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Influence of Using CFRP on Damaged Columns Repaired with Two Different Materials

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Abstract

In this work, the behavior of reinforced concrete columns under biaxial bending is studied. This work aims at studying the repairing of columns by using carbon fiber reinforced polymer (CFRP). The experimental work includes investigation of six reinforced concrete columns (150*150*500mm) tested under several load conditions. Variables considered in the test program include; effect of eccentricity and effect of repairing material (Epoxy and Sika repair). Test results are discussed based on load – lateral deflection behavior and ultimate load. The CFRP reinforcement enhances the behavior of damaged columns. The using of Epoxy material was more significant effect than the Sika repair material

Keywords: Repaired, RC Columns, Biaxial Bending, CFRP, Experimental.

1. Introduction

Confinement of concrete is an efficient technique used to increase the load carrying capacity and/or ductility of a column. It is precisely the lateral pressure that induces in the concrete a tri-axial state of stresses and consequently an increment of compressive strength and ultimate axial strain. The disadvantages that come along with the advantages in FRP applications are namely: lower quality control, and environmental stability (long term performance of certain components of the FRP jacket might not be optimum under different effects like ultraviolet radiation, thermal cycles, and humidity). **Rocca et al**(2008). In repairing RC columns wherein the lateral steel ties are present, an additional material may be used to increase the strength and ductility of an RC column. These materials maybe steel jackets, or fiber reinforced polymer (FRP) sheets. The different materials vary differently in construction and methodology. Reinforced concrete columns that are confined by both steel reinforcement and additional confining materials are sometimes referred to as “hybrid RC columns”. This type of column has now become common in existing buildings and bridges.

Amrul Kaish, Abdul Wahed and Rabiul Alam (2010) investigated the behavior of ferrocement encased square reinforced concrete (RC) columns subjected to monotonically increasing small eccentric load. The results obtained, show that the benchmark specimens (column without ferrocement encasement) fail with non-ductile mode of failure when the load reaches to its peak value. However, in case of jacketed specimens load carrying capacity and ductility performance are obtained to be more than those obtained from benchmark specimen.RC columns are not experienced concentric load practically, and are always carried eccentric load. Therefore, RC columns confined with Ferrocement jacketing under the effect of eccentric loads yet need in-depth investigations.

Rathish Kumar at el, 2007 Parvin, A., and Wang, W.(2001) investigated the effect of strain gradient and FRP thickness on square concrete columns reinforced with FRP wraps. The chosen eccentricity values are small enough not to produce any longitudinal tension in the wrap. Nine square concrete columns were tested under concentric load and two different levels of eccentricity. Experimental results were validated by nonlinear finite element analysis elsewhere.

[F.Rafea Hassan 2012] tested twenty eight R.C. columns under several loading statues. The investigation included tests the effect of longitudinal reinforcement and the eccentricity on square R.C. columns.

2. EXPERIMENTAL PROGRAM

2.1. Specimen Characteristics

Tests have been performed on six RC columns, 700 mm total length that was constructed for this study. All columns had a cross section of about (150x150 mm)as shown in Fig. 1

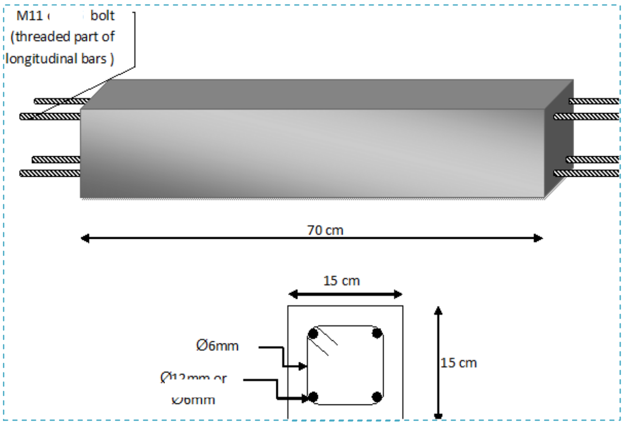


Fig.1 Column Specimen with Dimensions

In order to apply the moments at the end of column without causing local failure at column ends, two steel caps are used for this goal. The details of these steel caps will be shown later.

2.2. SPECIMEN NAMING SYSTEM

2.2.1. General. The test specimens have been given descriptive names. The specimen names, as shown in the second column of Table 1, are composed of groups of numbers and letters separated by hyphens. Each of these descriptive groups gives information about some aspect of the column in this order:

*2.2.2. Column Statue***.** C denotes reference (unjacketed), S denotes repaired with sika repair and E denotes repaired with epoxy.

