Behavior of Eccentrically Loaded Slender Concrete Columns Reinforced with GFRP Bars

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Abstract. This paper presents an experimental investigation on the behaviour of concrete columns reinforced with glass fibre reinforced polymers GFRP bars under concentric and eccentric loads. Six RC column specimens have been considered in the experimental tests with a cross section dimension of (135 mm × 135mm) at the middle portion of columns and (250 mm × 135 mm) (width xdepth) at the corbel with a total length of 1150 mm with the length between corbels (middle part) was 710 mm. Three specimens have been represented the reference specimens which are reinforced with steel bars and the other three were reinforced with GFRP bars. Tow variables have been considered in the experimental tests: the type of reinforcement (GFRP and steel) and the eccentricity ratio (e/h). All columns have been subjected to different values of eccentricity ratio (e/h): 0, 0.5, and 1. It has been concluded that the ultimate load capacity of columns reinforced with GFRP bars decreases by about 27.13% and 94.67% compared to columns reinforced with steel bars under eccentricity ratios (e/h=0) and (e/h =0.5), respectively. Whereas, ultimate load increases by about (4.79%) for the columns reinforced with GFRP bars compared to columns reinforced with steel bars at eccentricity ratios (e/h=1) . The result have also shown that all specimens that have been subjected to eccentricity ratio (e/h > 0) failed by compression failure.

Keyword: RC columns, GFRP bars, axial load, eccentricity, failure mode.

