The Effect of Diffrenet Types of Strengthening RC Columns Subjected to Eccentric Load

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Abstracts: In many constructions, columns are subjected to eccentric loads. So, they are unable to withstand higher loading requirements. Ferrocement jacketing and fiber-reinforced polymer (FRP) have demonstrated exceptionally high efficacy in comparison to other strengthening techniques. This paper presents the results of experimental studies on reinforced concrete columns strengthened with carbon fiber reinforced polymer (CFRP) and ferrocement layer composites under an eccentric load. The new techniques depended on the combination of (CFRP) and Ferrocement to strengthen RC columns, which are subjected to eccentric loads. To get the average result for the model, ten tested models are patterned using two of each specimen, totaling twenty tested specimens. Models are divided into four groups in accordance with the method of strengthening. The specimen in the first group has not been strengthened. The second group consists of six specimens strengthened with one, two, or three successive layers of the wire mesh with an outer 15 mm thickened coating. The third group consists of four specimens strengthened with one or two successively wrapped layers of the (CFRP). The fifth group consists of six specimens strengthened with one or two layers of CFRP and one or two layers of concrete wire mesh. The purpose of the current study is to compare the use of CFRP, ferrocement layers, or a combination of carbon fibers and ferrocement to strengthen concrete columns that are subjected to eccentric loads (e/t = 0.5). The study has also shown that mixing GFRP with ferrocement is more effective than using ferrocement or carbon, but more expensive.

Keywords: Ferrocement Jacketing, Carbon Fiber Reinforced Polymer (CFRP), Laminate, Reinforced Concrete, Column, Strengthening, Eccentricty.

1. INTRODUCTION

Reinforcement, or strengthening, is frequently required for concrete structures in order to maintain their resistance to varying loads. As a result, the strengthening process becomes necessary for a number of reasons, including increased live loads due to a change in use, deterioration issues in certain areas of the concrete structure (deterioration problems of the load-carrying elements), or errors following wrong designs. In these situations, the structure may require strengthening, repairing, or even retrofitting in one or more places. The unaxial load capacity of columns can be effectively increased by using common strengthening techniques such as fiber-reinforced polymer (FRP), concrete jacketing, steel jacketing, and ferrocement jacketing. These techniques help columns withstand the deterioration factors of different constructions. Former studies have paid little attention to the use of ferrocement and CFRP to strengthen columns that were subjected to eccentric loads. However, this research has surpassed other research as it developed an idea that gathers the CFRP laminates with the Ferrocement in a strengthening technique that helps recover columns' capacity against deterioration factors.

Over the last two decades, studies have seriously considered various techniques of strengthening and their effect on reinforcing concrete columns. A number of these studies concentrated on strengthening reinforced concrete columns (RC columns) with GFRP, CFRP, and ferrocement . No one spotted using CFRP laminate and Ferrocement jacketing together in the same specimen as a technique of strengthening.

Researches of Ferrocement technique studied the behavior of strengthened RC columns with different parameters; (shear, shear connectors, load capacity, stiffness, and ductility). K.Alenezi. [2] studied the behavior of shear connectors of the composite columns assembled together as a precast member. He came to the conclusion that the shear connector with 12mm diameter showed the highest shear capacity. On the other hand, Mohamed Taghi Kazemi et al. [3] studied seismic shear strengthening of R/C columns with Ferrocement jacket, and they concluded that using Ferrocement jacket had a great effect.

For strengthen shear deficient. Kaish et al [4] studied Ferrocement jacketing as a strengthed technique for square short column. He concluded that using additional wire mesh for the corner of the square cross-section decreased the concentration of stresses in this area. Xiong.[5] Studied strengthening the plain concrete columns with Ferrocement technique including steel bars. Ahmed M. El-Kholy et al. [6] studied the improving confinement of reinforced concrete columns. The results showed that the columns, confined with proposed lateral reinforcement, revealed significant improvement in the strength and ductility.

In the same way, researches of GFRP and CFRP technique focused on the performance of the strengthened RC columns under different conditions, Niloufar Moshiri et al. [7] studied the effect of strengthening RC columns by longitudinal CFRP sheets. They achieved that CFRP sheets postponed the buckling, subsequently the load capacity of the specimens. Amer M. Ibrahim et al. [8] studied the behavior and strength of bearing wall strengthening by CFRP. The results showed the efficiency of using CFRP as strengthening technique, subsequently increased the bearing load and the stiffness. P.Sangeetha.[9] studied the behavior of the GFRP wrapped concrete columns under uniaxial compression, the results of the study showed that confinement increased the strength of the concrete columns loaded axially. Qais F.Hasan et al.[10] studied NSM rebar and CFRP laminate strengthening for RC columns subjected to cycle loading. The results of this paper showed enhancement of the overall behaviors of columns like, crack pattern, yield and ultimate cyclic load capacities, and ductility ratios.

