3rd Conference on Sustainability in Civil Engineering (CSCE'21)
Department of Civil Engineering
Capital University of Science and Technology, Islamabad Pakistan

Numerical Analysis of Compressive Behavior of GFRP Reinforced Hollow Concrete Columns

[a]Tanwir Ullah*, [a]Afaq Ahmed, [a]Muhammad Yaqub, [b]Omer AlAjarmeh

a: Civil Engineering Department, University of Engineering and Technology, Taxila, Pakistan

b: University of Southern Queensland, Centre for Future Materials (CFM), School of Civil Engineering and Surveying, Toowoomba 4350, Australia

Corresponding Author: Email ID: engr662@gmail.com

***ABSTRACT*:** Glass-fiber-reinforced-polymer (GFRP) reinforcements provide a valuable substitute to conventional reinforcements in reinforced concrete frame structures, especially in vertical elements such as columns, due to improved anti-corrosion properties. On the other hand, the compressive behavior of GFRP-reinforced hollow concrete columns has been very rarely discovered. This purpose of this paper is to investigate the compression response of hollow concrete columns reinforced with GFRP bars and spirals. A concentric axial load of 20 KN was applied onto hollow circular columns of 250 mm external diameter and 1000mm height, having six GFRP bars of 14mm diameter each. FEA models of the columns were constructed using ABAQUS, by applying the same geometry, loading and boundary conditions. Numerical analysis of the modelled samples was performed after calibration and sensitivity analysis of the control model. The FEA analysis illustrated that hollow columns achieved greater confinement efficiency than the solid one. Moreover, hollow columns reinforced with GFRP showed higher compressive strength and deformation capacity than those reinforced with steel. The results of FEA analysis were in good agreement with the previously carried out experimental work.

Keywords- ABAQUS, GFRP columns, GFRP bars, Hollow Circular columns, Finite element modeling (FEM).

1 Introduction

Glass Fiber Reinforced Polymer (GFRP) reinforcements are increasingly being used as alternative to steel reinforcement in concrete structures, due to anti-corrosion properties [1]. Jabbar and Farid observed that in addition to higher corrosion resistance, the GFRP bars have 13% higher tensile strength and 58% higher tensile yield strain than the steel [2]. Ephraim et al. [3] reported that GFRP with 40% of fiber content showed about 25% more ductility than that recommended by ACI 440 Report [4]. Reinforced concrete columns, as structural members can be suitably reinforced with fiber reinforced polymer, for achieving greater strength [5].

Hollow RC columns are structurally more efficient in comparison to solid columns due to higher ductility and lower mass [6]. Hollow concrete columns have an obvious advantage over solid columns, owing to lesser weight, materials saving, higher axial capacity and higher resistance to bending[7]. Circular RC columns with fiber reinforcements showed more confined effect as compared to square one [8]. The longitudinal GFRP bars contribute in load carrying, upto 5% of the ultimate load in the high strength concentric columns [9]. Afifi quantified this effective share of GFRP longitudinal reinforcements in the design, to be 35% of the maximum column capacity [10]. Alajrmeh et al. found that the key factors affecting the structural axial response of hollow RC columns are the size and dia of GFRP bars, amount of lateral reinforcement, column's inner dia to outer dia ratio (i/o) and ratio of the actual load to axial capacity [11]. Kang et al. carried out FEA analysis tubular hollow composite columns with GFRP reinforcements and observed a gain in its bearing capacity by increasing the concrete strength or reducing the hollow ratio [12]. Nistico et al. developed a numerical model for solid concrete as a function of shape (circular and rectangular) and type of FRP [13]. Afaq et al. found that the performance of GFRP reinforced RC columns depends on type and shape of reinforcing material, with L-shape bars having higher capacity than round bars [14]. Raza et al. numerically investigated GFRP column with hybrid fibers and found close correlation between tests and FEM results thus validating the applicability of FEM [15].

The study of relevant literature suggests that there is a lack of numerical investigation on behavior of GFRP reinforced hollow columns. To fill this gap, the paper focuses on numerically analyzing the axial response of hollow concrete columns reinforced with GFRP bars and spirals, using ABAQUS software. The novelty of FEM study is that it is software based, instead of using cumbersome experimental tests, thus saving valuable time and effort. The GFRP reinforced hollow columns once fully applied in the structures will prove as valuable alternative to the traditional steel reinforcement, saving enormous cost and material.

