Electronic Journal of Structural Engineering

Original Article

Cite this: DOI:10.56748/ejse.23487

Received Date:22 July 2023
Accepted Date:11 December 2023

1443-9255
https://ejsei.com/ejse

Study the Behavior of Square Reinforced Concrete Columns Strengthened with CFRP

A.J. Dakhil[a], M. Falah[a,b], Z. Al-Khafaji[c,d,e*]
[a] Department of Roads and Transport Engineering, Collage of Engineering, University of Al-Qadisiyah, Al-Qadisiyyah, Iraq.
[b] Building and Construction Techniques Engineering Department, Al-Mustaqbal University, 51001 Hillah, Babil, Iraq.
[c] Scientific Research Center, Al-Ayen University, Thi-Qar, Iraq.
[d] Department of Design, Al-Turath University College, Baghdad, Iraq
[e] Department of Civil Engineering, Faculty of Engineering and Built Environment, University Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia.
*Corresponding author: p123005@siswa.ukm.edu.my

Abstract

There is a scarcity of research regarding the efficacy of Fiber Reinforced Polymer (FRP) confinement on low strength materials. This paper presents the findings of an experimental study that focuses on the behavior of concentrically loaded short concrete columns with high concrete strength, which are confined using CFRP wraps. A set of nine (9) square concrete columns of short length were subjected to testing. The experimental setup consisted of a single unconfined column, referred to as the control column, and eight additional columns that were confined utilizing externally bonded CFRP wraps. These confining schemes were determined based on the findings of a previous study conducted by the authors, which focused on short square columns with smaller cross sections. The study focused on examining the impact of various confinement schemes on the load carrying capacities of columns through the application of concentric uniaxial compression. The implementation of various confinement schemes led to an increase in the load carrying capacities of confined concrete columns, demonstrating the effectiveness of externally bonded CFRP wraps in enhancing the performance of short rectangular concentrically loaded concrete columns. The findings demonstrated the efficacy of carbon fibers in the restoration of impaired columns, as evidenced by a notable enhancement in the load-bearing capacity of the columns, ranging from 35% to 90%.

Keywords

Reinforcement Concrete, Square Column, Polymer CFRP Wraps, Mechanical, Structural Features

1. Introduction

There is a current demand for strengthening numerous reinforced concrete (RC) structures, particularly in developing nations (Al-Khafaji et al., 2021; Ali et al., 2022; Falah and Al-khafaji, 2022; Falah et al., 2020). The process of demolishing old buildings and constructing new ones is both financially burdensome and time intensive. The necessity of implementing strengthening practices arises from various factors, including the structural age and the detrimental effects caused by natural corrosive agents, earthquakes, and other natural phenomena (Parvin and Wang, 2001; Saljoughian and Mostofinejad, 2018; Wei et al., 2009). Furthermore, a frequently encountered issue that arises throughout the constructing phase of a structure is the absence of precise vertical alignment of the column axes. This lack of alignment results in an eccentricity in the axial force exerted on the column, thereby altering the column's behavior from shear to flexural. In this scenario, there is an evident requirement for enhancing the structural integrity of the columns. Strength capacity and ductility are significant variables that hold importance in the context of reinforced concrete (RC) columns. As the strength of these columns increases, their brittleness also intensifies, necessitating supplementary retrofitting measures to enhance their ductility and deformability characteristics. Columns, being the main load-bearing elements, are relatively less ductile components in typical reinforced concrete (RC) structures. Their failure does not exhibit significant visible deformations, particularly in cases where there is limited transverse reinforcement. One possible method for enhancing the strength of rectangular columns is by augmenting the cross-sectional area using either an additional layer of reinforced concrete, or by incorporating steel tubes or fiber-reinforced polymer (FRP) shells around the column shaft (Yan et al., 2006).

