Comparison of GFRP and conventional steel multistorey structure with ETABS and STAAD.Pro

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Abstract

In order to compete in the ever-growing competent market, it is very important for a structural engineer to save time, money and material. As a sequel to this, an attempt is made to analyze and design multi- storied buildings by using the software packages STAAD.Pro and ETABS. For analyzing multi-storied buildings, one has to consider all the possible loading condition and see that the structure is safe. This project deals with the design & analysis of 3 multi-storied residential buildings (G+7, G+8, G+9). The dead, live, seismic & wind loads have been applied and the design for beams, columns and footing is obtained through STAAD.Pro and ETABS individually. The objective is to compare GFRP structure with steel structures in multistoried frames in Seismic Zone II & Wind Zone II, and compare their behavior based on parameters like drift, displacement, cost and base shear.

Keywords: Seismic, GFRP, HYSD, Staad.pro, Structural analysis, Drift, Wind load.

Introduction

1.1 Introduction Of Project

Due to rapid industrialization and limited horizontal land, the concept of vertical development has been introduced. The conventional steel bars, being heavy and expensive while the GFRP rebars are compatible,durable and cheap. So the multistoried structures of G+7,G+8 and G+9 are analyzed with Steel bars and GFPR bars and the behavior of these are compared in seismic zone on the basis of parameters like base shear, storey drift, storey displacement, cost etc in STAAD. Pro software and ETABS.

1.2 Introduction on STAAD.PRO and ETABS

STAAD.PRO is a structural analysis and design software application originally developed by Research Engineers International in 1997.In late 2005, Research Engineers International was bought by Bentley Systems. STAAD stands for Structural Analysis and Design.

STAAD.Pro is one of the most widely used structural analysis worldwide. It can apply more than ninety international steel, concrete, timber and aluminum design codes.It can make use of various forms of analysis from the traditional static analysis to more recent analysis methods like p-delta analysis, geometric non-linear analysis, Pushover analysis (Static-NonLinear Analysis) or a buckling analysis. It can alsomake use of various forms of dynamic analysis methods from time history analysis to response spectrum analysis.The response spectrum analysis feature is supported for both user defined spectra as well as a number of international codes specified spectra.

ETABS is the abbreviation of "Extended3D Analysis of building System".

Large and most complex building models are easily configured with its best-integrated systems and its abilities, it guarantees:

- Powerful tools with graphical and object-based interfaces help to create a CAD-like drawing.
- Improves structural engineer’s productivity in the building industries.
- Saves major time and has more efficiency over general purpose programs.

1.3 Introduction of GFRP Rebars

GFRP rebars, also known as Glass Fiber Reinforced Polymer rebars, are a type of reinforcement bar used in construction to reinforce concrete structures. They are made of a composite material consisting of high-strength glass fibers embedded in a polymer matrix. Compared to traditional steel rebars, GFRP rebars offer several advantages. They are lightweight, corrosion-resistant, and have a high strength-to-weight ratio. This makes them ideal for use in environments where steel rebars would be prone to corrosion or where weight is a concern, such as in marine or coastal structures, bridges, and high-rise buildings. In addition, GFRP rebars have a lower thermal conductivity than steel, which can help reduce thermal cracking in concrete structures. They are also non-magnetic and non-conductive, making them suitable for use in sensitive electronic equipment environments.

1.4 NEED FOR TOPIC

The GFRP bars are flexible, light weight, cheaper and durable as compared to the conventional steel structures. As a result, the behavior of these GFRP bars in multistoried structures in seismic zones are evaluated and the comparison are made with conventional steel structures. Moreover, effects of GFRP bars in different configurations are also analyzed.

1.5 OBJECTIVE OF THE THESIS

- To compare GFRP structure with steel structures in multistoried frames.

1.6 AIM OF THE THESIS

- Aim is to check the feasibility of GFRP rebars instead steel bars.

Literature Review

S.NO	TITLE	AUTHOR	DESCRIPTION
1.	A simplified approach for design of steel-GFRP hybrid reinforced concrete sections	Mostafa Ibrahim, Alireza Asadian, and Khaled Galal, 01 March 2023.	The paper explores Glass Fiber-Reinforced Polymer (GFRP) reinforcing bars as an alternative to steel reinforcement. Based on established fundamental theories of RCC beams, the authors suggested design considerations for the design of hybrid steel-GFRP reinforced concrete flexural elements. The study involved analytical analysis to develop simplified design charts that can be used to replace an alternative steel-GFRP hybrid RC section using properties of a steel GFRP RC section that would suit its design purpose.

2.	Long-term tensile performance of GFRP bars in loaded concrete and aggressive solutions	Chunhua Lu, Zhonghao Qi, Yulong Zheng, Guangyu Xuan, and Yongdong Ya, 08 September 2022.	The paper investigated the long-term mechanical performance of GFRP bars under different aggressive environments. Tensile testing was carried out on GFRP bars after exposure to alkaline and saline solutions for 180 days and embedded in sustain-loaded concrete beams with or without NaCl solution wet-dry cycles for 366 days. The results showed that the failure modes and stress-strain curves of tested GFRP bars exhibited similar characteristics regardless of the aggressive conditions and exposure periods. The study also revealed that the degradation of tensile performance in saline solution was smaller than that in alkaline solution. Moreover, no significant degradation of elastic modulus was observed in the experiment.
3.	Earthquake resistant design of G + 5 multistorey residential building using STAAD.pro.	Supraja Duppati, R. Gopi, and K. Murali, 12 April 2021.	The study aimed to evaluate the structural stability of a G + 5 residential building with appropriate techniques, including selecting the standard configuration, the correct cross-section for column and beam, developing preferred requirements and different types of conditions of support, load types, and amalgamation of loads. Seismic calculations were performed for all the earthquake zones.
4.	Analysis of residential building with STAAD. Pro & ETABS	K. Surender Kumar, N. Lingeshwaran, and Syed Hamim Jeelani, 12 August 2020.	The study aimed to find better analysis for creating load cases, applying load combinations, support reactions, and reinforcement of columns and beams, reviewing whether the beam or column passed in the loads or failed. The complete design analysis was a case study of an ongoing building project in Hyderabad, and standard code books (IS 456: 2000, SP 16) were used for the building analysis.
5.	Experimental and analytical study of flexural performance of concrete beams reinforced with a hybrid of GFRP and steel	Husain Abbas and Aref Abadel,04 may 2022.	The influence of varying the proportion and configuration of steel and GFRP rebars on the flexural behavior of reinforced concrete beams. A total of sixteen under-reinforced concrete beams of 200 × 450 × 3000 mm were tested to failure under four-point flexure. The study revealed that the

