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# BEHAVIOR OF REINFORCED CONCRETE COLUMNS BY USING STEEL SLAG AND REINFORCED BY FRP GLASS BARS

**Qais M. Aljabri[1], Manar A. Ahmed[2], Ehab M. lofty[2] & Ibrahim H. El-kersh[2]**
[1] Civil Engineering Department, Faculty of Engineering, Thamar University, Yemen
[2] Civil Engineering Department, Faculty of Engineering, Suez Canal University, Egypt

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## ABSTRACT
Studying the axial compressive behavior of concrete columns reinforced with fiber-reinforced polymer (FRP) bars have been the subject of some studies, yet most studies focused on normal concrete without fibers. This study presents an experimental investigation of the axial behavior of concrete columns reinforced longitudinally with glass fiber-reinforced polymer (GFRP) bars by adding steel slag as a partial replacement of the coarse aggregate. Twelve columns are designed and tested in a vertical position and under compressive axial static loading to study how different parameters affect the axial compressive behavior of concrete column with steel slag and reinforced with (GFRP), the studied parameters are reinforcement type, longitudinal reinforcement ratio, spacing and ratio of steel ties, and the characteristic strength of concrete. All columns have the same cross-section dimensions 200*200mm and 1000mm height, the main (GFRP) reinforcements are 4#12mm, 6#12mm, and 8#12mm, and the transverse reinforcement is of steel stirrups. Results of specimens tests show that increasing main reinforcement, transverse reinforcement ratios in the column ends, or increasing characteristic strength of concrete have significantly enhanced the behavior of reinforced concrete columns contains steel slag as a partial replacement of the coarse aggregate, and reinforced by (GFRP) bars.

**Keywords**: Steel slag, Corse aggregate, Column, fiber-reinforced polymer, bars

## 1. INTRODUCTION
Column is compression element which locomotes loads form the upper levels to the bottom levels and then to the foundations which transfer loads to the soil, columns are the most important structural elements in the construction, the collapse of the structures is due to a partial or total failure of columns because lateral loads or vertical loads, they are several types and are classified according to the materials manufactured from them (Stone, Timber, brick, concrete, steel), most important is concrete columns because concrete is the most widely used material on earth after water[1], extensive portion of our daily life rely directly or indirectly on concrete, and it is Manufactured by mixing different constituents such cement, water, aggregates, etc. which is economically available. Concrete is a composed material of granular materials such coarse aggregates inserted in a matrix and restricted together with binder (cement) which fills the space between the particles and glues them together [2].

Steel reinforcement has a limited service life and entails high maintenance work costs because of corrosion. This high cost has spurred interest in alternate non corrosive reinforcing materials such as FRP bars. FRP bars offer many advantages over traditional steel bars including a density of 20 - 25 % that of steel, high tensile strength and no corrosion even in harsh chemical [1].

In the 1990s, the Japanese had the most FRP reinforcement applications. FRP design provisions were included in the design and construction recommendations of the Japan Society of Civil Engineers (JSCE). China has recently become the largest user of composite reinforcement for new construction in applications that span from bridge decks to underground works. Also the use of FRP reinforcement in Europe began in Germany with the construction of a prestressed FRP highway bridge in 1986, since the structure of this bridge; programs have been performed to increase the research and use of FRP bars reinforcement in Europe. Canadian civil engineers have developed provisions for FRP bars strengthening in the Canadian Highway Bridge Design Code and have constructed a number of projects. The Headingley Bridge in Manitoba included GFRP reinforcement. In the U.S., typical uses of FRP reinforcement have been in bridges construction (ACI 440R). The use of GFRP bars in MRI hospital room additions is becoming common, and in other applications such as waterfront construction, top mat reinforcing for bridges decks. GFRP reinforcement is used in the portion of concrete wall in tunnels work to be excavated by the tunnel-boring machine in many tunnels were built in major metropolitan areas of the world. For example (Bangkok, Hong Kong, and New Delhi) in Asia and (London and Berlin) in Europe [3]. Egyptians civil engineers have developed provisions for FRP strengthening in the Egyptian Design Code and requirements for the implementation of the use of polymers in fiber construction, which updated code in 2018.

Steel slag is produced as by-product during the oxidation of steel pellets in an electric arc furnace, there are two main slags called blast furnace slag and steel furnace slag [4], this by-product can be broken down to smaller sizes to be used as aggregates in asphalt and concrete, the idea of utilization of industrial waste, including (slag) material extends to a long time ago, leaving this waste without handling leads to damage to the eloquent environment, where the estimated amount of slag is about 0.3-1 tons per ton of cast iron [5]. Steel slag has been used in the construction industry as a partial substitute of either coarse aggregate or fine aggregate. For example the steelmaking industries in the U.S. generate 10- 15 million tons of steel slag every year. In 2006, about 50 to 70% of the total steel slag produced in the U.S. was used as aggregate for road and pavement construction, and the remaining 10 to 15% of the total steel slag generated is utilized in miscellaneous applications [6], also China occupies the first class in the world production of the steel slag is generated in 2009 nearly 740 million tons [7]. Every year, the State of Qatar produces about 500,000 tons of gravel and another 400,000 tons of steel slag [8]. Considering steel slag produced from all iron making plants in Egypt is actually a problem to be disposed of, which is produced in huge quantities estimated at about one million tons per year [9]. This slag is currently being used in road construction work and used as a percentage of coarse aggregates and high-density concrete production to use in radiation shielding purposes, so researchers began to study the steel slag properties and its impact on the concrete properties.

