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Analytical Study on Seismic Performance of Self-Compacting Concrete Column Reinforced with Steel and GFRP Rebar

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Abstract: *The self-compacting concrete is described as one of the environment friendly concrete which has several benefits over ordinary concrete. The main advantages of self-compacting concrete are that problem associated with vibration is eliminated. It is a non-segregating concrete that have benefits such as high bond to reinforcing steel, superior strength and durability, improved structural integrity etc. The Glass Fiber reinforced Polymer (GFRP) rebars are preferable alternative to steel rebars for minimizing corrosion problems In this paper, analytical study is carried out to investigate the seismic performance of self-compacting concrete circular columns reinforced with GFRP rebars and are compared with columns reinforced with steel rebars. The main parameters considered for the study are slenderness ratio and confinement techniques. The circular column of slenderness ratio 4, 6, and 8 are considered for the study. The seismic performance is carried out by Push over analysis using ANSYS software.*
Keywords*: Glass fiber reinforced polymer, Seismic performance, Self-compacting concrete, Pushover analysis*

I. Introduction

Columns are basically rigid vertical structural members which plays an important role in load transfer mechanism. The strength of column mainly depends on the material used, size and the shape. In this study, the self-compacting concrete is used for the construction of circular columns. The importance of self-compacting concrete (SCC) is that it maintains concrete's durability and other characteristics, meeting expected performance requirements. The SCC is an innovative material that can be used in complex forms and members that contain congestion of reinforcement, without needing vibration as it is able to compact under its own weight. Using of self-compacting concrete can produce several benefits and advantages over regular concrete. They are improved constructability, bond to reinforcing steel, improved structural Integrity, accelerate project schedules, superior strength and durability, produce a uniform surface. Nowadays, in construction field, there are different materials which are used as an alternative for steel reinforcement. The use of Glass Fiber-Reinforced Polymer (GFRP) reinforcement as an alternative to steel reinforcement has developed significantly in recent years due to its excellent corrosion resistance; high tensile-strength-to-weight ratio, non-magnetic, non-conductive and it also become a best solution for projects requiring improved corrosion resistance or reduced maintenance costs. In this study, the slenderness ratio and confinement technique have greater influence in the performance of column. According to slenderness ratio, columns are divided in to different heights and the FRP tube is used for the confinement of the circular column.

II. Literature Review

Ahmed Hassana, Fouad Khairallahb, Hala Mamdouhb, Mahmoud Kamala (2018) in their study evaluated the overall behavior of self-compacting short concrete columns with different reinforcement type .Major parameters, including reinforcement-type, confinement techniques and the slenderness ratio of columns, are studied. The FRP tube and spiral stirrups with two different volumetric ratios are considered as strengthening techniques. The behavior of columns were evaluated based on mode of failure, axial compressive load, load-displacement curve, stressreinforcement bars strain curve, ultimate, ductility and effect of the slenderness ratio. The slenderness ratios have an equivalent effect on column capacity for the different strengthening techniques, which have approximately 5% and 10% for the slenderness ratios of 6 and 8, respectively. The column capacity of steel reinforcement is higher compared to FRP bars by approximately 22% of the column capacity.

Mohammad Khanmohammadi & Mohammad Arabpanahan (2017) developed an analytical-empirical model inspired from damage mechanism observed in tests, to simulate the lateral response of columns reinforced with plain bars and validated with experimental tests accessible in literature. From an exact integration solution of the bond-slip degradation for tensile bar in column and footing, the slip part of displacements was calculated using displacement decomposition approach and a novel categorization of lateral behavior. The proposed approach was compared with available test results and by parametric study; a relationship was suggested to predict rotational capacity of the column. Pushover is a static-nonlinear analysis method where a structure is subjected to gravity loading and a monotonic displacement-controlled lateral load pattern which continuously increases through elastic and inelastic behavior until an ultimate condition is reached. Push over analysis is carried out using ANSYS software. The column is considered as fixed at the bottom and an axial load is applied at the top in order to restrain the column axially. The maximum lateral load considered for the study is 500kN.The column is subjected to incremental lateral load up to the breaking point.