1. Introduction

Due to its remarkable corrosion resistance, magnetic resistance, high tensile strength and low dead weight compared to the conventional steel bars, the using of FRP bars has widely been increased in reinforcing the structural concrete members in the last two decades. Up to dates, most of the structural applications of the FRP bars are in the flexural members were the tensile stresses dominate the structural behaviour and failure. However, for compression members such as columns, using FRP as a main reinforcement is not preferable due to the very low compressive strength as recommended by ACI -440-1R [1]. Nevertheless, for eccentrically loaded columns whereas a considerable tensile stresses might be developed, using FRP bars at the tension zone could be advantageous. Previous research studies has proven that the use of GFRP bars in columns under eccentric loads increases the ultimate failure load compared to steel bars [2–8]. The use of Glass fiber reinforced polymer (GFRP)
bars in concrete columns is limited to the research field, while their use for concrete beam is more common [2,5–7]. In addition, FRP composites have density ¼ to ⅓ of steel density, electrical and magnetic non conductivity, need small cover, and have lower elastic modulus compared with steel bars [1]. Issa et al. [2] have presented experimental results on six columns with cross section dimensions of (150 × 150) mm and total length of 1200 mm reinforced by GFRP and steel with diameter of 12mm and subjected to eccentrically axial loads. Two columns reinforced with 4Ø12 mm steel bars had cylinder compressive strength of 24.73 Mpa with tie space (80 or 130) mm with the eccentricity 50mm. Four of the RC column specimens are reinforced with GFRP bars. Two of GFRP RC had cylinder compressive strength of 24.73 Mpa with tie space (80 or 130) mm with the eccentricity (50 or 25) mm and the other two had cylinder compressive strength of 38.35 Mpa with tie space (80 or 130) mm with the eccentricity 50 mm. To reduce the stress at ends of columns and to simplification the application of eccentric load, the two heads at ends of each column added. It was concluded that GFRP bars strains larger than steel bars strains. It has also been concluded that tie spacing had no memorable effect on ductility and maximum lateral deflection of GFRP RC columns. However, there is a direct relationship between tie spacing and column deformation. When tie spacing is larger, the GFRP and steel strains are larger at high load. Results have also shown with initial eccentricity of 50 mm, the ratio between the average maximum stress and concrete compressive strength of all tested columns was about 60%. Tobbi et al. [9] investigated the mechanical behavior of FRP reinforced concrete columns subjected to concentrically loads. Several variables were considered including: the configuration of transverse reinforcement type of reinforcement (GFRP or steel bars), tie spacing, compressive strength, longitudinal reinforcement ratio, and confining volumetric stiffness. Twenty RC column specimens with square cross section (350 × 350) mm and 1400mm length were used and placed under concentric compressive load. Nineteen of the columns are reinforced with FRP and steel bars according to different details while one column was not reinforced (plain concrete). It has been concluded that the stress-strain behavior for unreinforced columns was similar until the peak point. After which, it was completely different. Results have also shown that FRP reinforcement is better for reducing ultimate axial strain than steel reinforcement. Alwash et al. [3] presented an experimental study on the behavior of CFRP RC short columns under eccentric load. Fourteen specimens with cross section dimensions of (140 × 140) mm and total length of 820 mm were investigated in the experimental tested. The length at the middle part between corbels is 400 mm. The maximum of these specimens were used as a control specimens: one without reinforcement and the other two with steel reinforcement whereas, eleven specimens were reinforced by CFRP bars. The effect of compressive strength, eccentricity ratio, and longitudinal reinforcement were all considered in the study. It has been concluded that columns reinforced with CFRP bars give an increase in ultimate load by 38.21 % under load eccentricity ratio (e/h=0.857), while give decrease in ultimate load by 3.78 % under axial load compare with the column reinforced with steel bars. This indicates that the use of CFRP reinforcement has an important effective on ultimate load capacity of column with high eccentricity. Hadhood et al. [4] presented experimental study on the behavior of circular concrete columns reinforced with GFRP bars and tied by GFRP hoops subjected to eccentricity loads. The sand – coated GFRP bars Ø16mm were used as longitudinal reinforcement but discrete hoops Ø10mm were used as transverse reinforcement. The effect of compressive strength, eccentricity ratio, and overlap lengths of discrete hoops were all considered in the study. Eight column specimens were tested. Four of them were tested under axial load, while the other four were tested under different eccentricities: 25 mm, 50 mm, 100 mm, and 200 mm. The GFRP hoops spaced at 80 mm, but it reduced to 50 mm outside the free region (250 mm of length) at both ends. It has been concluded that the failure of columns with concentric load was compression due to brittle concrete crushing combined by rupture of GFRP hoop and crushing of the vertical GFRP bars in an unexpected and explosive method. Results have also indicated that compression controlled failure due to concrete crushing was the failure mode of the eccentrically loaded RC columns at eccentricity of 25 and 50 mm , while flexural – tension failure is the failure mode for RC specimens tested at eccentricity of 100 and 200 mm. The flexural – tension failure was resulted from retrogression of concrete compressive block under constant axial loads and rupture of the GFRP bars. Othman et al. [7] presented an experimental study on eighteen RC columns with cross section dimensions of (150 × 150) mm and total length of 1500 mm subjected to
Eccentric axial loads. Fifteen of these columns are reinforced with CFRP bars and ties whereas three columns were reinforced with steel bars and ties as reference specimens. Specimens were divided into six groups, each group consists of three columns with similar reinforcement details, but tested under different eccentricity conditions of (e= 0, 75mm, and 150 mm). It has been concluded that the failure mode and the behavior of CFRP RC columns are affected by the percentage of eccentricity. For the concentric loaded, decreasing tie spacing has unnoticeable effects on the axial capacity columns. While, for columns subjected to eccentric load, decreasing tie spacing reduces the axial capacity by about 12.4% for a column with eccentricity 150mm (e/h =0.1). In addition, all CFRP RC columns under eccentric load failed by concrete crushing at compression side and the maximum tensile strain in the longitudinal bars did not exceed 34% of the ultimate tensile strain of the bar. Korramian and Sadeghian [8] presented experimental and analytical study on slender concrete columns reinforced with GFRP bars. Ten large scale concrete columns with rectangular cross section (203 × 305) mm and four lengths of 1036, 1341, 2438, and 3657 mm, different reinforcement ratios (4.7%, 2.82%, and 2.04%), and different slenderness ratios (17, 22, 40, and 60) subjected to eccentric loading up to failure. Nine of the specimens were reinforced with 19 mm GFRP bars and one of them was reinforced with 11.3 mm steel bars. It has been concluded that even after compressive crushing of concrete, the GFRP RC columns were able to sustain load. Furthermore, the load capacity decreased when the slenderness ratio and load eccentricity increased but the load capacity increased slightly when the reinforcement ratios increased. A study conducted by Al-Thairy and Al-Hasnawi [10] investigated the behavior of beams reinforced with GFRP bars under elevated temperature. Four GFRP RC beams with cross-section dimension of (250mm× 160 mm) and the total length was 1250 mm. One of the beam specimens tested at ambient temperature, while the other three exposed to different value of temperature (350, 500, and 600 ℃). It has been concluded that all beams failed by shear failure and the load failure decrease with increase the temperature compared with beam at ambient temperature. The results also shown that GFRP RC beams exhibit high deflection when exposing to high temperature and the ductility index of GFRP bars decreased due to increase in temperature. Al-Talqani and Al-Thairy [11] presented an experimental program to investigate the behaviour of normal weigh concrete encased steel columns under eccentric load and various value of temperature. Four columns with cross-section (150mm×150mm) at the middle part of column and (240mm×150mm) at the corbel ends with total length of 1250mm were tested. Encased steel section was (60×4×4×70 mm) (flange width× flange thickness× web thickness ×total height). It has been concluded that all columns specimens failed by flexural buckling with concrete crushing at compression zone. The results also show that the failure load decreased with increasing in temperature. It can be seen from the aforementioned research studies that using GFRP bars in concrete columns has a beneficial effect on the column strength. This is particularly at high eccentricity ratios where a high tensile stresses are developed at the column section which can be resisted by the GFRP bars more effectively than steel bars due to the higher rapture stress of the GFRP bars compare to steel bars. This study aimed at investigating the behaviour and failure of slender concrete column under eccentric loads were the P-δ effect has more influence compared to short columns.

