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Study of Seismic Performance of Vertical Irregular Structure with Glass Fiber Reinforced Shear wall.

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Abstract
At present days building a structure with all the regular configurations is not feasible in most of the cases due to the irregular plot dimensions, aesthetic visual and functional requirements in the urban cities. The structures with more irregular configuration either horizontally or vertically are more vulnerable to earthquake. Such vertical irregularity stabilized by providing Shear wall. GFRP bars are light weight, ductile and noncorrosive in nature so GFRP bars were used in shear wall. So, this study aims to find out seismic response of vertical irregular building with GFRP shear wall under seismic load. The setback at both sides building with GFRP shear wall at corner analyzed using Response spectrum analysis method using NBC 105:2020 and ACI 440 1R 2006 code on ETABS software. It found that percentage of decrease of displacement with GFRP shear wall 39.52% and 37.98% in X and Y-direction respectively, percentage of decrease of drift with GFRP shear wall 44.79% and 43.43% in X and Y-direction respectively and Base shear increased by 2.42%.

Keywords: Base shear, response spectrum, storey displacement, storey drift, storey stiffness

1. Introduction

The increasing in demand for high raised building, shortage of regular plot and some architectural purposed vertical irregular building are frequently used. These vertical irregularities are such as setback, mass irregularity, soft storey etc. This vertical irregularity can significantly influence the seismic behavior of structure often making them vulnerable to earthquake forces compare to the regular structure[1]. Therefore such vertical irregularity is critical area of research in structural engineering.

Such critical are is stabilized by using the shear wall. Shear walls are parts of a structure that resist two principal forces: a) in-plane shear forces and b) in-plane bending caused by moments developed as a result of such shear forces. Also, along with these, the shear wall, as a structural functional unit, also tends to resist plane shear in the vertical direction (as a direct consequence of shear in the horizontal direction) and the buckling effect of dead loads coming from the top[2]

Glass is a nonmetallic fibre, widely used as an industrial material these days. Glass fibres refer to the fibres that are derived from naturally occurring minerals consisting of (SiO2) monomers. Such glass fibre impregnated with an alkaline design, glass fibre reinforced polymer (GFRP) bars are made[3] At recent year Glass fiber reinforced polymer (GFRP) emerged as a promising material in engineering field of construction due to it's high strength to weight ratio, ductility, corrosive resistance . When GFRP is use in shear wall, offers effective load resistance contributing to the overall flexibility and durability of structure[4].

This study is aim to study the seismic performance of vertical irregular building with Glass fiber reinforced shear wall. The goal is to evaluate how composite material influences the seismic behavior of the vertical irregular (setback) building using ETABS software, Response Spectrum Method and NBC 105:2020[5] code. In this study such GFRP Bars are used instead of steel reinforcement in shear wall according to ACI 440.1R-06.The research parameters are such as storey displacement, storey drift, storey stiffness and base shear. The finding aim to provide the viability of GFRP reinforced shear wall as to seismic design solution in setback building.

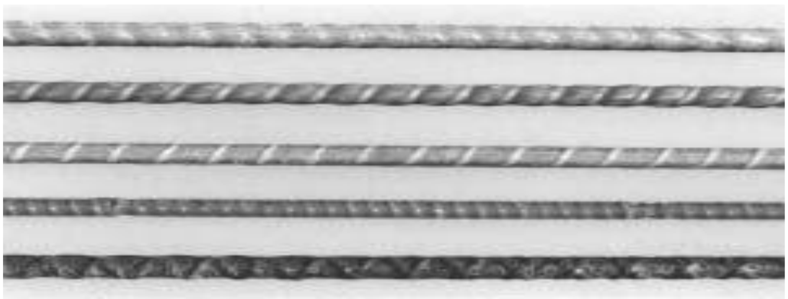


Figure 1 Different Dia of GFRP bars

2. Literature Review

Chavhan, 2015 conducted a study on "Vertical Irregularities in RC Building Controlled By Finding Exact Position of Shear Wall," using Response Spectrum Analysis method on 11th storey building with four concentric shear walls (2 shear walls in the x- direction and 2 shear walls in the y- direction), with thickness of 150 mm and 250 mm, respectively using ETABS software. It was concluded that shear wall should be placed at points by coinciding centroid of building and the center of gravity.

Student, 2018 conducted a study on "Seismic Analysis of Shear Wall at Different Location on Multi-story RCC Building," using Response Spectrum Analysis method on G+9storey building with different locations of shear wall. Four models of buildings with different locations of shear wall were modeled using STAAD PRO software. It was found that maximum lateral displacement increased as the story height increased and also time period increased as the model frequency increased. Due to the presence of a shear wall at the center of model 4, the minimum lateral displacement of building was reduced compare to all models. The maximum base shear was observed in model 4 in both X and Y-directions and minimum moment was observed for model 4 compared to other models. The maximum axial force was found to be in model 2 and the maximum shear force and moment were found in model 1 compared to all models. In types 2, 3 and 4 the maximum displacements were reduced to 40 to 50%, the maximum base shear was reduced to 10 to 20% and the maximum shear force was reduced by 30 to 50% as that of bare frame type. Hence the building with type 3 shear wall was more efficient than 6 all other type of shear walls.

