International Journal of Scientific & Engineering Research Volume 12, Issue 1, January-2021 630
ISSN 2229-5518

# Behavior of Columns Reinforced with BFRP Bars in case of Centric and Eccentric Conditions

Sayed Abd El-Baky [1], Sameh Yehia [2], Arafa M. A. Ibrahim [3] and Abdullah Moubarak [4]

[1] Professor, Strength & Properties of Materials, Housing & Building National Research Center, Egypt
[2] Associate Professor, Faculty of Engineering, Suez University, Egypt
dsyehia@hotmail.com / s.yehia@suezuni.edu.eg
[3] Assistant Professor, Faculty of Engineering, South Valley University, Egypt
[4] MSc. Student, Faculty of Engineering, South Valley University, Egypt

**Abstract**— This paper represents an experimental study to investigate the axial behavior of reinforced concrete (RC) columns which reinforced with steel or Basalt Fiber Reinforced Polymer (BFRP) bars. Three reinforced concrete columns with 2000 mm high and of square cross-section 200mm width were tested under compression loading test up to failure. The key parameters considered in this study were: reinforcement type, centric or non-centric load with small eccentricity of 5cm. The study gives a clear result for judge the capability of using BFRP in RC columns.

**Index Terms**—Basalt Bars, FRP, RC Columns, Loading Conditions, Axial Loading, Eccentric Sections

## 1 INTRODUCTION

Fiber Reinforced Polymers (FRP) as a kind of composite materials has become widespread in the strengthening of reinforced concrete structures as an alternative way of traditional strengthening methods. Usage of such polymers as an important application of composites for strengthening has rapidly increased in recent years.

**Ishag, A, et. al. (2013)**, investigated the behavior of Fiber-Reinforced Polymer (FRP) wrapped reinforced concrete circular columns and demonstrated it as an outstanding materialto strengthen existing structures. The FRP hybrid, however, was used as a confining material and integrated into the research, and it shows good results. **Su, ha Sang, et. al. (2017)**, It claimed that Hybrid FRP (fibre reinforced plastics) sheet reinforced circular columnwere tested under cyclic lateral load and costant axial load to assess the applicability of hybrid FRP sheets as reinforcing materials. Reinforcing the form of column, including glassfibre, carbon fibre and hybrid fibre sheet, are the main parameters. The non-reinforced control specimen was prepared for evaluating the effectiveness of reinforcing materials. The experimental results showed that, the yielding and maximum lateral loads of columns reinforced by fiber sheet are 1.1 times and 1.06 times greater than control specimen. Particularly, the behavior of column reinforced by Hybrid sheet was more ductile than columns reinforced with GFRP sheet specimen, showing that displacement ductility ratio and energy ductility ratio was approximately 174 % greater than the glass fiber sheet specimen. These results imply that, Hybrid sheet (combination between carbon fiber and glass fiber sheets), was highly effective to increase ductility of circular column.

**Sameh Yehia, (2018)** tested six circular columns with dimensions of 200mm diameter and having length of 1300mm. His first group, was three unreinforced concrete columns and the second one was three reinforced concrete columns with six bars having diameter of 12mm. Stirrups with 8mm diameter and spacing 150mm was used and low compressive strength concrete was used with 200kg/cm$^2$ strength after twenty-eight days. External glass fiber reinforced polymer (GFRP) sheet were used in the circumferential direction to confine circular columns by strips or jacket mode. The study was conducted to compare GFRP strengthened columns (strips or jacket) with control specimens (columns). Theoretical study was incorporated to verify the experimental results and investigate the effect of strength reduction factors in ACI design equations on experimental results. Test results revealed that, the two techniques significantly enhanced the capability of the low compressive strength columns to carrying axial load for both reinforced and unreinforced columns. The achieved conclusions confirmed that, the studied techniques capable of increasing the vertical load capacity of deficient columns with significant values.

**Gouda et. al (2009)**, discussed the most parameters may affect the behavior of the GFRP reinforced columns. This included replacing main longitudinal steel and stirrups by GFRP bars and sheet in two forms. Those forms were warped the longitudinal reinforcement of the column, and warped the square column from the outside. Also the reinforcement percentage was taken as a variable. Scott T. Smith, et. al. (2010), presented an investigation on the behavior of FRP confined concrete cylinders which were concentrically loaded. In his study, the effect of FRP number of layers and different overlap locations on the effectiveness of the FRP wrap was determined. Finally, the test results are found to correlate reasonably well with the **ACI 440.2R-08** predictions for FRP-confined concrete columns.