Externally restriction with carbon fiber-reinforced polymers (CFRPs) is a widely employed method for retrofitting and enhancing the load-bearing capacity of reinforced concrete (RC) columns. Carbon fiber reinforced polymer (CFRP) exhibits several notable benefits compared to other commonly used engineering materials. These benefits encompass a remarkable capacity for confinement when utilized in the form of a wrapping, exceptional stiffness and strength, extended durability, resistance to corrosion, adjustable thermal features, non-magnetic characteristics, and a lightweight composition (Al-Mekhlafi et al., 2020; Huang et al., 2020; Sayed-Ahmed et al., 2018; Xu et al., 2020). The influence of various parameters on the structural behavior of reinforced concrete (RC) columns strengthened with carbon fiber-reinforced polymer (CFRP) sheets is well-documented in the literature (Dundar et al., 2015; El Maaddawy, 2009; Falah et al., 2020; M W Falah et al., 2022; M.W. Falah et al., 2022). Among these variables, the mechanical characteristics of CFRP play a crucial role. Specifically, the kind of carbon fiber-reinforced polymers, material strength and modulus, CFRP thickness, CFRP layers' number, fibers' orientation, and the application method of CFRP are identified as the key factors with the highest influence on the behavior of RC columns confirmed with CFRP sheets. Carbon fiber reinforced polymer (CFRP) sheets can be conveniently affixed to a column utilizing a highly adhesive substance, thereby providing suitable confinement to the column. This confinement facilitates enhanced loading capacity and deformability of the column. The simplified installation process of carbon fiber reinforced polymer (CFRP) sheets has facilitated the retrofitting procedure, while their favorable cost has contributed to the increased adoption of these materials. The practice of retrofitting reinforced concrete (RC) columns through the application of carbon fiber reinforced polymer (CFRP) sheets has experienced a notable surge in popularity in recent times. The implementation of this retrofitting method serves the dual purpose of mitigating the buckling of the longitudinal reinforcement in the column and prolonging the collapse of the column by delaying the spalling of the concrete cover (Al-Nimry and Neqresh, 2019). The utilization of carbon fiber-reinforced polymer (CFRP) sheets for the purpose of reinforcing structural reinforced concrete (RC) members, specifically in areas prone to seismic activity, has demonstrated its efficacy (Dundar et al., 2015; Punurai et al., 2013). The implementation of carbon fiber-reinforced polymer (CFRP) sheets serves to augment the confinement of the concrete core within reinforced concrete (RC) columns, resulting in notable improvements in stiffness, ductility, and strength. Hence, the utilization of carbon fiber reinforced polymer (CFRP) sheets for the wrapping of reinforced concrete (RC) columns offers numerous benefits in various domains of civil engineering and construction practices.

Nevertheless, the implementation of these techniques results in an undesirable consequence of heightened rigidity. This drawback poses a challenge for structures that necessitate limited horizontal forces, such as those induced by seismic activity, to prevent brittle shear failure or the compromise of neighboring structural components. The act of encasing a pre-existing column's cross-sectional area with fiber-reinforced polymer (FRP) composites has the potential to enhance both its strength and ductility. Nevertheless, previous studies conducted by Rochette and Labossiere (Rochette and Labossiere, 2000) and Wang et al. (Wang et al., 2012) have demonstrated that the stress-strain responses display a phenomenon of post peak softening when the side-to-corner radius ratios exceed six. According to the findings of Karam and Tabbara (Karam and Tabbara, 2005), it has been demonstrated that smaller corner radii result in reduced effectiveness of confinement. The enhancement of confining behavior can be achieved by implementing a higher confinement proportion, as suggested by Wang and Hsu (Wang and Hsu, 2008). Nevertheless, the cost of this approach is relatively high, and the improvement in both ductility and strength is still less significant compared to circular columns (Mirmiran et al., 1998).

Numerous scholars have conducted investigations on potential strategies aimed at enhancing the confinement of rectangular columns characterized by small corner radii. In their study, Hussain, and Driver (Hussain and Driver, 2005) implemented the use of external hollow structural section collars in steel to effectively enhance the confined core area of square columns. Numerous scholarly investigations have been conducted to examine the application of fiber-reinforced polymer (FRP) for the confinement of concrete. The model proposed by Samaan et al. (Samaan et al., 1998) aims to predict the response of concrete confined with FRP sheets in both the axial and lateral directions. In addition, Barros et al. (Barros et al., 2008) introduced a methodology aimed at enhancing and enhancing the flexural capacity of columns under the influence of flexure and compression through the utilization of carbon fiber reinforced polymer (CFRP) sheets. Lam and Teng (Lam and Teng, 2003) conducted an evaluation of existing models and studies, upon which they developed a mathematical model that incorporates the specific fibers utilized in the production of fiber-reinforced polymer (FRP) wrappings. However, it is important to note that their proposed model does not consider the early rupture of these wrappings in columns.

