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BEHAVIOR OF CIRCULAR REINFORCED CONCRETE COLUMNS STRENGTHENED BY DIFFERENT TECHNIQUES SUBJECTED TO AXIAL LOADING

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Abstract

In recent years, CFRP is the most popular material in strengthening RC members (columns, beams, slabs…etc.) as well as the textile-reinforced mortar (TRM) was also used as an alternative method for strengthening RC columns. The present study includes fifteen circular RC columns: One control column, ten columns strengthened by one or two layers of CFRP using EBR or EBROG methods, two columns was strengthened by textile-reinforced epoxy on grooves and last two columns were strengthened by textile reinforced mortar without grooves. The parameters of this investigation are type of strengthening technique (EBR, EBROG and TRM), number of CFRP layers, and the grooves configuration. The results showed that the columns strengthened longitudinally with one or two layers of CFRP strips using EBR technique enhanced the load-carrying capacity by 2 and 7.13%, respectively, when compared with control column. However, the load carrying capacity of RC columns strengthened by EBROG increased by the range of 11.65% to 71.4%. in comparison with control column. Finally, TRM strengthening method enhanced the load carrying capacity by about 21% to 58.5%. Also, the results showed that the EBROG and TRM approaches were improved the stiffness and ductility of the columns in comparison with EBR method.

Keywords:

Strengthening;
EBROG;
TRM;
Grooves;
Concentric loading.

1 Introduction

Columns have a crucial role in reinforced concrete structures. In fact, the behavior of the structure is determined by the qualities of the columns. The columns must possess excellent strength, durability, and ductility to effectively withstand different types of loads. Excessive loads or weights and poor conditions surrounding the column might result in damage [1]. In the last two decades, many methods have been utilized to strengthen and improve the structural integrity of concrete columns. Recently, the methods of strengthening include externally bonded reinforced (EBR), externally bonded reinforced on grooves (EBROG), near surface mounted (NSM), and textile-reinforced mortar (TRM) [2]. The benefits of strengthening/retrofitting RC columns with CFRP composites (laminates, sheets) include corrosion resistance, attractive mechanical properties, ease of implementation, and substantial durability [3, 4]. Numerous studies have been carried out to examine the effects of fiber-reinforced polymer (FRP) composites on the behavior of reinforced concrete (RC) columns under both concentric and eccentric loading conditions.

Several studies have endeavored to enhance the strength of columns by employing longitudinal fiber-reinforced polymer (FRP) and investigating the effect of different fiber orientations of FRP on column performance [5-7]. Additional studies have been conducted to evaluate the effectiveness of columns wrapped latterly with CFRP composite sheets [8, 9]. An important drawback of strengthening reinforced concrete (RC) members by CFRP using EBR is the problem of debonding. To postponed/ eliminate the debonding of CFRP, alternative methods have been suggested.

Mostofinejad and Mohmoudabadi (2010) [10] introduced the externally bonded reinforcement on grooves (EBROG) technique, which involved creating longitudinal grooves on the outermost layer of the tension face of the beam section. Following the process of cleaning and filling the grooves with an appropriate epoxy resin, Carbon Fiber Reinforced Polymers (CFRP) were inserted and properly adhered

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to the concrete surface. Research on the implementation of this technique in strengthening concrete structures with CFRP sheets has shown that the occurrence of debonding is delayed or eliminated as a result of an increase in the contact area between the CFRP and the concrete [11, 12]. Furthermore, the application of grooving technique effectively postpones the buckling of CFRP from the concrete surface when it is subjected to compression [13].

Recently, Textile-reinforced mortar (TRM) has developed as an innovative and effective alternative method for strengthening structures. TRM has characteristics such as light weight, high strength, and minimum change in geometry [14, 15]. Additionally, the utilization of the TRM method provides high corrosion resistance, great vapor permeability, suitable integration with the concrete substrate, optimal performance under high temperatures or in the occurrence of fire, and simple application on wet surfaces. Currently, numerous experimental studies have been conducted to evaluate the efficacy of the TRM method in strengthening the exterior confinement system of RC concrete members. Several researches studies TRM strengthening technique and investigated some parameters such as textile type, the number of textile layers, mortar strength, and cross-section [16-19]. According to literature, few studies have been conducted to investigate the of TRM strengthening method on the behavior of RC columns [20, 21]. The most of them have concentrated on square or rectangular cross-sections without considering circular cross-sections [22].

This study aims to evaluate the effectiveness of the EBROG method in improving the performance of reinforced concrete columns strengthened by CFRP. The effect of groove orientation and the number of CFRP layers on the load-carrying capacity, ductility, and stiffness of the strengthened columns will be studied. Also, to study the behavior of reinforced concrete circular columns strengthened by textile reinforced mortar (TRM) under concentric loading will be investigated. To achieve the goal of the study, a total of fifteen circular reinforced concrete (RC) columns were cast and tested.

2 Experimental Program

2.1 Specifications of the Specimens

Fifteen reinforced concrete (RC) columns were cast and tested with 150 mm in diameter and 750 mm in length. The main reinforcement was 6Ø 8mm (steel ratio is1.7 %) with the limitation of ACI 318 - 19 [23]. The tied is Ø6mm @ 100 mm, however, Ø6mm @ 50 mm were used attends to prevent the failure at the ends. Fig. 1 shows the typical column dimensions and steel reinforcement.