	rebars,		increase in the area of steel rebars caused improvement in serviceability and enhancement in ductility. The incorporation of steel fibers in concrete improved the first crack-load and initial stiffness.
6.	Comparison of shear behavior of concrete beams reinforced with GFRP bars and steel bars	Jaroslav Halvonik, Viktor Borzovič, and Dagmar Láníova,27 June 2022.	Four research papers were analyzed to investigate the performance of concrete beams reinforced with different types of bars. The first study, conducted by Jaroslav Halvonik, Viktor Borzovič, and Dagmar Láníova, aimed to compare the shear behavior of concrete beams reinforced with Glass Fiber Reinforced Polymer (GFRP) bars and steel bars. The researchers subjected the beams to three-point loading with a shear slenderness of 3.0 and examined the effect of the axial stiffness of the longitudinal reinforcement. The results indicated that the axial stiffness of the longitudinal reinforcement had a favorable effect on the shear capacity in both cases. However, they observed that in the case of beams with GFRP bars, there was a better shear performance per unit increase of the axial stiffness than in beams with steel bars.
7.	The seismic performance of GFRP-Reinforced Concrete (RC) circular columns with different aspect ratios and concrete strengths	Amr E. Abdallah and Ehab F. El-Salakawy,01 March 2022.	They varied the spiral pitch and axial load level and tested the effects of concrete compressive strength and column aspect ratio on the seismic performance of GFRP-RC circular columns. The results showed that the seismic design requirements of the Canadian standards for confinement reinforcement in GFRP-RC circular columns were conservative with regard to the effects of high-strength concrete and different aspect ratios.
8.	A comprehensive review on the mechanical behavior of reinforced concrete structures reinforced with GFRP bars.	Ahmed, Ehab M., El-Sayed, Ahmed K., and El-Salakawy, Ehab F.	This literature review provides a comprehensive overview of the mechanical behavior of reinforced concrete structures reinforced with Glass Fiber Reinforced Polymer (GFRP) bars. The authors discuss the benefits and drawbacks of using GFRP bars as reinforcement in concrete structures, and describe the factors that can influence the bond

			strength between GFRP bars and concrete. The review also covers the analytical and experimental studies that have been conducted on this topic, including studies on the behavior of GFRP-reinforced concrete under different types of loading, such as tension, compression, and bending. The authors conclude that GFRP bars can be an effective alternative to traditional steel reinforcement in certain types of concrete structures, particularly those that are exposed to aggressive environments or where the use of non-magnetic reinforcement is required.
9.	The flexural performance of five large-scale continuous concrete beams reinforced with both steel bars and GFRP	Almahdi Mohamed Araba, Othman Hameed Zinkaah, Musab Alhawat, and Ashraf Ashour,16 December 2022.	The researchers explored the quantity of longitudinal steel reinforcement, GFRP reinforcement, and hybrid reinforcement ratio at the top and bottom layers of beams. The experimental findings indicated that using the hybrid reinforcement of steel and GFRP in multi-span continuous concrete beams exhibited a ductile behavior. However, the hybrid ratio of steel bars/GFRP was critical for restricting the extent of moment redistribution ratios. The hybrid beams strengthened by various hybrid ratios in the critical sections of the tested beams demonstrated a remarkable moment redistribution up to 43%.
10.	The effect of GFRP rebars and polypropylene fibers on the flexural strength of high-performance concrete beams with glass powder and microsilica	Maedeh Orouji and Erfan Najaf,2023	They compared the use of GFRP and steel rebars and found that using only GFRP reinforcing bars produced concrete beams with lower flexural strength than using steel reinforcing bars. However, simultaneous usage of 1.5% polypropylene fibers and GFRP rebars achieved the same flexural strength as steel rebars while decreasing the beam’s weight by about 4% and minimizing preparation costs and CO2 emissions. The addition of 0.5% polypropylene fiber enhanced the flexural strength of concrete reinforced with GFRP rebars by about 6%, while the addition of 1.5% fiber increased the compressive strength by 20%.

Methodology

Specification:

- Grade of concrete = M30
- Floor height = 3m
- Plinth height = 2m
- Depth of foundation = 2m
- Live load on floor = 2 KN/m
- Seismic zone = ZONE-II
- Wind zone = ZONE-II
- Air velocity = 44 m/s
- Type of soil = Medium soil
- Damping ratio for seismic = 5%
- Damping ratio for wind = 2%

Criteria	G+7	G+8	G+9
Length (m)	20	20	20
Width (m)	15	15	15
Height (m)	26	29	32
Beam size (m)(as per requirement)	0.3 X 0.25	0.3 X 0.25	0.3 X 0.25
Column size(m) (as per requirement)	0.6 X 0.5	0.6 X 0.5	0.6 X 0.5
Slab thickness (m)	0.2	0.2	0.2
Rebar	GFRP	GFRP	GFRP

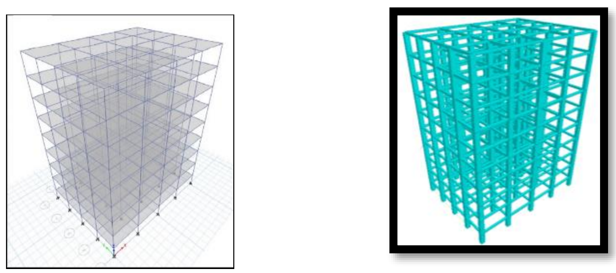
Basic Process:

1. set units
2. open new file
3. set grid lines and story height
4. define section properties
5. assigning properties
6. defining and assigning loads
7. edit the model if necessary
8. view model
9. define load combinations
10. analyses the model
11. generate output
12. save model

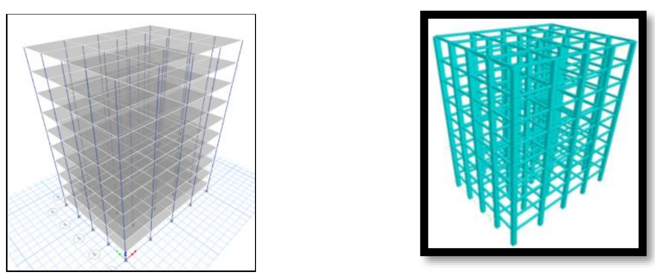
STATICS ANALYSIS:

It is able to do static evaluations for user-specified vertical and lateral floor or story loads. Vertical stresses on the floor are transmitted to the beams and columns by bending of the floor components if floors with out-of-plane bending capacity are modelled. Without explicit modelling of the secondary framing, vertical loads on the floor are automatically converted to span loads on neighboring beams or point loads on nearby columns, simplifying the laborious process of transferring floor tributary loads to the floor beams.