Conversely, various studies have examined the mechanical characteristics of slender columns enveloped with carbon fiber-reinforced polymer (CFRP) sheets and the impact of confinement on these columns when subjected to eccentric loading. In their study, Dundar et al. (Dundar et al., 2015) discovered that the utilization of bidirectional carbon fiber-reinforced polymer (CFRP) sheets resulted in enhanced ultimate strength capacity, ductility, and confinement efficacy. Furthermore, they observed that an increase in the number of CFRP sheet layers further enhanced the confinement efficiency and loading capacity of slender reinforced concrete (RC) columns. Specifically, the one-layer and two-layer wrappings led to approximately 20% and 40% increases in confinement efficacy and loading capacity, respectively. Furthermore, it has been determined that the compressive strength of concrete, load eccentricity, and slenderness significantly impact the performance of reinforced concrete columns that have been retrofitted with carbon fiber-reinforced polymer (CFRP) sheets. According to Maaddawy (Maaddawy, 2009), the investigation of reinforced concrete (RC) columns with square sections that were confined using carbon fiber reinforced polymer (CFRP) sheets under varying load eccentricities revealed a reduction in loading capacity (ranging from 3% to 27%) as the eccentricity increased. The stress-strain relationship of the confined concrete was modified in the mentioned study. According to the proposed modified model, as eccentricity approaches infinity, the compressive strength of the confined concrete becomes equivalent to that of the corresponding unconfined concrete. Furthermore, the paper introduced an equation that can be used to compute the mid-height lateral displacement of these columns when subjected to eccentric loading at both ends.

There have been several experimental studies conducted to investigate the performance of fibrous reinforced concrete (RC) members. Nevertheless, there is a dearth of experimental research in the literature that specifically examines the performance of these members when retrofitted with carbon fiber reinforced polymer (CFRP) sheets. The objective of the current research is to study the behavior of reinforced concrete columns strengthened with CFRP. The main objectives of this research work are to investigate the effects of CFRP on the behavior of reinforced concrete columns and experimental investigation for enhancing the mechanical features of column by CFRP. And showing the ability of CFRP to change the crack pattern in columns under static load.

2. Experimental work

This chapter consists of three parts: the first part includes the detailed description of specimens used to produce concrete mixture. The second part deals with materials features. Standard tests according to the American Society for Testing and Materials (ASTM) and Iraqi specifications (IQS) were conducted to determine the features of materials. The third part introduces the detailed description of the experimental work, models identification and strengthening schemes, models description, casting, curing which are carried out according to the American Society for Testing and Materials (ASTM).

2.1 Description of Specimens

This study included preparation and testing of nine columns that were made and tested under static load. The cross section for all columns was 150 × 150 mm, and the columns have a total length (L) of 450 mm. Four Ø6 mm deformed bars were provided as longitudinal reinforcement and stirrups reinforcement (Ø4 mm) were provided. Figure 1 illustrates all details of geometry and loading schemes of the tested specimens.

In this study, the experimental program consisting of nine samples: one control column without CFRP for comparison with other columns, two specimens strengthened with CFRP at the upper base, two specimens strengthened with CFRP at the lower base, two specimens strengthened with CFRP at the mid span of column and the last two specimens strengthened with CFRP at the upper and lower base, all specimens are identified in Table 1.

