

Analysis of concrete columns Reinforced by Fiber Reinforced Polymers Bars

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Abstract—The results of an analytical investigation achieved by using ANSYS software and conducted on RC columns reinforced by steel and fiber reinforced polymer bars (GFRP, AFRP and CFRP) are presented and discussed. In this research, the parameters that were taken into account in order to investigate the benefits of replacing steel bars with FRP bars in RC columns are type of reinforcement, longitudinal reinforcement ratio, and various states of loading (axial load, small eccentric load and large eccentric load). The main objective of this research is to study effectiveness of FRP bars reinforced concrete columns and compare the results with the conventionally used steel bars reinforced concrete columns.

Index Terms—Finite Element Analysis, Reinforced Concrete columns, fiber polymer bars, ANSYS, concrete compressive behavior.

I. INTRODUCTION

Since many decades structural engineers faced several problems in concrete structure such as corrosion of Steel because of combination of Chlorides output of steel and Co2 (carbonation of concrete) in presence of moisture produce corrosion of the steel. This problem causes many damages as brittle failure, deterioration of concrete, and eventually the loss of the usability of the structure. Until a few decades ago, steel bars were practically the only option from the perspective of the many for reinforcement of concrete structure. Although the presence of this strong relationship between the concrete and steel, but the corrosion of steel became a major problem that resulted in the verification of the alternatives and find a solution to this problem and this is what will be discussed in this research.

Using FRP material due to their excellent features like high strength to weight ratio, resistance to corrosion, convenience of transportation and installation, has been developing rapidly. Using FRP bars instead of steel bars Significantly prevent corrosion in concrete members specifically for seashore concrete structures. The most common types of FRP were aramid, glass, and carbon; AFRP, GFRP, and CFRP respectively.

Unfortunately, there was a lack of data about using FRP as reinforcement; the lack of a comprehensive database on FRP materials made it difficult for the civil engineer and designer to use FRP composites on a routine basis, although a number of reviews have been published recently related to durability and test methods. This research aims to study the behavior of reinforced concrete columns with steel, GFRP, AFRP and CFRP. The results and observations presented in this research

are useful to civil engineers who must predict the strength of concrete columns reinforced with FRP bars.

The objective of this research is to investigate the behavior and load capacity of FRP reinforced column. The different load conditions, axial compression, small and large eccentric compression are considered in the analysis. Also steel bars, carbon bars, glass bars and aramid bars are used.

II. MODELING

A 3-D nonlinear finite element model of FRP reinforced columns was developed for the purpose of this research. Column model has 250x250mm cross-section and 3.0m height. The column specimens were shown in table 1.

Table 1: Properties of column specimens

No	Type	Model	H. cm.	Area cm ²	Reinf	μ %
1	Steel	GS10	300	25 x 25	8 ϕ 10	1.00
2		GS13	300	25 x 25	8 ϕ 13	1.69
3		GS16	300	25 x 25	8 ϕ 16	2.57
4		GS18	300	25 x 25	8 ϕ 18	3.25
5	CFRP 235	GC10	300	25 x 25	8 ϕ 10	1.00
6		GC13	300	25 x 25	8 ϕ 13	1.69
7		GC16	300	25 x 25	8 ϕ 16	2.57
8		GC18	300	25 x 25	8 ϕ 18	3.25
9	AFRP	GA10	300	25 x 25	8 ϕ 10	1.00
10		GA13	300	25 x 25	8 ϕ 13	1.69
11		GA16	300	25 x 25	8 ϕ 16	2.57
12		GA18	300	25 x 25	8 ϕ 18	3.25
13	CFRP 120	GC10	300	25 x 25	8 ϕ 10	1.00
14		GC13	300	25 x 25	8 ϕ 13	1.69
15		GC16	300	25 x 25	8 ϕ 16	2.57
16		GC18	300	25 x 25	8 ϕ 18	3.25
17	GFRP	GG10	350	25 x 25	8 ϕ 10	1.00
18		GG13	300	25 x 25	8 ϕ 13	1.69
19		GG16	300	25 x 25	8 ϕ 16	2.57
20		GG18	300	25 x 25	8 ϕ 18	3.25

III. GEOMETRY OF SPECIMENS

The details of the tested columns were shown in Fig.1, and Fig.2. Analyses was carried out on twenty columns specimens. Analyzed columns have main reinforcement, GFRP, AFRP, CFRP and steel bars. The transverse reinforcement steel was $\varnothing 8$ mm stirrups in 200mm, and compression strength of concrete columns is 25 N/mm². All columns in this study are subject to load on top surface. At a plane of support location, the degrees of freedom for all the nodes of the solid65 elements were held at zero.