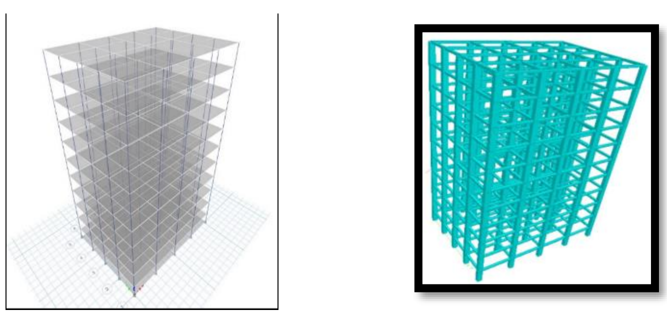
Plan Of Structures



G+7

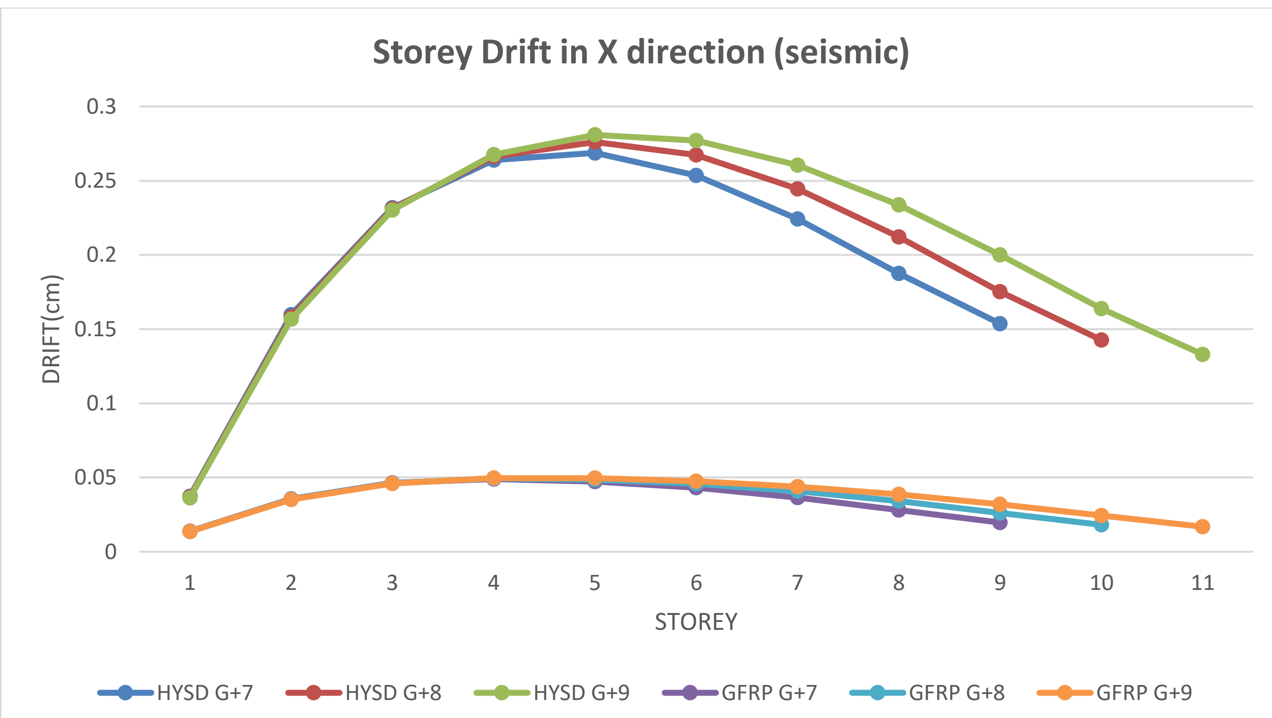


G+8

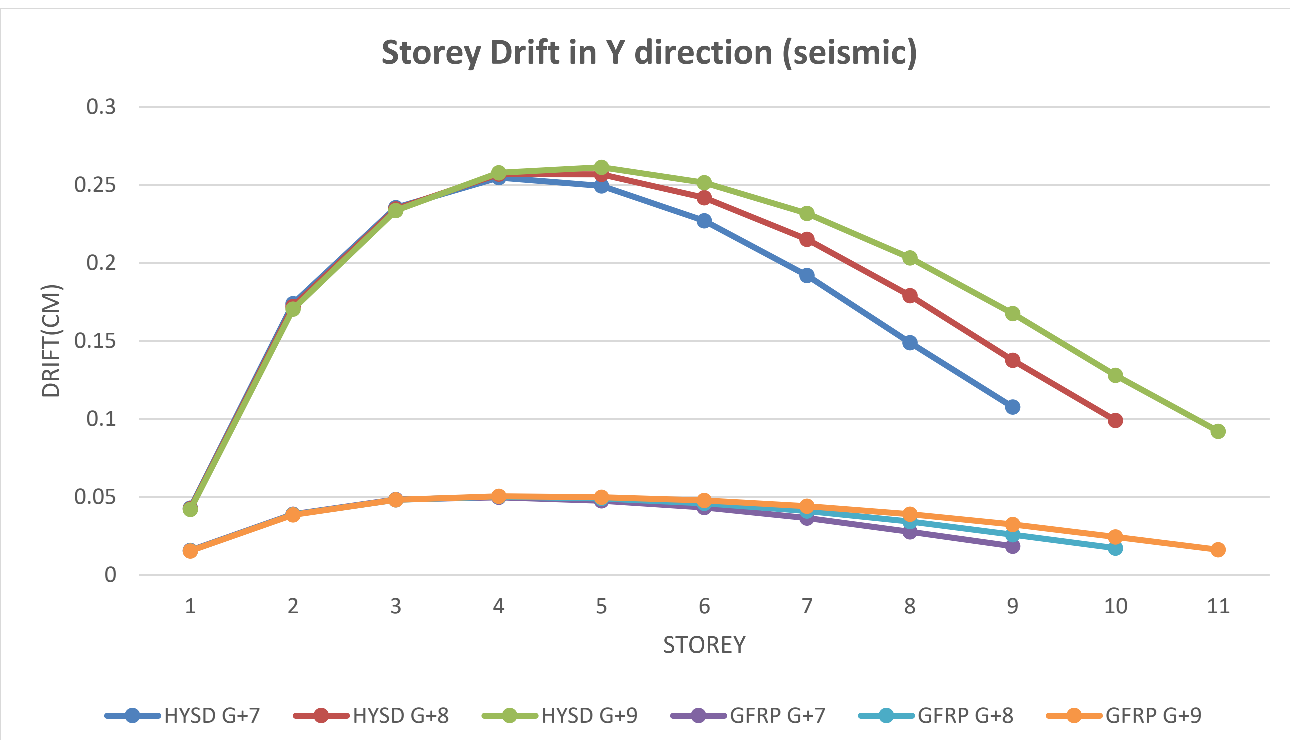


G+9

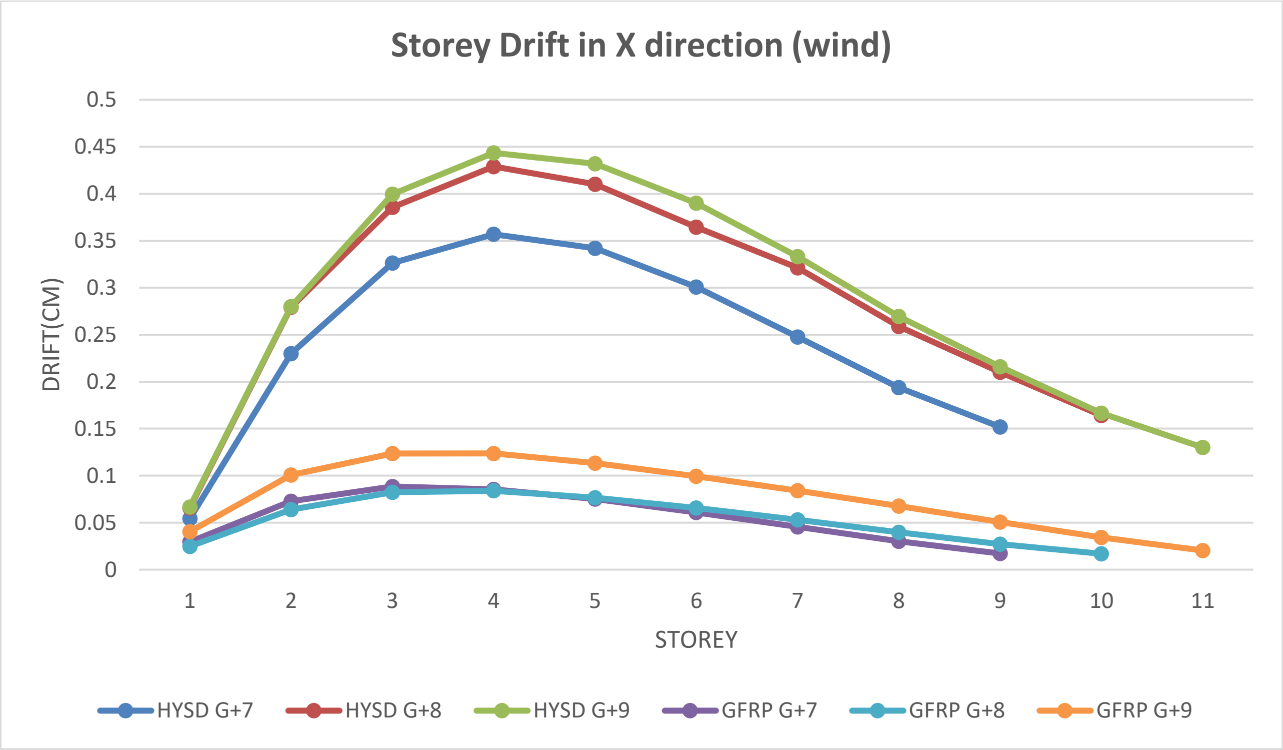
Storey Drift(cm) in X direction (seismic)						
	HYSD			GFRP		
Storey	G+7	G+8	G+9	G+7	G+8	G+9
2	0.0374	0.0369	0.0364	0.0138	0.0137	0.0136
5	0.1598	0.1583	0.1567	0.0357	0.0355	0.0352
8	0.2318	0.2312	0.2302	0.0464	0.0463	0.0461
11	0.264	0.2664	0.2676	0.049	0.0494	0.0496
14	0.2688	0.2761	0.2809	0.0474	0.0487	0.0496
17	0.2536	0.2673	0.2772	0.0431	0.0457	0.0475
20	0.2243	0.2446	0.2605	0.0365	0.0408	0.0438
23	0.1876	0.2121	0.2337	0.0281	0.0341	0.0387