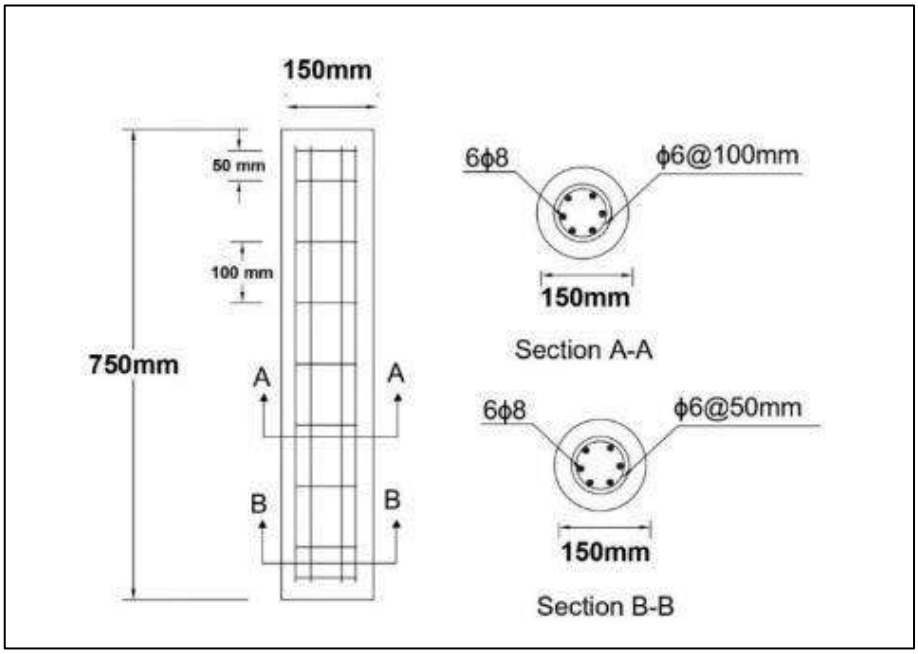


Fig. 1: Details of Reinforcement.

2 Materials Characteristics

A normal-strength concrete with a goal strength of 25 MPa at 28 days was designed by mixing natural fine aggregate, Portland cement, and crushed gravel with a maximum size of 9.5 mm. A

compression test was performed according to ASTM C39 [24] on cylindrical concrete samples having dimensions of 150 mm x 300 mm to get the compressive strength. Unidirectional Sika Wrap-300 C carbon fibers and Sikadur-330 epoxy resin were utilized in this study. In addition, carbon textiles with a mesh size of 10x10 mm (length x width) and 0.4 mm in thickness were employed also in this research with Sika Mono Top®-612 as a bonding mortar. The properties of materials are listed in Table 1 and Table 2 shows the proportions of the concrete mixture.

Table 1: Material Properties.

Material	Type	Yield strength	Ultimate tensile	Elastic modulus	Diameter/Thickness
		[MPa]	strength [MPa]	[GPa]	[mm]
Steel	No.6 No.8	378.5 329	424.5 492	200 200	6 8
CFRP	Sika Wrap-300c	-	4000	230	0.17
Resin	Sikadur-330	-	30	4.5	-
Textile	HM-CFN	-	4900	230	0.4
Mortar	Sika Mono Top®-612	-	8.3	25	-

Table 2: Proportions of mixed concrete.

Type of Mix	Material				Water/ Cement	Slump [mm]
Normal Concrete	Fine aggregate	Coarse aggregate	Cement [kg/m^3]	Water	0.55	40
	[kg/m^3]	[kg/m^3]		[kg/m^3]		
	765	1050	410	225		

2.3 Strengthening Techniques

The CFRP sheets were cut into strips measuring 650 mm in length and 50 mm in width. An epoxy resin was then employed to adhere the CFRP strips onto the columns' surfaces. The EBR technique involved the removal of a thin and structurally weak layer of concrete from the surface of the column. The concrete surface was subsequently cleaned. The carbon fiber sheets were then adhered to the surface of the columns using epoxy material. Fig. 2 illustrates the process of strengthening RC columns with CFRP.

However, in EBROG method, longitudinal grooves with 9mm in width an 9 mm in depth are created using a grinder machine and, in some specimens, transverse grooves with 9X9 mm^2 (width X depth) were prepared. Additionally, circular grooves with a depth of 9 mm and a width of 9 mm are created around the cross-section of certain specimens. Once the grooves are prepared and any dust is removed through washing with water and an air compressor, epoxy resin is used to fill the grooves. A thin layer of epoxy is also applied to the surface of the column that comes into contact with CFRP. Finally, carbon fiber sheets are applied to the surface of the column.

In strengthening by TRM method a grid of small groove lines with a width of 50 mm is formed on the surface of specimens using a small drilling machine to achieve a good bonding and, in some specimens, longitudinal or circular grooves were prepared. The grooves are then cleaned by using the air compressor, to remove the dust and grime, [Fig. 3a)]. Wetting the surface of the specimen to prevent absorbing the mortar's water. A mortar with a width of 50mm, a depth of approximately 3mm, and the required length for all specimens was applied, and the carbon textile was applied on the mortar with pressure by hand to achieve excellent bonding of the textile [Fig. 3b)], an additional layer of mortar with a thickness of 3mm was added to completely cover the textile, and the surface was leveled with a manual leveling machine [Fig. 3c)]. Finally, the specimens are kept for one day before the curing process begins.