2 Methodology

Numerical method was adopted to analyses the columns, using Finite Element Method (FEM). The commercial software Abaqus was utilized for the purpose of carrying out FEM analysis. Three concrete columns, each with 1000mm height and 250mm diameter, were modelled. The hollow GFRP reinforced column was used as benchmark to explore its axial behavior while a solid GFRP column and a hollow steel reinforced columns were modelled for comparison. A normal strength concrete with compressive strength of 25.6 MPa was used, with GFRP and steel bars as main reinforcement while GFRP spirals as lateral reinforcement. Material properties are tabulated in Table.

Table 1- Material Properties

Properties	Steel bars	GFRP bars	GFRP spiral	Concrete
Diameter (mm)	14	14	10	250
Area (mm^2)	153.8	153.86	70.8	-
Density (ton/mm^3)	7.85 x 10^{-9}	2 .1 x 10^{-9}	2 .1 x 10^{-9}	2.4 x 10^{-9}
Tensile Strength (MPa)	500	1237	1315	31.2
Modulus of Elasticity (GPa)	200	60	62.5	25.6
Poisson Ratio	0.30	0.21	0.21	0.25
Ultimate strain (%)	2.1	2.1	2.3	-

3 Finite Element Modelling (FEM)

3.1 *Geometry and Meshing*

For FEM analysis, CPD model of Abaqus was used for concrete simulation while steel and GFRP were simulated as elastic materials. In addition, steel plate, steel collars and rubber pads were applied at top and bottom surfaces for dilating load intensity. The 20mm Mesh was used for meshing GFRP and steel reinforcements with T3D2 elements whereas concrete with C3D8R elements.

3.2 *Constraints, Boundary Conditions and Loading*

"Tie" constraints using the concept of master and slave surfaces, were used to ensure smooth load transfer. The column's bottom end was fixed while top ends was let free to move. 25 KN concentric load was applied using 20 mm displacement. The initial and maximum loading increment size was 0.01, minimum as 10^{-15} and maximum number of increments was 1000.

3.3 *Control Model Calibration*

The controlled model was calibrated for various parameters by constructing a total of 58 x models. The calibrated FEA model which was produced with mesh size of 20mm, viscosity of 0.0018, shape factor of 0.667 and 36° dilation angle.

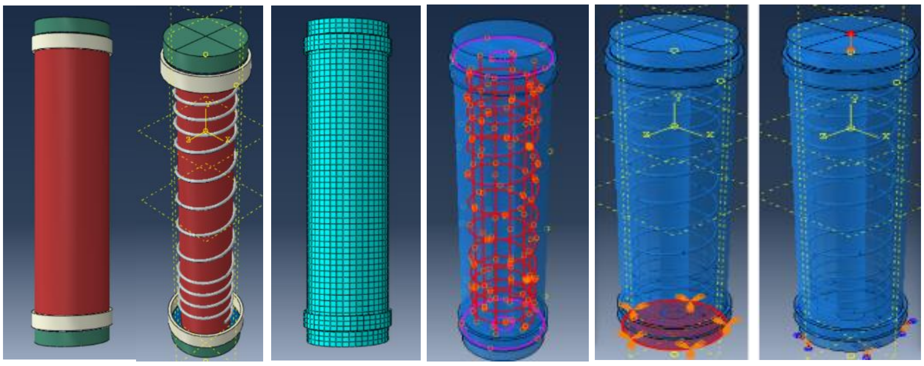

Figure 1: Column (a) assembly (b) meshing (c) constraints (d) boundry conditions (e) loading.

4 Discussions and Results

4.1 *Load-Deflection Behavior*

The modelled column showed a linear load–deflection curve in the initial phase, followed by a short nonlinear pattern just before the peak load. This brief nonlinearity is due to the initiation of cracks in the outer concrete core. The ultimate peak load of 1536 kN was obtained at an axial deflection of 9.49 mm. After the peak, an abrupt decreases in axial capacity was observed as the concrete cover spalled. However, due to the confining effect of GFRP spirals, another upward trend in the load capacity is observed in the post-peak phase. This upward increase is continued till the column finally fails when the GFRP bars and spirals reinforcements rupture. The same load-deflection pattern was observed by Alajarmeh et al. [11] by experimentally exploring the axial behavior of GFRP columns, as shown in Figure 2. Thus the numerical results are largely in agreement with the results of experimental work.