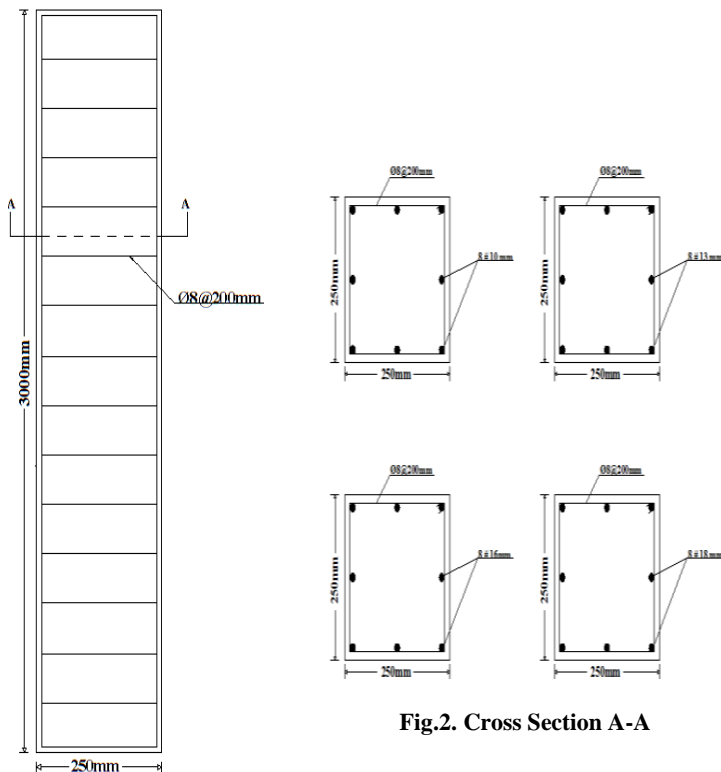


Fig.1. Stirrups Shape

IV. ELEMENT TYPES

An Extensive finite element analyzes using the ANSYS program (16) were carried out to study the behavior of RC columns of different reinforcement types and different reinforcement ratio (μ) (Diameters 10, 13, 16 and 18mm). Two types of elements are employed to model the columns. An eight node solid element, solid65, was used to model the concrete. The solid element has eight nodes with three degrees of freedom at each node, translation in the nodal x, y, and z directions. The used element was capable of plastic deformation, cracking in three orthogonal directions, and crushing.

A link180 element was used to model the reinforcement polymer bar and steel; two nodes are required for this element. Each node has three degrees of freedom, translation in the nodal x, y, and z directions. The element is also capable of plastic deformation. The finite element mesh used in the analysis is shown in Fig. 3.

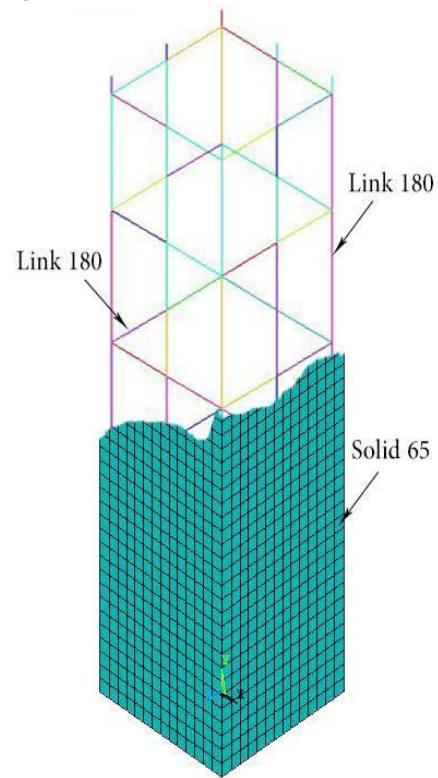


Fig.3. Finite element mesh for column model

V. MATERIAL PROPERTIES

The stress strain curve was linearly elastic up to about 30% of the maximum compressive strength. Above this point, the stress increases gradually up to the maximum compressive strength, f_{cu} , after that the curve descends into softening region, and eventually crushing failure occurs at an ultimate strain. The data for the concrete properties are shown in Table 2. Steel reinforcement used has yield stress f_y equal to 360 MPa and Elastic Tensile modulus equal to 200 GPa. The steel for the finite element models was assumed to be an Elastic perfectly plastic material and identical in tension and compression. Poisson's ratio of 0.3 was used for the steel reinforcement. CFRP reinforcement has high elastic tensile modulus equal to 235.0 GPa and tensile strength equal to 2768 MPa with Poisson's ratio is 0.3. CFRP reinforcement has low elastic tensile modulus equal to 120.0 GPa and tensile strength equal to 1222MPa with Poisson's ratio is 0.3. AFRP reinforcement has elastic tensile modulus equal to 83.0 GPa and tensile strength equal to 2130 MPa with Poisson's ratio is 0.3. GFRP reinforcement has elastic tensile modulus equal to 43.0 GPa and tensile strength equal to 758 MPa with Poisson's ratio is 0.3.

