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Research Article

Structural Behaviour of RC Multi-Storey Building With GFRP Reinforcement Subjected to Seismic Load By Linear Dynamic Analysis

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Abstract

Reinforced concrete multi-storey buildings undergo damages on a very large scale during an earthquake. It is indispensable to study the seismic behaviors of structure and make the structures safe. In recent time, studies have revealed that the use of GFRP material in building constructions. GFRP material is corrosion resistant, it has long term durability and high tensile strength, thus making its performance superior to that of steel material. Response Spectrum method is adopted for seismic evaluation of G+14 RC multi-storey building having steel rebar and GFRP rebar. The Modeling and Analysis is carried out in ETABS Ultimate 18.0.2 software. The steel rebar and GFRP rebar modeling is done for all three Soil Types in Seismic zone III as described in IS 1893 Part I: 2016. In this study the different models have been analyzed by using Response Spectrum function in Longitudinal and Transverse directions. The results of the analysis are acquired in terms of storey displacement, drift, shear, stiffness, modal acceleration, and modal time. From the current study it is seen that these results are fewer in GFRP rebar as compared to Steel rebar material.

Keywords: *RC multi-storey building, GFRP rebar, Steel rebar, Response Spectrum method, Responses, ETABS*

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Introduction

The Fibre reinforced polymer (FRP) is made up of composite materials. The evolution of FRP was initiated by various industries for optimum use in engineering applications. The FRP material are used significantly in aircraft, automobiles, and many other types of sports gears. Reinforced concrete is most widely used material for civil projects like buildings, bridges, highways, roads, marine structures and many more. The RC structures are having many disadvantages such as corrosion of internal reinforcing steel bars leads to maintenance, repairs and rehabilitation. The damages and deterioration of RC structures are very costly from the repair point of view and to maintain its serviceability for future use. This has become a motivation for engineers and researchers to find alternative for traditional reinforced concrete. Recently GFRP rebar materials are widely adopted in civil Engineering projects to increase the strength and corrosion resistance of structures by increasing their durability and in turn ensuring greater life of the structures.

Due to the unpredictable effect of earthquake, the entire world suffers huge losses and human life in the occurrence of earthquake. It is considered that the natural earthquake is most disastrous lateral forces acting on structure. It is a sudden transient motion of the ground which generates enormous energy in a fraction of second and the entire structural members are acted upon by earthquake forces. Impact of earthquake forces generates dynamic responses in the building due to induced ground motion. These responses caused due to seismic loads can be analyzed using Response Spectrum Analysis.

Lıterature Survey

Kumar and Vinod (2017) studied the seismic assessment of GFRP rebar and steel rebar of concrete structure. The study involves seismic analysis using equivalent lateral force method to get the parametric results. The results of seismic parameters are more in steel rebar than GFRP rebar. [5]

Prasad and Mathew (2017) conducted seismic analysis and cost estimation of a auditorium building by using GFRP and conventional steel. It was noted that GFRP is a good material when compared to RCC with respective easy to use, economic, fire resistance, corrosion etc. GFRP is better than steel rebar when compared with seismic parameters and in performance. [6]

Rafai and Sangave (2016) conducted a study on the nonlinear pushover analysis of a multi-storey building having FRP material. Seismic response of multi-storey, multi bay structure using GFRP reinforcement was obtained. The load sustain by GFRP reinforcement frame is more than the steel reinforcement frame and GFRP bars attracts more base shear force due to its anisotropic behavior. [7]

Arnaud et al. (2015) investigated the evolution of tensile properties and bond of GFRP bars under accelerated laboratory conditions in concrete. The GFRP rebars were studied as these bars are considered as they are most economical in comparison with conventional steel bars. [8]

Kattimani et al. (2018) conducted a study and concluded that the storey displacement, drift will be more in structure which uses steel reinforcement. The GFRP bars shows better results when it is compared to reinforcing steel bars. The load carrying capacity of GFRP rebar is more than Steel rebar so it can be utilized for construction of high-rise buildings. [9]

In present study structural behavior of RC multi-storey building with GFRP reinforcement is obtained under seismic condition by performing linear dynamic analysis.