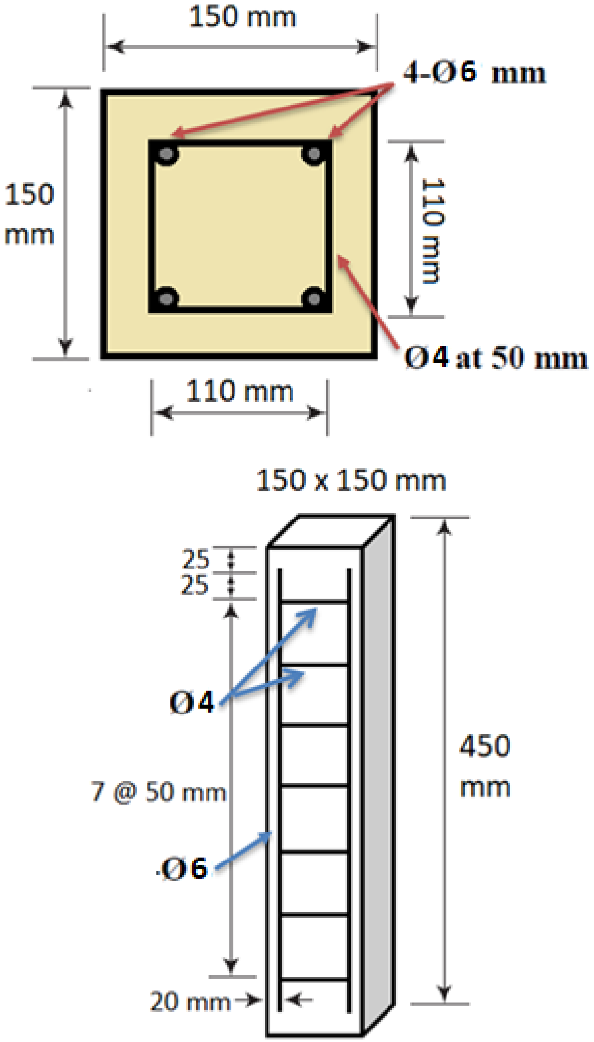

Figure 1. Geometry and Loading Scheme of Tested Specimens

Table 1. Identified of the Specimens

No.	Sample Name	Identification
1	C1	Column without CFRP (Control)
2	C2	Column with CFRP at the upper base (100 mm width)
3	C3	Column with CFRP at the lower base (100 mm width)
4	C4	Column with CFRP at the mid span (100 mm width)
5	C5	Column with CFRP at the upper and lower base (50 mm width)
6	C6	Column with CFRP at the lower base (100 mm width) under repeated 30% ultimate load
7	C7	Column with CFRP at the upper and lower base (50 mm width) under repeated 30% ultimate load
8	C8	Column with CFRP at the mid span (100 mm width) under repeated 30% ultimate load
9	C9	Column with CFRP at the upper base (100 mm width) under repeated 30% ultimate load

2.2 Materials features

The materials that used in the current research was suitable materials, with good quality and proportion based on selected concrete mixing design, and all tests have been conducted in Al-Mustaqbal university as following:

Cement

The cement utilized in this study is Ordinary Portland Cement (OPC), specifically referred to as crista. The evaluation of cement conformity is carried out in accordance with the Iraqi Standard No.5/1984 (Iraqi Specification No.5 -1984, 2010). Tables 2 and 3 present the chemical analysis and physical characteristics, respectively, of the cement utilized in the present investigation.

Table 2. Chemical Analysis of Cement

Compound Composition	Chemical Composition	Percentage By Weight	Limits Of IQS No.5/1984 [6]
Lime Oxide	CaO	59.89	-
Silica Dioxide	SiO_2	20.8	-
Alumina Oxide	Al_2O_3	5.50	-
Iron Oxide	Fe_2O_3	5.1	-
Magnesia Oxide	MgO	3.81	≤ 5.0%
Free Lime	Free CaO	0.67	-
Sulfate Trioxide	SO_3	1.8	≤ 2.5% if C_3A ≤ 5% ≤ 2.8% if C_3A >5%
Loss on Ignition	L.O. I	2.2	≤ 4.0%
Total	-	99.77	-
Insoluble Residue	I.R	1.1	≤ 1.5%
Lime Saturation Factor	L.S. F	0.86	0.66-1.02
Main Compounds (Bogue's Equation) Percentage by Weight of Cement			
Tricalcium Silicate	C_3S	46.35	-
Dicalcium Silicate	C_2S	23. 94	-
Tricalcium Aluminate	C_3A	5.12	-
Tetracalcium Alumino Ferrite	C_4AF	15.25	-

Table 3. Physical features of cement

Physical features		Test Results	Limits of IQS No.5/1984
Specific Gravity		3.15	-
Fineness (Blaine) (m2/kg)		346	≥ 230
Time of Setting (Vicat) (minute)	Initial time	180	≥ 45
	Final time	205	≤ 600
Compressive strength for cement paste cube mold (50 mm) (MPa)	3 days	20.50	≥ 15
	7 days	27.00	≥ 23

Fine Aggregate (Sand)

The present study utilized natural sand sourced from the Al-Akaidur area for the purpose of creating concrete mixes. Prior to utilization, the sand underwent a process of thorough cleansing through water immersion and subsequent drying with Fineness Modulus = 2.94. Figure 2 displays the grade of the fine aggregate. The findings gained in this study revealed that the grading of the fine aggregate met the specifications outlined in Iraqi requirements No. 45/1984 (IQS, 1984).

Coarse Aggregate (Gravel)

The rounded coarse aggregate sourced from the Al-Nebai quarry, with a max aggregate size of 10 mm, is utilized. The gravel underwent multiple cycles of water washing and cleaning until the effluent water became sufficiently clear. Subsequently, the gravel was dried prior to its utilization. The classification of the coarse aggregate is presented in Table 4 based on Iraqi requirements No. 45/1984 (IQS, 1984).