Table 2: Materials properties of concrete for FE modeling

Compression strength, f_{cu}	25 MPa
Compression elastic modulus	22.0 GPa
Ultimate uniaxial tensile strength	2.5 MPa

Poisson's ratio	0.2
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VI. NONLINEAR SOLUTION

A nonlinear structural analysis was performed to study the nonlinear material behavior of RC columns. In nonlinear analysis, the load applied to a finite element model is divided into a series of load increments called load step. At the completion of each load increment, the stiffness matrix of the model is adjusted to reflect the nonlinear changes in the structural stiffness before proceeding to the next load increment. The ANSYS program uses Newton-Raphson equilibrium iterations for updating the model stiffness. For the nonlinear analysis, automatic stepping in ANSYS program predicts and controls load step size. The maximum and minimum load step sizes are required for the automatic time stepping. Figure 4: shows the simplified stress strain curve for column model is constructed from six points connected by straight lines.

The curve starts at zero stress and strain. Point No. 1, at $0.3f'_c$ is calculated for the stress-strain relationship of the concrete in the linear range. Point Nos. 2, 3 and 4 are obtained from Equation (1), in which ϵ_0 is calculated from Equation (2). Point No. 5 is at ϵ_0 and f'_c . In this study, an assumption was made of perfectly plastic behavior after Point No. 5. The initial tangent modulus of elasticity for reinforced concrete, $E_0 = 4400\sqrt{f_{cu}}$ MPa.

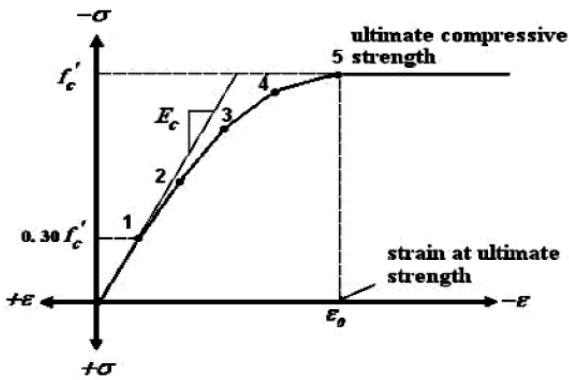


Fig 4: Simplified compressive axial stress-strain curve for concrete

$$f = \frac{E_c \epsilon}{1 + \left(\frac{\epsilon}{\epsilon_0}\right)^2} \tag{1}$$

$$\epsilon_0 = \frac{2f'_c}{E_c} \tag{2}$$

$$E_c = \frac{f}{\epsilon} \tag{3}$$

The multilinear isotropic stress-strain implemented requires the first point of the curve to be defined by the user. It must satisfy Hooke's Law.

$$E = \frac{f}{\epsilon} \tag{4}$$

VII. VERIFICATION

Tested model which is based on numerical study that study the behavior of concrete columns reinforced by fiber reinforced polymers bars need to be reasonably accurate so it has been relying on the model of Lotfy, E.M., "Nonlinear analysis of Reinforced Concrete Columns with Fiber Reinforced Polymer Bars". This model study the analysis of column with height equal to 1250 mm and cross section 250x250 mm as show in fig. 5., and reinforced by GFRP with elastic modulus equal to 44000 MPa and compressive strength of concrete equal to 25 N/mm². The result obtain from this model that the ultimate load equal to 790kN and deformation to this load equal to 0.72 mm, in the other hand the result obtain from tested model that the ultimate load equal to 784 kN and deformation to this load equal to 0.75 mm. The ultimate load at which the FEM predicted was about 0.07% less than that observed from Lotfy, E.M. model. Also it can be observed from fig. 6. , those tested models C2 it can be similar response to the Lotfy, E.M. model C1.