Methodology

A G+14 RC multi-storey building with GFRP Rebar and steel rebar subjected to seismic load for Soil Type I, II and III are modelled and analyzed for seismic zone -III by Response Spectrum Analysis using ETABS Ultimate 18.0.2 software. The six models have been created and analyzed for seismic lateral loads to obtain the responses in terms of maximum storey displacement, drift, shear, stiffness, modal acceleration, and modal time. IS:1893-2016 (Part 1), IS:456-2000, IS:875-1987 (Part 1) and IS:875-1987 (Part 2) are used in this study. Table I shows the general building data used as input for the analysis.

Table II shows the properties of materials, Table III shows member dimension, Table IV shows member dimension and Table IV shows the types od load used in the study.

Table I: detailed data of building

Building Type	Residential RC building with Steel Rebar and GFRP Rebar
Building plan dimensions	30 m X 20 m
Bays in X-direction and Y- direction	6 bays @ 5m each and 4 bays @ 5m each
No. of Storey	15 nos.
Floor to floor height	3m
Concrete Grade	M30
Steel Grade	Fe415
Grade of GFRP	GFRP AKS (1200 MPA)
Zone Factor (Z)	For Zone III; Z= 0.16
Soil Type	I, II and III
Importance factor	I = 1.2
Response Reduction Factor	R = 5

Table II: properties of materials

Material Properties	Steel	GFRP
Specific Weight Density (kg/m^3)	7849.047	1950
Modulus of Elasticity (MPA)	200000	55000
Coefficient of Thermal Expansion (per ^{0}C)	0.0000117	0.00001
Yeild Strength (MPA)	415	1200
Tensile Strength (MPA)	485	1200
Expected Yield Strength (MPA)	415	1200

Expected Tensile Strength (MPA)	485	1200
Cost (In Rupees per metric ton)	45,000/-	1,50,000/-

Table III: Member dimension

Size of Beam	0.3m × 0.45m
Size of Column	0.6m × 0.6m
Slab thickness	0.175m

Table IV: types of Load

Flooring	1.296 (kN/m^2)
Live load	3 (kN/m^2)
Live load on terrace	1.5 (kN/m^2)
Super Imposed	12.433 (kN/m^2)

The models are analyzed using Response Spectrum Method considering excitation both in longitudinal and transverse directions for different load combinations (Table V).

Table V: load combinations

Response spectrm analysis	Load Combinations
X-direction	1.2 [DL+ IL ± (ELx ± 0.3 ELy)] 1.5 [DL ± (ELx ± 0.3 ELy)] 0.9 DL ± 1.5 (ELx ± 0.3 ELy)
Y-direction	1.2 [DL+ IL ± (ELy ± 0.3 ELx)] 1.5 [DL ± (ELy ± 0.3 ELx)] 0.9 (DL) ± 1.5 (ELy ± 0.3 ELx)

Analysis is carried out for six models named as, Model l,2,3,4,5, and 6. First three models for steel rebar material (fig.1) are modeled and remaining three for GFRP rebar material (fig. 2) for Soil Type I, II and III in seismic zone-III.

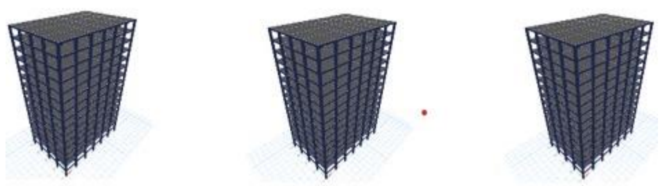

Fig. 1: Models 1, 2 and 3 for steel rebar for Soil Type I, II and III.

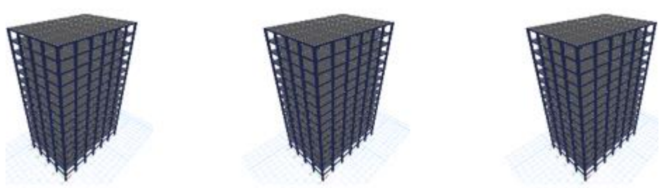

Fig. 2: Models 4, 5, 6 for GFRP rebar for Soil Type I, II, III.