Shahrooz & Moehle, 1990 conducted an experimental and Analytical study on "Seismic Response and Design of Setback Buildings," taking 6th storey building with a setback. The study combined of experimental test (simulate earthquake motion by shaking table) and analytical modeling (analysis using uniform Building code (UBC) static method and model analysis). It was found that both the conventional static and conventional dynamic design methods were found inadequate to prevent concentration of damage in members near the setback for certain configurations. Some building code defined effectively irregular setback buildings as those having either 33% reduction in floor mass at the setback or 25% reduction in plan dimension at the setback, the analysis of fame having various setbacks and designed by both static and dynamic method showed that simple definition was not appropriate. For setback structures, design should impose increased strength on tower and relative to the base. The static analysis method proposed that amplifies design forces and improves behavior of the tower.

Mohamed et al., 2014 conducted a study on "Experimental Investigation of Concrete Shear Walls Reinforced with Glass Fiber–Reinforced Bars under Lateral Cyclic Loading,". Four models of shear walls (1 steel reinforced shear wall and 3 GFRP shear walls) were used in this experimental study. GFRP bars with specific properties and compressive strength of 40 Map concrete were used. It was found that Glass fiber reinforced shear wall showed stable hysteretic behavior with no strength degradation, acceptable performance, drift capacity of over 3% for GFRP reinforced wall and 2.6% for steel reinforced wall. At high drift level moderate damage (cover splitting) occurred in GFRP reinforced walls compared to steel reinforced wall. GFRP reinforced shear wall showed elastic behavior with recoverable deformation up to lateral drift of 2%. GFRP reinforced shear wall dissipated energy as effectively as steel reinforced wall. Steel reinforced shear wall showed higher energy dissipation through inelastic deformation, whereas GFRP reinforced shear wall showed no permanent deformation up to 80% of ultimate capacity. Hence, GFRP reinforced shear walls demonstrated good strength, energy dissipation and deformation capacity, GFRP-reinforced walls showed recoverable and self-centering behavior up to allowable drift limits.

Mohamed et al., 2014a conducted an experimental study on "Drift Capacity Design of Shear Walls Reinforced with Glass Fiber-Reinforced Polymer Bars". Four samples (1 steel reinforced shear wall and 3 GFRP reinforced shear walls) were used in this experimental study. This study focused on getting the characteristics and behavior of GFRP reinforcement in shear wall. It was found that elastic deformation dominated in GFRP shear wall, whereas inelastic deformation dominated in the steel reinforced shear wall. In the GFRP reinforced shear walls the virtual plastic- hinge length lp was found to be equal to 0.5 lw and lw for the lower and upper limits respectively. The rotational capacity must be within 1.5% to 2.5% and for GFRP shear walls the minimum value of 0.4% for rotational demand must be provided to ensure a minimum level of deformability.

Sree & Priya, 2021 conducted a study on "Analysis of Vertical Irregular Building with Shear Wall Using ETABS". Two models of 10th story were modeled in ETABS with varying thickness of shear walls with a thickness of 150 mm and 200 mm respectively. Response spectrum analysis method was used to analyze the building to obtained shear force, torsion, bending moments, and displacements. The results of 150 mm and 200 mm thickness of shear walls were compared. It was found that 200 mm thickness shear wall performed better than the shear wall 150 mm thickness and the model 1 was less economical than the model 2.

3. Methodology

This study adopted the computational analytical approach to investigate the seismic response of vertical irregular (setback) with GFRP reinforced shear wall. This analysis is based on structural modeling using the simulation software. A regular building was model as (G+10) storey using ETABS software and response spectrum analysis conducted to check the design was safe or not and fixed the section dimension which satisfy the critical shape of building then the regular building was cut to make setback shape. Four setback buildings were made which were setback at half, setback at 2 positions, setback at both sides and setback at four sides. Among the 4 setback buildings setback at both sides found weakest shape using response spectrum analysis. Setback at both sides building was modeled with different location RC shear wall (at Corner, along X-axis, along Y-axis and Periphery). It's found that optimum location of shear wall of setback at both sides building was at corner, setback at both side building was modeled with GFRP reinforced shear wall at corner and Response spectrum analysis conducted.

3.1 Data collection

Story = G+10

Grade of concrete = M25

Grade of steel = HYSD- 500

Story height = 3 M

Column size = 800mm X 800mm

Beam size = 650mm X 750mm

Slab thickness = 125mm

Shear wall thickness = 230mm

Wall thickness = 230mm

Partition and Parapet wall thickness =115mm

Soil type- D and Zone factor (Z) = 0.35

Material = Glass fiber

Properties of the GFRP material as per[10].