Finally, M. M. Abdel-Hakam. [11] studied the effect of using new techniques of glass fiber laminates (GFRP) and ferrocement jacket on the behavior of strengthened RC columns, the results of the study showed that combination between 1 layer of GFRP and 1 layer of Ferrocement increase the ultimate load and energy absorption by 47 % and 119% respectively more than the unstrengthened columns.

This research aims to determine the effectiveness of using CFRP laminate with varying layers, ferrocement jacketing with varying numbers of wire meshes, and the combined technique between them as strengthening strategies at reinforced concrete columns.

2. MATERIEL AND METHODS

2.1. Materials

Different materials were used in this research, such as concrete with its different components in addition to the strengthening materials from Ferrocement jacketing to CFRP laminate. The properties of different materials were listed in Table (2).

2.1.1 Concrete Materials

The reinforced concrete for columns specimens consisted of fine, and coarse aggregate, cement, water, and steel. The used fine and coarse aggregate in this research were natural sand from 6 October quarries and basalt from Sinai quarries. They were tested according to Egyptian standard specifications. In the same way, the cement that was used in this research was Ordinary Portland Cement (OPC) ,and it was tested according to Egyptian standard specification.

In this study, two distinct types of steel reinforcement were used. The first type was high tensile steel with yield strength Fy = 360 N/mm2 for the longitudinal bars with diameter 10mm. The second type was mild steel with yield strength Fy = 280 N/mm2 for the stirrups, with diameter 8mm.The mechanical tests were performed on the two types of steel. Finally, the water that was used in this research was ordinary tap portable water.

2.1.1.2 Concrete Mix Design

The achieved compressive strength of the concrete was 25MPa. Table (1) shows the concrete mix for one cubic meter.

Table 1: Concrete mix content by weight for one cubic meter of concrete.

Mix. No.	Cement(Kg)	Water (lit).	Fine Agg.(Kg.)	Coarse Agg.(Kg.)
1	350	175	650	1300

Standardized cubes have been casted with 150mm, 150mm and 150mm dimensions and treated for twenty – eight days. The components' mixes are then mixed with a mechanical mixer; the fine and coarse aggregate are added first and next the supplemented cement with water, and then a three- minutes mixing process is to follow.

2.1.2 CFRP Laminates

2.1.2.1 Sika Wrap- 230C

The CFRP laminated was about fibers with thickness 0.129 mm, and width 500mm. the density of the material was 1.82 gm/cm^3. Tensile strength was 3500 N/mm^2. **Figure (1)** shows the used laminated material.

2.1.2.2. Epoxy Resin (Sikadur-330)

This material was divided into two components (A, and B) with ratio (4:1). The weight of the two component 4 kg, 3.2 for component A, and 0.80 kg for component B. density of the composite material is 1.31 kg/lt. Tensile strength is 30 N/mm^2 for the epoxy resin.

2.1.3 Ferrocement Jacket

2.1.3.1 Steel Anchors

Steel anchors of nominal diameter 8 mm and length 70 mm were used for fixing the steel wire mesh to the concrete specimens before mortar.

2.1.3.2 Steel Wire Meshes

One type of steel wire mesh is used in this paper. The steel wire mesh type is expanded wire mesh with closely hexagonal openings showed in **Figure (2).**

Table 2: properties of used materials

Materials	Parameter	Properties	values
Sikadur-330		Tensile strength(N/mm^2) =	30
		Elongation (%) =	0.90
Sikawrap-230C		Tensile strength (N/mm^2) =	3500
		Elongation (%) =	1.59
Kemapoxy 104		Density(kg/lit) =	1.49
Addibond(kg/m^3)		Density(kg/lit) =	1.02
Cement		Strength after 3 days(kg/cm^2)	210
Cement Steel	10mm	Strength after7 days(kg/cm^2)	290
		(Tensile strength kg/cm^2)	6914
Steel	8mm	(Tensile strength kg/cm^2)	3405

Figure1: CFRP Laminate (Sikawrap230C)

Figure 2: Hexagonal steel wire mesh

2.2. Preparations of test specimens

twenty specimens of reinforced concrete columns have been casted and tested. Each of the columns is 120 cm in height and in dimensions of 10 cm and 10 cm. However, each two specimens represent one model. Within each model, two specimens have been casted for the sake of reaching the average result for each model. A long with that, the models have been classified into four groups(C, CC, CF and CCF) depending on the model of strengthening dedicated for each. Table (3) shows the details of the specimens.