ISSN 2229-5518

## 2 Experimental Program

This experimental investigation of the tested columns included instrumentations, material properties, test procedure, loading mechanics and column specimen's details. The main parameters which taken in this study were reinforcement type (steel, or Basalt Fiber Reinforced Polymer (BFRP), centric or non-centric loading. The influence of these parameters were studied on the behavior of reinforced concrete columns under static loading. **Table (1)** shows the details of specimens.

**Table 1**: Details of tested columns

| Column Code | Fcu N/mm² | AC (mm²) | $A_s$ | $A_f$ BFRP | Remarks |
|---|---|---|---|---|---|
| **C1** | 35 | 40000 | 4Φ12 | - | Control |
| **C2** | 35 | 40000 | - | 4Φ12 | Centric |
| **C3** | 35 | 40000 | - | 4Φ12 | Eccentric |

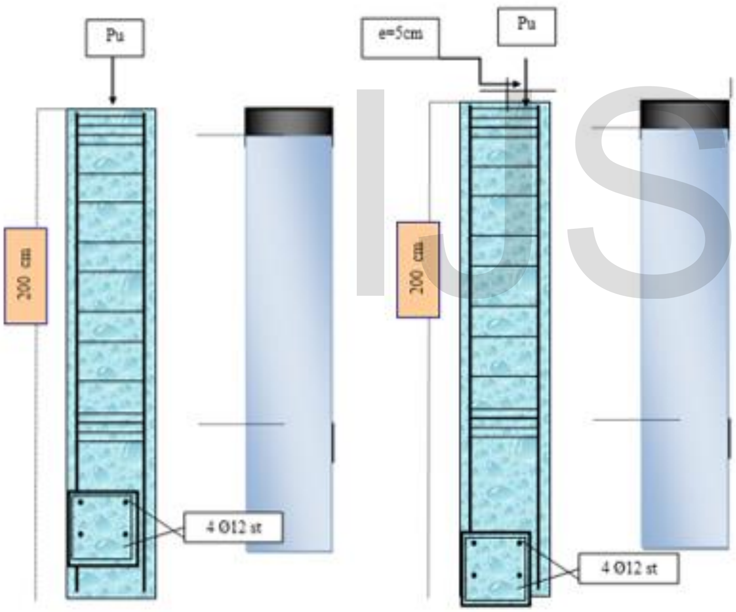

**Figure. 1:** Details of Specimens

A concrete mix was designed to produce concrete of cube strength of about 35 MPa after 28-day age. The mix proportions by weight were as follows in **Table (2)**. Natural sand obtained from pyramid quarry in Egypt was used. It has specific gravity, volume weight and fineness modulus of 2.65, 16.8 KN/m³ and 2.53 respectively. The sand was clean and very fine sand was excluded from the mixture. The result of the sieve analysis carried out is shown in **Table (3)**. Natural crushed stone having maximum aggregate size of 20mm was used. This coarse aggregate was supplied from Attaka quarry in Egypt. The specific gravity, volume weight and fineness modulus were 2.58, 16.6 KN/m³ and 6.68, respectively. The sieve analysis of tested coarse aggregate is presented in **Table (4)**. Portland cement (El Suez Cement) with CEMI 42.5 N was used in the mixture. Testing of cement was carried out according to the Egyptian Code of Particles, ESS: 4756-1-2013 and its appendages. Mechanical and physical properties of the used cement are given in **Table (5)**. Drinking water was used for mixing and curing of concrete. BFRP bars of 2000 mm length and 12mm diameter were used as a main reinforcement in concrete specimens. The tensile testing for three sample of ribbed BFRP bars with 550 mm length were done by putting it into steel tubes in the ends with filling an epoxy material (Sikadur 31CF). Steel tubes of length 200 mm and 3 mm thickness were used. The specimens were kept more than 7 days before testing to allow curing. The mechanical properties obtained from the tensile test according to the specification of ACI as average tensile strength, tensile modulus and elongation % are reported in **Table (6)**. The longitudinal steel reinforcement used was 12 mm diameter while diagonal steel reinforcement used 8 mm diameter. Both proof and ultimate strengths for each diameter as obtained from the experimental test are listed in **Table (7)**.