Karim, et al., (2016)[10] investigated the fatigue axial load-axial deformation behavior of circular reinforced concrete columns with GFRP bars and spirals. The study was conducted on 5 circular columns of 205 mm in diameter and 800 mm in height were cast and tested under axial compression and the specimens were reinforced either with GFRP bars and GFRP spirals or only with GFRP spirals. Results showed that diminution the spacing of the GFRP spirals or confinement the samples with CFRP sheet led to development in the strength and ductility of the samples. Hadi, et al., (2016)[11] studied 12 circular RC samples under different loading cases. The samples were reinforced with normal steel bars and spirals, GFRP bars, and different of GFRP spirals. Maranan, et al., (2016)[12] studied concentrically loaded geopolymer-concrete circular columns reinforced longitudinally and transversely with glass fiber-reinforced-polymer (GFRP) bars. Tobbi, et al., (2014)[13] investigated the fatigue behavior of columns reinforced longitudinally with glass FRP (GFRP), carbon FRP (CFRP), and steel bars, and transversally with GFRP and CFRP ties subjected to concentric monotonic axial compression and the experimental studied 23 nearly full-sized concrete columns of 350 x 350 cross-section and 1400mm height, where results showed that FRP ties safely increased concrete strength and ductility.

## 2. MATERIALS AND METHODS

### 2.1 Description and construction of specimens

In this research, tests were carried out on 12 column specimens, where all columns had the same dimensions of 200*200 mm cross-section and 1000 mm height. Tested specimens were divided into four groups as shown on table 1, figure 1 shows the setup arrangement of column specimen test, and figure 2 shows the Details of reinforcement of tested columns.

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***Table 1. Series specimens details.***

| Gro. No . | Col. No. | Steel slag % | Bar type | Long. reinf. | Transverse reinf. | $\rho_S$ % | fcu (N/mm$^2$) |
|---|---|---|---|---|---|---|---|
| 1 | C1-1 | 0 | Steel | 4#12mm | Ø 6mm @120mm Shape(A) | 1.131 | 30 |
| | C1-2 | 0 | GFRP | 4#12mm | Ø 6mm @120mm Shape(A) | 1.131 | 30 |
| | C1-3 | 30 | GFRP | 4#12mm | Ø 6mm @120mm Shape(A) | 1.131 | 30 |
| 2 | C2-1 | 30 | GFRP | 4#12mm | Ø 6mm @120mm Shape(A) | 1.131 | 30 |
| | C2-2 | 30 | GFRP | 6#12mm | Ø 6mm @120mm Shape(A) | 1.698 | 30 |
| | C2-3 | 30 | GFRP | 8#12mm | Ø 6mm @120mm Shape(A) | 2.263 | 30 |
| 3 | C3-1 | 30 | GFRP | 4#12mm | Ø 6mm @120mm Shape(A) | 1.131 | 30 |
| | C3-2 | 30 | GFRP | 4#12mm | Ø 6mm @60mm Shape(B) | 1.131 | 30 |
| | C3-3 | 30 | GFRP | 4#12mm | Ø 6mm @60mm Shape(C) | 1.131 | 30 |
| 4 | C4-1 | 30 | GFRP | 4#12mm | Ø 6mm @120mm Shape(A) | 1.131 | 30 |
| | C4-2 | 30 | GFRP | 4#12mm | Ø 6mm @120mm Shape(A) | 1.131 | 35 |
| | C4-3 | 30 | GFRP | 4#12mm | Ø 6mm @120mm Shape(A) | 1.131 | 40 |

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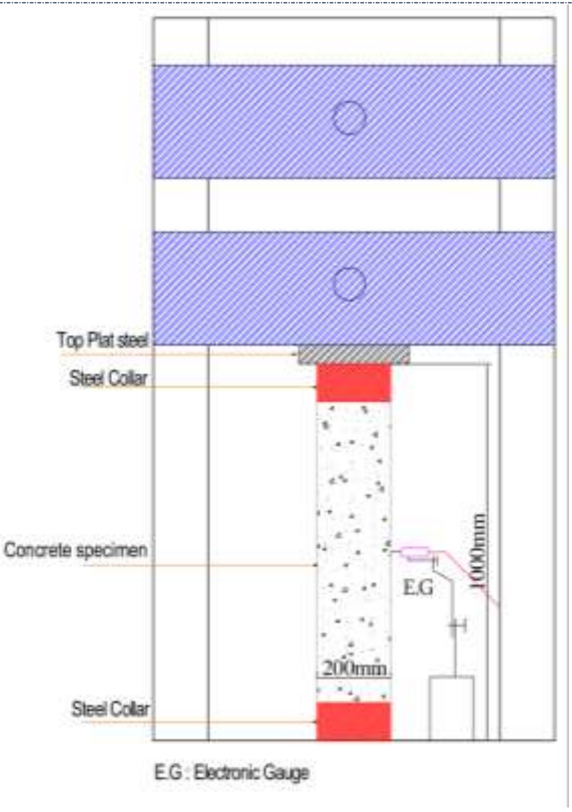