Fig. 2: Specimens strengthened using CFRP strips.



a) b) c)

Fig. 3: Procedure of TRM technique.

2.4 Classifications of Specimens

The classification of the specimens enhanced by various strengthening techniques is detailed in Table 3. A brief explanation of the strengthening method for each column are presented in the following:

1) Reference specimen (CCN-CO-0): This specimen is a control without strengthening.

2) Specimens strengthened longitudinally with one and two strips of CFRP using EBR method sampled by CEBR-1 and CEBR-2 respectively: Four longitudinal FRP strips, each strip with 50 mm wide and 650 mm long, were installed to strengthen these specimens using the EBR method.

3) Using the EBROG method for strengthening the specimens (CLOG-1, CLOG-2) with one and two layers. The specimens were strengthened by longitudinal CFRP strips: The concrete cover was cut into four longitudinal grooves that were evenly distributed around the column. CFRP strips were then applied on these grooves.

4) Applying the EBROG technique to enhance the strength of the specimens (CLTOG-1, CLTOG-2) using one and two layers. The specimens were strengthened using CFRP strips running longitudinally and transversely around the circumference of the column. The concrete cover was cut into four longitudinal and twenty transverse grooves, which were evenly distributed around the column. Subsequently, CFRP strips were fixed onto these grooves.

5) Using EBROG method for strengthening specimens (CCROG-1, CCROG-2) with one and two layers: The concrete cover was cut into five circular grooves uniformly distributed around the column. CFRP strips were then adhered to these grooves.

6) Specimens distinguished by (CLCROG- 1, CLCROG- 2) strengthened with one and two longitudinal and circular CFRP strip covering the column using the EBROG method., Four longitudinal and five circular grooves were cut into the concrete cover. Four longitudinal and five circular CFRP strips were then applied on the grooves.

7) The specimen (CXIM- 1) strengthened by TRM: One layer of longitudinal carbon textile covered with mortar were used to strengthening the column.

8) Specimen distinguished by (CCRXIMOG- 1) strengthened with one circular textile strip covering the column using the TRM method., five circular grooves were cut into the concrete cover. five circular textile strips were then applied on the grooves.

9) The specimen is identified by the (CLCRXIMOG-1) code and has been strengthened employing one TRM-applied carbon textile strip that is both circular and longitudinal. The concrete cover included five circular grooves and four longitudinal ones cut into it. Then, the grooves were covered with four longitudinal and five circular textile strips.

10) The Specimen (CXIEM- 1) strengthened by TRM: Four longitudinal grooves were cut into the concrete cover and filled with epoxy. One layer of longitudinal carbon textile covered with mortar were used to strengthening the column.

Table 3: Configuration of strengthening columns under concentric loading.

Name	Strengthening Type	Type of groove	Length of groove [mm]	No. of grooves	No. of layers
CCN-CO-0	-	-	-	-	-
CEBR-1	EBR	-	-	-	One
CEBR-2	EBR	-	-	-	Two
CLOG- 1	EBROG	Longitudinal	650	Four	One
CLOG- 2	EBROG	Longitudinal	650	Four	Two
CCROG-1	EBROG	Circular	471	Five	One
CCROG-2	EBROG	Circular	471	Five	Two
CLTOG- 1	EBROG	Longitudinal	650	Four	One
		Transverse	70	Twenty	
CLTOG- 2	EBROG	Longitudinal	650	Four	Two
		Transverse	70	Twenty	
CLCROG- 1	EBROG	Longitudinal	650	Four	One
		Circular	471	Five	
CLCROG- 2	EBROG	Longitudinal	650	Four	Two
		Circular	471	Five	
CXIM- 1	TRM	-	-	-	One
CCRXIMOG- 1	TRM	Circular	471	Five	One
CLCRXIMOG- 1	TRM	Longitudinal	650	Four	One
		Circular	471	Five	
CXIEM- 1	TRM	Longitudinal	650	Four	One

Note: C: column, CN: column control, CO: concentric load, EBR: externally bonded reinforced, L: longitudinal, OG: externally bonded reinforced on grooves, T: transverse, CR: circular, XI: textile, E: epoxy, M: mortar, 1 and 2: number of layers.

2.5 Testing the Columns under concentric loading

The main components of the loading system designed to test columns under compression by a system with two loading plates and a testing machine with a 2,000-kN hydraulic jack to provide the necessary force. As indicated in Fig. 4, a concentric loading plate set was used with loading increment of 5 kN up to failure. The plate set was made up of two main components: (Axial displacements on the column were measured using linear variable differential transducers (LVDTs) with a level of accuracy of 0.005 mm.

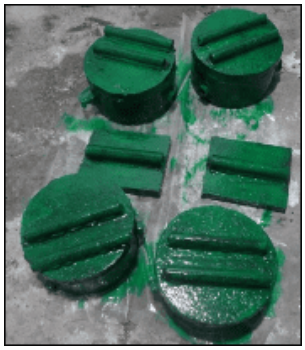


Fig. 4: Supports System.

