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Analysis of Compressive Strength of Columns Reinforced with Steel & FRP Bars

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***Abstract*-To match up the requirements of advanced infrastructure, better building materials and latest technologies are required. Due to increase in corrosion problem in RC structures the useful age of structure gets reduced. So to overcome this problem engineers all over the world are getting inclined towards fiber reinforced polymers (FRP) bars in place of steel bars.**

This paper presents the results of an analytical investigation done on the behavior of concrete columns reinforced with steel, GFRP and CFRP bars.Linear analysis of 18 column specimens is accomplished using ANSYS software. The parameters investigated in this analysis includes reinforcement ratio, ultimate load bearing capacity and deformations. Also a comparative study is done amongst steel , GFRP and CFRP on the basis of these parameters.

***Keywords*-- Fiber reinforced polymer (FRP), axial behaviour, linear analysis, ANSYS.**

I. INTRODUCTION

Fibre-reinforced polymer is a complex material consisting of a polymer matrix reinforced with fibers.

The most common types of fibers used in structural applications are glass fiber reinforced polymer , aramid fiber reinforced polymer , and carbon fiber reinforced polymer. The GFRP is the least expensive but has lower strength and significantly lower stiffness compared to other alternatives. CFRP is the stiffest, durable, and expensive one. AFRP has improved durability and excellent impact resistance. FRP reinforcement is available in different forms such as bars, grids, prestressing tendons and laminates to serve a wide range of purposeses.

Earlier the use of FRP was limited to aerospace and defense purpose due to its high cost, but the increase in demand for the utilization of FRP in other fields around the world has aided the growth in research for better performance of composites at minimized costs. .

The reinforcement has high durability and stiffness whilst the matrix binds the fibres together, allowing stress to be transferred from one fibre to another and producing a consolidated structure.

In the last few years, FRP materials have emerged as promising alternative repair materials for reinforced concrete structure.

FRP plates or sheets can be bonded to the exterior of concrete structures using high strength adhesives to provide tensile or confining reinforcement which supplement that provided by internal reinforcing steel.

This research work focuses on using GFRP and CFRP bars as an internal reinforcing material for concrete columns.

II. OBJECTIVES

The main objectives of this study are

- To examine the ultimate load bearing capacity of columns reinforced with Steel, GFRP & CFRP bars.
- To examine the deformations on columns.
- To examine the effect of variation of percentage of reinforcement on strength of the column.
- To compare the loads & deformations on columns reinforced with steel,GFRP and CFRP.

III. ANALYSIS USING ANSYS SOFTWARE

The finite element analysis (FEA) using ANSYS 12.1 includes modeling a concrete column; define element type for materials, real constant, material properties, meshing, loading and boundary conditions. This section describes the different tasks and entries to be used to create the finite element model.

3.1 Modeling of Column

To create the finite element model in ANSYS 12.1 there are multiple tasks that have to be completed for the model to run properly. Using command prompt line input or the Graphical User Interface model can be created. The graphical user interface (GUI) is utilized to create this model.

In Finite Element Analysis (FEA) modelling is the most important features. It takes around 40% to 60% of the total solution time. Improper modelling of the structures leads to the unexpected errors in the solution. So, proper care should be taken for modelling the structures to avoid errors.

The model is 3200 mm long with a cross section of 300 mm X 300 mm. The characteristic compressive strength of the column is 30 N/mm^2. The details of Column specimens are shown in table I [2]. The Finite Element model of the column model is shown in Figure 1.

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TABLE I
DETAILS OF COLUMN REINFORCEMENT

Column	Main Reinf Size	Reinforcement.ratio	Stirrups size and spacing	Remarks
C1	6#12mm	0.8	(ø8mm@200mm)	Steel reinforcement in both directions
C2	8#12mm	1.005	(ø8mm@200mm)	
C3	6#16mm	1.34	(ø8mm@200mm)	
C4	8#16mm	1.787	(ø8mm@200mm)	
C5	6#20mm	2.094	(ø8mm@200mm)	
C6	8#20mm	2.792	(ø8mm@200mm)	
C7	6#12mm	0.8	(ø8mm@200mm)	GFRP reinforcement in both directions
C8	8#12mm	1.005	(ø8mm@200mm)	
C9	6#16mm	1.34	(ø8mm@200mm)	
C10	8#16mm	1.787	(ø8mm@200mm)	
C11	6#20mm	2.094	(ø8mm@200mm)	
C12	8#20mm	2.792	(ø8mm@200mm)	
C13	6#12mm	0.8	(ø8mm@200mm)	CFRP reinforcement in both directions
C14	8#12mm	1.005	(ø8mm@200mm)	
C15	6#16mm	1.34	(ø8mm@200mm)	
C16	8#16mm	1.787	(ø8mm@200mm)	
C17	6#20mm	2.094	(ø8mm@200mm)	
C18	8#20mm	2.792	(ø8mm@200mm)	