Water

In this study, conventional tap water is utilized for the purposes of both blending and curing.

Steel Reinforcement

The study utilized steel bars with diameters of 4 and 6 mm, as depicted in Figure 3. Tension tests were conducted on three samples of each bar. The findings obtained from the examination of steel reinforcement show that the steel strength was changed based on the nominal diameter (4mm and 412 MPa) and (6mm and 423 MPa).

Carbon Fiber Reinforced Polymer (CFRP)

In this work, one type of fiber was used SikaWarp® Hex-230C (ViscoCrete®-5930, 2010), the features of the CFRP are given in Table 5.

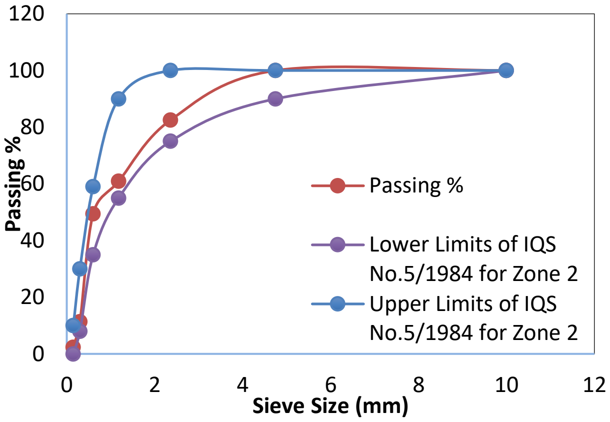

Figure 2. Particle size distribution of fine aggregates (IQS, 1984)

Figure 3. Photograph for Shape of the Steel reinforcement

Table 4. Grading of Coarse Aggregate.

No.	Sieve Size (mm)	% Passing	Limits of IQS No.5/1984 (IQS, 1984)
1	14	100	100
2	9.5	100	85-100
3	4.75	20.7	0-25
4	2.36	2.5	0-5

Table 5. The Features of CFRP

Features	SikaWarp®Hex-230C
Tensile strength (MPa)	4300
E-modulus (GPa)	234
Elongation at break (%)	1.8
Width (mm)	60
Thickness (mm)	0.131

2.3 Mix Proportion

Every sample was cast using high strength concrete. The mixture was prepared with a weight ratio of 0.35:2:1.25:1 for water cement proportions, gravel, sand, and cement, respectively. The molds used for column testing were fabricated with internal dimensions measuring 150 mm in width and height, and 450 mm in length. A total of nine columns were fabricated and subjected to curing procedures within controlled lab conditions. Furthermore, the Compressive Strength Test involves the examination of three standard cubes measuring 150×150×150 mm. These cubes are subjected to testing using a hydraulic compression machine with a capacity of 2000 kN, as depicted in Figure 4. The mean values of three cubes were utilized for each test.

2.4 Procedure of the Experimental Work

The experimental work including the details of material features (cement, fine, and coarse aggregate) and production of the samples and testing procedure are shown in figure 4:

Figure 4. Procedure of the Experimental Work

3. Experimental results and discussion

The main objective of the current study is to explore the effect of CFRP on overall behavior of R.C. columns. In this chapter, the results are presented and discussed for all the tested specimens described in chapter two. The experimental program consisted of testing nine reinforced concrete columns. To make an investigation for the behavior of columns with different location of CFRP with the same amount, nine columns are presented in this study with or without CFRP strengthened.

3.1 Mechanical Features of Concrete Results

All the mechanical features of concrete for all specimens are 50.29 MPa and 43.73 MPa for cubes and cylinders, respectively, each value is the average of three specimens. After 28 days, three standard concrete cubes of (150×150) mm for compressive strength were taken out of the container in accordance with the standard specifications.

3.2 Crack Pattern and Ultimate Load

The columns underwent the loading pattern as outlined in Table 1. The loading event in question transpired when the applied load was centered along the columns' axis. Concrete cracks were visually identified and marked at various stages of testing to document the progression of damage in each column. The condition of the member was visually examined and documented, with particular attention given to its behavior, extension of cracks, and any damage that may have happened throughout the loading process. These observations were recorded, and Figure 5 provides a short column in the testing machine.