M. Mahgub, A. Ashour, D. Lam, X. Dai (2017) conducted an experimental study on the axial compressive behavior of self-compacting concrete filled elliptical steel tube columns. In this study, ten specimens were tested including two empty columns, with various lengths, section sizes and concrete strengths. The experimental results indicated that the failure modes of the self-compacting concrete filled elliptical steel tube columns with large slenderness ratio were higher due to global buckling. It was also clear that the composite columns possessed higher critical axial compressive capacities than hollow section due to the composite interaction. The change of compressive strength of concrete core did not shown significant effect on the critical axial compressive capacity of concrete filled columns due to large slenderness ratio. The axial compressive capacity increased with increase in the concrete grade. It was concluded that the comparison between the axial compressive load capacities obtained from experimental study and from prediction using simple methods from Euro code 4 for concrete-filled steel circular tube columns showed an approximately similar results.

Ahmed Hassana, Fouad Khairallah, HalaMamdouh, MahmoudKamala (2019) conducted an experimental and analytical study to investigate the behavior of GFRP reinforcement versus traditional steel reinforcement in self-compacting concrete columns under eccentric loads. The SCC columns reinforced by steel and GFRP longitudinal rebars having different slenderness ratios were considered. The two confining techniques of tubes and spirals were used. The column specimens were tested using a three-dimensional steel frame set-up under an incremental force control until failure. The result indicates that GFRP-reinforced columns have lower carrying capacities than the steel-reinforced columns. Furthermore, the two confining materials improve this reduction. The ductility and compressive strength of the steel and GFRP-reinforced concrete column specimens decrease with an increase in the slenderness ratio. The steel-reinforced concrete column specimens have a higher ductility than the GFRP-reinforced concrete column specimens, with a difference of 17%. The analytical results show good agreement with the experimental results for steel-reinforced columns, but in case of GFRP reinforced column it was not a good agreement.

Kissman V, Lenin Sundar (2019) conducted study on the introduction of Glass Fiber Reinforced Polymer wrap (GFRP) on the existing concrete element. For this study the concrete specimens of cube, cylinder and column were casted in a concrete grade of M40 and the structural behavior of RC column retrofitted with GFRP wraps were investigated including the compressive strength, split tensile strength, load deflection behavior, ultimate load carrying capacity etc. The properties of concrete with GFRP sheet wrapping was compared to the conventional concrete. From the study, it was concluded that there is considerable improvements in the load carrying capacity due to GFRP wrapping. The concrete cube specimen with GFRP gives the compressive strength, greater than normal Concrete. Axial and lateral deflection of both single and double layer GFRP columns are increased compared to the conventional column

Shahad Abdul Adheem Jabbar et.al (2018) conducted study on the mechanical characterizations of reinforced concrete with GFRP rebars and compared with that of steel rebars. The concrete samples such as unreinforced concrete, smooth GFRP reinforced concrete, sand coated GFRP reinforced concrete and steel reinforced concrete with fixed ratio of ingredients (1:1.5:3) and the W/C ratio of 0.5 were prepared at two curing ages of 7 and 28 days in ambient temperature. The volume fraction of GFRP and steel rebars in the reinforced concrete was equally distributed with specified distances in the mould. The results show that the tensile strength of GFRP rebar is 593 MPa and bend strength is 760 MPa. The compressive strength was within reasonable range of concrete and it is about 25.67 MPa. The flexural strength of unreinforced concrete is 3 MPa and reinforced concrete with GFRP rebar, especially sand coated GFRP RC is 13.5 MPa.

Huang Yijie , Xiao Jianzhuang, Shen Luming (2016) prepared a model for evaluating structural damage of recycled aggregate concrete filled steel tube (RCFST) columns under seismic effects. The proposed model takes the lateral deformation and the effect of repeated cyclic loading into account. Available test results were collected and utilized to calibrate the parameters of the proposed model. The recycled coarse aggregate (RCA) replacement percentage and the bond-slip property are the main test parameters involved in the study. The results indicate that the RCA content have influence on seismic performance and their damage index increases with increase in RCA replacement percentage. By the variation of the RCA replacement percentage, the damage degree of RCFST changes. Finally, it was suggested to implement an improvement procedure to compensate the performance difference between the RCFST and normal concrete filled steel tubes (CFST) by comparing the RCA contents, lateral deformation ratio and damage degree.

III. Analytical Study

Pushover is a static-nonlinear analysis method where a structure is subjected displacement controlled lateral loading. Push over analysis is carried out using ANSYS software.