2.2.1 Classification of the test models

Series C contains one specimen that holds a dimensional cross – section of 100×100 mm. The sole specimen is considered the reference sample that is deprived of any sort of strengthening techniques. This specimen's internal is furnished with a 10-mm diameter deformed steel bars and a 8 mm stirrups providing a longitudinal steel ratio of “μ= 2.50%”. All specimens share the same ferroconcrete and the same rate of steel.

Series CC encompasses two specimens of concrete columns that share the same dimensional cross – section of the reference column but layered with an outer supplement of three successive CFRP layers;CC1 and CC2.

Series CF shares the same ferroconcrete of former series. However, one,two or three thickened 1mm successive hexagonal wire mesh layers are added, and then all sides of the cross – section are coated with a thickened 2.5 cm of a concrete coverage tointroduce a final 15×15 cm cross – section.

Series CCF is of four specimen but supplied with an advanced strengthening technique that strengthens the specimen with a one or two layer of the CFRP that is subsequently layered with one or two layer of hexagonal wire mesh, and then supplemented with a 15 mm thickened coating of cement plaster to generate a final cross-section of 17×17 cm.

Table 3: Details of the research specimens:

Series	Specimen	Cross-section(cm)	Length (cm)	Slenderness ratio	RFT	Parametric study
C “Control”	C	10×10	120	10	4Φ10	**Control-specimen**
CC “CFRP”	CC1	10×10	120	10	4Φ10	**One layer GFRP**
	CC2	10×10	120	10	4Φ10	**Two layers GFRP**
CF “Ferrocement”	CF1	15×15	120	8	4Φ10	**One layer wire mesh with cover**
	CF2	15×15	120	8	4Φ10	**Two layers wire mesh with cover**
	CF3	15×15	120	8	4Φ10	**Three layers wire mesh with cover**
CCF “CFRP &Ferrocement”	CC1F1	17×17	120	7	4Φ10	**One layer CFRP +one layer wire mesh with cover**

	CC1F2	17×17	120	7	4Φ10	**One layer CFRP +two layer wire mesh with cover**
	CC2F2	17×17	120	7	4Φ10	**two layer GFRP +two layer wire mesh with cover**

2.3. Instrumentation and testing

The specimens are subjected to axial compressive loading. Tests are executed using hydraulic loading machine of 1000 kN capacity. All specimens are placed on the rigid two RC blocks that are rested on the rigid steel floor of the machine. The concrete column is loaded after being installed vertically with a cylindrical bar at a distance from the center of the column equal to half the thickness (e = 0.5 t) to ensure the required eccentric loading. A vertical displacement transducer is used on top of the column sample in the vertical direction to measure the axial deflection, and a horizontal displacement transducer is also used, which is fixed next to the sample to measure horizontal displacement. Load and displacement are monitored and recorded using an automatic data acquisition system**.**

3. RESULTS AND DISCUSSIONS

All specimens were tested up to failure. The data logger that was connected to the compression machine was used to gather the load and displacement data.The test results of all series are presented in **Table 4.**

Table 4: Test results of all specimens

Series	Specimen Code	Pult (kN)	(P/Pc) %	Displacement(mm) at ($P_{ult)}$	(D/ Dc) %
C	C	220	100%	15.25	100%
CC	CC1	282	128%	13.50	88.5%
	CC2	385	175%	12.75	83.6%
CF	CF1	241	110%	13.25	87%
	CF2	324	147%	12.75	83.6%
	CF3	435	198%	14.25	93%
CCF	CC1F1	313	142%	12.25	80.3%
	CC1F2	431	196%	11.25	73.7%
	CC2F2	476	216%	10.5	69%