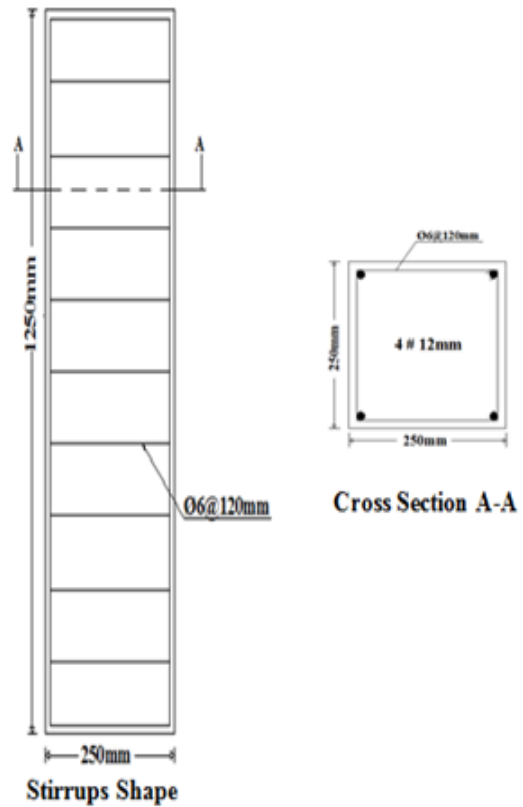


Fig.5. Details of reinforcement of tested column

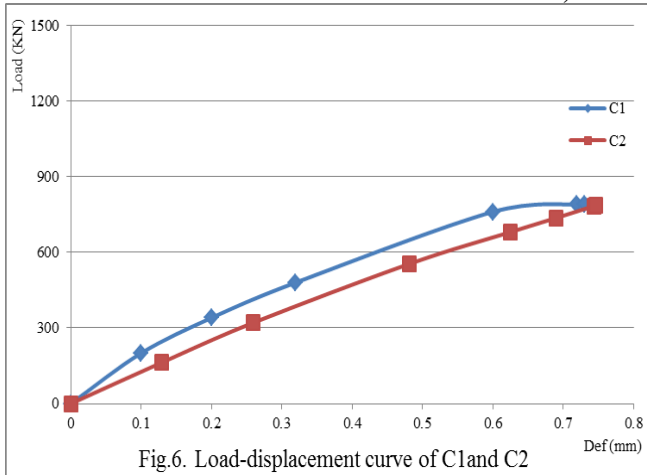


Fig.6. Load-displacement curve of C1 and C2

VIII. ANALYZE RESULTS AND DISCUSSION

A parametric study is performed on the different reinforcement ratio to study the behavior of the columns reinforced by steel, GFRP, AFRP and CFRP under various states of loading. Load displacement curves for different reinforcement ratio as 1.00, 1.69, 2.57 and 3.25 % are done and the failure load with displacement are obtained.

For column under axial load

Figure 7: shows the relation between the load and displacement for different reinforcement types as CFRP235, steel200, CFRP120, AFRP83 and GFRP43 at 3.00m column height with reinforcement ratio equal to 1.00%. It is shown that the ultimate load values are 1130, 1112, 1070, 1053 and 1033kN respectively, and displacements increasing with increase of load until load reach to ultimate load.

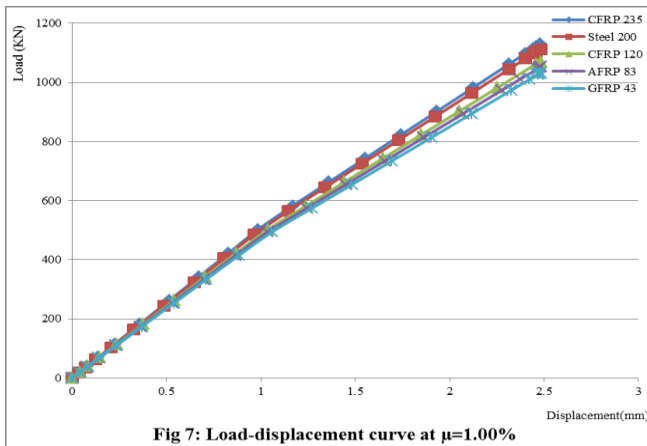


Fig 7: Load-displacement curve at $\mu=1.00\%$

Figure8: shows the relation between the load and displacement for different reinforcement types as CFRP235, steel200, CFRP120, AFRP83 and GFRP43 at 3.00m column height with reinforcement ratio equal to 1.69%. It is shown that the ultimate load values are 1216, 1186, 1114, 1086 and 1049kN respectively. Displacement is increasing with increase of load until load reach to ultimate load. We can note that the steel has the greatest ultimate load after CFRP with high elastic modulus afterwards CFRP with low elastic

modulus, AFRP and GFRP. The displacement values are nearly equal 2.5mm for all columns.

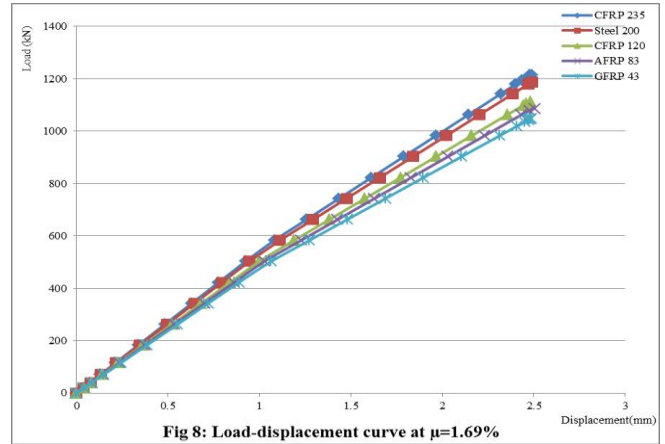


Fig 8: Load-displacement curve at $\mu=1.69\%$

Figure 9: shows the relation between the load and displacement for different reinforcement types CFRP235, steel200, CFRP120, AFRP83 and GFRP43 at 3.00m column height with reinforcement ratio equal to 2.57%. It is shown that the ultimate load values are 1303, 1275, 1166, 1122 and 1085kN respectively, and displacement increasing with increase of load until load reaches to ultimate load. The displacement values are vary from 2.44 to 2.63mm.