Specimen details:

The analytical study is carried out to investigate the seismic behavior self-compacting concrete column reinforced with steel and Glass fiber reinforced polymer (GFRP) rebar. The main parameters involved in the study are slenderness ratio, types of reinforcement and confinement techniques. The different slenderness ratios taken are 4, 6, and 8.The confinement techniques used is FRP tube confinement. In this study, 12 circular column specimens were tested in which 6 columns are confined with FRP tube. The column specimens are classified in to three different heights according to slenderness ratio i.e., 60cm, 90cm, and 120cm. The thickness of the FRP tube is 4.5mm. The inner and outer diameter of the FRP tube is 150mm and 159mm respectively. The column design details are shown in Table no.1.

Table no 1:Column design details.

Compressive strength (f_{ck})	25N/mm^2
Diameter of column (D)	150mm
Core diameter (D_{core})	70mm
Main reinforcement	6no.s of 12mm diameter bars
Helical reinforcement	6mm diameter bars @40mm c/c

The properties of reinforcements and FRP tube are given in Table no. 2 and Table no.3 respectively. The specimen details are shown in Table no.4.

Table no 2: Properties of reinforcements

Type of reinforcement	Tensile strength (N/mm^2)	Young’s Modulus
Steel	415	20000
GFRP	1191.46	51000

Table no 3: Properties of FRP tube

Thickness (mm)	Inner diameter (mm)	Outer diameter (mm)	Young's Modulus(MPa)	Tensile strength(MPa)
4.5	150	159	3447	58

Table no 4: Specimen details

Specimen name	Height (cm)	Type of reinforcement
S60	60	Steel
S90	90	
S120	120	
G60	60	GFRP
G90	90	
G120	120	
Column with FRP confinement		
SF60	60	Steel
SF90	90	
SF120	120	
GF60	60	GFRP
GF90	90	
GF120	120	

Modeling, Loading and support conditions:

Finite element modeling is carried out using ANSYS workbench. The column reinforced with steel reinforcement, with GFRP reinforcement, and column confined with FRP tube reinforced with steel reinforcement as well as GFRP reinforcement are modeled. In case of column without FRP confinement, concrete have mesh size of 20mm and for column with FRP confinement, the mesh size of FRP tube is 5mm. The column is fixed at the bottom and an axial pressure of 53kN is applied at the top to restrain the column axially. The maximum lateral load considered is 500kN. The column is subjected to incremental lateral load up to the breaking point to evaluate the seismic behavior. The modeling diagram and the loading and support condition diagram of column with varying heights are shown in figures below. The reinforcement details and loading diagram of the column are shown in Fig no 1 and Fig no 2.