3 Experimental Results and Discussion

Table 4 shows the test results represented by maximum load $P_{max,}$ as well as increase in load carrying capacity, ductility, and stiffness ratio, respectively. Ductility is defined as the ratio of the ultimate displacement (∆u) to the displacement at yielding (∆y), where (∆u) is the displacement at (0.85 Fu) [25], and the ductility index equal to (D.I = ∆u / ∆y). On the other hand, stiffness (K) can be defined as the resistance exhibited by any elastic body under the effect of the force (F) that is applied to it, divided by the deformation (∆) that takes place in it. This definition is represented by the formula: (K= F / ∆), where F is service load at 0.7 Fu in (kN), ∆ or (∆y) is displacement in (mm) [26], as shown in Table 5. Moreover, the increase in the load carrying capacity for all tested columns under concentric loading and strengthened with different methods; EBR, EBROG and TRM are presented in Fig. [5].

Table 4: Summary of test results of columns.

Sample code	Strengthening type	Maximum load P max [kN]	Increase in load capacity [%]
CCN-CO-0	……..	469.3	……..
CEBR-1	EBR	478.4	2
CEBR-2	EBR	502.7	7.13
CLOG- 1	EBROG	524	11.65
CLOG- 2	EBROG	558	18.9
CCROG-1	EBROG	660.2	40.6
CCROG-2	EBROG	736.6	56.9
CLTOG- 1	EBROG	560	19.3
CLTOG- 2	EBROG	610.8	30.15
CLCROG- 1	EBROG	690.5	47.1
CLCROG- 2	EBROG	804.6	71.4
CXIM- 1	TRM	567.5	20.9
CCRXIMOG- 1	TRM	726.2	54.71
CLCRXIMOG- 1	TRM	744.2	58.5
CXIEM- 1	TRM	575.4	22.6

Table 5: Ductility and Stiffness values of tested columns.

Sample code	Ductility (∆u) / (∆y)	Service load 0.7 Fu [kN]	Displacement at 0.7∆u [mm]	Stiffness [kN/mm]	Increase in Ductility ratio [%]	Increase in Stiffness ratio [%]
CCN-CO-0	1.11	328.55	2.847	115.4	…….	……..
CEBR-1	1.21	334.92	2.81	119.1	6.14	3
CEBR-2	1.32	351.95	2.79	126	15.79	9
CLOG- 1	1.35	366.8	2.66	137.9	18.42	15
CLOG- 2	1.38	390.6	2.66	146.8	21	27
CCROG-1	2.01	462.1	2.68	172.4	76.3	49.2
CCROG- 2	2.24	515.6	2.57	200.4	96.5	73.35
CLTOG- 1	1.41	392	2.61	150.2	23.7	30
CLTOG- 2	1.51	427.5	2.66	160.7	32.45	39
CLCROG- 1	2.1	483.38	2.27	212.9	84.2	84.17
CLCROG- 2	2.72	563.2	2.45	229.9	138.6	99
CCRXIMOG- 1	2.17	508.36	2.35	216.3	90.35	87.1
CLCRXIMOG- 1	2.31	520.95	2.36	220.7	102.6	91
CXIEM- 1	2.18	402.8	2.57	156.7	91.2	35.55
CXIM- 1	1.61	482.4	2.53	157	41.23	35.8

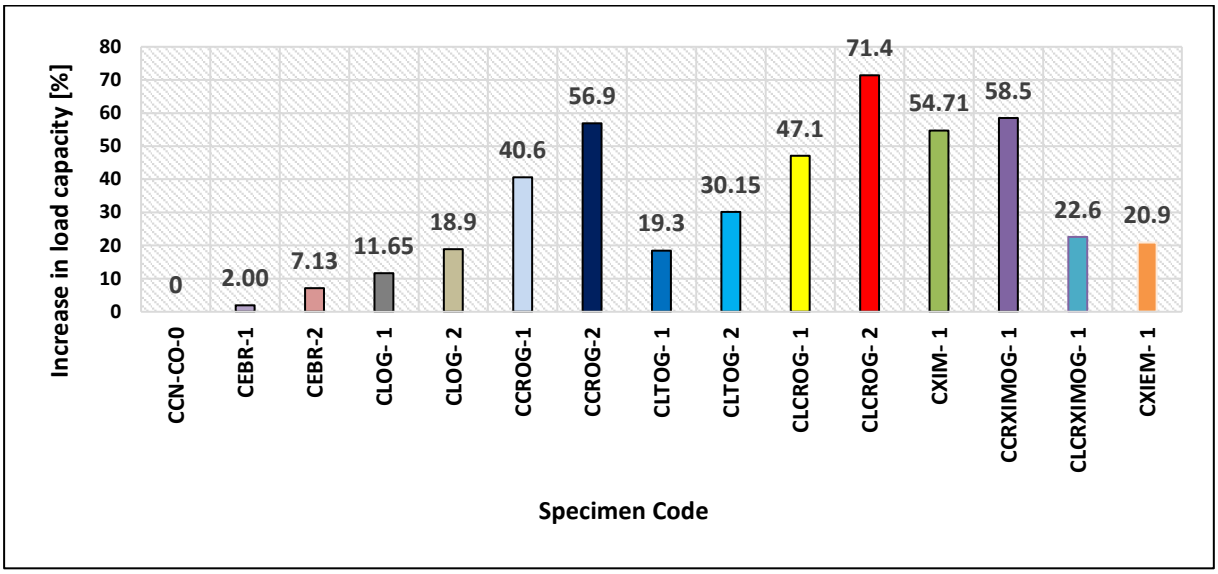


Fig. 5: Increase ratio.