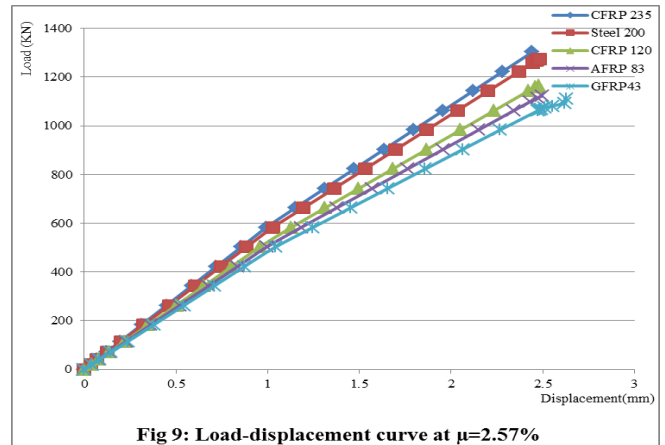


Fig 9: Load-displacement curve at $\mu=2.57\%$

Figure10: shows the relation between the load and displacement for different reinforcement types CFRP235, steel200, CFRP120, AFRP83 and GFRP43 at 3.00m column height with reinforcement ratio equal to 3.25%. It is shown that the ultimate load values are 1400, 1344, 1210, 1150 and 1102kN respectively, and displacement increasing with increase of load until load reaches to ultimate load. The displacement values are nearly equal 2.5mm for all columns.

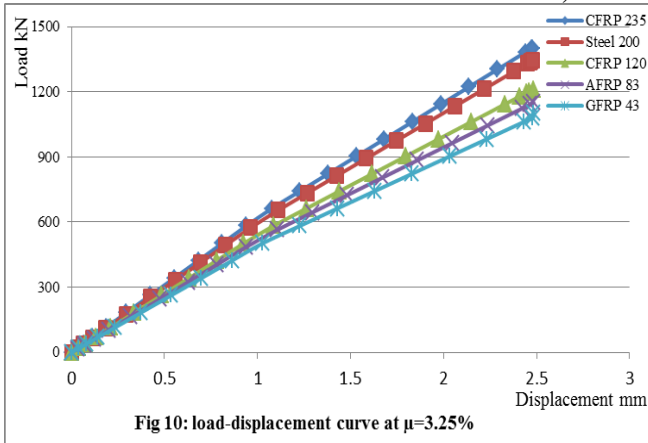


Fig 10: load-displacement curve at $\mu=3.25\%$

From what has been clarify above, we can draw that; when the reinforcement ratio increase from range 1.00 to 3.25 %, the strength of column increasing and therefore the ultimate load increasing and the displacement of column decrease. Thus CFRP with high elastic modulus has the highest strength then Steel, CFRP with low elastic modulus, AFRP and GFRP. Under axial load the behavior of FRP and steel models are nearly linear with little softening at final stage.

For column under small eccentric load

Figure 11: shows the relation between the load and displacement for different reinforcement types as CFRP235, steel200, CFRP120, AFRP83 and GFRP43 at 3.00m column height with reinforcement ratio equal to 1.00%. It is shown that the ultimate load values are 476, 446, 409, 388 and 357kN respectively, and displacements increasing with increase of load until load reach to ultimate load.

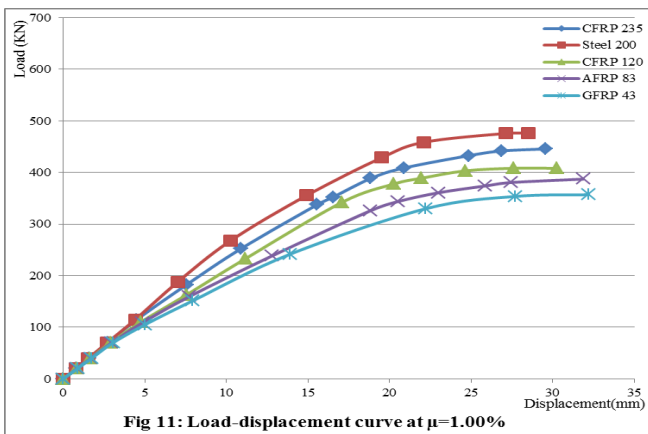


Fig 11: Load-displacement curve at $\mu=1.00\%$

Figure 12: shows the relation between the load and displacement for different reinforcement types as CFRP235, steel200, CFRP120, AFRP83 and GFRP43 at 3.00m column height with reinforcement ratio equal to 1.69%. It is shown that the ultimate load values are 548, 511, 456, 411 and 383kN respectively. Displacement is increasing with increase of load until load reach to ultimate load. We can note that the steel has the greatest ultimate load after CFRP with high elastic modulus afterwards CFRP with low elastic modulus, AFRP

and GFRP. The displacement values are 28, 28.5, 29, 30 and 31mm respectively.