*2.2.3. Eccentricities***.** ex-ey denote biaxial moments.

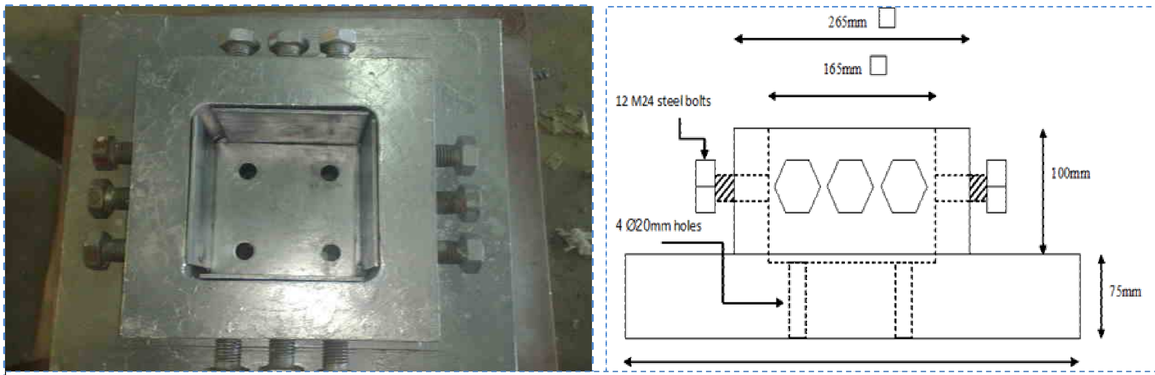
Table 1 Columns Codes

Column No.	Column Name
1	C 45-45
2	S 45-45
3	E 45-45
4	C 60-30
5	S 60-30
6	E 60-30

2.3. LOADING CAPS.

The loading cap has four Ø20mm holes in the internally lower face that allows the thread part of the longitudinal reinforcement passing through them to give more development length in case of eccentric loading.

Each side of loading cap includes three M24 female threads with bolts that fasten the loading cap with the column through 5*100*148mm imbedded steel plates. The steel plates are intended to prevent the column from damage when the M24 bolts are tightened on the column. In addition to these steel plates, other imbedded steel plates (5x150x150) are added on the top and bottom of columns with four holes (Ø15mm). The advantage of using this steel plate is to protect the column from damage during preparing to test. The final shape, the dimensions of loading cap and the steel plates are shown in Fig 2.



a- Top View b- Side View

Fig. 2 Loading Cap

2.4. SUPPORT SYSTEM

The main difficulty during testing columns under eccentric loading especially with high value of eccentricity or at stage of high curvature is the stability of the column (column may be moved to the opposite side of eccentricity). In order to stabilize the column during testing, a support system is added to the testing machine. It consists of four opposite bolts at the top and the base of column in touch with the sides of loading caps with steel balls at their ends shown in Fig 3. These steel balls prevent the support system from contributing in loading capacity of column and constraining the horizontal movement but it allows the longitudinal motion.

Others advantages of the supporting system are moving the column easily inside testing machine until the column reached the intended eccentricity and keeping the column in the constant horizontal position when the column is moving vertically to apply fixation load before test.

2.5 .LOADING TECHNIQUE

In case of eccentric loading, a new loading system was developed. This loading system consists of three parts steel shaft with half sphere hole at its end, Ø45 steel ball and (10x90x90mm) square steel plate with sector sphere hole at its middle as shown in Fig 4.

The steel shaft can be moving vertically in fixed steel ring, see Fig. 5. This ring is used for the purposes located the centers of upper and lower bases of the testing machine and prevent steel shaft from horizontal sliding during loading. This loading system ensures that the load still had a constant position during loading when the loading caps rotated on the steel shaft .The center of steel plate was located and the column was moved horizontally using supporting system until it had the intended eccentricity that the column should be tested, see Fig. 6.

Fig. 3 Loading System

Fig. 4 Supporting System

Fig. 5 Steel Shaft Inside Steel Ring

Fig. 6 Loading System During Loading

2.6. DIMENSIONS OF SPECIMENS

Each specimen had a middle test region 500 mm long and the remaining parts (each part 100mm long) are inside the steel caps as shown in Fig 7. This configuration forced general failure to occur in the test region and prevented premature failure at the ends. The imbedded ends also served to stabilize the column during testing and to simulate the general column-foundation or column-slab/beam interface. The test region of 500 mm was about 3.33 times greater than the dimension of the cross section to allow for a uniform strain and stress distribution in this region.