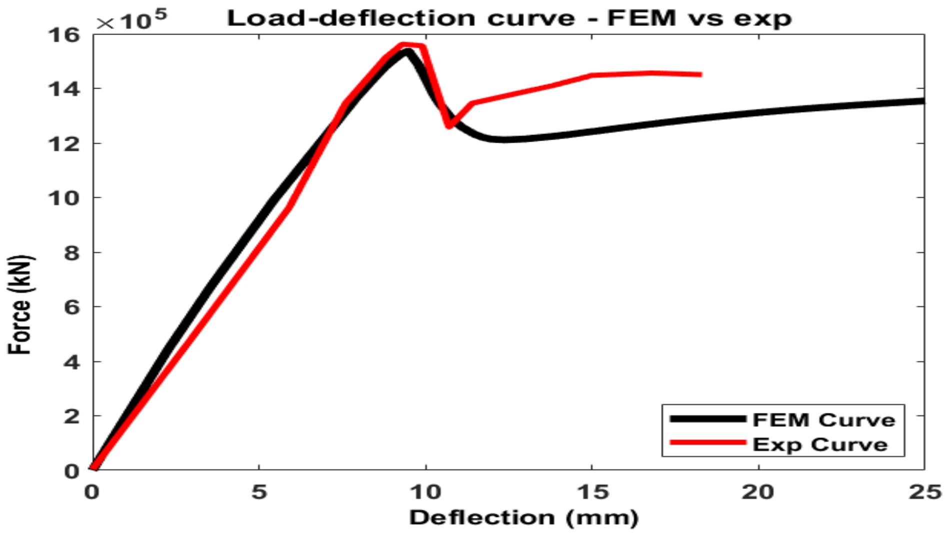

Figure 2: Load-deformation curves (FEM vs Experimental results)

4.2 *Comparison with Steel reinforced Columns*

A comparison of the axial behavior of GFRP-reinforced column was drawn with the steel reinforced column of the same dimension. For this purpose, a new model was generated having the same properties of concrete and GFRP spirals, but having steel longitudinal bars instead of GFRP. The steel reinforced column gave almost the same peak axial load as that of GFRP. However, in the post-peak phase, it showed a comparatively lower strength capacity. This shows that GFRP bars are structurally more efficient than the conventional steel bars of the same size. The comparison has been shown in the Figure 3 (a) below.

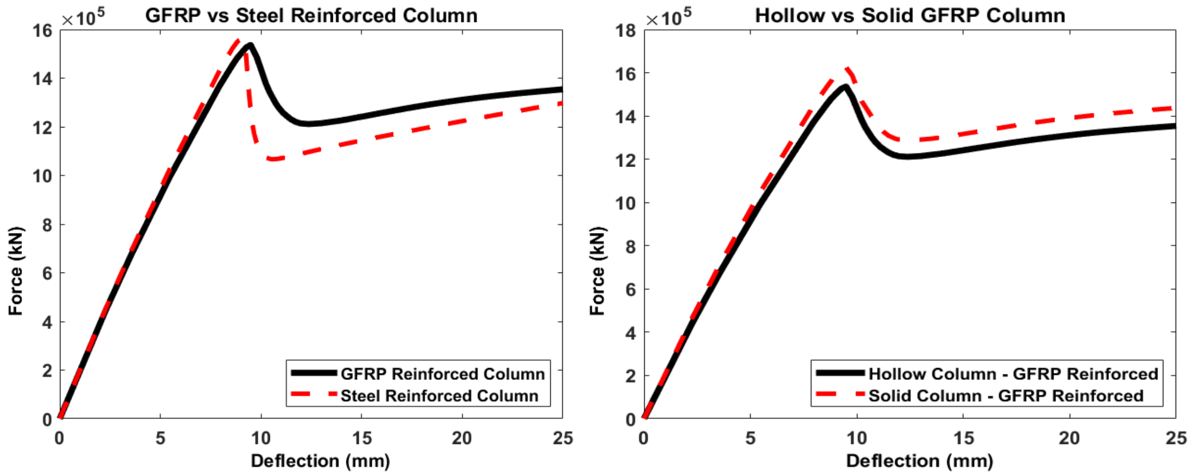

Figure 3: (a) GFRP vs Steel columns (b) Effect of Hollowness

4.3 *Effect of Inner Hollow*

To ascertain the role of inner hollow in the column, another column was simulated having the same longitudinal and spiral reinforcement but a solid cross section instead of hollow one. The load-deflection curve for both these columns have been compared in the Figure 3 (b). The solid column showed comparatively higher peak axial strength (1625000 KN vs 1536000 KN i.e. 5.8%) and more improved post-peak behavior. This can be attributed to the more confining effect provided by the inner solid concrete core. However, the relatively sharp decline in the strength after peak capacity shows that solid column is less ductile than the hollow one.