Results And Discussion

Results by conducting the Response spectrum analysis in longitudinal and transverse directions are represented in terms of maximum storey displacement, drift, shear, stiffness, modal acceleration, and modal time.

Discussion about the results is described briefly below the respective figures. The quantity and cost comparison between Steel rebar material and GFRP rebar material is shown in the respective table and figure.

Fig.3 and fig.4 shows the maximum displacement for longitudinal and transverse direction respectively. The maximum storey displacement was observed in longitudinal and transverse direction is in steel rebar material as compared to GFRP rebar material.

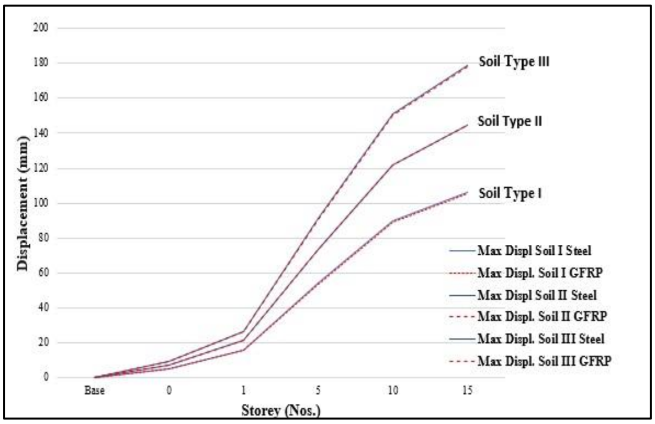

Fig. 3: Maximum Storey Displacement in longitudinal direction for Soil Type I, II, III

The maximum storey displacement is observed at top storey in Steel rebar material for Soil Type I, II and III. This may be due to high ductility of Steel rebar material and as GFRP rebar material are brittle.

Fig. 5 and 6 shows the maximum drift in longitudinal and transverse direction. It is seen that maximum storey drift in longitudinal and transverse direction is fewer in GFRP rebar

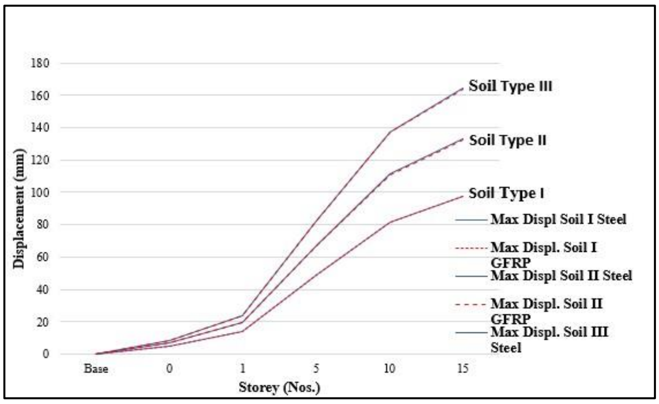

Fig 4: Maximum Storey Displacement in transverse direction for Soil Type I, II, III

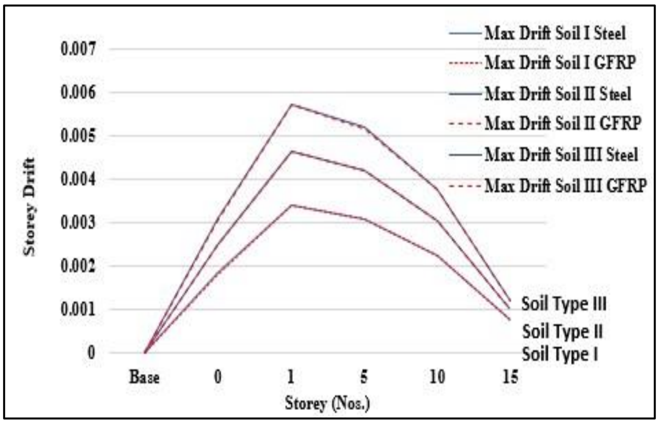

Fig 5: Maximum Storey Drift in longitudinal direction for Soil Type I, II, III

as compared to Steel rebar. Maximum storey drift observed in-between ground and first floor level in Steel rebar material for all Soil Types. It is worth to note that there is a marginal variation of in the maximum storey drift between GFRP rebar and Steel rebar material.