*Fig. 1. Setup arrangement of column specimen test*

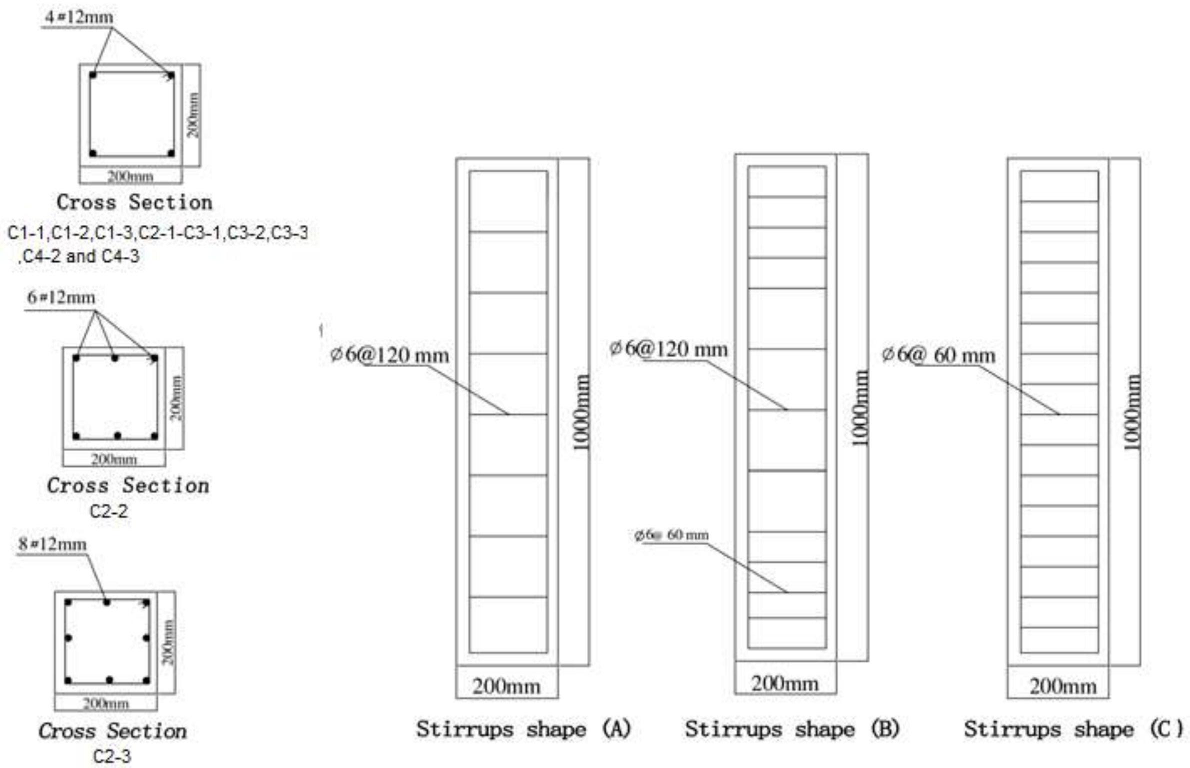


*Fig. 2. Details of reinforcement of tested columns.*

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**2.2 Material properties**
Materials used in preparing the test specimens are the concrete (cement, water, aggregates), steel reinforcement bars (for control samples), GFRP bars, and steel slag. Tests were performed to determine the properties of these materials were carried out according to the Egyptian Standard Specifications (ESS) and the Egyptian Code ECP 203-2007 [14]. All tests were conducted at the Research Center - Suez Canal Authority - Egypt.

***2.2.1 Cement***
The cement used in this investigation is SUEZ CEMENT I 42.5 N. Testing of cement was carried out as per the Egyptian Standard Specifications **Specifications, (2005)** [15], see Table 2.

***Table 2. Mechanical and physical properties of cement.***

| NO | Test | Results | Specification limits |
|---|---|---|---|
| 1 | Time of setting | Initial = 2 hours, 10 min. | Not less than 50 min |
| | | Final = 4 hours, 20 min. | Not more than 10 hours |
| 2 | Compressive strength, N/mm2 | At 2 days= 14.1N/mm2 | Not less than 8 N/mm2 |
| | | At 7 days= 35.5N/mm2 | - |
| | | At 28 days= 42.9N/mm2 | Not less than 40 N/mm2 |

***2.2.2 Aggregates***
***Steel slag:*** Steel slag is an industrial by-product obtained through fusion of steel junk from the impurities and melting factors, which form the liquid slag floating through the electrical arc. It is defined by the American Society for Testing and Materials (ASTM) as a non-metallic product, consisting principally of calcium silicates and ferrites combined with fused oxides of iron, manganese, aluminum, calcium and magnesium that are developed together with steel in basic oxygen, electric arc furnace **Khafaga, *et al.*, (2014)**[16]. In this research the used steel slag is produced from Iron and Steel Company, located in Helwan – Cairo - Egypt, mechanical and physical properties tests of steel slag coarse aggregates were done, table 3 shows the test results.

***Table 3. Mechanical and physical properties of steel slag coarse aggregates.***

| Property | Results | Available limits |
|---|---|---|
| Specific gravity | 3.29 | - |
| Volumetric weight t/m$^3$ | 1.926 | - |
| Water Absorption % | 1.30 | 2.5 % |
| Impact coefficient % | - | - |
| Los Angles Abrasion coefficient % | 19.16 | 30 % |
| Crushing coefficient % | 14.5 | 30 % |

***Sand :*** Natural middle sized sand was used as a fine aggregate in this study, testing of sand was carried out according to the ES 1109/2008. Its specific weight is 2.5 and volume weight is 1.635t/m$^3$. Sand grading is given on table 4.

***Table 4. Grading of natural fine aggregate.***

| Sieve Size (mm) | 6.30 | 5.60 | 4.75 | 2.5 | 1.25 | 0.63 | 0.30 | 0.15 | 0.08 |
|---|---|---|---|---|---|---|---|---|---|
| Passing % | 100 | 99.50 | 99.0 | 94.0 | 81.5 | 43.5 | 7.50 | 3.50 | 0.50 |

***Coarse aggregates:*** The coarse aggregate was passed through sets of sieves, the portion passing through sieve (20mm) and retained on sieve (9.5mm) was used. The natural coarse aggregate grading is given on table 5 according to the US standard specifications ACI.