26	0.1537	0.1752	0.2	0.0196	0.0261	0.032
29		0.1427	0.1638		0.0181	0.0244
32			0.1329			0.0169



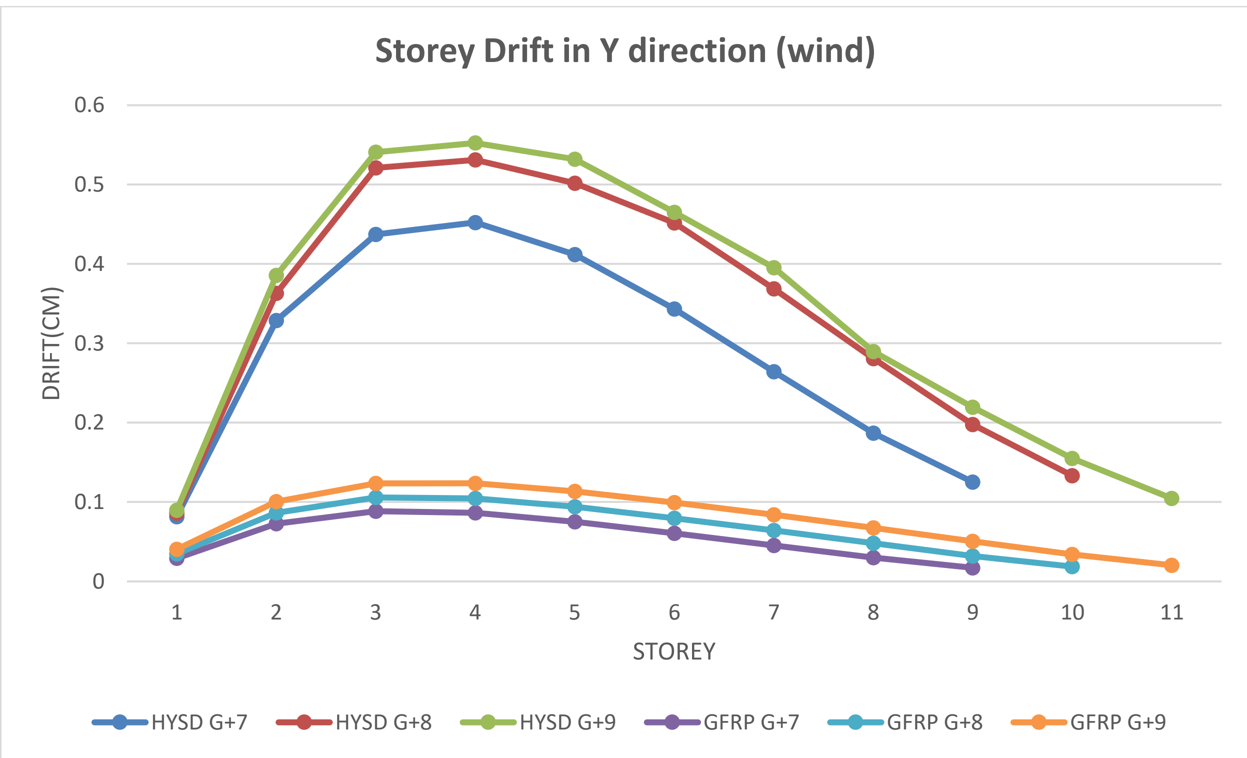
Storey Drift(cm) in Y direction (seismic)						
	HYSD			GFRP		
Storey	G+7	G+8	G+9	G+7	G+8	G+9
2	0.0429	0.0424	0.0419	0.0157	0.0155	0.0154
5	0.1738	0.1721	0.1705	0.039	0.0387	0.0385
8	0.2355	0.2346	0.2335	0.0483	0.0482	0.0481
11	0.2547	0.2569	0.2578	0.0497	0.0501	0.0504
14	0.2494	0.2567	0.2613	0.0476	0.049	0.0498
17	0.2271	0.2417	0.2515	0.0432	0.0459	0.0477
20	0.192	0.2151	0.2317	0.0364	0.041	0.044
23	0.1488	0.1791	0.2033	0.0277	0.0342	0.039
26	0.1076	0.1375	0.1676	0.0183	0.0258	0.0323
29		0.099	0.1279		0.0171	0.0243
32			0.092			0.0162