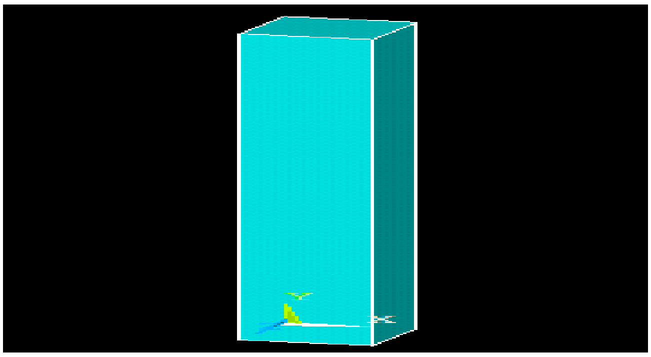

Figure 1: Finite Element Model of Column

3.2 Element Types

The element types for the model are shown in Table II.

TABLE II
ELEMENT TYPES FOR MODEL

S.no	Material	Element for Material in ANSYS
1	Concrete	Solid 65
2	Steel/GFRP/CFRP Reinforcement	Link 8

A Solid65 element is used for concrete. This element has eight nodes with three degrees of freedom at each node translation in the nodal x, y, and z directions. [6]. A schematic of the element is shown in Figure 2.

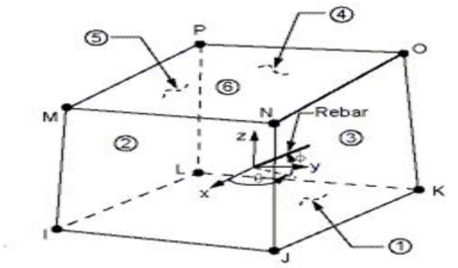

Figure 2: Element for Concrete

A Link8 element is used for steel, GFRP and CFRP reinforcement. This element has two nodes with three degrees of freedom translations in the nodal x, y, and z directions [6]. This element is capable of plastic deformation and the element is shown in the Figure 3.

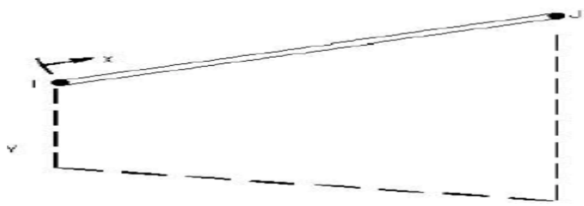

Figure 3: Element for reinforcement

3.3 Real Constants

Real Constant Set 1 is used for the Solid65 element. Real constant set 2 & set 3 are used for link 8 elements. The values of cross-sectional areas are entered.

Set 2: Longitudinal reinforcement area in mm^2

Set 3: Transverse reinforcement area in mm^2

3.4 Material Properties:

Material properties are taken from different codes [8], [9], [10], [11].

TABLE III
PROPERTIES AS PER ACI CODE

	Concrete	Steel Reinf	GFRP	CFRP
Unit Weight(N/mm3)	2.40E-05	7.90E-05	2.10E-05	1.60E+05
Ultimate compressive Strength(N/mm2)	30	N.A	N.A	N.A
Tensile Strength (N/mm2)	2.2	490	510	2070
Elastic Modulus (N/mm2)	2.40E+04	2.00E+05	5.10E+04	1.52E+05
Poisson ratio	0.2	0.3	0.2	0.2

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TABLE IV
PROPERTIES AS PER BS CODE

	Concrete	Steel	GFRP	CFRP
Unit Weight (N/mm3)	2.40E-05	7.90E-05	1.60E-05	1.50E-05
Ultimate compressive Strength (N/mm2)	30	N.A	N.A	N.A
Tensile Strength (N/mm2)	2.2	500	490	1650
Elastic Modulus (N/mm2)	2.00E+04	2.00E+05	5.00E+04	1.10E+05
Poisson ratio(μ)	0.2	0.3	0.25	0.3