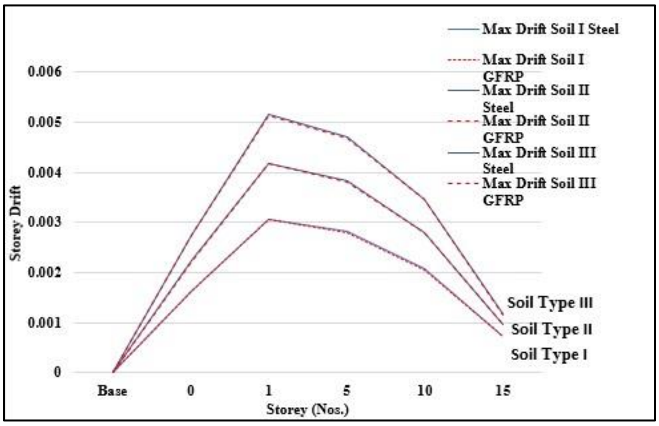

Fig 6: Maximum Storey Drift in transverse direction for Soil Type I, II, III

The storey shear is shown in fig. 7 and fig. 8 for longitudinal and transverse direction respectively. Storey shear in longitudinal and transverse direction is less in GFRP rebar

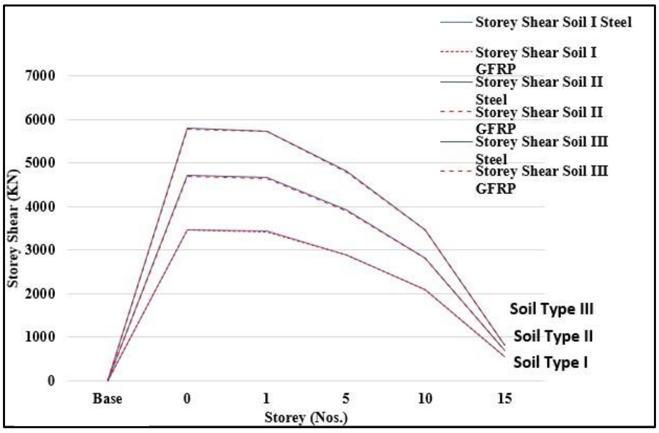

Fig 7: Storey Shear in longitudinal direction for Soil Type I, II, III

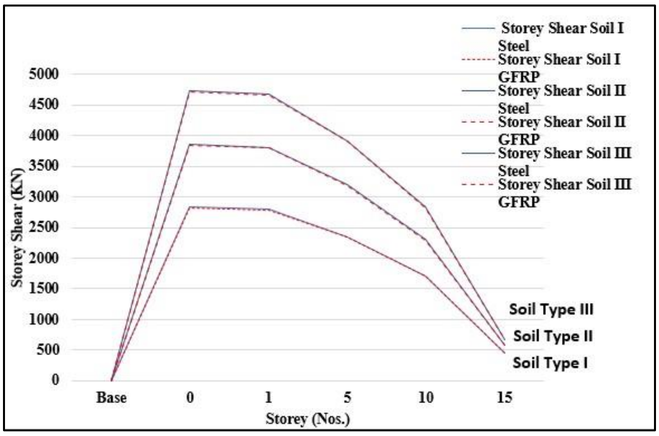

Fig 8: Storey Shear in transverse direction for Soil Type I, II, III

material as compared to steel rebar material. Ground floor shows the maximum storey shear also known as base shear is less in GFRP rebar material when compared to steel rebar material. It is seen that there is a variation of 0.40% to 0.50% in the storey shear between GFRP rebar and Steel rebar material. This may be due to the anisotropic behavior of GFRP rebar material.

Fig. 9 and fig. 10 shows the story stiffness in longitudinal and transverse direction respectively.