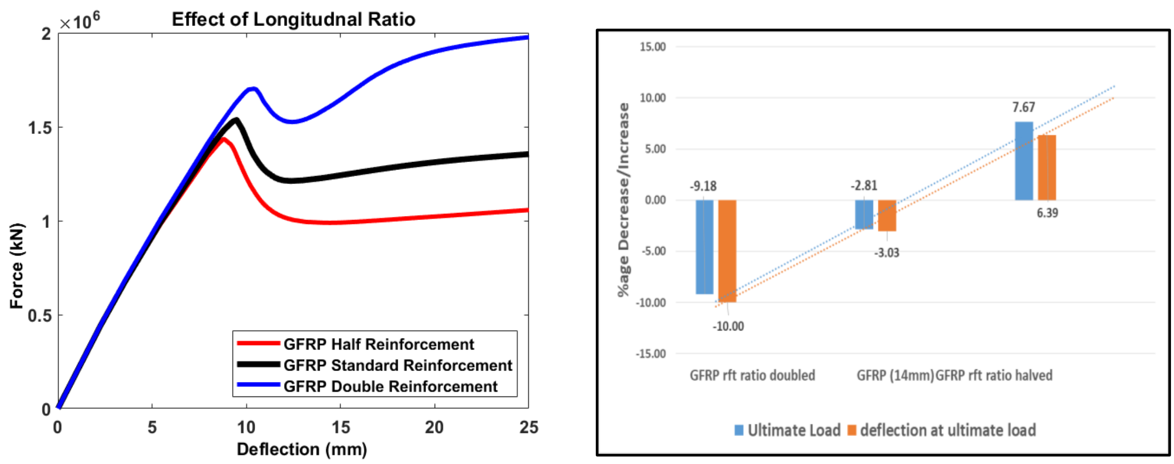

Figure 4: Effect of longitudinal ratios on load-deflection curve.

4.4 *Effect of Longitudinal Reinforcement Ratio*

The standard modelled column consisted of six 14mm GFRP longitudinal having area of 152mm^2 and reinforcement ratio of 1.86. To explore the effect of variation in GFRP reinforcement's longitudinal ratio, two more columns were modelled by doubling and halving the longitudinal ratio (one column with 10mm diameter / 76mm^2 area and second with 20mm diameter / 304mm^2 area). The increase and decrease in reinforcement ration led to a difference of +7.67 and -9.18%, respectively, in the axial load capacity of the column, thus implying a direct relationship between the axial capacity and reinforcement ratio as illustrated in Figure 4.

5 Application

The paper analyzes GFRP reinforced columns as a viable alternative to traditional steel reinforcements. FEM analysis will help all researchers to validate the results of already conducted experimental work on GFRP columns. the paper will also help designers and engineers to design and construct structurally stronger and more efficient buildings, using GFRP reinforcing materials having lesser cost and longer life than the steel reinforcements.".

6 Conclusions

This aim of the numerical study was to analyze the axial response of GFRP reinforced hollow columns, using FEM. Following are the key findings of the study:

- The load-deflection curve of FEM analysis coincided with the experimental curves of already conducted experiments, thus proving efficacy of the model.
- The GFRP-reinforced columns showed greater axial capacity and improved post-peak behavior than the steel reinforced counter-parts, thus proving GFRP reinforcement as a viable alternative to steel.
- The hollow concrete columns showed relatively lower axial capacity but considerably improved ductility than the hollow columns.
- The numerical parametric study revealed that increasing longitudinal ratio of the GFRP reinforcement, results in increased axial strength and post-peak behavior of the columns.

Acknowledgment

The authors would like to thank the advisor and all other person, who helped thorough out the research work. The careful review and constructive suggestions by the anonymous reviewers are gratefully acknowledged.

References

[1] A. Ahmad *et al.*, "Strength model for concrete columns reinforced with fiber-reinforced polymer bars and ties," *Compos. Struct.*, vol. 24, no. 1, pp. 2–3, 2020, doi: 10.1155/2020/8841795.