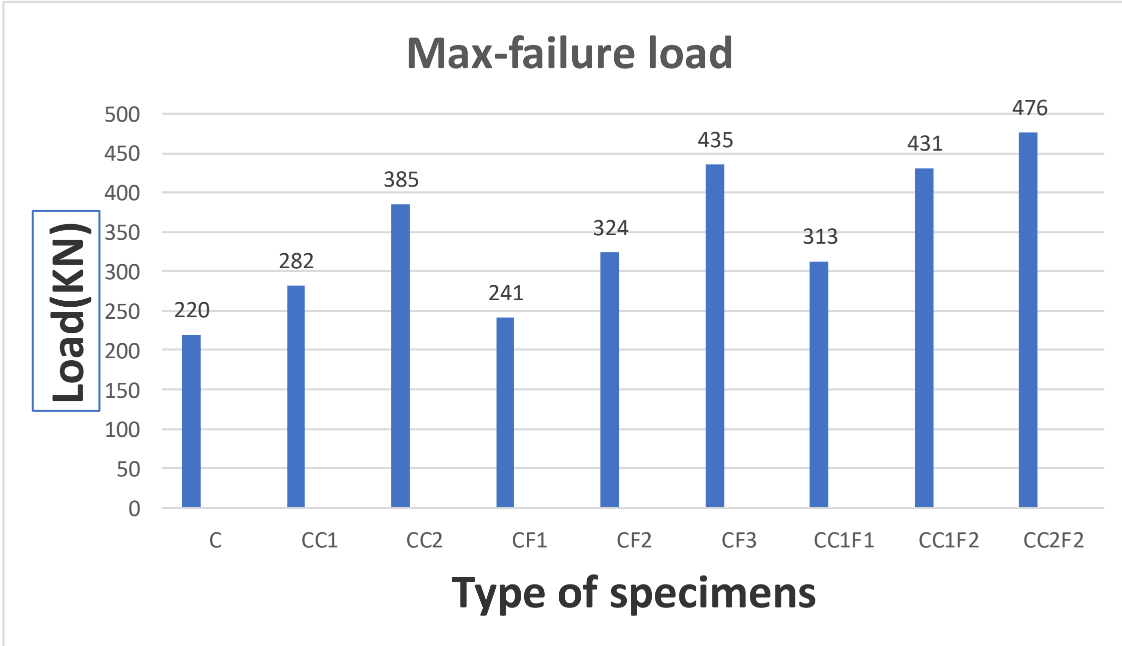

Figure 3: Maximum failure load of all specimens

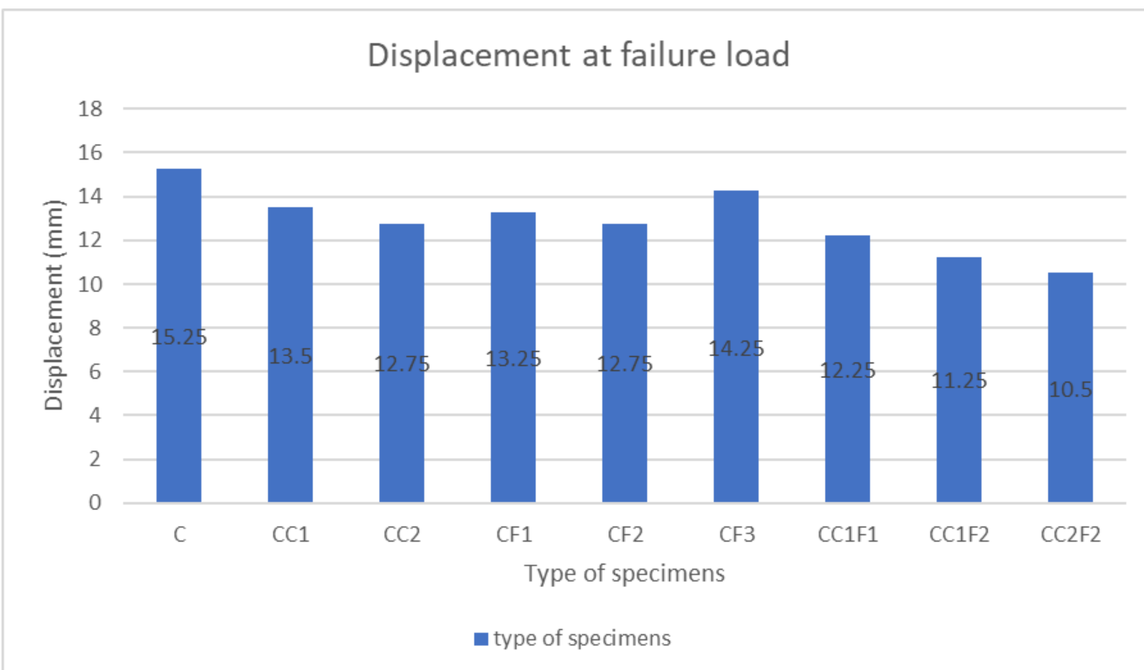

Figure 4: Load-Displacement curve for all specimens.