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***Table 5. Grading of natural coarse aggregate.***

| Sieve Size (mm) | 31.5 | 25 | 20 | 16 | 12.5 | 10 | 8 | 6.3 | 5.6 | 4.8 |
|---|---|---|---|---|---|---|---|---|---|---|
| Passing % | 100 | 98.8 | 80 | 51.2 | 21.8 | 7 | 2.2 | 1 | 0.2 | 0.1 |

### *2.2.3 Steel reinforcement*

Two types of reinforcing steel bars were used in this study to reinforce the steel RC specimens: first, deformed steel bars of diameter 12.0mm for longitudinal reinforcement, second, smoothed steel bars of diameter 6.0mm for transverse strips reinforcement. Table 6 shows the mechanical proprieties of steel used in this study.

***Table 6. Properties of used steel bars.***

| Commercial Dia. (mm) | Actual Dia.(mm) | Yield strength (N/mm2) | Ult. Strength f (N/mm2) | Elongation% |
|---|---|---|---|---|
| 6 | 6 | 390 | 560 | 39.6 |
| 12 | 12 | 540 | 620 | 29 |

### *2.2.4 Fiber reinforced polymers bars (GFRP)*

GFRP is characterized by the lowest tensile elastic modulus, however, it exhibits the highest ultimate tensile strain between different types of FRP, GFRP also is considered the most economical among FRP. Table7 shows the mechanical proprieties of used GFRP bars.

***Table 7. Properties of used GFRP bars.***

| No | Diameter (mm) | Proof strength (N/mm2) | Ult. Strength (N/mm2) | Strain (%) |
|---|---|---|---|---|
| Sample No 1 | 12 | 385 | 481 | 4.30 |
| Sample No 2 | 12 | 400 | 500 | 4.75 |

## 2.3 Matrix preparation and testing

### *2.3.1 Concrete mix proportions*

Table 8 shows the concrete mix proportions used to get three grades of concrete resistance; 30, 35 and 40 N/mm². Compression test is conducted on cube specimens at 7 and 28 days.

***Table 8. Weights of the used components in concrete mix design.***

| Mixture | Fine aggregate (kg/m$^3$) | Coarse aggregate (kg/m$^3$) | Steel slag aggregate (kg/m$^3$) | Cement content (kg/m$^3$) | w/c ratio | Water (Lit) | Grade of concrete |
|---|---|---|---|---|---|---|---|
| N M | 643 | 1144 | 0 | 375 | 0.53 | 200 | M30 |
| M with 30 % SS | 643 | 800.8 | 422.8 | | | | |
| N M | 662 | 1080 | 0 | 410 | 0.40 | 162 | M35 |
| M with 30 % SS | 662 | 756 | 418 | | | | |
| N M | 638 | 1042 | 0 | 450 | 0.36 | 160 | M40 |
| M with 30 % SS | 638 | 729.4 | 403.3 | | | | |

Normal mixture (NM), Mixture (M) and Steel Slag (SS)

### *2.3.2 Compression test of concrete cubes*

Compression testing for three prepared 150 mm cubes specimens was done for each type of concrete at 7 and 28 days to get the stress - strain curve of different mixes and the compressive strength (*fc*) as shown on table 9.

***Table 9. Compressive strength test of the concrete mixtures of M30, M35 and M40 at 7 and 28 days.***

| Sample No. | Compressive Strength after 7 days kg/cm$^2$ | Compressive Strength after 28days kg/cm$^2$ |
|---|---|---|
| M30 | 296 | 377 |
| M30 with 30% steel slag | 294 | 357 |
| M35 | 407 | 431 |
| M35 with 30% steel slag | 320 | 416 |
| M40 | 415 | 468 |
| M40 with 30% steel slag | 370 | 453 |

## 2.4 Column specimens preparation and testing

### *2.4.1 Fabrication of the test specimens*

Processing of specimen's reinforcement cages were done as shown in figure 3 and put inside steel forms, then concrete was casted while compacted in successive layers.

***Fig. 3. Overview of the GFRP cages.***

### *2.4.2 Moistening and paint the specimens*

After casting of specimens in the steel forms, the specimens covered with a wetted purled till the testing date, and specimens were painted after curing so that we can identify the cracks early accurately and clearly when testing.

### *2.4.3 Instrumentations and test setup*

External instrumentation was used in this study to read the lateral displacement and vertical displacement. Two Electronic Displacement Gauges (EDGs) were positioned to measure the lateral displacement of each specimen. The columns specimens were tested under axial compression load using a calibrated hydraulic testing machine with a capacity of 300 tf and accuracy of 0.01 tf, see figure 4.

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***Fig. 4. Overview on setup compression tests of concrete columns.***

## 3. RESULTS AND DISCUSSION

Table 10 summarizes the results of the first cracking and the fracture loads and its corresponding displacement of the tested column specimens. Figure 5 shows the load - vertical displacement curves of the tested columns from C1-1 to C4-3.