[2] S. A. A. Jabbar and S. B. H. Farid, "Replacement of steel rebars by GFRP rebars in the concrete structures," *Karbala Int. J. Mod. Sci.*, vol. 4, no. 2, pp. 216–227, 2018, doi: 10.1016/j.kijoms.2018.02.002.

[3] P. Ephraim M. E., Adetiloye A.Harcourt, "Mechanical Properties of Glass Fibre Reinforced Polymer Based on Resin from Recycled Plastic.," *Int. J. Sci. Eng. Res.*, vol. 6, no. 3, pp. 145–152, 2015.

[4] ACI Committee 440, *ACI 440.1R-15 Guide for the design and construction of structural concrete reinforced with Firber-Reinforced Polymer (FRP) bars*. 2015.

[5] A. M. Gora, J. Jaganathan, M. P. Anwar, and U. J. Alengaram, "Finite element analysis of rectangular reinforced concrete columns wrapped with FRP composites," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 431, no. 7, 2018, doi: 10.1088/1757-899X/431/7/072005.

[6] O. S. AlAjarmeh, A. C. Manalo, B. Benmokrane, W. Karunasena, and P. Mendis, "Effect of Spiral Spacing and Concrete Strength on Behavior of GFRP-Reinforced Hollow Concrete Columns," *J. Compos. Constr.*, vol. 24, no. 1, p. 04019054, 2020, doi: 10.1061/(asce)cc.1943-5614.0000987.

[7] A. Ahmad *et al.*, "Flexural behaviour of concrete slabs reinforced with GFRP bars and hollow composite reinforcing systems," *Compos. Struct.*, vol. 236, no. February, pp. 2–3, 2020, doi: 10.1016/j.compstruct.2019.111836.

[8] N. Tello, Y. Alhoubi, F. Abed, A. El Refai, and T. El-Maaddawy, "Circular and square columns strengthened with FRCM under concentric load," *Compos. Struct.*, vol. 255, no. September 2020, p. 113000, 2021, doi: 10.1016/j.compstruct.2020.113000.

[9] A. Hadhood, H. M. Mohamed, and B. Benmokrane, "Experimental Study of Circular High-Strength Concrete Columns Reinforced with GFRP Bars and Spirals under Concentric and Eccentric Loading," *J. Compos. Constr.*, vol. 21, no. 2, p. 04016078, 2017, doi: 10.1061/(asce)cc.1943-5614.0000734.

[10] M. Z. Afifi, H. M. Mohamed, and B. Benmokrane, "Strength and Axial Behavior of Circular Concrete Columns Reinforced with CFRP Bars and Spirals," *J. Compos. Constr.*, vol. 18, no. 2, p. 04013035, 2014, doi: 10.1061/(asce)cc.1943-5614.0000430.

[11] O. S. AlAjarmeh, A. C. Manalo, B. Benmokrane, K. Karunasena, W. Ferdous, and P. Mendis, "Hollow concrete columns: Review of structural behavior and new designs using GFRP reinforcement," *Eng. Struct.*, vol. 203, no. August 2019, p. 109829, 2020, doi: 10.1016/j.engstruct.2019.109829.

[12] K. He, Q. Lin, Y. Chen, and Z. Guo, "Compressive behavior of concrete-filled GFRP tubular stub columns after being subjected to freeze-thaw cycles," *Compos. Struct.*, vol. 255, no. May 2020, p. 112904, 2021, doi: 10.1016/j.compstruct.2020.112904.

[13] N. Nisticò, F. Pallini, T. Rousakis, Y. F. Wu, and A. Karabinis, "Peak strength and ultimate strain prediction for FRP confined square and circular concrete sections," *Compos. Part B Eng.*, vol. 67, pp. 543–554, 2014, doi: 10.1016/j.compositesb.2014.07.026.

[14] A. Ahmad and M. Iqbal, "INVESTIGATION OF DIFFERENT SHAPE OF COMPOSITE GFRP BARS IN," no. February, 2021.

[15] A. Raza, "Efficiency of GFRP Reinforcement in Concrete Columns having Hybrid Fibers : Experiments and Finite Element Analysis Efficiency of GFRP Reinforcement in Concrete Columns having Hybrid Fibers : Experiments and Finite Element Analysis," no. February, 2021.