3.1 Failure Mode

The failure modes of columns are presented in Figs. [6–8]. Crushing of the concrete is the mode failure of the control specimen. However, the specimens strengthened by longitudinal CFRP sheets (without hoop wraps), the debonding of CFRP with a thin layer of the concrete cover is the failure mode of specimens strengthened by EBR method. In contrast, concrete cover separation is the mode of failure of the specimens strengthened by longitudinal strips of CFRP using EBROG method. The rupture of CFRP that laterally wrapped the columns is the mode failure of specimens strengthened by longitudinal and transverse, as well as longitudinal and circular of CFRP. RC columns confined with TRM showed a few small cracks on the surface of the TRM strengthening layer when a peak load of 80% was achieved, then, part of the textile rupture at column's maximum load, as shown in Table 6.

Table 6: Details of Failure mode.

Specimen code	Strengthening Type	Type of groove	Failure mode
CCN-CO-0	-	-	Concrete crushing
CEBR-1	EBR	-	Debonding of CFRP
CEBR-2	EBR	-	Debonding of CFRP
CLOG- 1	EBROG	Longitudinal	Concrete cover separation
CLOG- 2	EBROG	Longitudinal	Concrete cover separation
CCROG-1	EBROG	Circular	Rupture of CFRP
CCROG-2	EBROG	Circular	Rupture of CFRP
CLTOG- 1	EBROG	Longitudinal	Rupture of CFRP
		Transverse	
CLTOG- 2	EBROG	Longitudinal	Rupture of CFRP
		Transverse	
CLCROG- 1	EBROG	Longitudinal	Rupture of CFRP
		Circular	
CLCROG- 2	EBROG	Longitudinal	Rupture of CFRP
		Circular	
CXIM- 1	TRM	-	Small crack and rupture of textile
CCRXIMOG- 1	TRM	Circular	Small crack and rupture of textile
CLCRXIMOG- 1	TRM	Longitudinal	Small crack and rupture of textile
		Circular	
CXIEM- 1	TRM	Longitudinal	Small crack and rupture of textile



a) b) c)

Fig. 6: Mode of Failure: a) Control column, b) CEBR-1 column, c) CEBR-2 column.



a) b) c) d) e) f) g) h)

Fig. 7: Mode of Failure for columns strengthened using EBROG technique: a) CLOG-1. b) CLOG-2, c) CCROG-1, d) CCROG-2, e) CLCROG-1, f) CLCROG-2, g) CLTOG-1, h) CLTOG-2.



a) CXIM-1 b) CXIEM-1 c) CCRXIMOG-1 d) CLCRXIMOG-1

Fig. 8: Mode of Failure for specimens strengthened using TRM technique: a) CXIM- 1, b) CXIEM- 1, c) CLCRXIMOG- 1, d) CCRXIMOG- 1.

3.2 Effect of Strengthening Technique

Referring to results presented in Table 4, the load-carrying capacities of strengthened columns by EBR (CEBR-1 and CEBR-2) tested with concentric loading are 478.4 and 502.7 kN, respectively. These values indicated an increase in the load carrying capacity of 2 and 7.13% in comparison with control column. While the column specimens strengthened by CFRP using EBROG- (CLOG-1, CLOG-2, CCROG- 1, CCROG- 2, CLTOG-1, CLTOG-2, CLCROG- 1, CLCROG- 2) failed at the load of 524 to 804.6 kN, representing an increasing in the load carrying capacity by 11.65 to 71.4%, in comparison with control specimen. The load-carrying capabilities of the specimens strengthened by TRM (CXIM- 1, CXIEM- 1, CCRXIMOG- 1, CLCRXIMOG- 1) are 567.5 to 744.2 kN with increase in the load carrying capacities of 20.9 to 58.5% over the control column. The results showed that the EBROG and TRM techniques have a significant effect on improving the load-carrying capacity. This is maybe due to the EBROG have ability to increase the contact area between the surface of concrete and epoxy, resulted in good contact between CFRP and concrete surface. The EBROG method provides good lateral support for the CFRP, and as a result to delay buckling. Also, it can be concluded that the improvement in the load capacity and ductility of the columns strengthened by TRM technique is due to high mechanical properties of the textile material and it is a two–direction material which led to support the column in the longitudinal and transverse direction. In addition, the high compressive strength of the mortar, which lead to improve the bonding mechanism.

3.3 Effect of Number of layers

The load carrying capacity of column strengthened longitudinally by one and two layers of CFRP using EBR method increased by 2 and 7.13% respectively, in comparison with unstrengthened column. Furthermore, the rigidity of these columns increased by 3 and 9 %, also, the ductility increased by 6.14 and 15.79 % in comparison with unstrengthened column. In the same manner, the load carrying capacity of columns strengthened by one and two layers of CFRP using the EBROG increased by 11.65 to 71.4 %, respectively, in comparison with control column, and the stiffness values increased significantly by 15 to 99%, while the ductility values increased by 18.42 to 138.6 %, respectively, in comparison with control column.