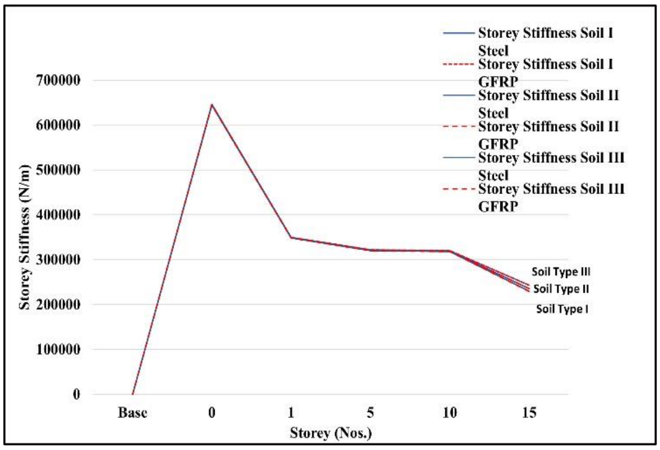

Fig 9: Storey Stiffness in longitudinal direction for Soil Type I, II, III

It is observed from fig. 9 and fig. 10 that the floor stiffness in longitudinal and transverse direction is less in GFRP rebar material as compared to Steel rebar material. The maximum storey stiffness is observed at the ground floor which is less in GFRP rebar material when compared with Steel rebar material. It is seen that there is a minimum variation in the storey stiffness between GFRP rebar and Steel rebar material, this may be due to GFRP rebar material has less modulus of elasticity as compared to the Steel rebar material.

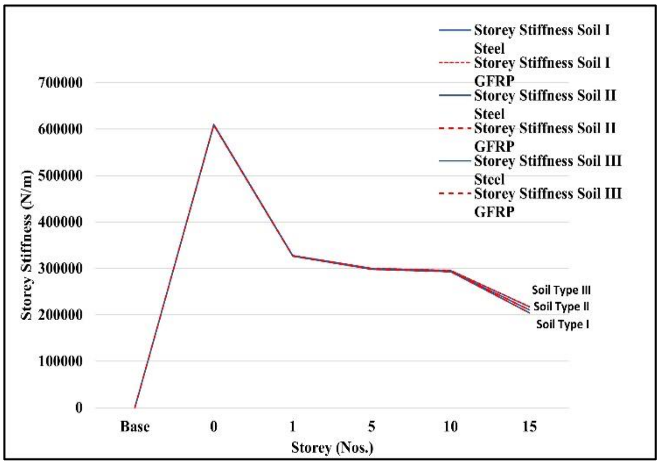

Fig 10: Storey Stiffness in transverse direction for Soil Type I, II, III

Modal acceleration is shown in fig. 11 and 12 for longitudinal and transverse direction. This is worth to note the modal acceleration in longitudinal and transverse direction is more in GFRP rebar material over steel rebar material for mode 1 and is less in GFRP rebar material than Steel rebar material as the mode number increases. The maximum modal acceleration is noticed 2214.08, 2222.27, 2237.03 mm/sec^2 in mode number 12 for Soil type I, II and III in longitudinal direction for steel rebar material.

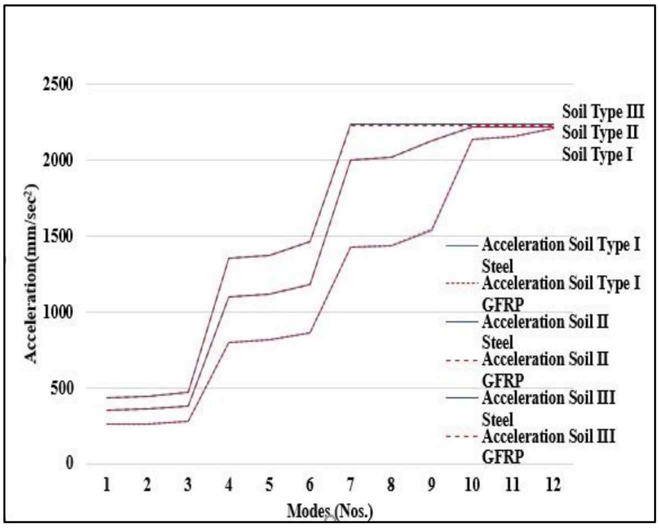

Fig 11: Modal Acceleration in longitudinal direction for Soil Type I, II, III

The maximum modal acceleration (fig.11 and fig.12) is noticed 1838.68, 1845.56, 1857.54 mm/sec^2 in mode number 12 for Soil type I, II and III in longitudinal direction in the Steel rebar material. The modal acceleration is less in Soil Type I as compared to Soil Type II and III as acceleration is based on frequency and damping, higher the damping lower will be the acceleration.