2. Experimental work
An experimental program was prepared to investigate the behavior of concrete columns reinforced with longitudinal GFRP and steel bars and subjected to concentric and eccentric axial loads. The following sections present the geometrical, material properties and reinforcement details of the RC column specimens.

2.1 Column specimens
Six specimens with square cross section (135 mm × 135 mm) at the middle and (250mm × 135mm) at the corbel with a total length of 1150 mm. The length between corbels (middle part) was 710 mm. Specimens were reinforced according to ACI 318R-19 and ACI 440.1R-15 [1,12]. The columns specified as a slender columns because the slenderness ratio (kl/r) was 29 that is more than 22 for columns reinforced with steel bars based on ACI 318-19 and more than 17 for columns reinforced
with GFRP bars based on Mirmiran et al [13]. Each column has been reinforced longitudinally with 6ø10 steel or GFRP according to the type of reinforcement and transversely with 8ø8 steel bars at 126 mm c/c. The details of the reinforcement and the mould are shown in Figure (1) and table (1). The first letter of the symbol of the specimens refers to the type of the reinforcement. The number after the first letter refers to the eccentricity ratio (e/h).

**Table 1.** Reinforcement details and eccentricity ratios of the tested columns.

| Specimens symbol | Longitudinal reinforcement | Eccentricity values (mm) | Eccentricity ratios (e/h) |
|------------------|----------------------------|--------------------------|--------------------------|
| S0               | 6ø10                       | 0                        | 0                        |
| S0.5             | 6ø10                       | 67.5                     | 0.5                      |
| S1               | 6ø10                       | 135                      | 1                        |
| G0               | 6ø10                       | 0                        | 0                        |
| G0.5             | 6ø10                       | 67.5                     | 0.5                      |
| G1               | 6ø10                       | 135                      | 1                        |
2.2 Concrete mix and reinforcement bars:
Three trials mixes were prepared to select the target compressive strength. For each trial mix, three concrete cubes with dimensions of (150mm ×150mm ×150mm) were cast, cured and tested and the average value of compressive strength of the cubes as shown in Table (2). According to the compressive strength tests, the mix No.1 was considered to prepare the columns specimens with the proportion ratio of 1: 1.5: 1.6: (cement: sand: aggregate). Table (2) shows the details of trail mix with the corresponding compressive strengths.

| No. | Cement | Gravel | Sand | W/C | Silica fume* | Superplasticizer** | Average compressive strength(Mpa) |
|-----|--------|--------|------|-----|-------------|-------------------|----------------------------------|
| 1   | 1      | 1.5    | 1.6  | 0.4 | 0.1         | 0.01              | 40                               |
| 2   | 1      | 1.5    | 1.6  | 0.4 | 0.1         | 0.0125            | 38.46                            |
| 3   | 1      | 1.5    | 1.6  | 0.4 | 0.1         | 0.015             | 28.97                            |

* this proportion is taken as a replacement of cement weight.
** this proportion is taken as a percentage of cementitious content (cement and silica fume).

2.2.1 Portland cement
Ordinary Portland cement named Al-DOUH that has been produced by ALDOUH Iraqi Company for cement industries was used. The physical and chemical tests were conducted in the Laboratories of College of Engineering at AI- Qadisiya University. Tests results were conformed to the requirements of the limits of the Specification of Iraq (IQS NO. 5, 1984).