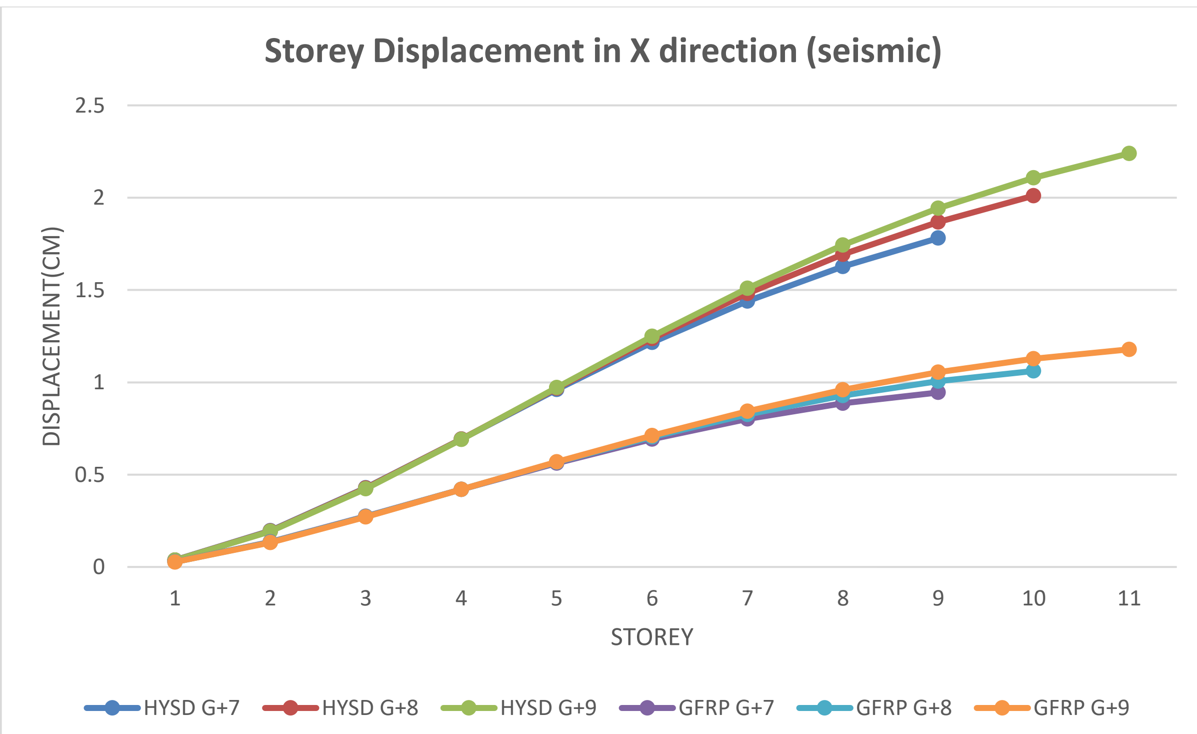
Storey Drift(cm) in X direction (wind)						
	HYSD			GFRP		
Storey	G+7	G+8	G+9	G+7	G+8	G+9
2	0.0543	0.0657	0.0668	0.0294	0.0248	0.0406
5	0.2299	0.2793	0.2799	0.0728	0.0641	0.1006
8	0.3264	0.3855	0.3995	0.0885	0.0823	0.1235
11	0.3569	0.429	0.4435	0.0854	0.0839	0.1237
14	0.342	0.4102	0.432	0.0752	0.0767	0.1134
17	0.3008	0.3645	0.39	0.0608	0.0656	0.0994
20	0.2475	0.3211	0.3333	0.0455	0.053	0.0839
23	0.1938	0.259	0.2696	0.0302	0.0399	0.0676
26	0.1518	0.2101	0.2158	0.0172	0.0272	0.0507
29		0.1642	0.1666		0.0169	0.0342
32			0.13			0.0204