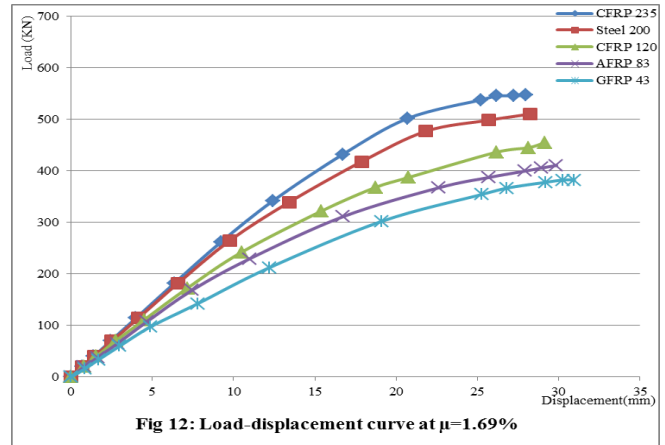


Fig 12: Load-displacement curve at $\mu=1.69\%$

Figure 13: shows the relation between the load and displacement for different reinforcement types CFRP235, steel200, CFRP120, AFRP83 and GFRP43 at 3.00m column height with reinforcement ratio equal to 2.57%. It is shown that the ultimate load values are 618, 571, 502, 451 and 419kN respectively, and displacement increasing with increase of load until load reaches to ultimate load. The displacement values are 26.5, 28, 28.5, 29 and 30 mm respectively.

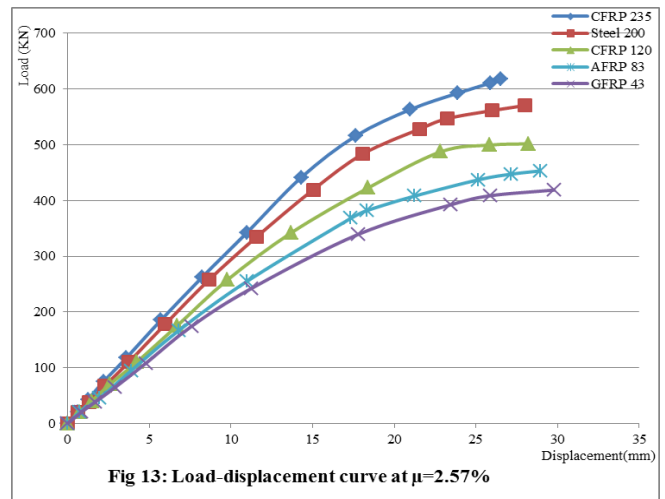


Fig 13: Load-displacement curve at $\mu=2.57\%$

Figure 14: shows the relation between the load and displacement for different reinforcement types as CFRP235, steel200, CFRP120, AFRP83 and GFRP43 at 3.00m column height with reinforcement ratio equal to 3.25%. It is shown that the ultimate load values are 687, 640, 550, 508 and 450kN respectively and displacement increasing with increase of load until load reaches to ultimate load. The displacement values are 26, 27, 28, 28.5 and 29mm respectively.

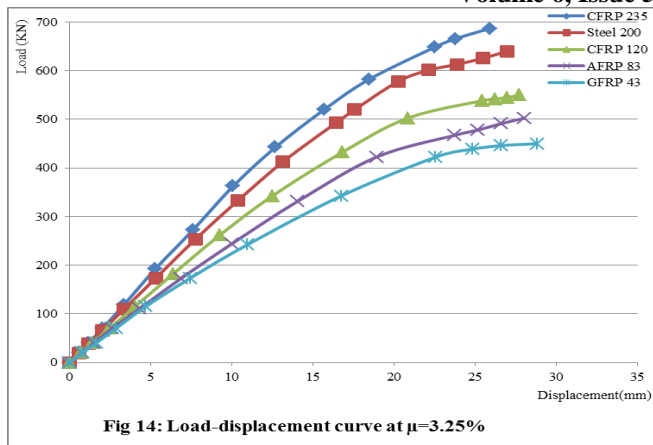


Fig 14: Load-displacement curve at $\mu=3.25\%$

From what has been clarify above, we can draw that; when the reinforcement ratio increase from range 1.00 to 3.25 %, the strength of column increasing and therefore the ultimate load increasing and the displacement of column decrease. Thus CFRP with high elastic modulus has the highest strength then Steel, CFRP with low elastic modulus, AFRP and GFRP. Under small eccentric compression, the behaviors of columns with different reinforcing bars are nonlinear in shape with significant softening near failure.