***Table10. Results of the tested columns.***

$\rho_S$ : Reinforcement ratio        δ : displacement

| Group No . | Specimen | $\rho_S$ % | Initial cracking loads Pcr ( Kn) | Ultimate loads Pu (KN) | Ultimate Vertical δ(mm) Y-axis | Ultimate lateral δ(mm) x-axis | Ultimate lateral δ(mm) Z-axis |
|---|---|---|---|---|---|---|---|
| 1 | C1-1 | 1.131 | 410 | 774 | 4.455 | 0.081 | 0.505 |
| | C1-2 | 1.131 | 430 | 630 | 4.713 | 0.445 | 0.551 |
| | C1-3 | 1.131 | 425 | 640 | 4.30 | 0.339 | 0.614 |
| 2 | C2-1 | 1.131 | 425 | 640 | 4.30 | 0.339 | 0.614 |
| | C2-2 | 1.698 | 325 | 680 | 9.50 | 0.458 | 0.227 |
| | C2-3 | 2.263 | 445 | 724.50 | 3.52 | 0.751 | 0.261 |
| 3 | C3-1 | 1.131 | 425 | 640 | 4.30 | 0.339 | 0.614 |
| | C3-2 | 1.131 | 450 | 751.8 | 5.81 | 0.828 | 0.731 |
| | C3-3 | 1.131 | 430 | 837.33 | 4.084 | 0.935 | 0.548 |
| 4 | C4-1 | 1.131 | 425 | 640 | 4.30 | 0.339 | 0.614 |
| | C4-2 | 1.131 | 500 | 1011.4 | 3.196 | 0.628 | 0.649 |
| | C4-3 | 1.131 | 470 | 1137.6 | 5.016 | 0.536 | 0.506 |

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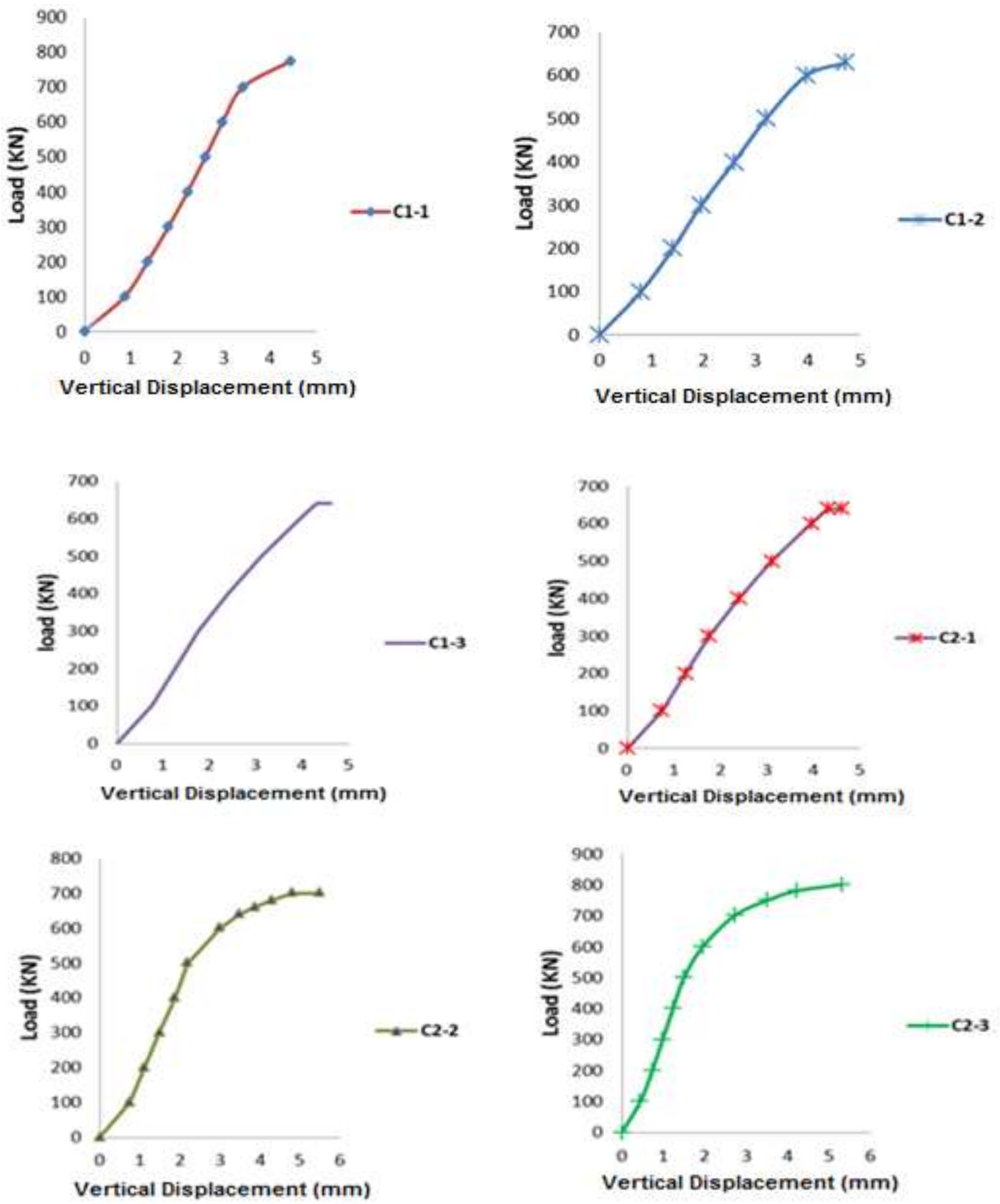