2.7. REINFORCEMENT ARRANGEMENT

Columns were reinforced with four longitudinal rebars with threaded ends (M11), one located at each corner of the cross section. Each longitudinal bar had washer and nut at its ends imbedded in the column during casting fresh concrete. The nut and washer transmit part of the compression load directly to the longitudinal rebars. In the test region of the specimens, 15 mm of clear cover was provided for the transverse reinforcement in the columns. Transverse reinforcement consisted of 5.74mm deformed dowel. Transverse reinforcement was placed at 72mm to provide the necessary confinement according to ACI 318M-11 requirements. The ties were fabricated with 50- mm extensions on 135-degree hooks. Fig 8 shows reinforcement details.

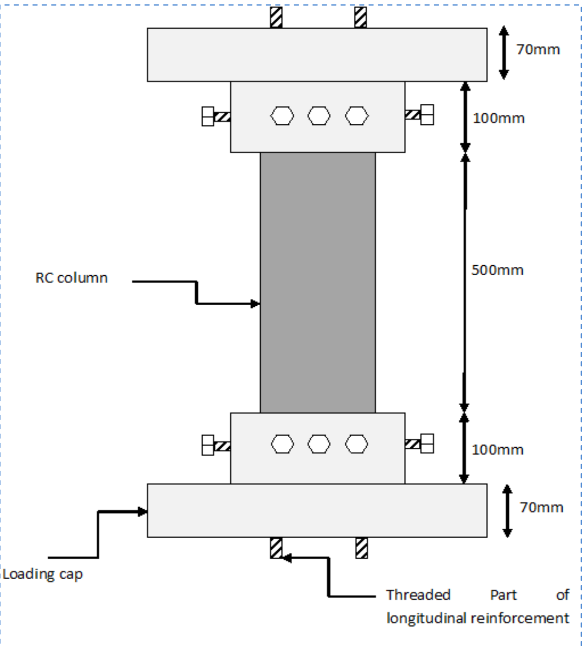


Fig 7. The Specimen Details and Dimensions

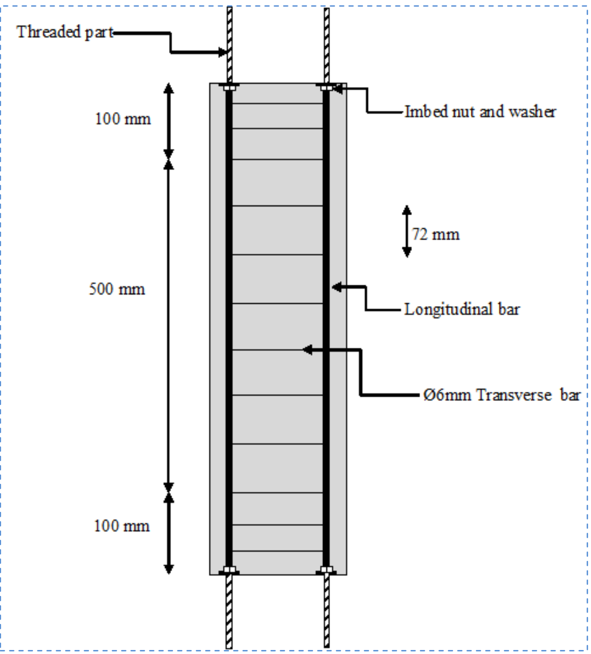


Fig. 8.Reinforcement Details

Corner rounding is a well-accepted procedure that is commonly used when strengthening or repairing rectangular RC columns with FRP composites. The importance of the effect of the sharpness of the corners comes into play when one considers the tradeoff between the expense of grinding larger, smoother corners and the increase in jacket performance that comes from this activity. The undamaged corners of the square columns are rounded with the corner radius 10 mm.

The grinding machine was used for this task. To insure that the all column edges had approximately the same radius, one quarter of steel washer with internal diameter 20 mm are moving along the column's corner during the grinding.

2.9. REPAIRING

In this work the column was damaged at one corner (at maximum compression stress) by removing the concrete from this corner as shown in Fig 9a. Two materials were used to fill this corner. First material was by using SikaRepair-640 as shown in Fig 9b.The other one was Sikadur-330.as shown in Fig. 9c.