For column under large eccentric load

Figure 15: shows the relation between the load and displacement for different reinforcement types as CFRP235, steel200, CFRP120, AFRP83 and GFRP43 at 3.00m column height with reinforcement ratio equal to 1.00%. It is shown that the ultimate load values are 381, 361, 296, 258 and 226 kN respectively, and displacements increasing with increase of load until load reach to ultimate load.

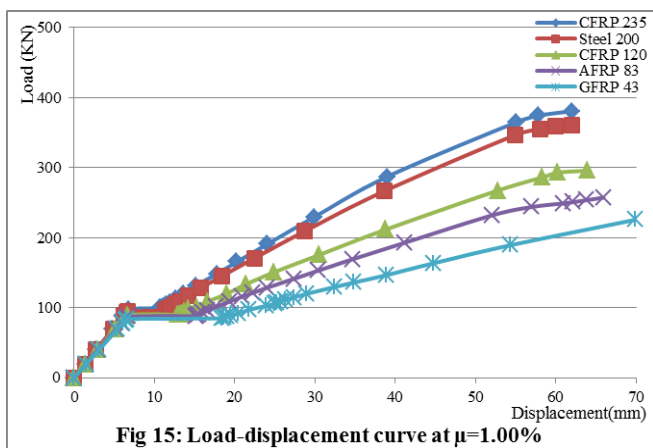


Fig 15: Load-displacement curve at $\mu=1.00\%$

Figure 16: shows the relation between the load and displacement for different reinforcement types as CFRP235, steel200, CFRP120, AFRP83 and GFRP43 at 3.00m column height with reinforcement ratio equal to 1.69%. It is shown that the ultimate load values are 429, 412, 345, 311 and 240kN respectively. Displacement is increasing with increase of load until load reach to ultimate load. We can note that the steel has the greatest ultimate load after CFRP with high

elastic modulus afterwards CFRP with low elastic modulus, AFRP and GFRP. The displacement values are 53, 54, 57, 58 and 63mm respectively.

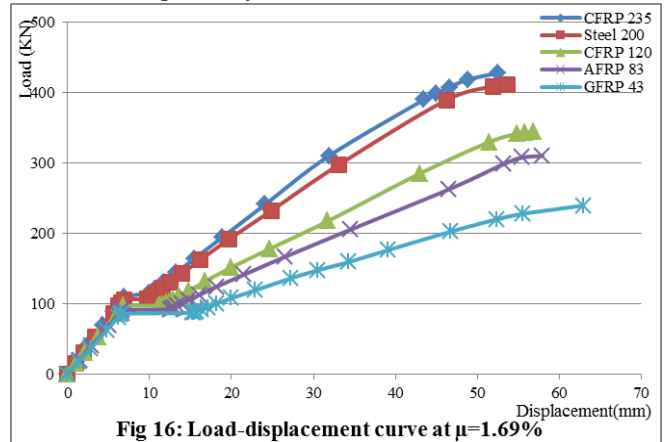


Fig 16: Load-displacement curve at $\mu=1.69\%$

Figure 17: shows the relation between the load and displacement for different reinforcement types CFRP235, steel200, CFRP120, AFRP83 and GFRP43 at 3.00m column height with reinforcement ratio equal to 2.57%. It is shown that the ultimate load values are 463, 436, 371, 322 and 256kN respectively, and displacement increasing with increase of load until load reaches to ultimate load. The displacement values are 46, 48, 49, 52 and 58mm respectively.

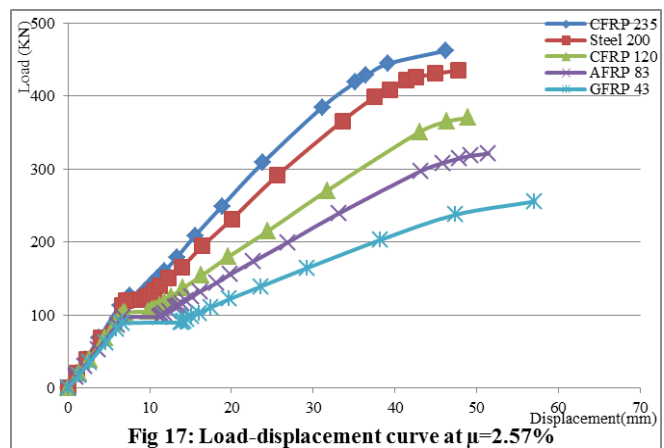


Fig 17: Load-displacement curve at $\mu=2.57\%$

Figure 18: shows the relation between the load and displacement for different reinforcement types as CFRP235, steel200, CFRP120, AFRP83 and GFRP43 at 3.00m column height with reinforcement ratio equal to 3.25%. It is shown that the ultimate load values are 486, 466, 402, 363 and 312kN respectively, and displacement increasing with increase of load until load reaches to ultimate load. The displacement values are 43, 44, 45, 49 and 54mm respectively.