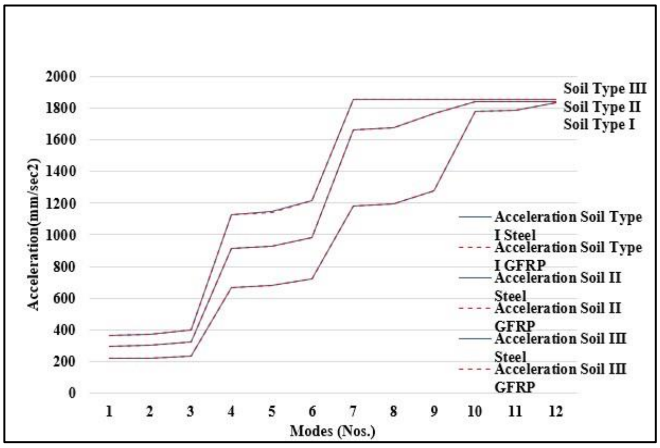

Fig 12: Modal Acceleration in transverse direction for Soil Type I, II, III

Modal time period for longitudinal and transverse direction is shown in Table VI. Modal time period for Soil type I, II and III in longitudinal and transverse direction is less in GFRP rebar material as compared to Steel rebar material. This may be due to time period varying based on the stiffness criteria. The Steel rebar material has more stiffness as compared to GFRP rebar material.

Table VI: Modal Time period

Mode	**Modal Time (Sec)**					
	Soil I		**Soil II**		**Soil III**	
	Steel	GFRP	Steel	GFRP	Steel	GFRP
1	3.428	3.421	3.428	3.421	3.428	3.421
2	3.373	3.366	3.373	3.366	3.373	3.366
3	3.163	3.157	3.163	3.157	3.163	3.157
4	1.11	1.108	1.11	1.108	1.11	1.108
5	1.093	1.091	1.093	1.091	1.093	1.091
6	1.025	1.023	1.025	1.023	1.025	1.023
7	0.627	0.626	0.627	0.626	0.627	0.626
8	0.621	0.62	0.621	0.62	0.621	0.62
9	0.582	0.581	0.582	0.581	0.582	0.581
10	0.42	0.419	0.42	0.419	0.42	0.419
11	0.416	0.415	0.416	0.415	0.416	0.415
12	0.389	0.388	0.389	0.388	0.389	0.388

Table VII and fig. 14 respectively show the weight and cost comparison for both the materials. It is perceived that the quantity and cost required is less for G+14 RC multi-storey building having GFRP rebar material, thus making it a cost-effective alternative.

Table VII: Steel and GFRP weight (tons.) and Cost (Rs.) Comparision

Member	Weight (tons)					
	Soil I		Soil II		Soil III	
	Steel	GFRP	Steel	GFRP	Steel	GFRP
Column	99.61	16.81	101.24	19.52	112.23	21.52
Beam	45.64	9.96	80.97	11.34	87.60	15.94
Slab	14.83	3.68	14.83	3.68	14.83	3.68
Total	160.09	30.46	197.04	34.55	214.68	41.15
Cost (**Lakhs**)	72.04	45.70	88.67	51.83	96.60	61.73
% saving in GFRP	36.56		41.54		36.10	