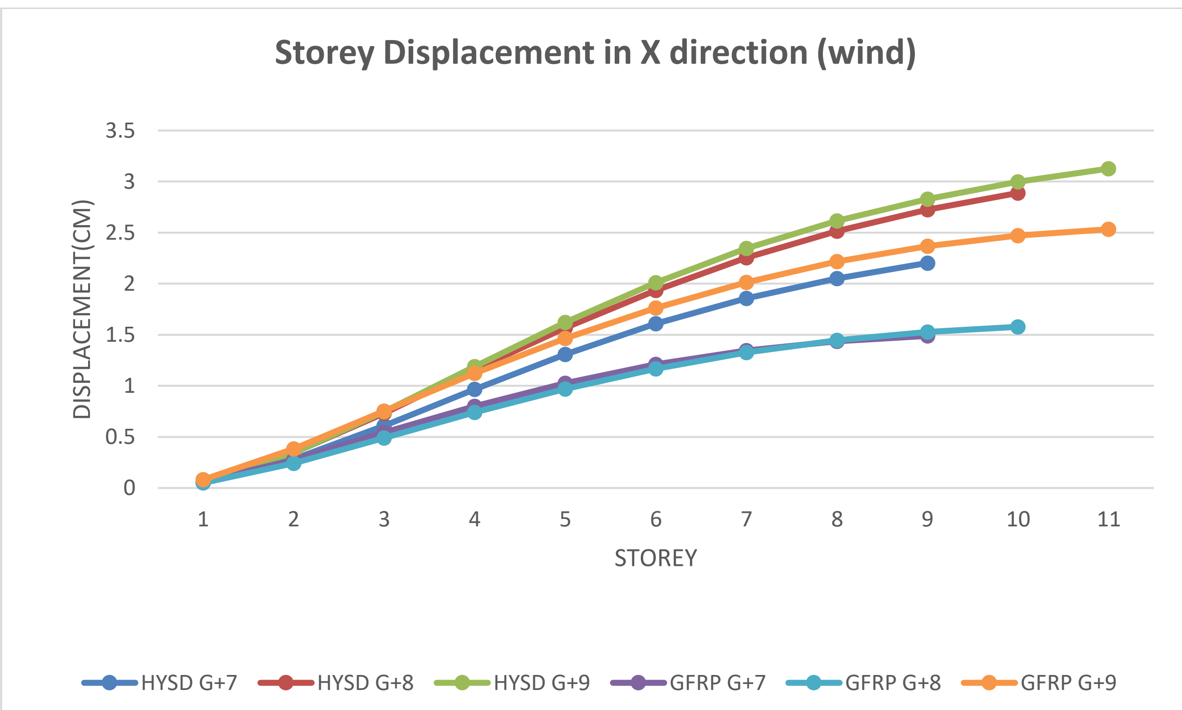
Storey Drift(cm) in Y direction (wind)						
	HYSD			GFRP		
Storey	G+7	G+8	G+9	G+7	G+8	G+9
2	0.0817	0.0861	0.0897	0.0294	0.0349	0.0406
5	0.3286	0.3629	0.3855	0.0728	0.0865	0.1006
8	0.4371	0.521	0.5408	0.0885	0.1058	0.1235
11	0.4523	0.5311	0.5524	0.0864	0.1047	0.1237
14	0.4117	0.5019	0.5321	0.0752	0.094	0.1134
17	0.3434	0.4519	0.4651	0.0608	0.0797	0.0994
20	0.2644	0.3685	0.3954	0.0455	0.0642	0.0839
23	0.1868	0.2808	0.2895	0.0302	0.0481	0.0676
26	0.1253	0.1978	0.2197	0.0172	0.0321	0.0507
29		0.1332	0.1548		0.0187	0.0342
32			0.1047			0.0204



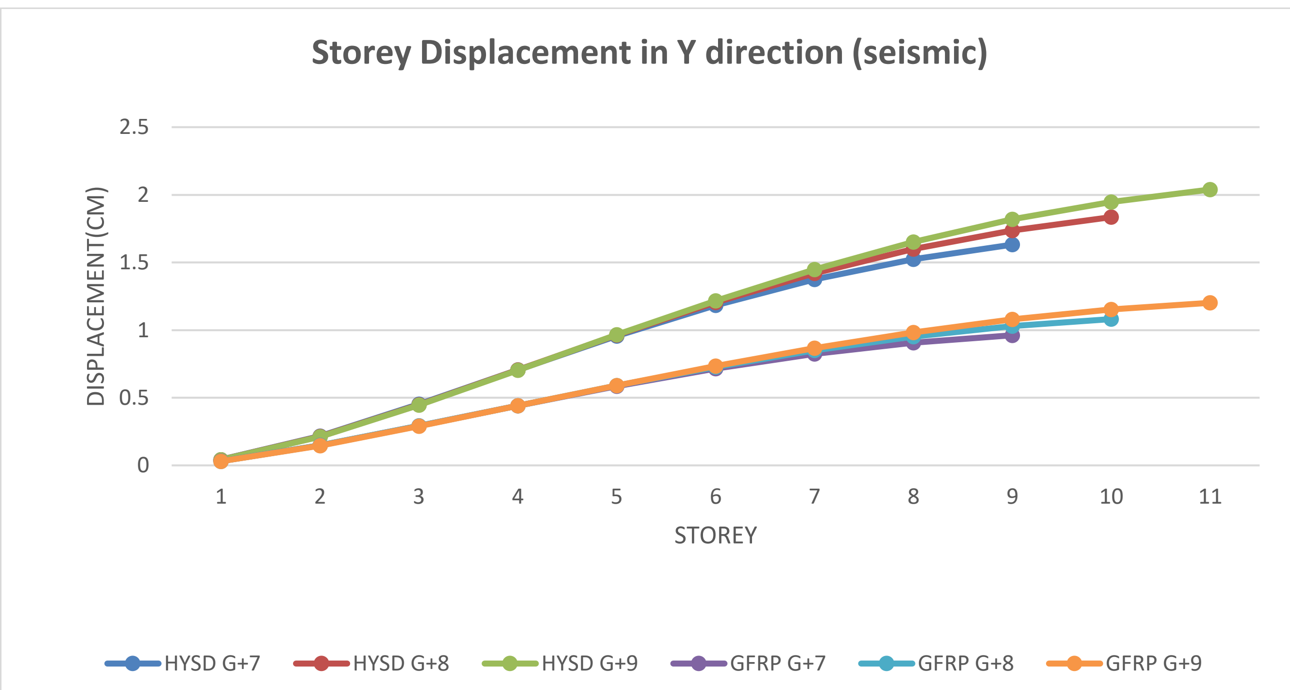
Storey Displacement(cm) in X direction (seismic)						
	HYSD			GFRP		
Storey	G+7	G+8	G+9	G+7	G+8	G+9
2	0.0374	0.0369	0.0364	0.0277	0.0274	0.0272
5	0.1972	0.1951	0.1931	0.1349	0.1338	0.1328
8	0.429	0.4263	0.4233	0.274	0.2726	0.2711
11	0.6931	0.6928	0.6908	0.4208	0.4207	0.4198
14	0.9618	0.9689	0.9718	0.5631	0.5669	0.5685
17	1.2154	1.2362	1.249	0.6923	0.7041	0.7111
20	1.4398	1.4808	1.5095	0.8017	0.8265	0.8426
23	1.6274	1.6929	1.7432	0.886	0.9289	0.9586
26	1.7811	1.8681	1.9432	0.9448	1.0071	1.0547
29		2.0108	2.107		1.0614	1.1277
32			2.2399			1.1785



