CFRP jackets
3. The confinement effect of CFRP jacketing was more evident in case of confined plain concrete square columns compared to the confined reinforced concrete square columns
4. The axial load carrying capacity of the plain concrete square columns could be enhanced up to 25% when wrapped with CFRP jackets.
5. The axial load carrying capacity of the reinforced concrete square columns was increased up to 14% when wrapped with a single layer of CFRP jackets

Based on the experimental results, the CFRP confinement is very effective for enhancing the axial load carrying capacity of the concrete square columns in the buildings which have been constructed with defective or less reinforcement. Therefore, the external use of fiber reinforced polymer wrap is very effective for enhancing the axial load carrying capacity of the bridge piers in which the reinforcing bars are seriously damaged due to corrosion.

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