2.2.2 Fine and coarse aggregate
Natural fine aggregate and coarse aggregate were used in this study. The physical and chemical tests of both types of the aggregate along with the tests of the sieve analysis for coarse aggregate were conducted in the constructional engineering Al-Sebtayn laboratory in Diwaniyah governorate. The test results were conformed to the requirements of the limits of the Specification of Iraq (IQS NO. 45, 1984)
2.2.3 Super plasticizers
A superplasticizer is water reducing admixture under trade name Sikament – 221N added to the concrete mix to give high workability and improve compressive strength. The superplasticizer is in compliance with ASTM C-494/ C494M, type G.

2.2.4 Silica fume
Silica Fume is a very fine pozzolanic under trade name Mega Add MS (D) that meets the requirements of ASTM C-1240. Silica fume was used to improve concrete strength.

2.2.5 GFRP bars
The Glass fiber reinforced polymer GFRP bars with diameter of 10mm were used for longitudinal reinforcement. It was manufactured by Nanjing Fenghui Composite Material Co.,Ltd in China. Properties of GFRP according to manufactured data are shown in Table (3).

| Properties                     | Value          |
|--------------------------------|----------------|
| Density (G/cm³)                | 1.9-2.2        |
| Tensile strength (Mpa)         | 827            |
| Elastic modulus (Mpa)          | 46000          |

2.2.6 Steel bars
Three types of deformed reinforcing steel bars were used in this study: steel bar with a diameter of Ø16 mm was used as corbel reinforcement; steel bar with a diameter of Ø10 mm was used as horizontal reinforcement for the corbels and as a longitudinal reinforcement for steel RC columns, and steel bar with a diameter of Ø 8 mm was used as transverse ties for all columns. The uniaxial tensile test results of the reinforcement steel bars are summarized in Table (4).

| Diameter (mm) | Yield stress Fy (Mpa) | Ultimate strength Fu (Mpa) | Elongation (%) |
|---------------|-----------------------|----------------------------|----------------|
| 8             | 521                   | 662                        | 11.7           |
| 10            | 650                   | 731                        | 9              |
| 16            | 557                   | 679                        | 9              |

2.3 Casting, curing and testing of the column specimens
Six columns specimens, six cubes, and six cylinders were cast and cured by immersing in water tank. After 28 days of curing, the specimens were removed from water and left to dry. Compressive strength and splitting tensile tests were made on the cubes and cylinders to determine the compressive and tensile strengths, respectively. Details of the casting and curing of the columns specimens were shown in Figure (2).

In order to investigate the behaviour of the RC columns under concentric and eccentric loads, three values of eccentricity ratios were considered: e/h=0, e/h=0.5, and e/h=1. In order to avoid the stress concentration at the top and the bottom ends of the column and to prevent concrete crushing under eccentric loads, steel bearing plates were placed which represents as a pin and hinge supports. To achieve the required eccentricity value, the dimensions and location of the bearing plate were selected such that the distance from the centre lines of the plate and the column section is equal to the intended eccentricity. Figure (3) shows the casting and curing of all specimens.
Figure 2. a- Casting and b- curing of tested specimens.

Figure 3. The dimensions and location of the bearing plate to achieve eccentricity ratio
(a) e/h=0    (b) e/h=0.5    (c) e/h = 1.

Columns specimens were tested in a vertical position under compressive concentric and eccentric loading at the bottom face of columns up to failure. The applied load was measured by a hydraulic pressure device with capacity of 1500kN at University of Al- Qadisiya /College of Engineering in Iraq. The test rig was made from I-section of steel with 30 mm thickness, 1m width, and 2.25m height and two steel plates at the top and the bottom with a thickness of 80 mm, (see Figure(4)). Through the test, many data were monitored and recorded such as: The load at first crack, the ultimate failure load, the lateral displacement at the tension side of column in mid-height, the axial displacement and crack width. Two electronic dial – gauges were used to measure the lateral and axial displacement of each
RC column specimen until failure and microscope (AEM40X) with efficiency of 0.05 mm was used to measure the crack width.

3. Results and discussion:

This section presents and discusses in details the results of the experimental tests conducted in this study in terms of the load-displacement curves at the two reinforcement types considered in the study and for the three eccentricity ratios used. The effect of the eccentricity ratio and reinforcement type on the crack pattern and failure modes will also be discussed and evaluated in this section.