Figure 5. The Column Tested in This Study

The experimental findings from column C1 indicate that the initial occurrence of fractures was noticed at a load of 160.37 kN. As the applied load increases, new cracks propagate from both sides of the column, extending towards the top and bottom surfaces. Some of these cracks connect at the mid-depth of the column's top surface, while others extend diagonally at the top due to shear forces. Furthermore, additional fissures emerged and expanded during this phase. The failure mode of specimen C1 occurred suddenly after reaching peak load as expected. Failure occurred in a brittle manner because of concrete cleavage and simultaneous buckling of the longitudinal bars at load (256.41 kN). Figure 6 shows cracking pattern for the column without CFRP.

Figure 6. Cracks Pattern for Column Without CFRP (Control)

According to the data in column C2, the initial occurrence of fractures was noticed at a load of 213.99 kN. Under increased loading, new cracks emerged on both sides of the column, extending towards the middle depth. Additionally, certain cracks at the bottom of the column exhibited diagonal extensions, which can be attributed to shear forces. Furthermore, additional fissures emerged and expanded during this phase. The application of an initial concrete cover spalling took place at midspan, with an applied load of 345.82 kN. The width of the primary crack at the midpoint has evidently increased. Failure occurred by flexure at load (449.55 kN). Figure 7 shows cracking pattern for the column with CFRP at the upper base.

Figure 7. Cracks Pattern for Column with CFRP at the upper base

Figure 8 shows cracking pattern for the column with CFRP at the lower base. The experimental data obtained from column C3 indicates that the initial occurrence of fractures was observed at a force magnitude of 186.34 kN. Under increased load, new cracks emerged on both sides of the column, extending towards the mid-depth. Additionally, certain cracks at the top of the column exhibited diagonal extension because of shear forces. Also, new cracks appeared and extended at this stage. The main crack at the upper base increased clearly in width. The column C3 failed in a gradual manner because of concrete cleavage and simultaneous buckling of the longitudinal bars at load (433.61kN).

Figure 8. Cracks Pattern for Column with CFRP at the lower base

Figure 9 shows cracking pattern for the column with CFRP ath the mid span. The data obtained from column C4 indicates that the initial occurrence of fractures was observed at a load of 162.13 kN. The occurrence of spalling in the initial concrete cover was observed at the top base under an applied load of 241.42 kN. The primary fissure located at the upper base exhibited a noticeable increase in its width. The failure of specimen C4 occurred gradual due to spalling of concrete cover at load (345.82kN).

Figure 9. Cracks Pattern for Column with CFRP at the mid span

Figure 10 shows cracking pattern for the column with CFRP at the top and bottom base. The data obtained from column C5 indicates that the initial occurrence of cracks was noticed at a load of 174.87 kN. The primary fissure located at the midpoint of the structure exhibited a noticeable expansion in its breadth. The failure of specimen C5 occurred gradually due to spalling of concrete cover at load (426.99 kN).

Figure 10. Cracks Pattern for Column with CFRP at the top and bottom base.

There are two stages of loading of the repaired column C6-C9:

1. First stage, apply a load of approximately 30% of ultimate load for control column (C1), and then released the applied load.
2. In the second stage, the column is strengthened by CFRP sheet at the bottom base and then the load is applied from zero until failure load (453.75kN) which is greater than the control column (C1) by 76.96%.

Figure 11 shows cracking pattern for the column with repaired column. The data obtained from column C6 indicates that the initial occurrence of fractures was noticed at a force of 157.49 kN. The initial process of concrete crushing took place at the upper base under an applied load of 343.76 kN. The primary fissure at the upper foundation exhibited a noticeable increase in its width. The failure of specimen C6 occurred gradual due to spalling of concrete cover at load (453.75 kN).

Figure 11. Cracks Pattern for Column with CFRP at the bottom base.

Figure 12 shows cracking pattern for the column with repaired column. Initial concrete crushing occurred at the upper base at applied load equal to (400.54 kN). The main crack at the upper base increased clearly in width. The failure of specimen C7 occurred gradually due to spalling of concrete cover at load (441.42kN).

Figure 12. Cracks Pattern for Column with CFRP at the upper and lower base (50 mm width) under repeated 30% ultimate load

Figure 13 shows cracking pattern for the column with repaired column. The data presented in cell C8 indicates that the initial occurrence of fractures was noticed at a load of 162.95 kN. The initial process of crushing concrete took place at the upper base, where an applied load of 360.42 kN was exerted. The primary fissure at the upper foundation exhibited a noticeable expansion in its breadth. The failure of specimen C8 occurred gradually due to spalling of concrete cover at load (451.55 kN).