TABLE V
PROPERTIES AS PER EGYPTIAN CODE

	Concrete	Steel	GFRP	CFRP
Unit Weight(N/mm3)	2.40E-05	7.90E-05	1.60E-05	2.10E-05
Ultimate compressive Strength in N/mm3	30	N.A	N.A	N.A
Tensile Strength (N/mm2)	2.2	400	600	2145
Elastic Modulus (N/mm2)	2.40E+04	2.00E+05	4.00E+04	1.20E+05
Poisson ratio(μ)	0.2	0.3	0.25	0.3

3.5 Meshing

To obtain accurate results from the Solid65 element, the use of a rectangular mesh is recommended [6]. Hence, the mesh is set up such that square or rectangular elements are created. No mesh for the reinforcement is needed because individual elements are created in the modeling. The meshing of the column is shown in Figure 4.

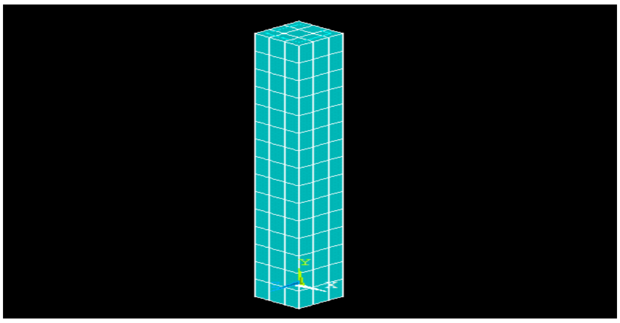

Figure 4: Meshing of Finite Element Model

3.6 Loading and Boundary Conditions

Boundary conditions are needed to constraint the model to get a unique solution. To assure that the model acts the same way as the experimental Column, boundary conditions need to be applied. The column is fixed at the bottom and load is applied on top in the form of pressure. The loading and boundary conditions of the Column are shown in Figure 5.

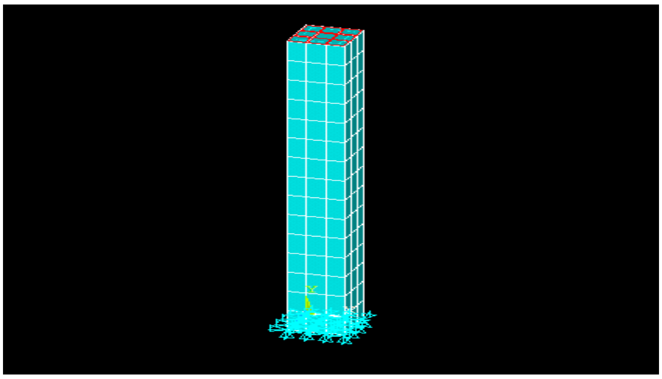

Figure 5: Displacement of column

Table VI shows the ultimate loads on columns using ultimate load carrying capacity formula on the basis of different codes [8], [9], [10], [11].

TABLE VI
ULTIMATE LOAD IN VARIOUS COLMNS (KN)

Column	Reinforcement ratio (%)	Ultimate Load in KN as per Various Code								
		ACI			BS-8110			EGYPTIAN		
		Steel	GFRP	CFRP	Steel	GFRP	CFRP	Steel	GFRP	CFRP
C1,C7,C13	0.8	1442	1449	1914	1351	1345	1975	1126	1217	1920
C2,C8,C14	1.005	1500	1510	2254	1441	1434	2274	1187	1308	2245
C3,C9,C15	1.34	1577	1590	2475	1562	1552	2672	1268	1429	2678
C4,C10,C16	1.787	1680	1698	2903	1723	1710	3203	1376	1591	3256
C5,C11,C17	2.094	1751	1772	3197	1833	1818	3568	1450	1702	3653
C6,C12,C18	2.792	1912	1940	3865	2085	2065	4397	1618	1955	4556

The ultimate load bearing capacity of column reinforced with CFRP is more than steel as well as GFRP. The result shown graphically from Figure 6 to Figure 8.

IV. COMPARISON OF RESULTS:

4.1 Linear analysis:

Table VII shows analytical results of deformations using ANSYS and also shows the comparison of deformations in columns using Steel, GFRP & CFRP as a reinforcement as per various codes. The analysis results are shown graphically from Figure 9 to Figure 11.