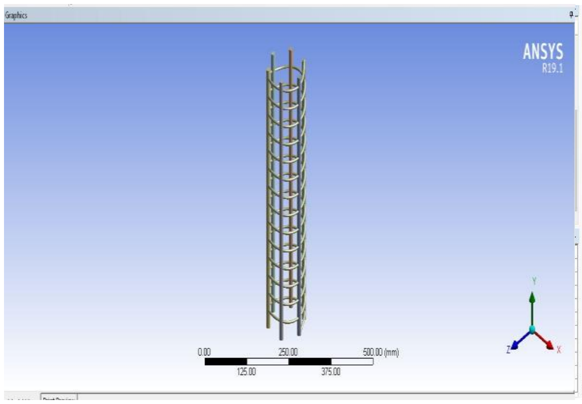

Fig no. 1 Reinforcement details

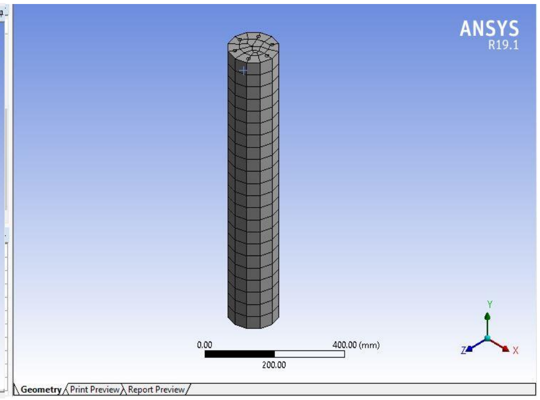

Fig no. 2 Mesh diagram of column without confinement

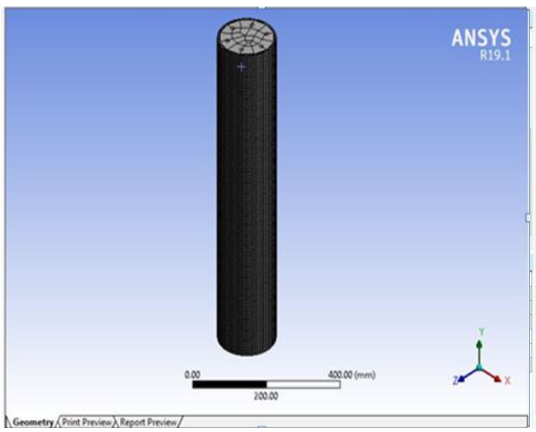

Fig no.3 Mesh diagram of column with confinement

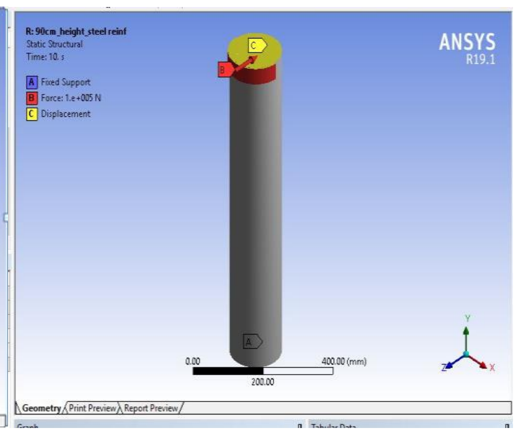

Fig no.4 Loading and support condition

Column without confinement:

The modeling diagram of column without confinement of height 60cm, 90cm and 120cm are shown in Fig no. 5, Fig no.6 and Fig no.7 respectively**.**