***Fig. 5. Load- vertical displacement curves of tested columns from C1-1 to C4-3.***

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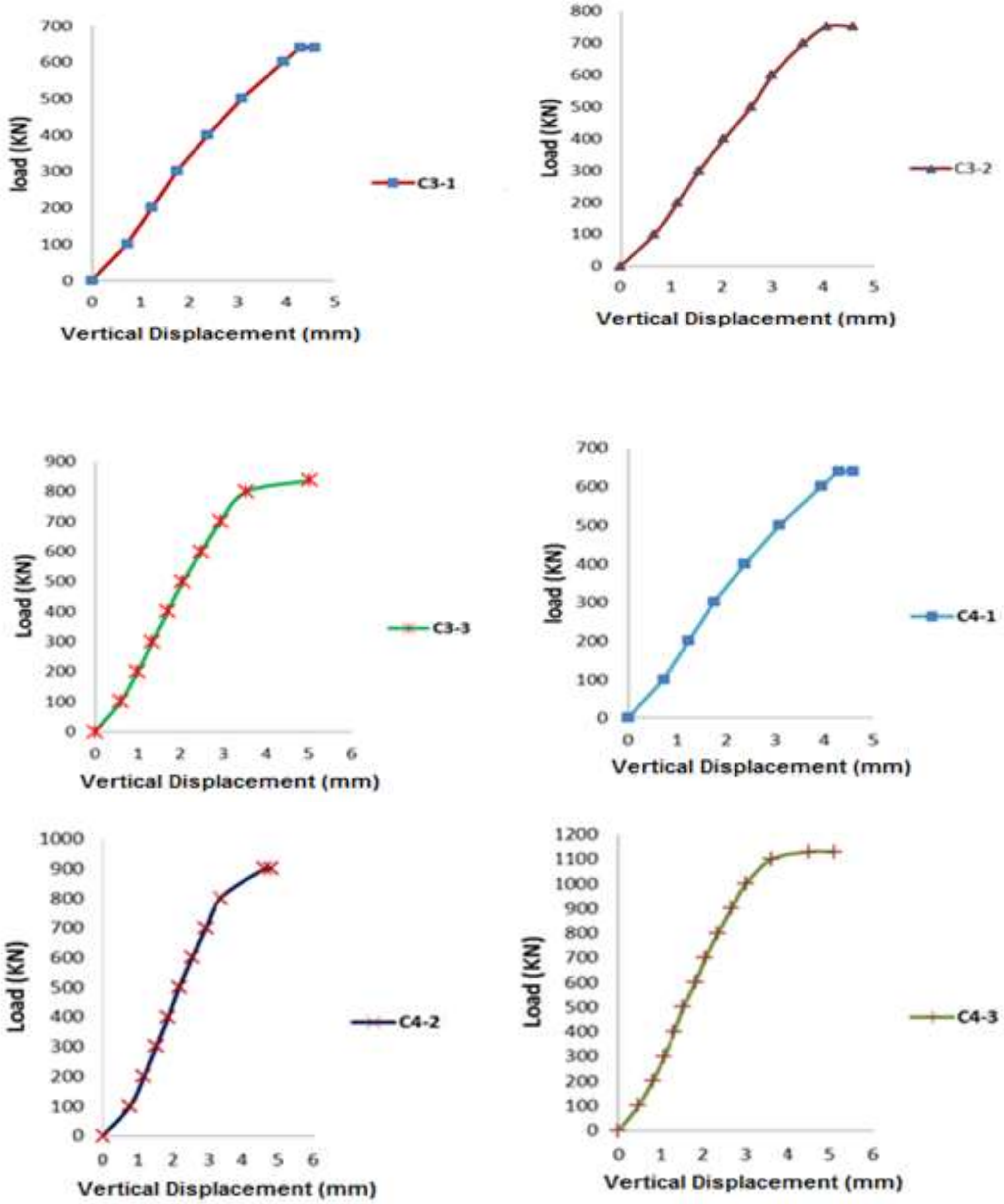


*Cont. Fig. 5. Load- vertical displacement curves of tested columns from C1-1 to C4-3.*

### 3.1 The main reinforcement ratio

Figure 6 shows the load-vertical displacement curves of columns C2-1, C2-2 and C2-3 which reinforced by 4 # 12 mm, 6 # 12 mm and 8 # 12 mm GFRP reinforcement ($\rho_S$ % is 1.131, 1.698 and 2.263%) respectively. It can be noticed that increasing GFRP reinforcement ratio leads to increase the toughness and ductility of tested columns. Figure 7 shows the effect of the main reinforcement ratios on the ultimate load that the columns resists, where increasing of main reinforcement ratios has a significant effect on ultimate loads, it is observed that load increasing corresponding to increasing the reinforcement ratio from 1.131to 1.698 % is larger than that for increasing the ratio from 1.698 to 2.263%.

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### 3.2 The main reinforcement type and steel slag effects

Figure 8 shows the load-vertical displacement curves of columns C1-1, C1-2 which reinforced with 4#12mm (1.131%) of steel, GFRP, tested column with steel reinforcement has ductility more than column with GFRP reinforcement. Also figure 8 shows the load-vertical displacement curves of columns C1-2, C1-3 which reinforced with 4#12mm (1.131%) of GFRP, and GFRP with steel slag, tested columns with GFRP reinforcement has ductility more than column with GFRP reinforcement adding steel slag. From table 10, it can be seen that initial cracking and ultimate loads of C1-2 to C1-1 is 105, 81% and C1-3 to C1-2 is 98, 102 % respectively.