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TABLE VII
DEFORMATION IN VARIOUS COLUMNS USING ANSYS
(Linear analysis)

Column	Reinforcement ratio (%)	Deformation in column as per various codes(mm)								
		ACI			BS-8110			EGYPTIAN		
		Steel	GFRP	CFRP	Steel	GFRP	CFRP	Steel	GFRP	CFRP
C1,C7,C13	0.8	2.131	2.142	2.831	2.396	2.385	3.505	1.665	1.799	2.839
C2,C8,C14	1.005	2.216	2.231	3.328	2.556	2.543	4.035	1.753	1.934	3.32
C3,C9,C15	1.34	2.331	2.35	3.661	2.77	2.752	4.742	1.873	2.112	3.96
C4,C10,C16	1.787	2.483	2.509	4.293	3.056	3.033	5.685	2.033	2.35	4.816
C5,C11,C17	2.094	2.558	2.618	4.729	3.25	3.225	6.335	2.143	2.157	5.397
C6,C12,C18	2.792	2.826	2.867	5.718	3.697	3.662	7.807	1.988	2.891	6.742

4.2 Validation for deformations: The values of deformations obtained from ANSYS (In Linear Analysis) are validated with the help of Equation of Elasticity for composite material [3]. Table VIII shows the validation of deformation when steel and GFRP is used as reinforcement in concrete columns.

TABLE VIII
VALIDATION FOR DEFORMATION (mm)

Column	Reinforcement ratio (%)	ACI			BS-8110			EGYPTIAN		
		Steel	GFRP	CFRP	Steel	GFRP	CFRP	Steel	GFRP	CFRP
C1,C7,C13	0.8	2.01	2.112	2.038	2.233	2.346	3.371	1.569	1.78	2.741
C2,C8,C14	1.005	2.132	2.19	3.139	2.327	2.486	3.83	1.622	1.905	3.166
C3,C9,C15	1.34	2.101	2.29	3.379	2.448	2.669	4.423	1.689	2.07	3.718
C4,C10,C16	1.787	2.166	2.423	3.871	2.598	2.909	5.693	1.774	2.288	4.428
C5,C11,C17	2.094	2.208	2.507	4.181	2.694	3.071	5.698	1.828	2.436	4.899
C6,C12,C18	2.792	2.297	2.713	4.865	2.897	3.431	6.776	1.353	2.767	5.922

4.3 Deformation under the constant loading: Table IX shows the observations, when constant load is applied on column reinforced with Steel,GFRP & CFRP.

TABLE IX
DEFORMATION UNDER CONSTANT LOAD(mm)

Column	Reinforcement ratio (%)	Deformation in column as per various codes(mm)								
		ACI			BS-8110			EGYPTIAN		
		Steel	GFRP	CFRP	Steel	GFRP	CFRP	Steel	GFRP	CFRP
C1,C7,C13	0.8	2.131	1.892	1.732	2.396	2.121	1.960	1.665	1.476	1.366
C2,C8,C14	1.005	2.216	1.958	1.776	2.556	2.248	2.063	1.753	1.556	1.423
C3,C9,C15	1.34	2.331	2.044	1.830	2.77	2.417	2.283	1.873	1.653	1.496
C4,C10,C16	1.787	2.483	2.157	1.900	3.056	2.638	2.492	2.033	1.781	1.682
C5,C11,C17	2.094	2.558	2.235	1.947	3.25	2.786	2.486	2.143	1.868	1.652
C6,C12,C18	2.792	2.826	2.505	2.045	3.697	3.117	2.731	1.988	2.061	1.788