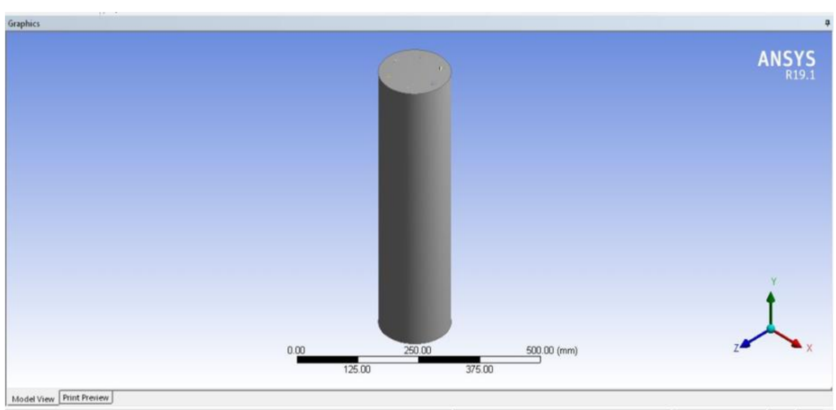

Fig no.5 Column of height 60cm

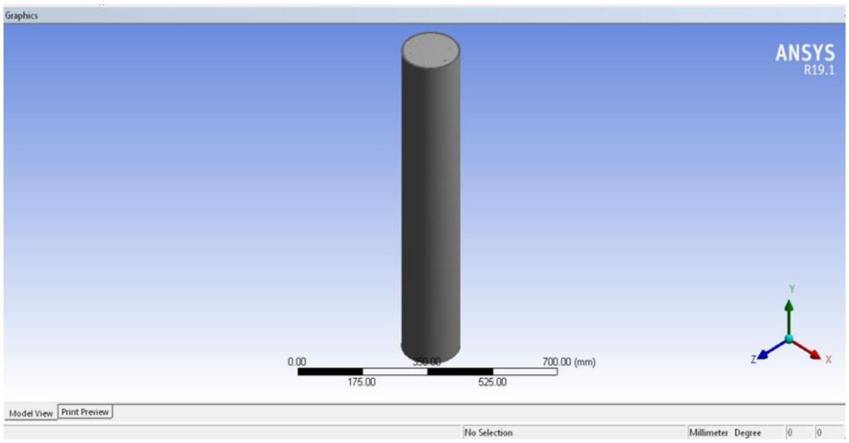

Fig no.6 Column of height 90cm

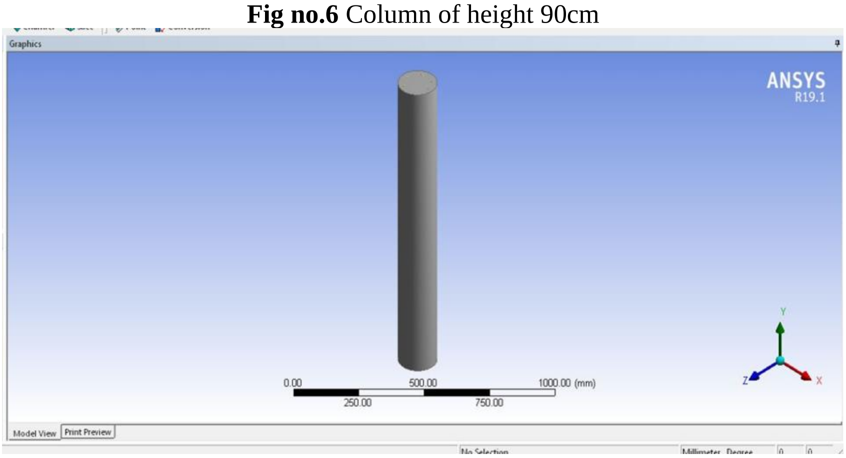

Fig no.7 Column of height 120cm

Column without confinement

The modeling diagram ofcolumn with FRP tube confinement of height 60cm, 90cm and 120cm are shown in Fig no. 8, Fig no.9 and Fig no.10 respectively.