Figure 13. Cracks Pattern for Column with CFRP at the mid span (100 mm width) under repeated 30% ultimate load)

Figure 14 shows cracking pattern for the column with repaired column. The initial occurrence of fractures was observed at a load of 158.70 kN, as indicated by the data in column C9. The primary fissure located at the upper base exhibited a noticeable increase in its width. The failure of specimen C9 occurred gradually due to spalling of concrete cover at load (487.38 kN).

Figure 14. Cracks Pattern for Column with CFRP at the upper base (100 mm width) under repeated 30% ultimate load

All the un-strengthened and strengthened RC column samples were tested up to failure. The recorded ultimate loads for these column specimens are presented in Table 6. Column (C9) give more value in ultimate load when comparison with other columns. Finally, it was found that increasing in the ultimate load for the columns strengthened with CFRP about (35% - 90%) with respect to column without CFRP.

Table 6. Result of The Tested Specimens

Column	First crack load (KN)	Ultimate Load (KN)	Increase Rate in Ultimate Load %
C1	160.37	256.41	-------
C2	213.99	449.55	75.32468
C3	186.34	433.61	69.10807
C4	162.13	345.82	34.86993
C5	174.87	426.99	66.52627
C6	157.49	453.75	76.96268
C7	170.12	441.42	72.15397
C8	162.95	451.55	76.10468
C9	158.70	487.38	90.07839

4. Conclusions

Depending on the findings gained from the experimental work for reinforced concrete columns with different location on CFRP at the same amount under static loading, the following conclusions could be stated within the study scope:

- The number of cracks observed was higher, and their distribution was uniform and extended throughout the length of the member. This suggests that the use of CFRP (carbon fiber reinforced polymer) is advantageous in distributing stresses along the column. This is attributed to the enhanced ductility offered by these fibers.
- The column with CFRP at the upper base shows' significant enhancement in ultimate loads and ductility when compared with other columns.
- It was found that increasing in the ultimate load for the columns with CFRP about (35% - 90%) with respect to column without CFRP.

Acknowledgments

The authors thank, Ministry of higher education and scientific research, University of Mustansiriayah. Moreover, this work was supported by Al-Mustaqbal University (grant number MUC-E-0122)

References

Al-Khafaji, Z.S., Falah, M.W., Shubbar, A.A., Nasr, M.S., Al-Mamoori, S.F., Alkhayyat, A., Al-Rifaie, A., Eissa, A., Al-Mufti, R.L., Hashim, K., 2021. The Impact of Using Different Ratios of Latex Rubber on the Characteristics of Mortars Made with GGBS and Portland Cement. IOP Conference Series: Materials Science and Engineering 1090, 012043. https://doi.org/10.1088/1757-899x/1090/1/012043

Al-Mekhlafi, G.M., Al-Osta, M.A., Sharif, A.M., 2020. Behavior of eccentrically loaded concrete-filled stainless steel tubular stub columns confined by CFRP composites. Engineering Structures 205, 110113.

Al-Nimry, H., Neqresh, M., 2019. Confinement effects of unidirectional CFRP sheets on axial and bending capacities of square RC columns. Engineering Structures 196, 109329.

Ali, A.M., Falah, M.W., Hafedh, A.A., Al-Khafaji, Z.S., 2022. Evaluation the influence of steel- fiber on the concrete Characteristics. Periodicals of Engineering and Natural Sciences 10.

Barros, J.A.O., Varma, R.K., Sena-Cruz, J.M., Azevedo, A.F.M., 2008. Near surface mounted CFRP strips for the flexural strengthening of RC columns: Experimental and numerical research. Engineering Structures 30, 3412–3425.

Dundar, C., Erturkmen, D., Tokgoz, S., 2015. Studies on carbon fiber polymer confined slender plain and steel fiber reinforced concrete columns. Engineering structures 102, 31–39.

El Maaddawy, T., 2009. Strengthening of eccentrically loaded reinforced concrete columns with fiber-reinforced polymer wrapping system: Experimental investigation and analytical modeling. J. Compos. Constr 13, 13–24.

Falah, M., Al-khafaji, Z., 2022. Behaviour Of Reactive Powder Concrete Hollow Core Columns Strengthened with Carbon Fiber Reinforced Polymer Under Eccentric Loading. Electronic Journal of Structural Engineering 22, 28–38.