### 3.3 The transverse reinforcement ratio

Figure 9 shows the Load-Vertical displacement curves of columns C3-1, C3-2 and C3-3, increasing of transverse reinforcement ratio leads to increase the toughness and ductility of tested columns. From table 10, the ultimate loads and initial cracking loads of C3-2 and C3-3 to C3-1 are (117, 106%) and (131, 101%) respectively. Figure 10 shows the effect of the transverse reinforcement ratios in the column ends on the ultimate load of the column, where the growing of transverse reinforcement ratios has a significant effect on ultimate loads. Figure 11 shows the Load-Vertical displacement curves of columns C1-1, C3-1, C3-2 and C3-3, the increasing of stirrups with columns reinforced by GFRP increase the toughness and ductility of columns more than using steel reinforcement bars with normal stirrups distribution, the behavior of column C1-1 with steel bars are between the behaviors of C3-2 and C3-3. From Table 10, it can be seen that, ultimate loads and initial cracking loads of C1-1, C3-2 and C3-3 to C3-1 are (121, 96 %), (117,106 %) and (131,101 %) respectively.

### 3.4 The characteristic strength of concrete

From table 10, it can be seen that, ultimate loads and initial cracking loads of C4-2 and C4-3 to C4-1 are (158 and 118%) and (177 and 111%) respectively. Figure 12 shows the load-vertical displacement curves of columns C4-1, C4-2 and C4-3, increasing the characteristic strength of concrete has significant effect on the behavior of tested columns, where increase hardness and ductility of tested columns. Increasing of characteristic strength of concrete has also significant effect on ultimate loads as seen from figure 13.

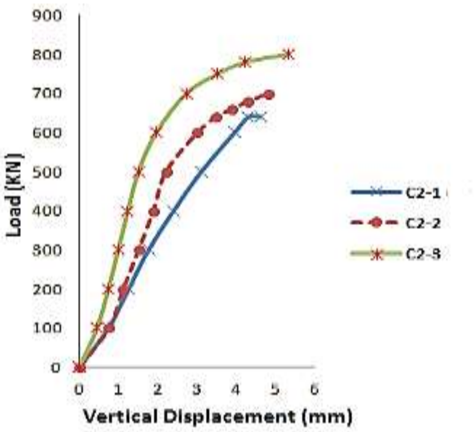


*Fig. 6. Load- Vertical displacement of C2-1,C2-2 and C2-3.*

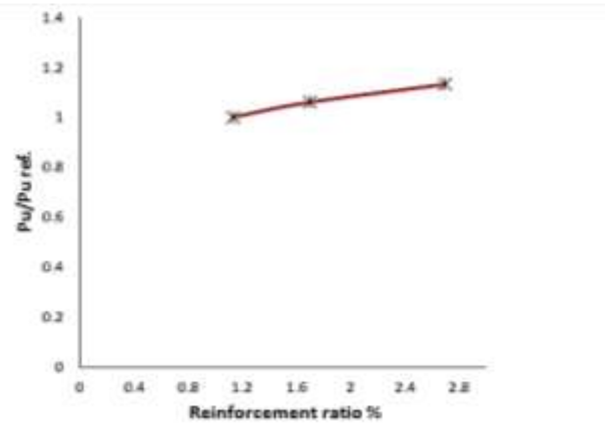


*Fig. 7. Ultimate load of C2-2,C2-3 to C2-1 vs main reinforcement ratio.*

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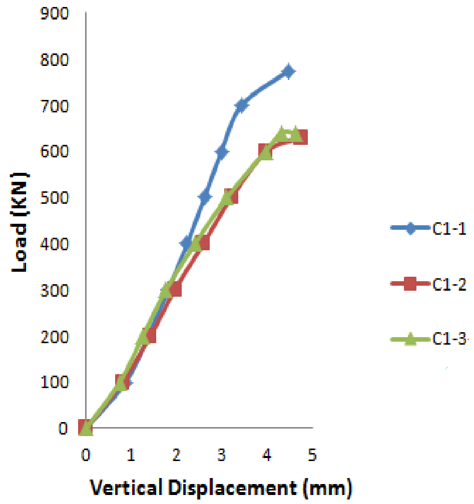