The steps of adding CFRP are followed:

1- The specimens were cleaned by washing with pressurized water and allowed to dry prior to composite application.
2- Just before composite application, the columns were wire brushed and vacuumed as well.
3- Apply the mixed resin Sikadur -330 for the two types of columns prepared substrate using a trowel in a quantity of approximately (0.7 to 1.2 kg / m^2)
4- The SikaWrap Hex-230C fabric was cut by scissors to portions at (500*700mm)
5- Placed the SikaWrap Hex -230C fabric onto the resin with a towel until the resin is squeezed out between the roving.
6- In addition to jacket, three strips were added to the column (40*600mm) placed two at edges of column and one at the middle to prevent deboned.
7- The CFRP sheets were overlapped 110 mm.

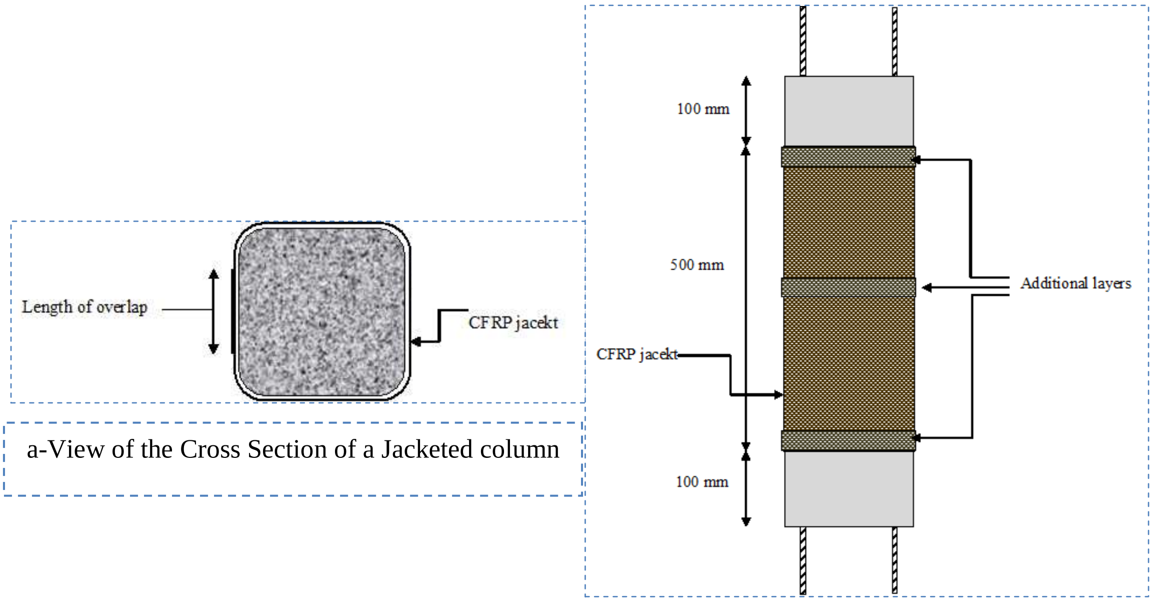
As a covering layer an additional resin of approximately (0.5kg/m^2) broadcast with the trowel can be added, which will serve as a bonding coat for following cementitiuos coating. Details are shown in Fig 10.

a-Damaged Column

b- Column with Sika Repair-640

c- Column with Sikadur®-330

Fig 9. Repaired of Columns



a-View of the Cross Section of a Jacketed column

b-Elevation View of a Jacketed Column

Fig 10. CFRP Details

2.10. PROPERTIES OF CONSTRUCTION MATERIALS

2.10.1. Steel Reinforcement. Two sizes of steel reinforcing bars were used in the tested columns, deformed bars of size Ø12mm were used as longitudinal reinforcement, and deformed bars of size Ø6mm were used as transverse ties. The yield stress and ultimate strength are summarized in Table.2.

Table.2. Specification and Test Results of Steel Reinforcing Bars Values

Nominal Diameter (mm)	Measured Diameter (mm)	Yield Stress (MPa)	Ultimate Strength (MPa)	Modulus of Elasticity (GPa)
6	5.74	566	587	195.9
12	11.88	652	725	208.3

2.10.2. COMPRESSIVE STRENGTH (f'_c)

For each batch, the strength of concrete (f /c) was determined by testing three standard cylinders (100mm x 200mm) at 28days of age. The properties of hardened concrete are summarized in Table.3.

2.10.3. CFRP PROPERTIES

The mechanical properties of CFRP fibers are taken from manufacturing specifications and as shown in Table. 4. Mechanical properties of epoxy (Sikadur-330) are given in Table. 5.