Falah, M W, Al-Khafaji, Z.S., Yaseen, R., Yousif, D.F., Hamza, K.A., Radhi, S.S., 2022. Finite element simulations for the sustainable CFRP retrofitted hollow square columns. Electronic Journal of Structural Engineering 22, 1–13.

Falah, M.W., Al-Khafaji, Z.S., Yaseen, R., Yousif, D.F., Hamza, K.A., Radhi6, S.S., 2022. Finite Element Simulations of the CFRP Retrofitted Hollow Square Columns. Electronic Journal of structural Engineering.

Falah, M.W., Ali, Y.A., Al-Mulali, M.Z., Al-Khafaji, Z.S., 2020. Finite Element Analysis Of CFRP Effects On Hollow Reactive Powder Concrete Column Failure Under Different Loading Eccentricity. Solid State Technology 63.

Huang, Z., Shen, J., Lin, H., Song, X., Yao, Y., 2020. Shear behavior of concrete shear walls with CFRP grids under lateral cyclic loading. Engineering Structures 211, 110422.

Hussain, M.A., Driver, R.G., 2005. Experimental investigation of external confinement of reinforced concrete columns by hollow structural section collars. ACI Structural Journal 102, 242.

IQS, 1984. No. 45, Aggregate from natural sources for concrete and construction. Iraqi Specif.

Iraqi Specification No.5 -1984, second modify 2010, 2010. Portland cement.

Karam, G., Tabbara, M., 2005. Confinement effectiveness in rectangular concrete columns with fiber reinforced polymer wraps. Journal of composites for construction 9, 388–396.

Lam, L., Teng, J.G., 2003. Design-oriented stress-strain model for FRP-confined concrete in rectangular columns. Journal of reinforced plastics and composites 22, 1149–1186.

Maaddawy, T. El, 2009. Strengthening of eccentrically loaded reinforced concrete columns with fiber-reinforced polymer wrapping system: Experimental investigation and analytical modeling. Journal of Composites for Construction 13, 13–24.

Mirmiran, A., Shahawy, M., Samaan, M., Echary, H.E.L., Mastrapa, J.C., Pico, O., 1998. Effect of column parameters on FRP-confined concrete. Journal of Composites for construction 2, 175–185.

Parvin, A., Wang, W., 2001. The behavior of FRP jacketed concrete columns under eccentric loading. Journal of Composites for construction 5, 146–152.

Punurai, W., Hsu, C.-T.T., Punurai, S., Chen, J., 2013. Biaxially loaded RC slender columns strengthened by CFRP composite fabrics. Engineering Structures 46, 311–321.

Rochette, P., Labossiere, P., 2000. Axial testing of rectangular column models confined with composites. Journal of composites for construction 4, 129–136.

Saljoughian, A., Mostofinejad, D., 2018. Grooving methods in square RC columns strengthened with longitudinal CFRP under cyclic axial compression. Engineering Structures 174, 724–735.

Samaan, M., Mirmiran, A., Shahawy, M., 1998. Model of concrete confined by fiber composites. Journal of structural engineering 124, 1025–1031.

Sayed-Ahmed, E.Y., Shaat, A.A., Abdallah, E.A., 2018. CFRP-strengthened HSS columns subject to eccentric loading. Journal of Composites for Construction 22, 4018025.

ViscoCrete®-5930, S., 2010. High Performance Superplasticiser Concrete Admixture. Product data sheet. Edition 6.

Wang, Y.-C., Hsu, K., 2008. Design of FRP-wrapped reinforced concrete columns for enhancing axial load carrying capacity. Composite structures 82, 132–139.

Wang, Z., Wang, D., Smith, S.T., Lu, D., 2012. CFRP-confined square RC columns. I: Experimental investigation. Journal of Composites for Construction 16, 150–160.

Wei, H., Wu, Z., Guo, X., Yi, F., 2009. Experimental study on partially deteriorated strength concrete columns confined with CFRP. Engineering Structures 31, 2495–2505.

Xu, T., Liu, J., Wang, X., Guo, Y., Chen, Y.F., 2020. Behaviour of short CFRP-steel composite tubed reinforced normal and high strength concrete columns under eccentric compression. Engineering Structures 205, 110096.

Yan, Z., Pantelides, C.P., Reaveley, L.D., 2006. Fiber-reinforced polymer jacketed and shape-modified compression members: I-experimental behavior. ACI structural journal 103, 885.