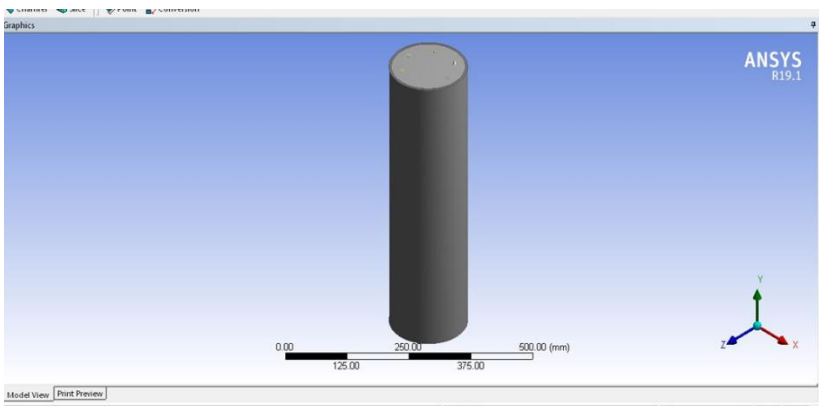

Fig no.8 Column of height 60cm

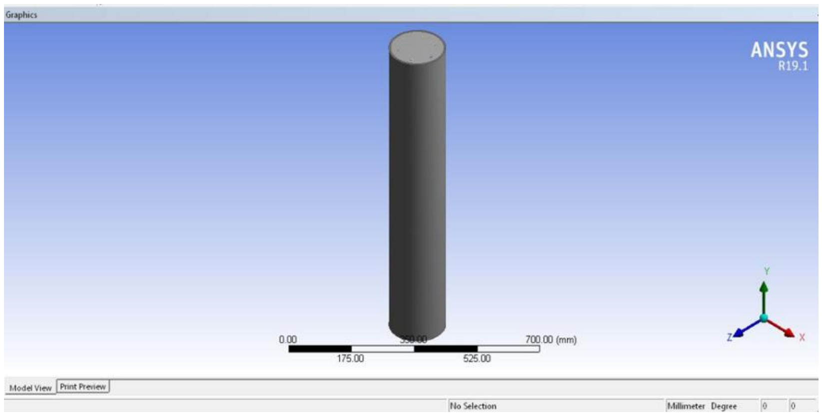

Fig no.9 Column of height 90cm

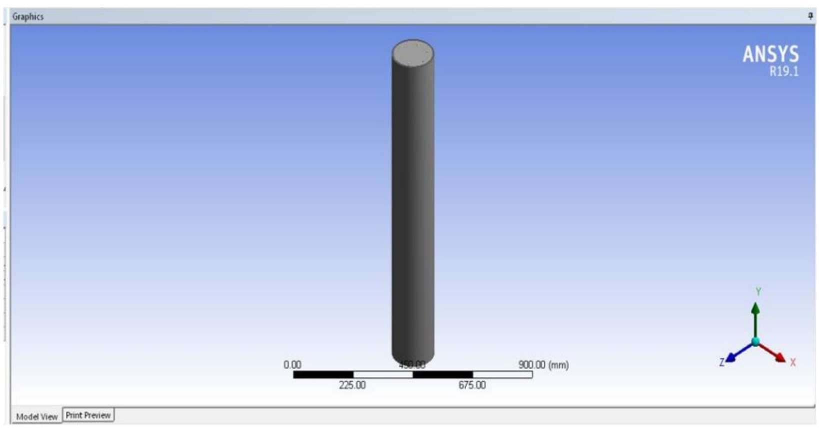

Fig no.10 Column of height 120cm

IV. Results and Discussions

Column without confinement

- **Model S60 and Model G60:**

The load deformation graph of 60cm height column reinforced with steel and GFRP rebar is shown in Fig no.11. From the below graph, it is clear that the load carrying capacity and deformation of column reinforced with GFRP rebars is higher than column reinforced with steel rebar. The maximum load and maximum deformation of the column is shown in Table no.2. The energy absorption capacity of column reinforced with GFRP rebar is $2.87*10^5$N-mm and the column reinforced with GFRP rebar is $8.69*10^5$N-mm.

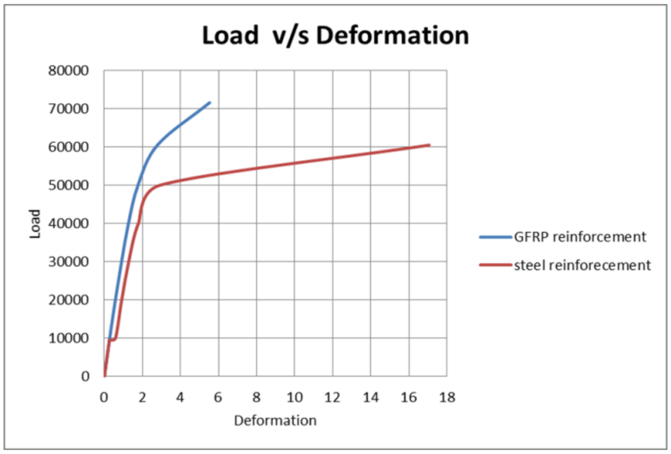

Fig no.11 Load v/s Deformation graph of Model S60 and Model G60

Table no.2 Maximum load and Maximum deformation of Model S60 and Model G60

Model S60		Model G60	
Maximum load (N)	Maximum deformation (mm)	Maximum load (N)	Maximum deformation (mm)
60509	17.064	71594	5.529

- **Model S90 and Model G90**

The load deformation graph of 90cm height column reinforced with steel (Model S90) and GFRP rebar (Model G90) is shown in Fig no.12 .From the below graph, it is clear that the load carrying capacity and deformation of column reinforced with GFRP rebars is higher than column reinforced with steel rebar. The maximum load and maximum deformation of the column is shown in Table no.3. The energy absorption capacity of column reinforced with GFRP rebar is greater and it is about $1.42*10^6$N-mm. The energy absorption capacity of column reinforced with steel rebar is $3.16*10^5$N-mm.

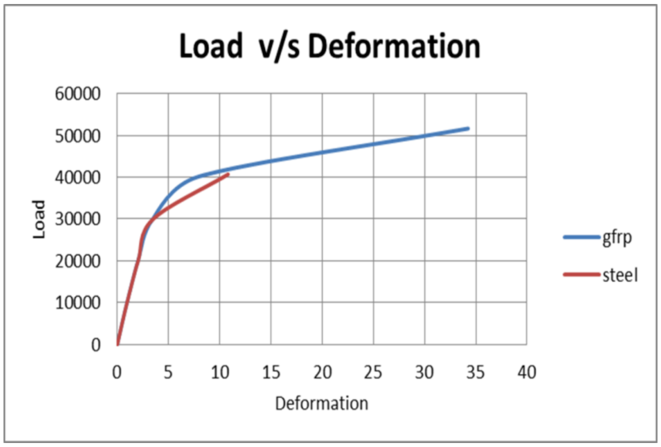

Fig no.12 Load v/s Deformation graph of Model S90 and Model G90

Table no.3 Maximum load and Maximum deformation of Model S90 and Model G90

Model S90		Model G90	
Maximum load (N)	Maximum deformation (mm)	Maximum load (N)	Maximum deformation (mm)
40677	10.809	51647	34.25