Table.3. The Properties of Hardened Concrete

Test (MPa)	Experimental	Standard Specification	Note
(f'_c)	33.23 @28 day 34.38 @testing	----	----
Splitting Tensile Strength (f_{ct})	3.35	3.23	[illegible]
Modulus of Elasticity (E_c)	26580 @28 day 26961 @testing	27093 27558	$4700\sqrt{f'_c}$

Table.4. Mechanical Properties of CFRP Laminates. Sika report 2003

Sika Fiber	Tensile Strength, (MPa)	Tensile Modulus, (GPa)	Elongation at Failure, (%)	Major Poisson's Ratio
Sika Wrap - 230C	4300	234	1.8	0.22

Table.5. Mechanical properties of sikadur-330

Test	Result
Tensile Strength,(MPa)	30
Tensile Modulus,(GPa)	3.8
Bond Strength(MPa)	≥4

Table.6. Mechanical properties of Sika®Repair®-640.

Test	Result
Compressive Strength,(MPa)	40-60
Compressive Strength,(MPa),	6
Bond Strength (MPa)	1.5

2.11. TEST MEASUREMENTS AND INSTRUMENTATION

For the biaxially loaded columns, lateral deflection measurements were taken with two perpendicular directions at the column mid-height and 220mm above and below mid-height using six dial gages as shown in Fig.11.

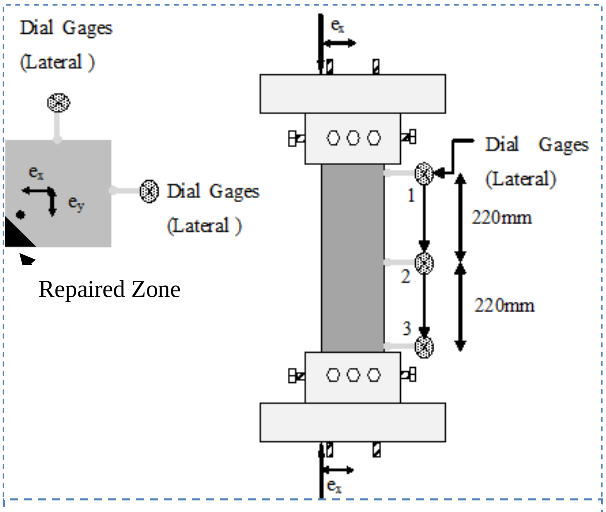


Fig.11. Instrumentation of Biaxial Loaded Columns

2.12. TESTING PROCEDURE

The hydraulic testing machine shown in Fig.12. The load was applied gradually. At each load increment, readings were acquired manually.

Testing was performed as follows:

1. Applying the column inside the lower loading cap. Then the upper loading cap was placed on the column.
2. Moving the column horizontally using the supporting system until reaching the intended eccentricity.
3. The longitudinal bars that may undergo tension were tightened to the loading caps.
4. The load was applied slowly in increments of (10kN).

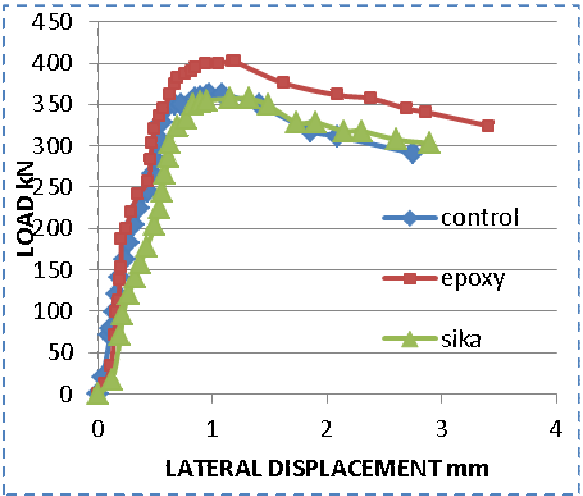
Fig.12. Test Machine and Instrumentation

3. TESTING REAULTS

General observations concerning the failure of the columns, the effects of the various test variables and the behavior of the CFRP jacket are discussed.

3.1. Columns under Equal Moments (Mx = My)

Three columns were tested under 45 – 45mm value eccentricities, C45-45, S45-45 and E45-45. The results of these tests are shown in the Fig.13 and 14. These figures showed that the column repaired with epoxy has ultimate load more than the others while the column repaired with sika repair 640 approximately the same behavior of control column.