3.1.Series C (Control)

The results of the test program show that the maximum load capacity and the lateral displacement at this load were 220 KN, 15.25mm, respectively.

3.2. Series CC (CFRP)

The percentage of increasing in the maximum failure load corresponding to the control specimen for columns model CC1 and CC2 were 128% and 175% respectively. In the same way, the percentage of decreasing in lateral displacement compared with the control specimens for columns model CC1, CC2, and were 88.5% and 83.6% respectively.

The column models with 2 CFRP layers had the highest value of ultimate failureload, and the lowest value of the lateral -displacement comparing with the control model, and the other models in the same series.

3.3. Series CF (Ferrocement)

The percentage of the increase in the maximum failure load about the control specimen for columns model CF1, CF2, and CF3 were 110%, 147%, and 198%, respectively. In the same way, the percentage of the increase in lateral displacement about the control specimens for columns model CF1, CF2, and CF3 were 87%, 83.6%, and 93%, respectively.

The column models with 3 wire mesh layers had the highest value of ultimate failure load comparing with the control model, and the other models in the same series.

3.4. Series CCF (CFRP and Ferrocement)

The percentage of the increase in the maximum failure load about the control specimen for columns model CC1F1, CC1F1, and CC2F2 were 142%, 196%, and 216%, respectively. In the same way, the percentage of the increase in lateral displacement about the control specimens for columns model CC1F1, CC1F2, and CC2F2 were 80.3%, 73%, and 69%, respectively.

The maximum load capacity of CC2F2 specimen considered the highest result comparing with the specimens with the same case, such as CC1F1, CC1F2, and CF3.

1 Failure modes

showed the failure modes of all specimens. It was observed that the failure mode crushed in all specimens at the top of column under the head(local failure) . From the crack patterns of specimens, it was showed that Ferrocement jacketing specimens were more ductile than CFRP techniques; on the other hand, CFRP laminate specimens were more brittle, it is result to the effect of epoxy resin in CFRP.

Control Specimen's failure "C"(local failure)

Specimen "CF1" (eccentric failure)

Specimen "CF2"(local failure)

Specimen "CF3" (local failure)

Specimen ''CC1''(eccentric failure)

Specimen ''CC2'' (local+eccentric failure)

Specimen "CC1F1"(eccentric failure)

Specimen "CC1F2"(local + eccentric failure)

Specimen "CC2F2"(local + eccentric failure)

CONCLUSIONS

Several methods were employed in this study to improve the behavior of the RC column

under eccentric load. The main findings of this investigation can be summed up as follows:

1- A combination between 2 layer of CFRP and 2 layer of Ferrocement increase the ultimate load and energy absorption by 116 % more than the unstrengthened columns. This technique had a great bearing under the effect of the eccentric load, as it was compared with the specimens at the same case.

2- New techniques had a great effect on the load capacity and it was more low cost than using CFRP only. it was increased the ductility of reinforced concrete columns.

3- Adding polymer materials to the cement mortar, helped to increase the cohesive between coating and the old concrete or GFRP laminates. It was effect on the mode of failure and increases the ultimate column load capacity

4- The maximum load capacity between the test columns was for “CC1F2” specimen with 476 KN, and CC1F1 became in the second place with 431 KN, and the lowest specimen was C the control specimen with ultimate load equal 220 KN, and CF1 became at the second place with ultimate load equal to 241 KN.

5- Applying CFRP technique to the reinforced concrete columns increased the maximum load capacity by 128% and 175% for 1 and 2 layers respectively comparing with columns without strengthening.

6- Applying Ferrocement jacketing to the reinforced concrete columns increased the maximum load capacity by 110%, 147%, and 198% for 1, 2, and 3 layers of wire mesh respectively, comparing with columns without strengthening.

7- The effect of applying CFRP technique was greater than the effect of the Ferrocement jacketing on the bearing capacity of the concrete columns which were subjected to eccentric load , but it was more cost than the Ferrocement technique.

8- From modes of failure of the test specimens, it was observed that Ferrocement jacketing specimens were more ductile than GFRP technique; on the other hand, CFRP specimens were more brittle than other specimens.

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