**Table 2:** Proportion of concrete mixture

| Fcu (MPa) | Cement (kg/m³) | Fine Aggregate (kg/m³) | Coarse Aggregate (kg/m³) | Water (liter/m³) |
|---|---|---|---|---|
| 35 | 450 | 608.7 | 1126 | 202 |

**Table 3:** Sieve analysis of fine aggregate

| Sieve Size (mm) | 5 | 2.5 | 1.25 | 0.63 | 0.31 | 0.16 |
|---|---|---|---|---|---|---|
| **Passing %** | 100 | 95.4 | 85.39 | 54.25 | 10 | 1.9 |

**Table 4:** Sieve analysis of coarse aggregate

| Sieve Size (mm) | 40 | 20 | 10 | 5 |
|---|---|---|---|---|
| **Passing %** | 100 | 98.8 | 32.5 | 0.6 |

**Table 5:** Mechanical and Physical Properties of Cement

| Property | | Results | Specifications Limits |
|---|---|---|---|
| Compressive Strength ($N/mm^2$) | 2 days | 22.7 | Not less than 10 $N/mm^2$ |
| | 7 days | 33.9 | - |
| Soundness (mm) | | 4 | Not more than 10 mm |
| Fineness of Cement ($cm^2$/gram) | | 3190 | - |
| specific gravity | | 3.15 | - |
| Setting Time (minutes) | Initial | 170 | Not less than 60 Minutes |
| | Final | 220 | - |

**Table 6:** Mechanical properties of BFRP Bars.

| Type | Actual Diameter (mm) | Tensile strength (MPa) | Tensile modulus of elasticity (GPa) | Elongation (%) |
|---|---|---|---|---|
| BFRP Bars | 12 | 1085 | 49.3 | 2.2 |

**Table 7:** Mechanical properties of Steel Bars.

| Properties | Measured Values | | Minimum Specification Limit (ESS: 262/2015) | | |
|---|---|---|---|---|---|
| | High Grade Steel B400B-R - Y10mm | Mild Steel B240B-P - R8mm | High Grade Steel B400B-R | Mild Steel B240B-P | Grade 60 |
| Yield /Proof Stress | 527 $N/mm^2$ | 372 $N/mm^2$ | 400 $N/mm^2$ | 240 $N/mm^2$ | 420 $N/mm^2$ |
| Rm/Re | 1.22 | 1.23 | 1.08 | 1.08 | - |
| % of Elongation | 21.8% | 28.3% | 14% | 20% | 9% |

All columns were tested at the age of twenty-eight days. The setup for tested columns is shown in Photo. 1. Firstly, columns were loaded by minimum load representing the weight of machine tare (1.5 ton), then, the loading process started gradually up to failure. The reading of dial and strain gauges were recorded. By the way, the rate of loading of the machine was constant as 140/ $kg/cm^2$/minute.

**Photo. 1:** Test Setup of Specimens

## 3 Results and Discussion

All specimens were tested to failure and the crack damages were observed. For all test specimens, different load measurements were captured at all stages of testing, the results include load-deflection and load-concrete strain an augmented understanding of the behavior. Discussions of all test results are provided here. This analysis and discussion aimed to study the effect of different parameters on behavior and deformation of the tested columns.

**Table 8:** Test results for concrete column

| Column Code | Fcu $N/mm^2$ | $A_s$ | $A_f$ | Pu (KN) | Du (mm) | Energy Absorption (KN.mm) |
|---|---|---|---|---|---|---|
| C1 | 35 | 4Φ12 | - | 922 | 1.04 | 440 |
| C2 | 35 | - | 4Φ12 | 910 | 0.90 | 395 |
| C3 | 35 | - | 4Φ12 | 422 | 0.58 | 175 |