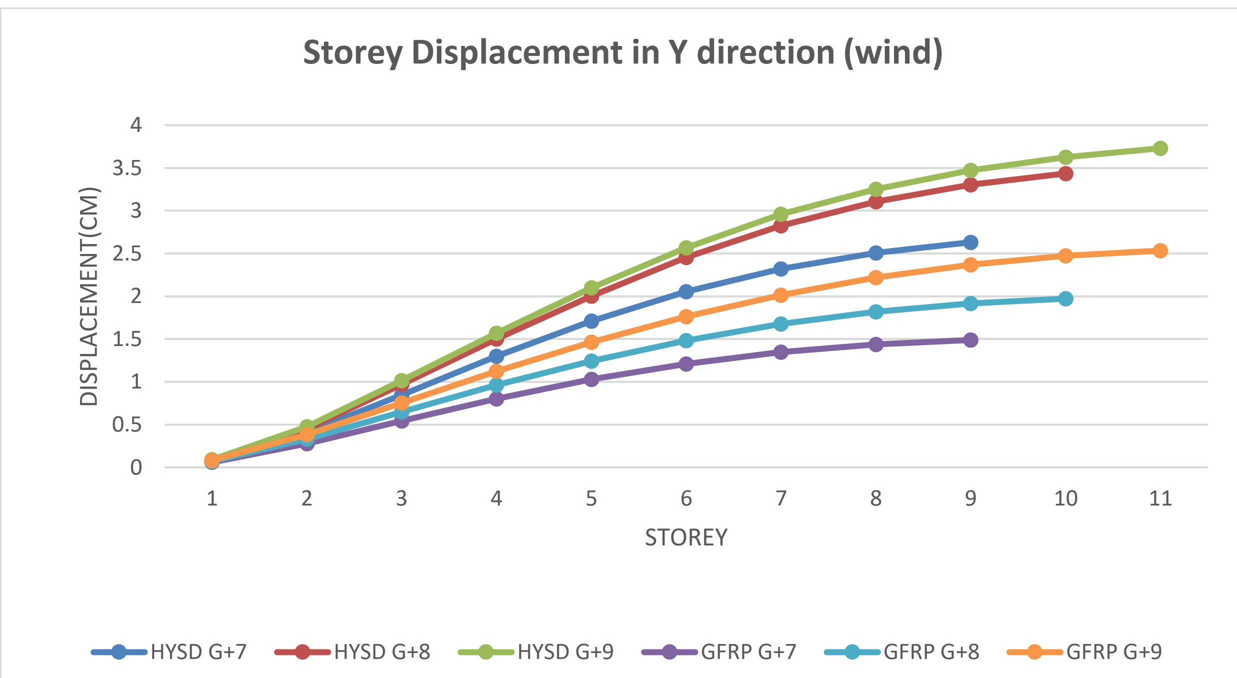
Storey Displacement(cm) in X direction (wind)						
	HYSD			GFRP		
Storey	G+7	G+8	G+9	G+7	G+8	G+9
2	0.0543	0.0657	0.0668	0.0589	0.0497	0.0811
5	0.2842	0.345	0.3467	0.2773	0.2419	0.382
8	0.6105	0.7305	0.7462	0.5429	0.4888	0.7535
11	0.9674	1.1595	1.1897	0.802	0.7405	1.1246
14	1.3094	1.5697	1.6217	1.0277	0.9706	1.465
17	1.6102	1.9342	2.0117	1.2103	1.1675	1.763
20	1.8577	2.2553	2.345	1.3467	1.3266	2.0147
23	2.0515	2.5143	2.6146	1.4373	1.4462	2.2174
26	2.2033	2.7244	2.8304	1.4891	1.5277	2.3695
29		2.8886	2.997		1.5783	2.4721
32			3.127			2.5332



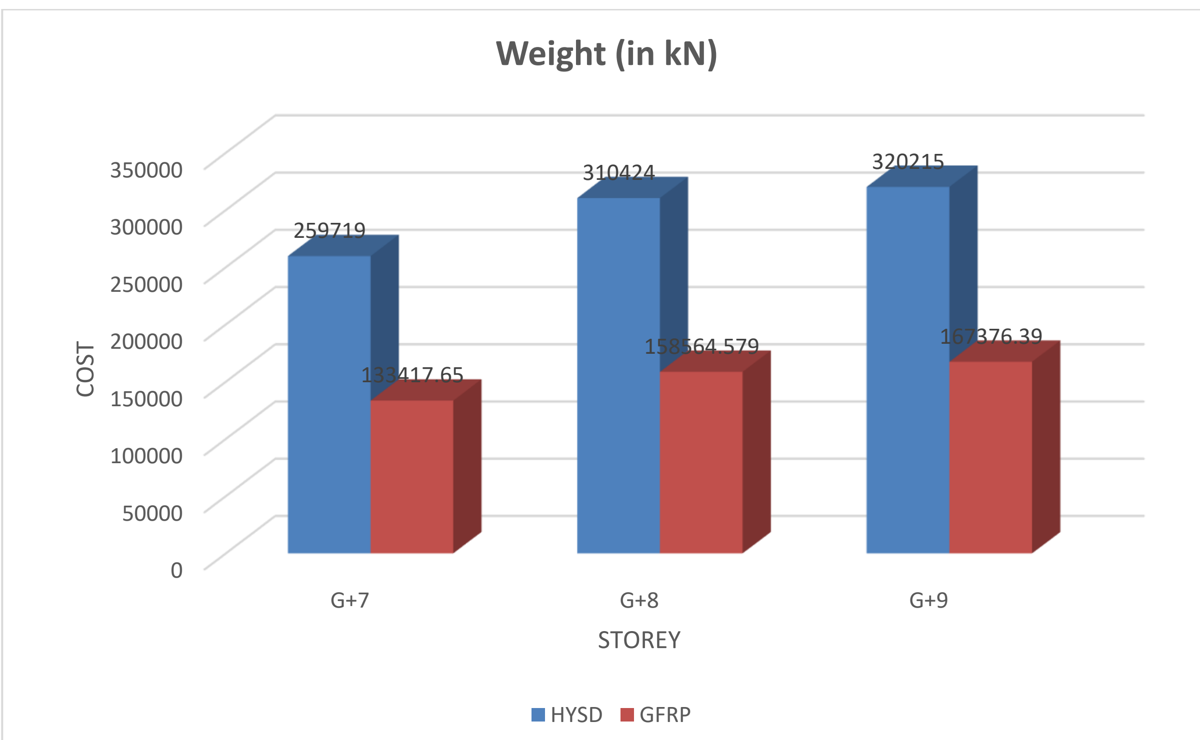
Storey Displacement(cm) in Y direction (seismic)						
	HYSD			GFRP		
Storey	G+7	G+8	G+9	G+7	G+8	G+9
2	0.0429	0.0424	0.0419	0.0313	0.0311	0.0308
5	0.2168	0.2145	0.2123	0.1483	0.1472	0.1463
8	0.4522	0.4491	0.4458	0.2931	0.2918	0.2904
11	0.707	0.706	0.7037	0.4422	0.4422	0.4415
14	0.9563	0.9627	0.9649	0.5851	0.5892	0.591
17	1.1834	1.2044	1.2164	0.7146	0.7268	0.734
20	1.3754	1.4195	1.4482	0.8239	0.8497	0.8661
23	1.5243	1.5986	1.6514	0.907	0.9523	0.983
26	1.6319	1.736	1.819	0.9619	1.0299	1.08
29		1.8351	1.9469		1.0812	1.153
32			2.0389			1.2016