3.4 Load- Displacement diagrams

The load-axial displacement responses for all tested specimens were reported in Figs. [9-14]. For all strengthening method: EBR, EBROG, and TRM, the load-axial displacement curves can be divided into three distinct stages. The concrete core initially carried the applied longitudinal load, but the CFRP and textile layer were not activated; the curves were nearly linear. However, the pre-peak curve slope was varied for all specimens, demonstrating that the axial displacement stiffness of specimens (displacement at 0.7 Fu) reduced slightly as the initial loading increased. The concrete core was damaged and lost its bearing capacity once the curve reached the peak stress of an unconfined concrete column, whereas the CFRP and textile layers for columns strengthened using EBR, EBROG, and TRM techniques began to activate gradually along the column length and contributed to the load carrying capacity in different percentages, as shown in Table 4. Finally, the crushed concrete core appeared associated with the rupture of the CFRP or textile layer, and the curve demonstrated a declining phase. Furthermore, it was discovered that utilizing more CFRP layers or various strengthening techniques improved the ductility index (i.e. $\Delta u / \Delta y$) and stiffness of concentrically loaded columns compared to the control column.

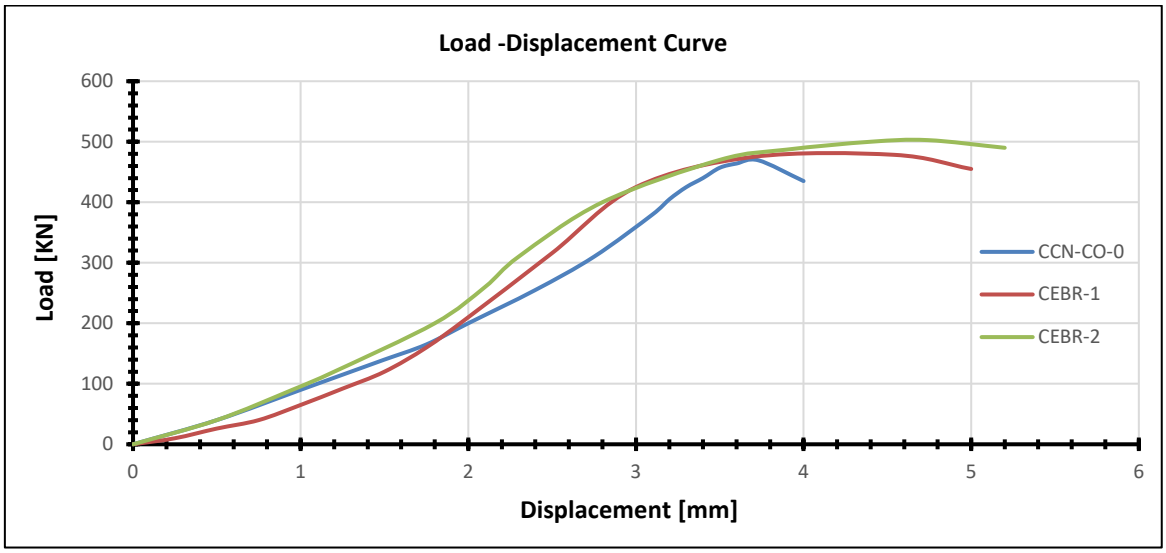


Fig. 9: Comparison between the control column and columns strengthened using EBR technique.

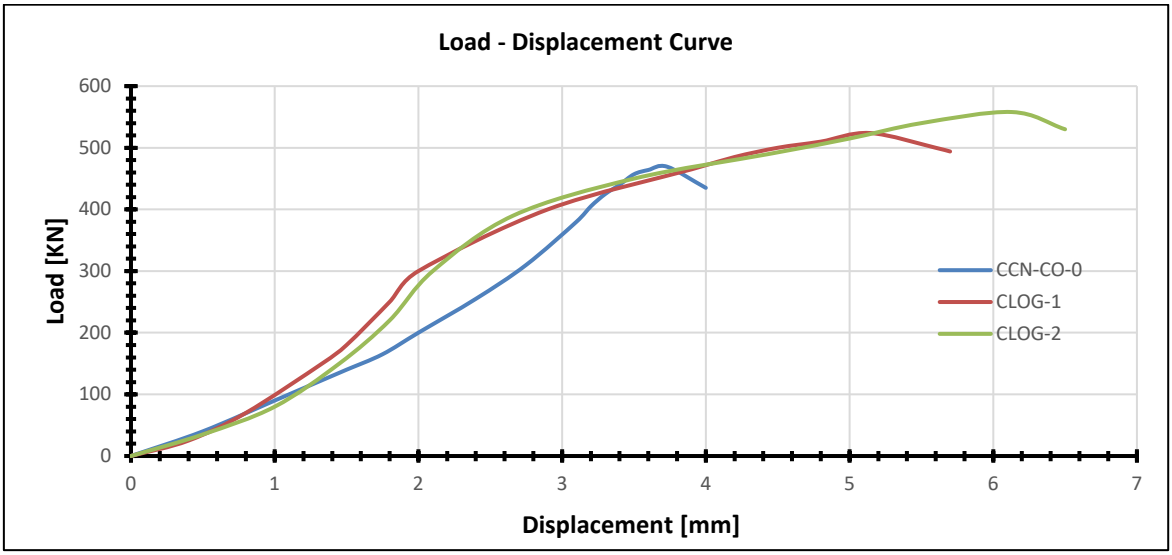


Fig. 10: Comparison between the control column and columns strengthened in longitudinal direction using EBROG technique.