- **Model S120 and Model G120:**

The load deformation graph of 120cm height column reinforced with steel (Model S120) and GFRP rebar (Model G120) is shown in Fig no.13 .From the below graph, it is clear that the load carrying capacity and deformation of column reinforced with GFRP rebar is higher than column reinforced with steel rebar. The maximum load and maximum deformation of the column is shown in Table no.4. The energy absorption capacity of column reinforced with GFRP rebar is greater and it is about 970476.61N-mm. The energy absorption capacity of steel reinforced column is 485113.10N-mm.

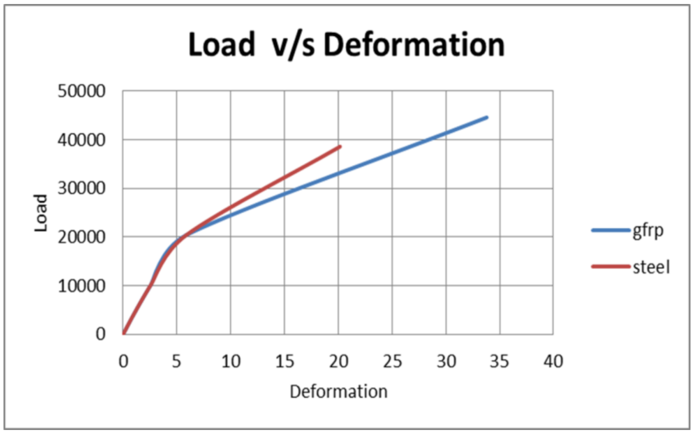

Fig no.13 Load v/s Deformation graph of Model S120 and Model G120

Table no.4 Maximum load and Maximum deformation of Model S120 and Model G120

Model S120		Model G120	
Maximum load (N)	Maximum deformation (mm)	Maximum load (N)	Maximum deformation (mm)
38564	20.167	44551	33.795

Column with FRP tube confinement

- **Model SF60 and Model GF60:**

The load deformation graph of 60cm height column reinforced with steel (Model SF60) and GFRP rebar (Model GF60) is shown in Fig no.14 .From the below graph, it is clear that the load carrying capacity and deformation of column reinforced with GFRP rebar is higher than column reinforced with steel rebar. The maximum load and maximum deformation of the column is shown in Table no.5. The energy absorption capacity of column reinforced with GFRP rebar is greater and it is about2.65*10^6N-mm. The energy absorption capacity of column reinforced with steel rebar is 1.55*10^6N-mm.

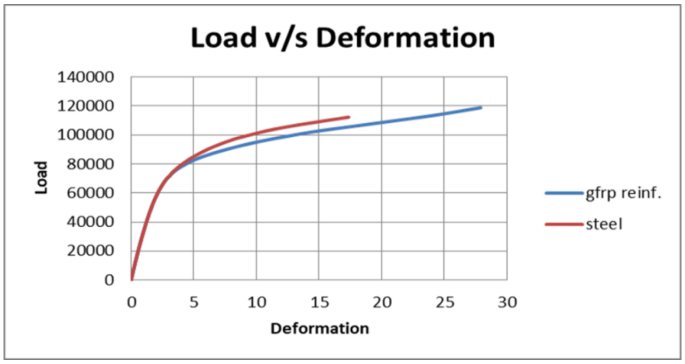

Fig no.14 Load v/s Deformation graph of Model SF60 and Model GF60

Table no.5 Maximum load and Maximum deformation of Model SF60 and Model GF60

Model SF60		Model GF60	
Maximum load (N)	Maximum deformation (mm)	Maximum load (N)	Maximum deformation (mm)
1.12*10^5	17.353	1.19*10^5	27.886

- **Model SF90 and Model GF90:**

The load deformation graph of 90cm height column reinforced with steel (Model SF90) and GFRP rebar (Model GF90) is shown in Fig no.15.From the below graph, it is clear that the load carrying capacity and deformation of column reinforced with GFRP rebar is higher than column reinforced with steel rebar. The maximum load and maximum deformation of the column is shown in Table no.6. The energy absorption capacity of column reinforced with GFRP rebar is greater and it is about1.92*10^6N-mm. The energy absorption capacity of column reinforced with steel rebar is 1.32*10^6N-mm.