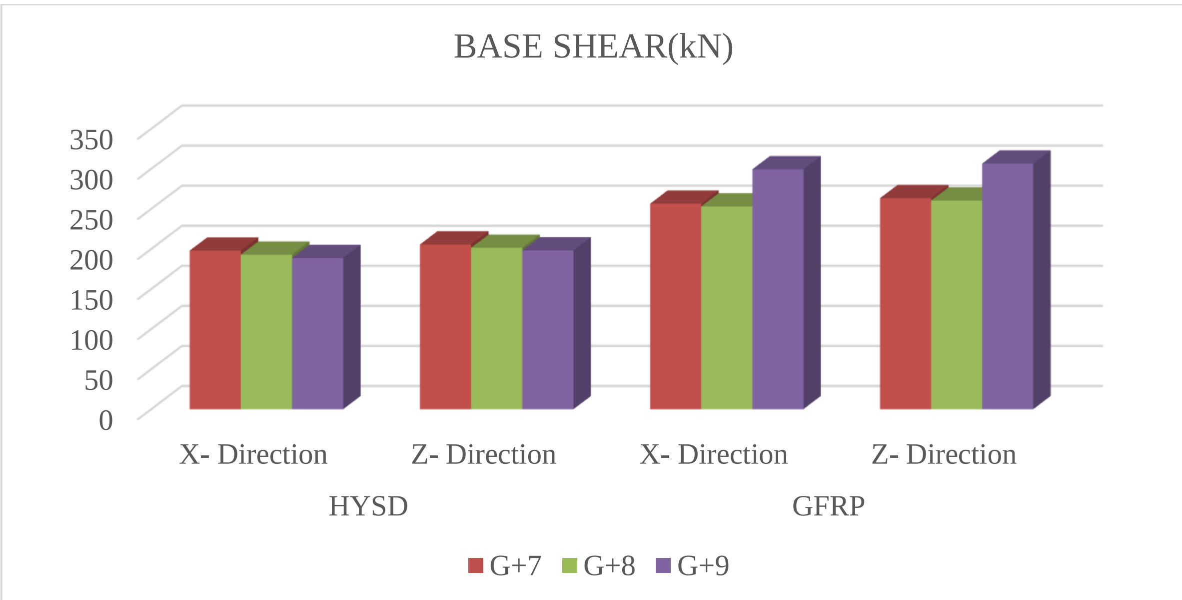
Storey Displacement(cm) in Y direction (wind)						
	HYSD			GFRP		
Storey	G+7	G+8	G+9	G+7	G+8	G+9
2	0.0817	0.0861	0.0897	0.0589	0.0698	0.0811
5	0.4103	0.449	0.4752	0.2773	0.3294	0.383
8	0.8473	0.97	1.016	0.5429	0.6467	0.7535
11	1.2996	1.5011	1.5684	0.802	0.9609	1.1246
14	1.7114	2.003	2.1005	1.0277	1.243	1.465
17	2.0547	2.4549	2.5656	1.2103	1.4823	1.763
20	2.3191	2.8234	2.961	1.3467	1.6749	2.0147
23	2.5059	3.1042	3.2505	1.4373	1.8192	2.2174
26	2.6313	3.302	3.4702	1.4891	1.9156	2.3695
29		3.4352	3.625		1.9717	2.4721
32			3.7297			2.5332



Weight (in kN)		
Structure	HYSD	GFRP
G+7	259719	133417.650
G+8	310424	158564.579
G+9	320215	167376.39



	Base Shear (in kN)			
Structure	HYSD		GFRP	
	X- Direction	Z- Direction	X- Direction	Z- Direction
G+7	197.895	205.653	256.5638	263.3522
G+8	192.7647	201.4089	253.0613	260.3412
G+9	188.6488	198.1765	299.3356	306.5264



Future Scope

- GFRP bars being cheaper and lower in weight when compared to HYSD bars, these can be utilized in construction of Hybrid (GFRP+HYSD) structures for better economy and strength.
- Further research can be done to increase the flexural strength of GFRP Rebar.
- GFRP structures can be tested in higher seismic zones for better performance as the material being more flexible than steel reinforcement.
- The use of FRP reinforcement in concrete structures can help reduce the environmental impact of construction projects. Future research could investigate the environmental benefits of using FRP reinforcement and explore ways to enhance its sustainability.

Conclusion

- The drift caused due to seismic load in X direction is reduced by 82.34% in G+9, 82.10% in G+8 & 81.42% in g+7 when longitudinal rebars are replaced from traditional HYSD bars.
- In Y direction we can observe that Seismic drift of G+7, G+8, G+9 story building has respectively 82.34%,80.49%,80.71% less drift in structure with GFRP Rebars than that of HYSD rebars.
- In case of X- direction (wind drift) parameter, there is a reduction in GFRP rebar's G+7, G+8, G+9 building values as compared to RCC building as – 75.20 %,80.44 % and 72.11 %.
- The drift caused due to wind load in Y direction is reduced by 77.60% in G+9, 80.07% in G+8 & 80.43% in G+7 when longitudinal rebars are replaced from traditional HYSD bars.
- The Displacement caused due to seismic load in X direction is reduced by 42.92% in G+9, 47.21% in G+8 & 46.95% in G+7 when longitudinal rebars are replaced from traditional HYSD bars.
- In Y direction we can observe that Seismic displacement of G+7, G+8, G+9 story building has respectively 41.05%,41.08%,41.06% less displacement in structure with GFRP Rebars than that of HYSD rebars.
- In case of X direction (wind displacement) parameter, there is a reduction in GFRP rebar's G+7, G+8, G+9 building values as compared to RCC building as –

32.41%,45.36% and 18.98%.

- The displacement caused due to wind load in Y direction is reduced by 32.08% in G+9, 42.60% in G+8 & 43.40% in G+7 when longitudinal rebars are replaced from traditional HYSD bars.
- GFRP structures are 48.63%, 48.92%, 47.73% lighter than HYSD structures in respectively seventh, eight, nineth stories.
- The base shear in X direction is 2.577%,2.796%,2.345% in G+7, G+8,G+9 respectively less than Y direction in GFRP rebars.
- Overall, the future scope of GFRP construction is promising, and its use is expected to increase in the coming years.

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