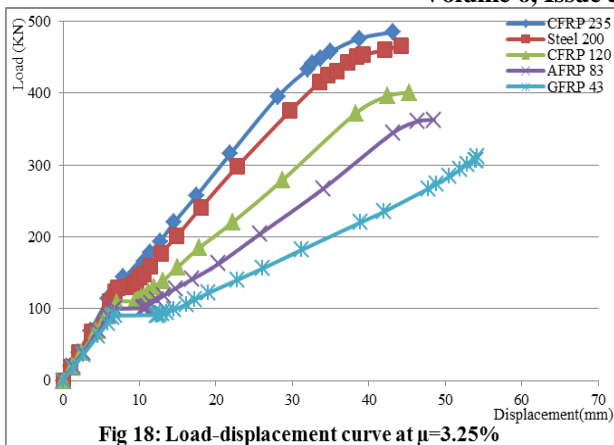


Fig 18: Load-displacement curve at $\mu=3.25\%$

From what has been clarify above, we can draw that; when the reinforcement ratio increase from range 1.00 to 3.25 %, the strength of column increasing and therefore the ultimate load increasing and the displacement of column decrease. Thus CFRP with high elastic modulus has the highest strength then Steel, CFRP with low elastic modulus, AFRP and GFRP. Under large eccentric compression, the behaviors of columns with different reinforcing bars are nonlinear in shape with significant softening near failure with horizontal part defining the crack load.

Figure 19: shows the relation between the ductility ratio and different reinforcement ratio for different reinforcement types as CFRP235, steel200, CFRP120, AFRP83 and GFRP43 at 3.00m column height with reinforcement ratio equal to 3.25%. It is shown that when reinforcement ratio increases, ductility ratio is increasing. However the value of GFRP is not affected by increase of reinforcement ratio but remains constant

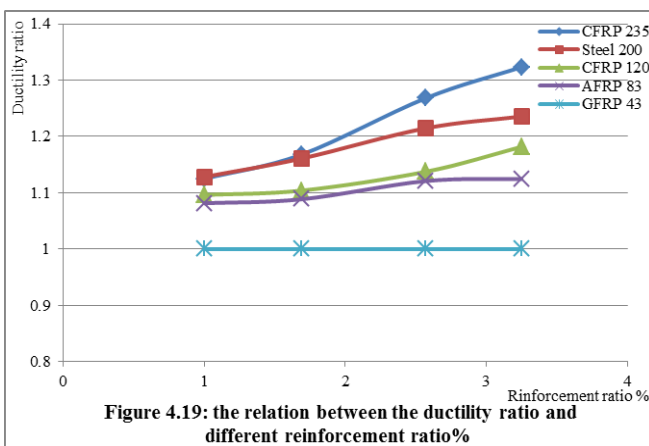


Figure 4.19: the relation between the ductility ratio and different reinforcement ratio%

IX. CONCLUSIONS

The behavior of twenty columns are investigated in the current study under the effect of axial load, small and large eccentric load applied with the FE analysis program ANSYS. Several parameters are investigated including type of reinforcement, longitudinal reinforcement ratio, and various states of loading (axial load, small eccentric load and large

eccentric load). The study focuses on the consequences of the investigated parameters on the displacement and ultimate load. The conclusions made from this investigation are:

- The steel bars can be replaced by FRP bars without significant reduction in strength.
- Under axial load the behavior of FRP and steel models are nearly linear with little softening at final stage.
- Under small eccentric compression, the behaviors of columns with different reinforcing bars are nonlinear in shape with significant softening near failure.
- Under large eccentric compression, the behaviors of columns with different reinforcing bars are nonlinear in shape with significant softening near failure with horizontal part defining the crack load.
- The high elastic modulus CFRP as well as steel RC columns behaved in a similar manner up to of their failure loads. The axial strength of the CFRP RC columns was on average 1.6-3 % higher than their steel RC counterparts.
- The low elastic modulus CFRP and steel RC columns behaved in a similar manner up to of their failure loads. The axial strength of the CFRP RC columns were on average 3-8 % lowers than their steel RC counterparts.
- The AFRP RC columns behaved lower than steel in failure loads. The axial strength of the GFRP RC columns were on average 5-12 % lowers than their steel RC counterparts.
- The GFRP RC columns behaved lower than steel in peak loads. The axial strength of the GFRP RC columns were on average 7-13 % lowers than their steel RC counterparts.
- CFRP bars with high elastic modulus were introduced good load capacity in resisting compression load more than steel.
- Increasing FRP reinforcement ratio leads to increasing column strength.
- In the large eccentric stage, when the reinforcement ratio increase the cracking load increase for different type of reinforcement such as high elastic modulus CFRP, steel, low elastic modulus CFRP, AFRP and GFRP and also high elastic modulus CFRP has the highest value of cracking load while GFRP has the lowest.

- When the reinforcement ratio increase the ductility ratio of the column reinforced with FRP bar increase.

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