3.1. Effect of reinforcement type on failure modes and load-displacement relationship

3.1.1. At eccentricity ratio (e/h=0)

The crack patterns and failure modes of the steel and GFRP RC column subjected to concentric loads (e/h = 0) are shown in Figure 5.a and 5.d, respectively. The initial cracks appeared at loads values of 278kN and 321kN for steel and GFRP reinforced concrete column respectively. These load value are relatively large compared to that of columns under eccentric load. When the axial load increased, more cracks were started to develop at the corbel under bearing plate and propagated toward the direction of the applied load longitudinally. Eventually, the failure of S0 column occurred gradually by crushing of concrete under the upper bearing plate at the tension side of the corbel (see Figure 5.a). While, for G0 column specimen, failure occurred suddenly due to crushing in concrete at the tension and compression zones combined by rupture of GFRP bars in the tension zone (see Figure 5.d). This sudden failure is due to low ductility of the GFRP bars compared with steel bars.

On the other hand, (Figures 6.a and 6.b) illustrate load-the lateral and load - axial displacement curves of the RC columns specimens reinforced by GFRP and steel bars. It can be seen from these figures that the ultimate load capacity of the GFRP RC columns decreased by (27.13%) compared with steel RC columns with increasing the lateral and axial displacement by (6.25%) and (10.19%) respectively. On the other hand, it can be seen from Table (5) that the ductility of the RC column decreased in GFRP RC columns compared to steel RC column by 51%. This is due to the low ductility properties of the GFRP bars compared to steel bars. Whereas the ductility (µ) is defined as the ratio of ultimate deformation to yield deformation for RC steel columns. For FRP RC structures, it called the
It can be noticed from Figure (6) that the load versus mid-height lateral or axial displacement behavior have three stages: The first is being an first straight part of the load-displacement curve representing the elastic stage, the second is a nonlinear part with obvious change in slope with increasing lateral displacements (elastic-plastic stage), and the third is also a nonlinear part but has a slight increase in load will cause larger lateral displacements (represent the plastic stage).

3.1.2. At eccentric ratio \((e/h=0.5)\)

The crack patterns and failure modes of the steel and GFRP RC column subjected to eccentric loads \((e/h = 0.5)\) are clarified in Figure 5.b and 5.e, respectively. The initial cracks appeared at loads values of 114 and 50 for steel and GFRP reinforced concrete column respectively. When the axial load increased, cracks were started to develop at the tension face of the middle height of column specimens (the part between corbels) and propagated toward the compression zone. Eventually, the failure of S0.5 and G0.5 columns occurred gradually by crushing of concrete at compression zone (see Figure 5.b and 5.e). On the other hand, (Figures 6.c and 6.d) illustrate load-the lateral and load - axial displacement curves of the RC columns specimens reinforced with GFRP or steel bars. It can be seen from these figures that the ultimate load capacity and the lateral and axial displacement of the GFRP RC columns decreased by 94.67%, 321%, and 438%, respectively compared with steel RC columns. On the other hand, it can be visible from Table (5) that the ductility of the RC column decreased in GFRP RC columns compared to steel RC column by 39%.

3.1.3. At eccentricity ratio \((e/h=1)\)

The crack patterns and failure modes of the steel and GFRP RC column subjected to eccentric loads \((e/h = 1)\) are shown in Figure 5.c and 5.f, respectively. At high eccentricity, number of crack increases with decreasing crack width compared with other eccentricities and the initial cracks appeared at loads values of 53 and 50 for steel and GFRP RC column respectively. When the axial load increased, cracks were started to develop at the tension face of the middle height of column specimens (the part between corbels) and propagated toward the compression zone. Eventually, the failure of S1 and G1 columns occurred gradually by crushing of concrete at compression zone (see Figure 5.c and 5.f). On the other hand, (Figures 6.e and 6.f) illustrate load-the lateral and load - axial displacement curves of the RC columns specimens reinforced by the types of materials.

It can be seen from these figures that the ultimate load capacity and the lateral and axial displacement of the GFRP RC columns increased by 4.79%, 36.79%, and 36.53%, respectively compared with steel RC columns. On the other hand, it can be seen from Table (5) that the ductility of the RC column decreased in GFRP RC columns compared to steel RC column by 11%. Table (5) illustrates the summery of the test results for all specimens.

| Specimens | P ult. (kN) | P cracking (kN) | Crack width (mm) | Max. lateral Disp. (mm) | Ductility index(µ) | Failure mode |
|-----------|-------------|----------------|-----------------|------------------------|-------------------|--------------|
| S0        | 670         | 278            | 0.5             | 0.16                   | 3.4               | Spalling of concrete in corbel under the top plate in tension side |
| S0.5      | 292         | 114            | 0.3             | 8.84                   | 8.84              | Compression failure |
| S1        | 139         | 53             | 0.1             | 7.2                    | 4.6               | Compression failure |
| G0        | 527         | 321            | 0.8             | 0.16                   | 2.25              | Combined failure attached by rupture of GFRP bars |
| G0.5      | 150         | 50             | 0.5             | 2.1                    | 6.36              | Compression failure |
| G1        | 146         | 50             | 0.1             | 11.39                  | 4.14              | Compression failure |
Figure 5. Failure modes of the tested RC column specimens.