ISSN 2229-5518

### 3.1. Load –Mid-span Deflection Response of Columns

The relationship between the applied load and the measured axial shortening is illustrated in Figure 2 for the different tested columns. Through this Figure, it is obvious that, the first stage of the curves was linear for all columns. At the end of the linear phase, the columns began to crack. The second segment of the load – axial shortening curves deviated than the initial linear part. This indicated that, the concrete transform from linear state to nonlinear state due to the loss of modulus of elasticity value for columns after cracking. The reduction in modulus of elasticity varied according to column code. Column C3 recorded ultimate load 422 KN which is less than column C1 by 54.23% and less than C2 by 53.63%. Column C2 having ultimate load 910 KN and less than C1 by 1.30%. The axial shortening for C3 was 0.58 mm and less than column C1 by 43.96% and less than column C2 by 35.55%. Column C2 having axial shortening of 0.90 mm which is less than column C1 by 13.04%. Column C3 recorded energy absorption by 175 KN.mm and this value less than column C2 energy absorption by 55.69% and less than column C1 Energy absorption by 60.22%.

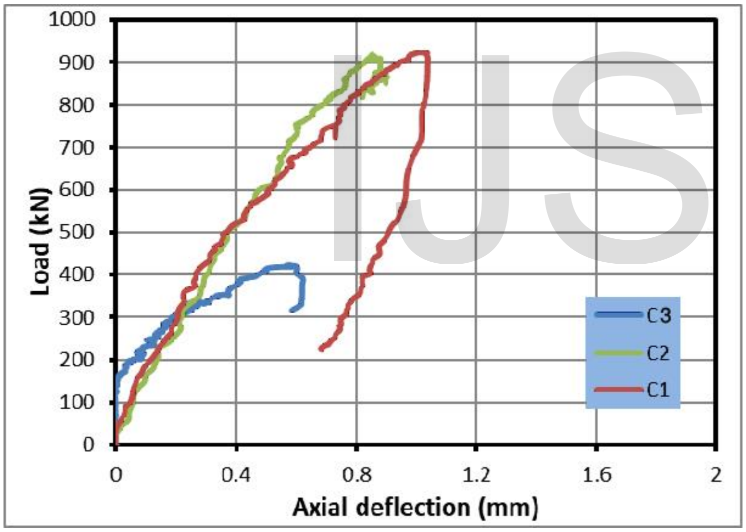


**Figure. 2:** Load – Axial Shortening for Tested Specimens

The tensile strain in the main reinforcement (steel and Basalt FRP bars) of columns was measured. The measured values were plotted against the applied load from level of zero loading up to failure. Through Figure (3), it is obvious that, for basalt FRP reinforced concrete column C2, the rate of increasing in strain recorded highly value in comparison to column C1 and C3. Column C1 recorded the minimum value of strain at the ultimate load value. Column C3 presented low strain and low ultimate load in comparison to column C3 due to shortage in column load capacity, so that, it's recommended to use BFRP bars under the effect of concentric loading only. Also, it's seem that, the measured strain at failure of columns C2 and C3 which have BFRP reinforcement was larger than that in column C1.

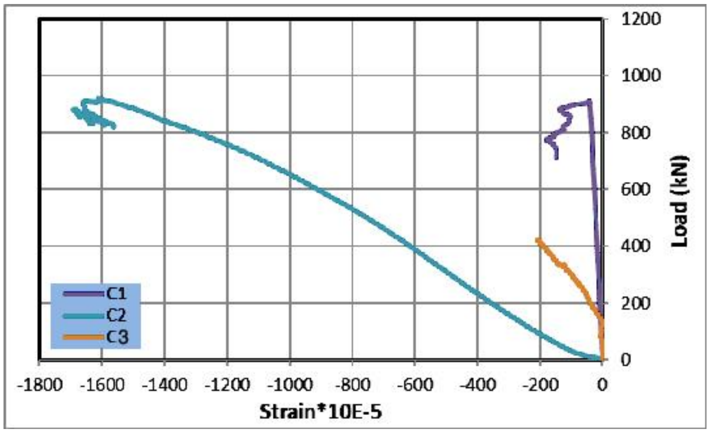


**Figure. 3:** Load – Strain in Main Reinforcement for Tested Specimens

### 3.2. Crack patterns and failure modes

Failure was governed by failure between the medium third to the lower third for tested columns. The failure of column C1 started with superior cracks in column base followed by bending in longitudinal main bars, crushing in concrete took place and failure classified as crushing failure. Column C2 was subjected to shallow cracks appeared due to increase of loading, shear failure took place at the base of column and the failure classified as shear failure. Due to eccentric loading column C3 didn't hold up and superior cracks appeared in the side of eccentric load at low level of loading, longitudinal main bars bended and concrete crushed. The descripted failure classified as crushing failure. See **Photos (2) to (4)**.