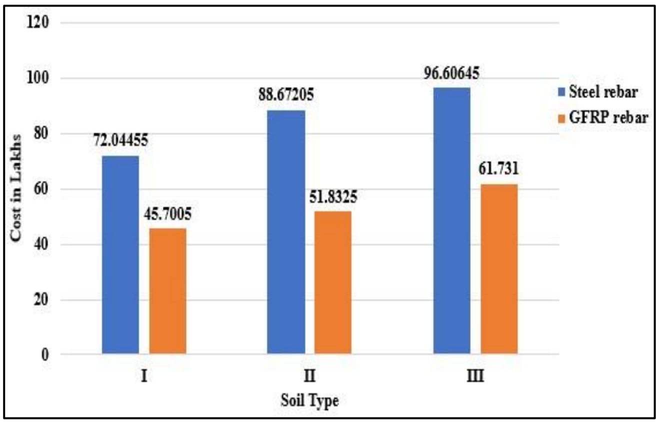

Fig 14: Cost comparison between Steel rebar and GFRP rebar for Soil Type I, II, III

Table VIII: base shear calculation in Longitudinal and Transverse direction

Base Shear (kN) in Longitudinal and Transverse direction							
Soil I							
Steel Rebar		GFRP Rebar		Manual Calculation			
				Steel		GFRP	
x	y	x	y	x	y	x	y
3468	2832	3454	2820	3575	2913	3572	2910

Validation of Result

1. Seismic weight of the Structure = 147151.176 KN
2. Natural period (T_a) of the building

$$T_{a(x)} = \frac{0.09 \times h}{\sqrt{d}} = \frac{0.09 \times 48}{\sqrt{30}} = 0.788 \text{ (Sec)}$$

$$T_{a(y)} = \frac{0.09 \times h}{\sqrt{d}} = \frac{0.09 \times 48}{\sqrt{20}} = 0.965 \text{ (Sec)}$$

$$\text{In Longitudinal direction, } \frac{S_a}{g} = 1.269$$

In Transverse direction, $\frac{S_a}{g} = 1.036$

3. Base shear (V_B) of the building

$$V_B = A_h \times W,$$

$$\text{Where } A_{h(x)} = \frac{Z \times I \times S_a}{2 \times R \times g} = \frac{0.16 \times 1.2 \times 1.267}{2 \times 5} = 0.0243$$

$$A_{h(y)} = \frac{Z \times I \times S_a}{2 \times R \times g} = \frac{0.16 \times 1.2 \times 1.035}{2 \times 5} = 0.0198$$

$$\text{Therefore, } V_{B(x)} = 0.0243 \times 147151.176$$

$$= 3575.773 (KN)$$

$$V_{B(y)} = 0.0198 \times 147151.176$$

$$= 2913.593 (KN)$$

Summary Of Results

Maximum storey displacement is more in the Steel rebar material than in the GFRP rebar material by average 0.4% in longitudinal and transverse direction.

Maximum storey drift is more in the Steel rebar material than GFRP rebar material by average 0.4% in both the directions.

Storey shear is more in Steel rebar material than the GFRP rebar material by average 0.4% in longitudinal and transverse direction.

Storey stiffness is more in Steel rebar material than in the GFRP rebar material by 0.0001% in longitudinal and transverse direction.

Modal acceleration in GFRP rebar material is greater than in Steel rebar material by average 0.015% in longitudinal and transverse direction.

Modal time is more in Steel rebar material than GFRP rebar material by average 0.2% in Mode 1 direction.

The quantity of GFRP rebar material required in the G+14 building is less than Steel rebar material, hence it is a better option over Steel rebar material.

Conclusions

Following conclusions are drawn from the present study,

1. In GFRP rebar material maximum storey displacement, drift, shear and stiffness is less than Steel rebar material.
2. The Modal Acceleration in the GFRP rebar material is more in longitudinal and transverse directions than the Steel rebar material in Soil Type I, II and III.
3. The Modal time period by using GFRP rebar material is less than the Steel rebar material.

4. It is accomplished that the percentage profit is more in GFRP rebar material against Steel rebar material is 36.5%, 41.54% and 36.1% for Soil Type I, II and III respectively in Zone III.

5. The performance of GFRP rebar is better than Steel rebar, hence it can be a good alternative to Steel rebar in RC multi-storey buildings and high-rise buildings.

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