Figure 6. Load-displacement relationships of GFRP and steel RC columns under the same eccentricity ratio.
3.2. Effect of reinforcement type on the (load-moment) interaction diagrams

Figure (7) shows the load-moment interaction diagrams of the RC column reinforced by steel and GFRP bars. This Figure represents the values of moments or eccentricities at which failure of the RC columns corresponding to each axial load values occurred. It can be seen from the Figure that at the eccentricity ratio of e/h = 0.5 (i.e. at moment = 10.125 kN.m and 19.71 kN.m for GFRP and steel bars RC columns, respectively), the failure moment of steel bars RC columns, is higher than GFRP bars RC columns by about 48.6%. However, for eccentricity ratio of e/h = 1 (i.e. at moment = 19.71 kN.m and 18.765 kN.m for GFRP and steel bars RC columns, respectively), failure moment of steel bars RC columns is lower than that in GFRP bars RC columns by about 5%. This increasing in the moment by increasing the eccentricity ratio is due to increase of high tensile strength capacity for GFRP RC compared with columns reinforced with steel bars.

![Figure 7](image-url)

**Figure 7.** P-M interaction diagrams of the steel and GFRP RC columns

3.3. Load – Eccentricity relationship

Figure (8) shows the load-eccentricity relationship of the RC column reinforced by steel and GFRP bars. It can be seen from Figure that the load failure decreased with the increase in eccentricity ratio for both type of the reinforcement. When compared with steel and GFRP bars RC columns with e/h=0, the load failure for steel and GFRP bars RC columns decreased by 129% and 251% for e/h=0.5 and 382% and 260% for e/h=1, respectively.

![Figure 8](image-url)

**Figure 8.** Load - eccentricity relationship of the steel and GFRP RC columns.
4. Conclusion
In this paper, an experimental investigation on the response of GFRP RC column under eccentric loads was presented. Six RC column specimens subjected to different eccentricity ratio (e/h): 0, 0.5, and 1 were considered. Two variables were considered in the experimental tests including: the type of longitudinal reinforcement (steel and GFRP) and the eccentricity ratio (e/h). The following conclusion can be drawn from the present study:

1. For small eccentricity ratio (e/h=0 and 0.5), the ultimate load capacity of the GFRP RC columns decreased compared with steel RC columns accompanied by increasing the lateral and axial displacement for e/h=0 and decreasing the lateral and axial displacement for e/h=0.5. Further, the ductility of the RC column decreased in GFRP RC columns compared to steel RC column by 51% and 39%, respectively. However, for high eccentricity ratio (e/h=1), the ultimate load capacity and the lateral and axial displacement of the GFRP RC columns increased compared with steel RC columns. Furthermore, the ductility of the RC column decreased in GFRP RC columns compared to steel RC column by 11%.

2. When the eccentricity ratio increased, the number of crack increased with the decrease of crack width. For most tested RC column specimens, the cracks developed at tension zone at the third middle of columns and propagated toward the compression zone. While for other specimens, the cracks appear at corbels under the top and bottom bearing plates where the load applied and propagated longitudinally toward the applied load.

3. Failure mode of column reinforced with GFRP bars under axial load occurred suddenly due to crushing of concrete attached by rupture of GFRP bars in compression and tension zone. Also, for column reinforced with steel bars under axial load, failure occurred gradually due crushing of concrete under the top plate in corbel in direction of the axial load in tension side or failed gradually by compression failure. While, for the other columns, failure occurred gradually due to crushing of concrete at compression zone.

4. The failure moment of steel bars RC columns at e/h=0.5, is higher than GFRP bars RC columns by about 48.6%. However, for eccentricity ratio of e/h =1, failure moment of steel bars RC columns is lower than that in GFRP bars RC columns by about 5%.

5. The failure load decreased with the increasing the eccentricity ratio for the same type of the reinforcement. When compared with steel and GFRP bars RC columns with e/h=0, the load failure for steel and GFRP bars RC columns decreased by 129% and 251% for e/h=0.5 and 382% and 260% for e/h=1, respectively.

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