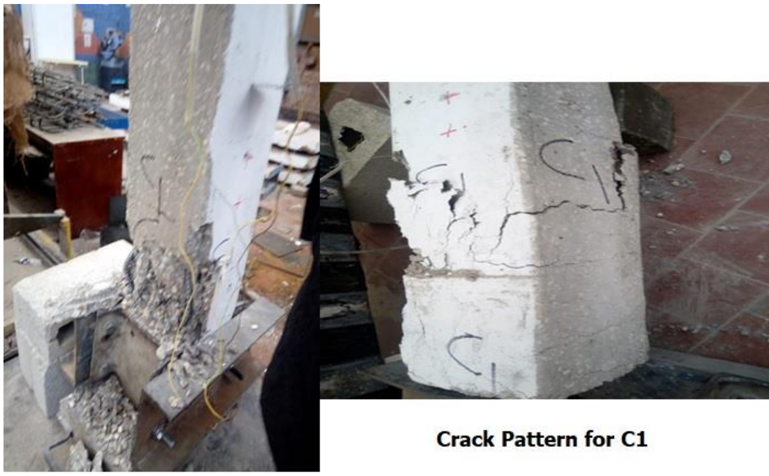


**Photo. 2:** Crack Pattern for Column C1

ISSN 2229-5518


**Photo. 3:** Crack Pattern for Column C2


**Photo. 4:** Crack Pattern for Column C3

## CONCLUSIONS

This paper presents an experimentally study to investigate the axial capacity for reinforced concrete columns which reinforced with steel or Basalt Fiber Reinforced Polymer (BFRP) bars. Based on the results obtained, the following conclusions can be drawn:

- Using BFRP bars decreasing the column load capacity by slightly value.
- Using BFRP bars decreasing the axial shortening for tested columns in comparison to traditional columns.
- Strain in main reinforcement for BFRP bars specimens recorded the maximum values in comparison to traditional columns.
- Axial shortening for BFRP bars specimens almost the same in comparison to traditional columns at the same case of loading.
- Eccentric loading decrease the column load capacity of BFRP bars specimens by 53.62%.
- Using of BFRP bars in columns doesn't the best choice in comparison to traditional columns specially in case of eccentric loading.

## REFERENCES

[1] ACI: 440.2R-02, "Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures," ACI Committee 440, American Concrete Institute.

**[2]** ECP: 203-2007, Egyptian Code of Practice for Reinforced Concrete Construction.

[3] ECP: 208-2005, Egyptian Code of Practice for Using Fiber Reinforced Polymers in Construction.

[4] ESS: 262/2015, Egyptian Standards for Steel Reinforcement.

**[5]** Gouda Ghaniem, Nagi Fouad, Tarek Ali, Sameh Yehia (2009), "Behavior of Short RC Columns Reinforced with FRP Bars", News of the Kazan State University of Architecture and Engineering Journal, ISSN:2073-154X, 2(12), 2009.

**[6]** Ishag, A, Wu, G, Deng, F (2013), "Behavior of Reinforced Concrete Columns Wrapped with Fiber-Reinforced Polymer", International Conference on Material Science and Environmental Engineering (MSEE 2013), Pages: 451-456.

*[7]* Sameh Yehia (2018), "Experimental and Theoretical Study on Strengthened Low Compressive Strength Deficient Columns", International Journal of Engineering Research (IJER), Volume 7, Issue 4, April, 2018.

**[8]** Scott T. Smith, M.ASCE, Seo Jin Kim and Huawen Zhang (2010), "Behavior and Effectiveness of FRP Wrap in the Confinement of Large Concrete Cylinders", Journal of Composites for Construction, Volume 14, Issue 5.

***[9]*** -Su, ha Sang, Kim, Eun-Kyum (2017), "Flexural Behavior of Reinforced Concrete Circular Columns Strengthened with Hybrid FRP Sheet", Journal of Korean Society for Urban Railway, Volume:5, Issue:3, Pages:927-934.