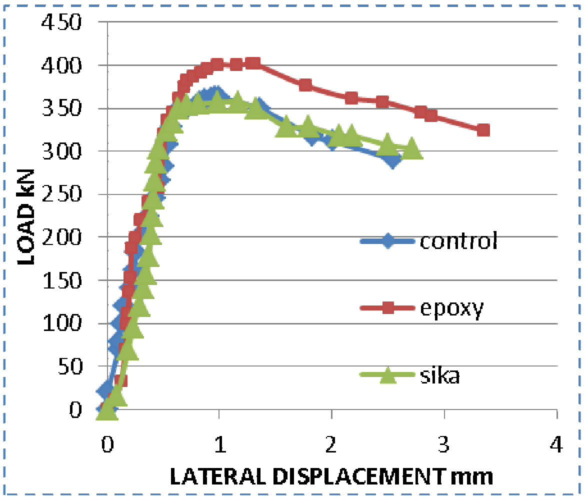
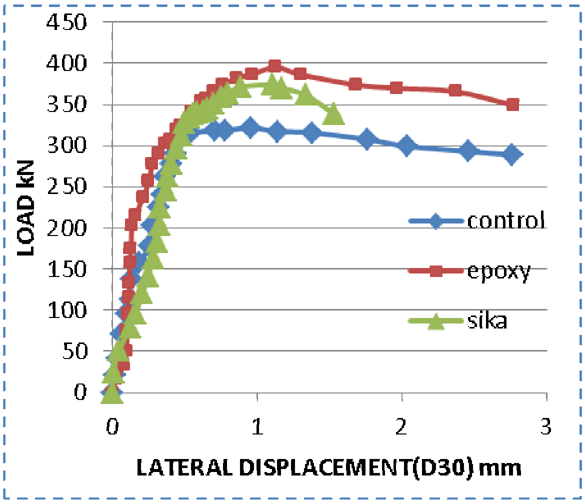


Fig.13. Load-Lateral Displacement at Mid height for Tested columns. C45-45,S45-45and E45-45.(first direction)

Fig.14. Load-Lateral Displacement at Mid height for Tested columns. C45-45,S45-45and E45-45.(second direction)

3.2. Columns under Unequal Moments (Mx = 2My)

Three columns were tested under 60 – 30mm value eccentricities, C60-30, S60-30 and E60-30. The results of these tests are shown in the Fig.15 and 16. In these figures it can be noted that the ultimate load of repaired columns (with epoxy and sika repair 640) is more than the control column and approximately are equal.



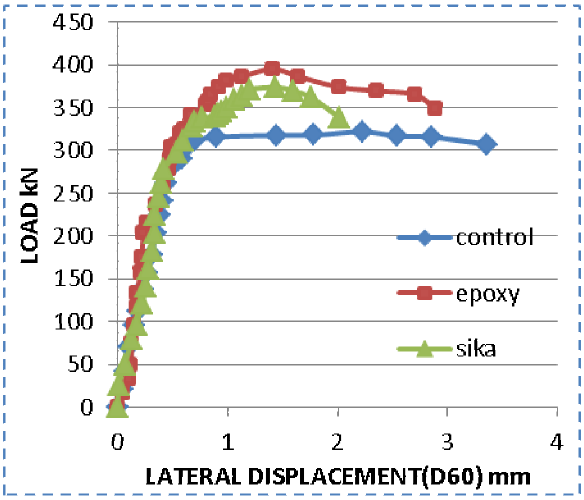


Fig.15. Load- Lateral Displacement at Mid Height for Tested columns. C60-30,S60-30and E60-30.(with(ex =30)direction)

Fig.16. Load-Lateral Displacement at Mid Height for Tested columns. C60-30,S60-30and E60-30.(with(ex =60)direction)

4. CONCLUSIONS

Based on the results obtained from the experimental work, the following conclusions are presented.

1. The results showed that both methods of repairing enhanced the behavior of repaired RC columns.
2. The percentages of change in ultimate load for (E45-45and S45-45) were (10.8% and -1.5 %,), respectively.
3. The percentages of increase in ultimate load for (E60-30and S60-30) were (22.7% and -15.1 %),

respectively. The distribution of compression stress for 60-30 eccentric columns was large more than 45-45 eccentric columns

4. For both epoxy repair and sika repair 640, it was found that at the same total eccentricity (e) where (e = ex + ey), the maximum benefit from CFRP repairing occur when (ex = 2ey).
5. Repairing with epoxy enhanced the behavior of damaged columns more than repaired with sika repair.

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