*Fig. 8. Load- Vertical displacement of C1-1, C1-2 and C1-3.*

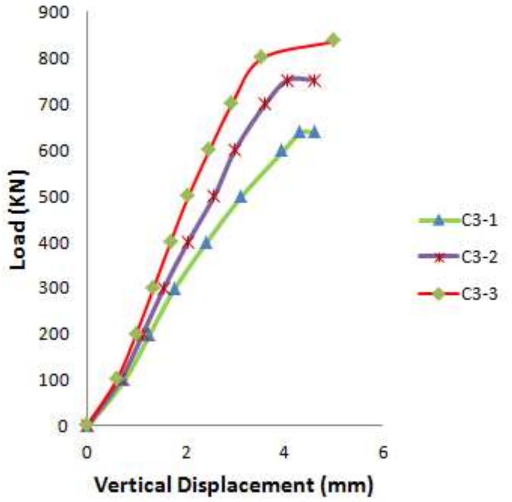


*Fig. 9. Load- Vertical displacement of C3-1, C3-2 and C3-3.*

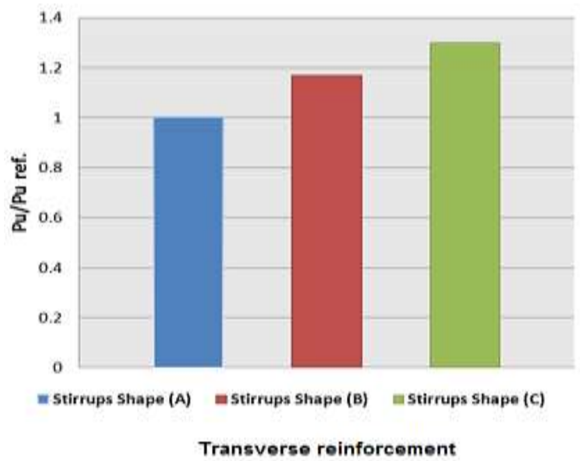


*Fig. 10. Ultimate Load of C3-1, C3-2and C3-3 vs transverse reinforcement.*

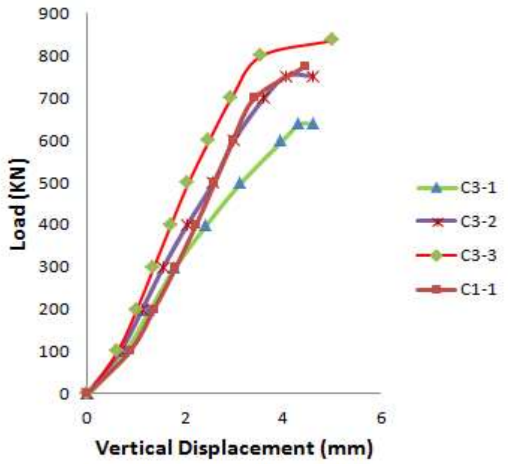


*Fig. 11. Load- Vertical displacement of C3-1, C3-2, C3-3and C1-1.*

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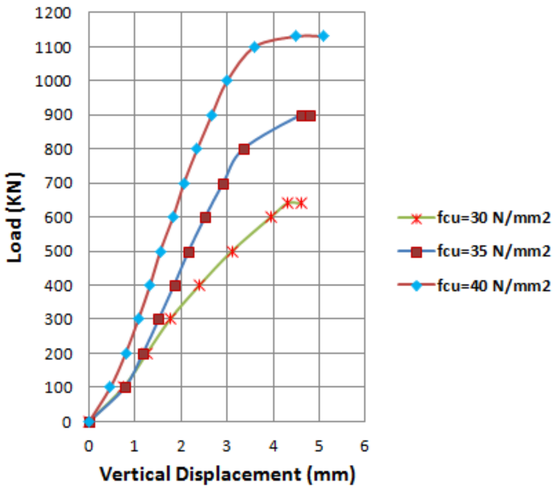


*Fig. 12. Load- Vertical displacement of C4-1, C4-2 and C4-3.*

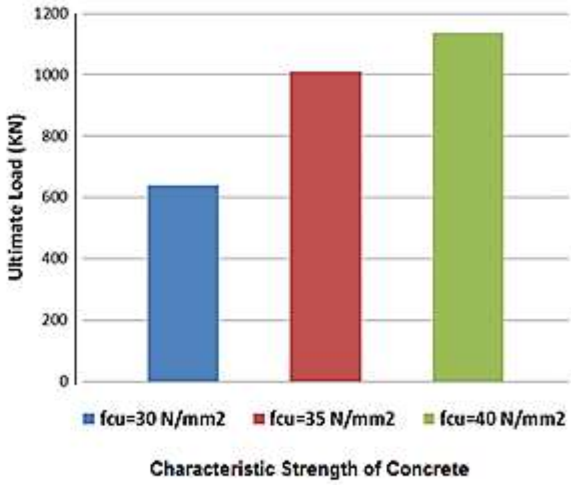


*Fig. 13. Ultimate Load of C4-1, C4-2 and C4-3 vs characteristic strength of concrete*

## 4. CONCLUSION

This paper presents a study on the behavior of reinforced concrete (RC) columns by adding steel slag and reinforced by FRP Glass bars. The experimental results from 12 RC columns with steel slag as a coarse aggregate reinforced by glass fiber reinforced polymer (GFRP) bars demonstrate the influences of the main reinforcement ratio, the main reinforcement type, the transverse reinforcement ratio, and characteristic strength of concrete on the ultimate loads and initial cracking loads. Based on the experimental results, the following conclusions may be made:

- Columns with steel reinforcement has ductility more than column with GFRP reinforcement and columns with GFRP reinforcement with adding steel slag, where ultimate load and initial cracking loads of column with steel reinforcement increase with 122, 120 and 95, 96 % respectively compared to columns with GFRP reinforcement and GFRP reinforcement with adding steel slag, might refer to that GFRP bars in compression is typically complicated by the occurrence of fiber micro-buckling and due to the anisotropic, non-homogeneous nature of the GFRP material.
- Increasing the main reinforcement ratios of GFRP bars with steel slag increase the ductility, and it has a significant effect on the initial cracking loads and ultimate loads of columns.
- The increasing of GFRP reinforcement ratios with 30% steel slag from 1.131 to 1.698 % has a noticeable significant effect on the behavior of tested columns more than increasing the reinforcement ratios from 1.698 to 2.263 %.
- The increasing of transverse reinforcement ratio in columns reinforced by GFRP bars with adding steel slag increase the hardness and ductility, where the increasing of transverse reinforcement ratios confines the columns, so it is lead to increase the ultimate loads which columns resist, hence increasing ultimate strain, and initial cracking loads. Columns with steel slag, GFRP bar has toughness and ductility more than column with steel bars and normal stirrups distribution.
- The increasing of longitudinal reinforcement ratios has significant effect on maximum load and vertical displacement of tested columns .
- The increasing of characteristic strength of concrete has significant effect on the behavior of tested columns reinforced by GFRP bars where it increases toughness and ductility of tested columns.
- Using steel slag as a coarse aggregate replacement and GFRP bars might prove an economical solution for short columns.

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