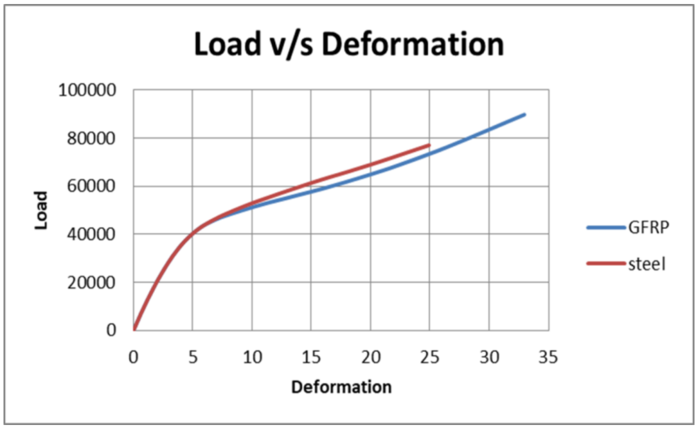

Fig no.15 Load v/s Deformation graph of Model SF90 and Model GF90

Table no.6 Maximum load and Maximum deformation of Model SF90 and Model GF90

Model SF90		Model GF90	
Maximum load (N)	Maximum deformation (mm)	Maximum load (N)	Maximum deformation (mm)
77009	24.926	89710	32.968

- **Model SF120 and Model GF120:**

The load deformation graph of 120cm height column reinforced with steel (Model SF120) and GFRP rebar (Model GF120) is shown in Fig no.16.From the below graph, it is clear that the load carrying capacity and deformation of column reinforced with GFRP rebar is higher than column reinforced with steel rebar. The maximum load and maximum deformation of the column is shown in Table no.7. The energy absorption capacity of column reinforced with GFRP rebar is greater and it is about1060748.05N/mm. The energy absorption capacity of column reinforced with steel rebar is 766048.24N/mm.

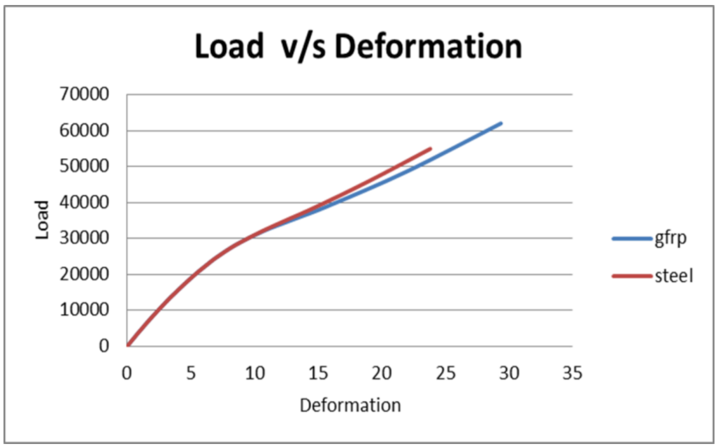

Fig no.16 Load v/s Deformation graph of Model SF120 and Model GF120

Table no.7 Maximum load and Maximum deformation of Model SF120 and Model GF120

Model SF120		Model GF120	
Maximum load (N)	Maximum deformation (mm)	Maximum load (N)	Maximum deformation (mm)
54960	23.812	62041	29.362

V. Conclusion

The seismic performance of self-compacting concrete column reinforced with steel and GFRP rebar were evaluated. It was concluded that,

- In case of each height, the column reinforced with GFRP rebars have higher seismic behavior compared to column reinforced with steel rebar.
- The load carrying capacity is higher for columns reinforced with GFRP rebar than columns reinforced with steel rebars.
- The deformation is also higher for all columns reinforced with GFRP rebars except column of height 60cm without confinement.
- The energy absorption capacity is higher for columns reinforced with GFRP rebar except column of height 60cm without confinement.
- The maximum deformationcapacity is for columns of height 90cm reinforced with GFRP rebars both in case of with and without confinement.
- The deformation of column of height 90 cm with and without confinement is 32.968mm and 34.25mm respectively.
- The maximum load carrying capacity is for columns of height 60cm reinforced with GFRP rebars both in case of with and without confinement.
- The load carrying capacity of column of height 60 cm reinforced with GFRP rebars with and without confinement is $1.19*10^5$ N and 71594N respectively

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