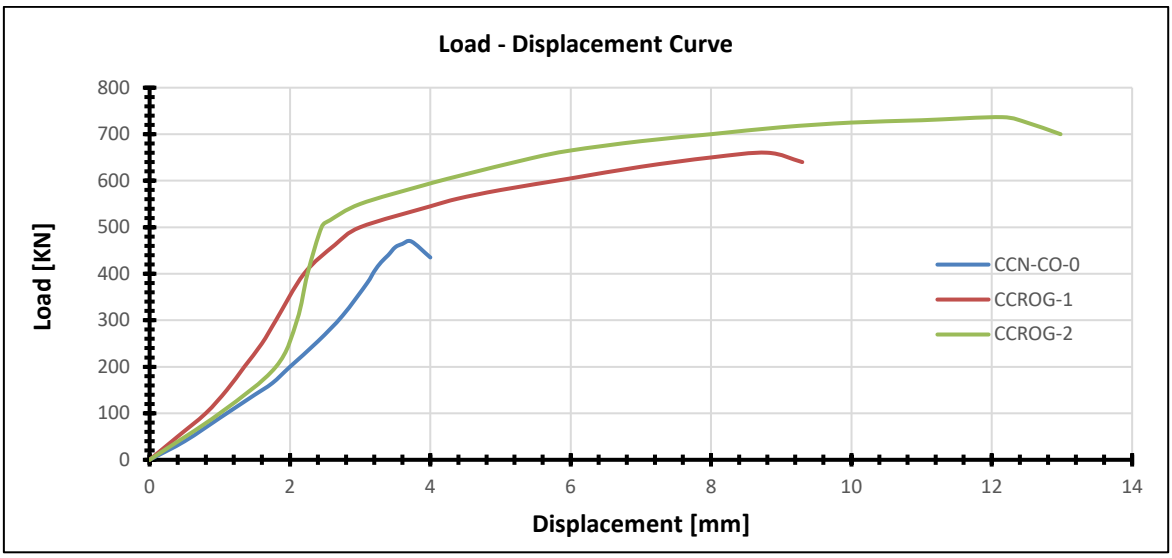


Fig. 11: Comparison between the control column and columns strengthened in circular direction using EBROG technique.

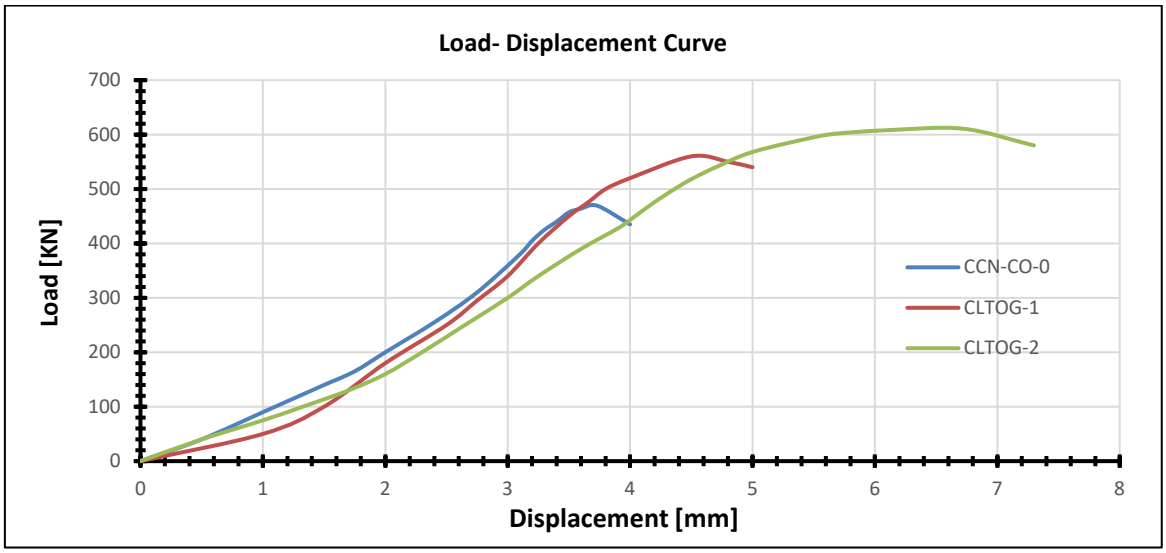


Fig. 12: Comparison between the control column and columns strengthened in longitudinal and transverse direction using EBROG technique.