4.4 Reinforcement ratio Vs ultimate load Graph:

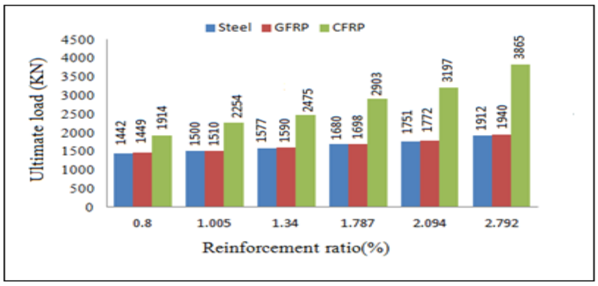

Figure 6: Reinforcement ratio Vs Ultimate load Graph as per ACI code

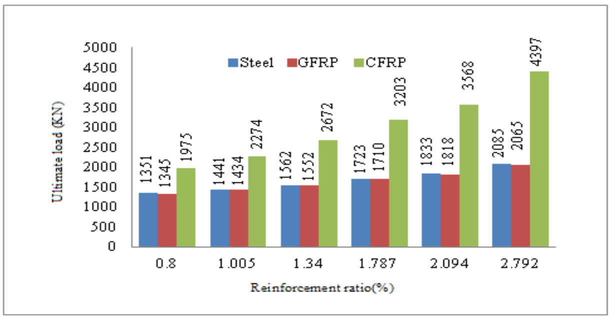

Figure 7: Reinforcement ratio Vs Ultimate load Graph as per BS code

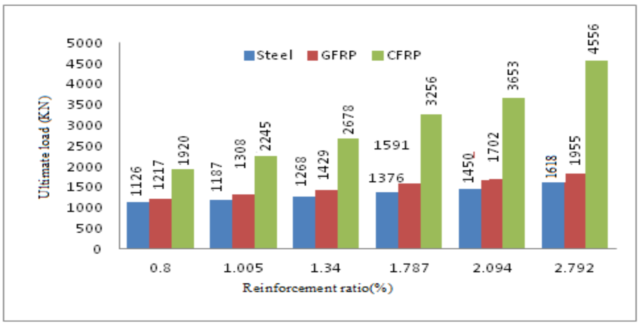

Figure 8: Reinforcement ratio Vs Ultimate load Graph as per EGYPTIAN code

7.5 Reinforcement ratio Vs deformation Graph

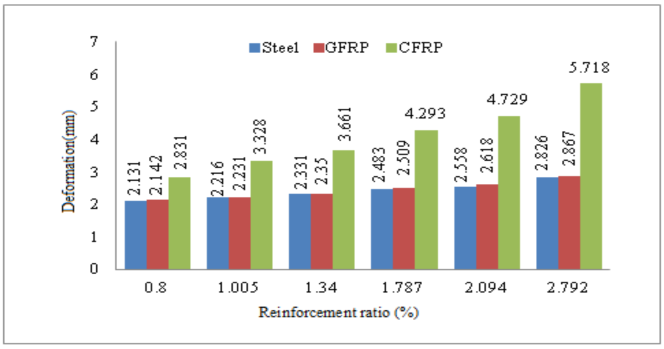

Figure 9: Reinforcement ratio Vs Deformation Graph as per ACI code

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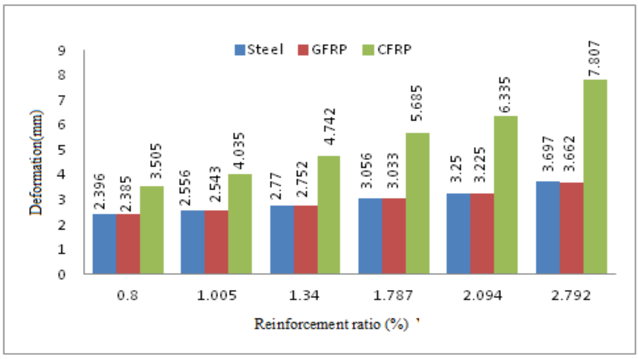

Figure 10: Reinforcement ratio Vs Deformation Graph as per BS code

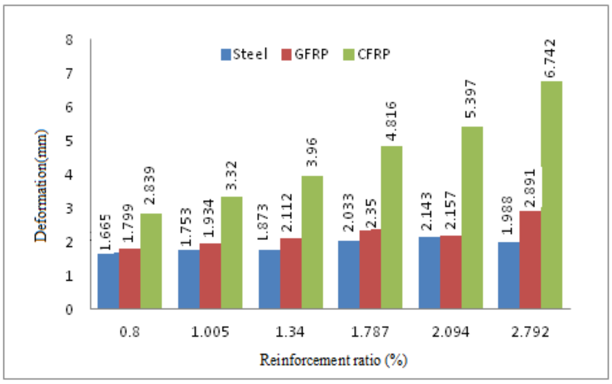

Figure 11: Reinforcement ratio Vs Deformation Graph as per EGYPTIAN code

V. CONCLUSION

The Conclusion made from this analysis are as follows:

- The deformation results from Finite Element analysis are in good agreement with the values of deformations obtained from equation of elasticity for composite material.
- Increasing reinforcement ratio from 0.8 to 2.792 % has a significant effect on ultimate loads.
- In case of CFRP the ultimate load bearing capacity of the column is significantly increased as per all codes.(32% to 181%)
- In case of GFRP the ultimate load bearing capacity of the column is significantly increased as per Egyptian code(7% to 20%),whereas there is slight increase as per ACI code(0.48% to 1.464 %) and slight decreas as per BS code(0.44% to 0.95%).
- For the same load CFRP gives 18% less deformation as compared to steel.
- For the same load GFRP gives 11% less deformation as compared to steel.

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