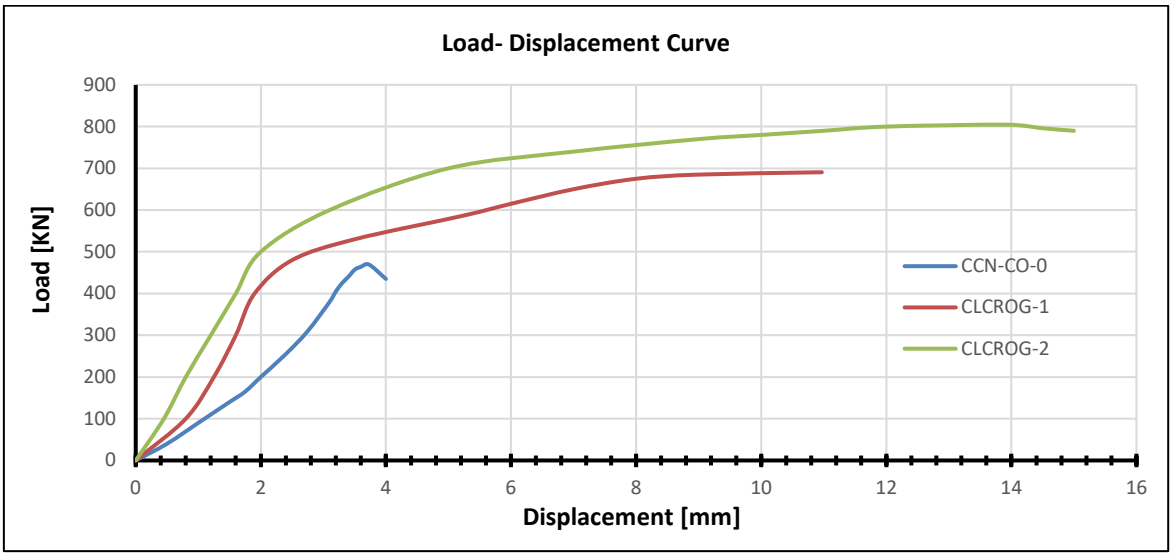


Fig. 13: Comparison between the control column and columns strengthened in longitudinal and circular direction using EBROG technique.

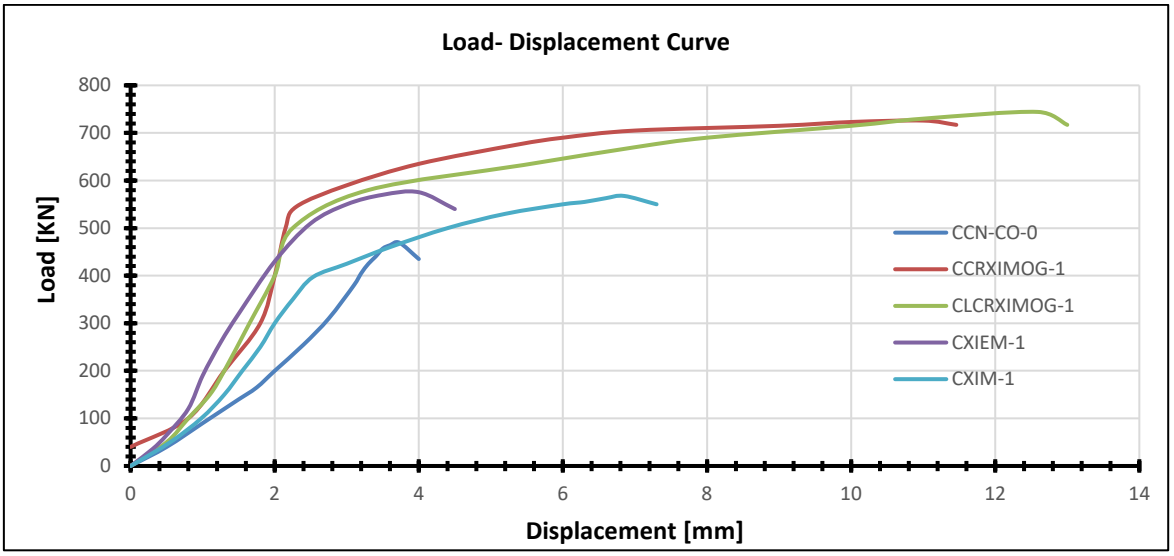


Fig. 14: Comparison between the control column and columns strengthened using TRM technique.

4 Conclusion

The objective of this study is to assess the effects of EBR, EBROG, and TRM strengthening techniques on the behavior of circular columns strengthened with CFRP under concentric loading. Based on the experimental results, the following conclusions can be drawn:

1) The effect of longitudinal CFRP strips using EBR on improving the load capacity of columns is very limited for one and two layers.

2) The load-carrying capacity of the columns strengthened by longitudinal CFRP strips using EBROG are higher than the same columns strengthened by EBR method. The load-carrying capacity of the columns strengthened by CFRP using EBROG with different configuration of grooves increased by range of 12% to 71.4 % in comparison to the control column.

3) Using transverse strips from CFRP to confining the longitudinal CFRP has a significant effect on load-carrying capacity. The increasing in capacity reached up 56.9 % when using transverse strips in comparison with unstrengthened column. However, the increasing in the capacity of columns strengthened by longitudinal strips only is 18.9 % in EBROG method.

4) Columns strengthened by one layer of longitudinal and circular layer of textile using textile reinforced mortar (TRM) method recorded an increasing in the load carrying capacity reached up 58.5% relative to the control.

5) Using EBROG technique has a significant increase in the ductility values compared to the traditional method (EBR). The columns strengthened by EBROG method recorded an increase in the ductility up to 138.6 % compared to the control column. Also, the increasing in the ductility of the column strengthened by TRM technique was up to 102.6% compared to control column. However, the increasing in the ductility of the column strengthened by the EBR method was 41.2% compared to the control specimen.

6) Compared to the EBR, the strengthening using EBROG and TRM techniques significantly improved the stiffness of the columns. The increasing in the stiffness was ranged from 99 to 115 % when using EBROG technique and ranged from 36 to 91 % when using TRM technique compared to control column. However, the stiffness of the columns strengthened by the traditional method (EBR) increased by up to 13% with compared to control specimen.

7) Using EBROG technique with two layers has a significant effect in increasing the load carrying capacity, ductility, and stiffness of the columns over the traditional method (EBR).

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