Density = 2100 kg/m3

Modulus of Elasticity = 50000 MPa

Coefficient of the thermal expansion = 6 x 10-6 1/C

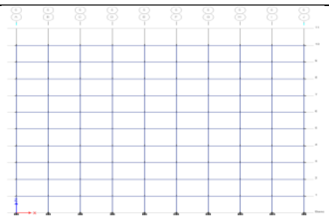
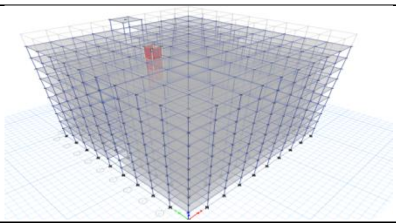
Tensile Strength = 483 to 1600 Mpa

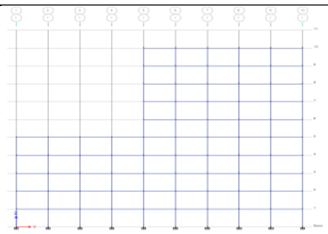
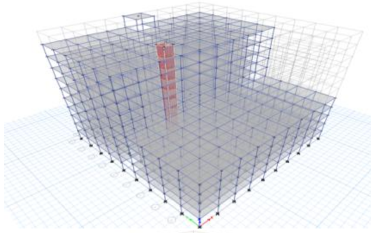
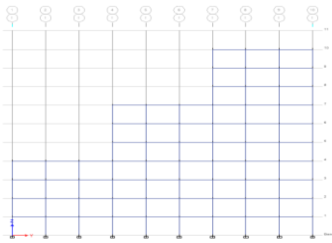
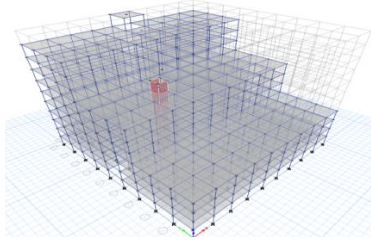
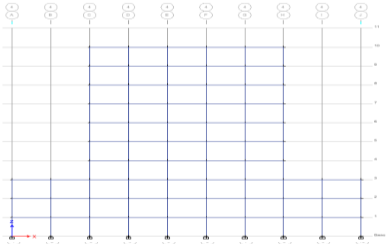
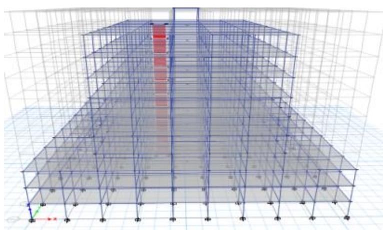
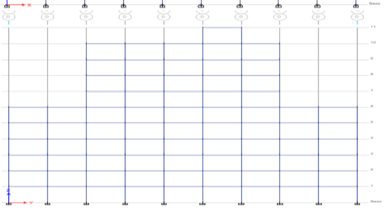
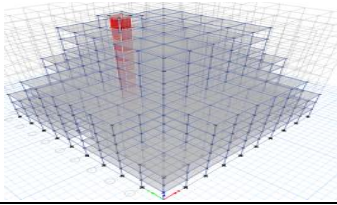
It has high electrical insulating properties.

Good heat resistant material.

It has Less stiff and light weight.

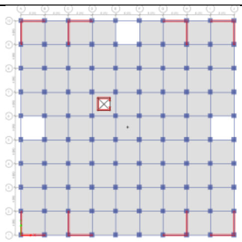
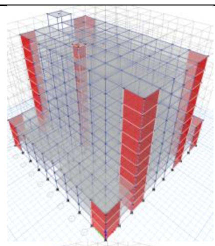
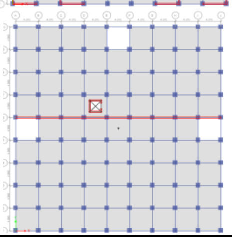
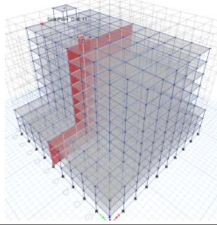
Table 1 Different types of building.

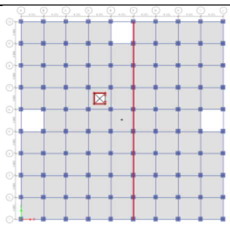
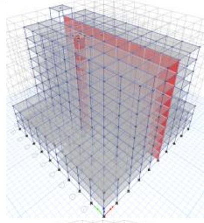
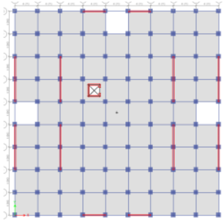
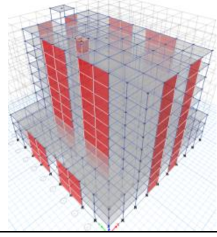
Type of building	Elevation	3D model
Regular building		

Setback at half with shear		
Setback at 2 positions		
Setback at both sides		
Setback at four sides		

Setback at both sides building found weakest setback shape among four setback shapes. Setback at both sides building modeled with the shear wall at different position of building which are at corner, along X-axis, along Y-axis and at periphery are tabulated below.

Table 2 Setback at both sides buildings with different position of shear wall

Position of shear wall	Plan	3D model
Shear wall at Corner		
Shear wall along X-axis		

Shear wall along Y-axis		
Shear wall at Periphery		

4. Result and Discussion

From the Response Spectrum analysis of setback at both sides building with GFRP shear wall at corner in ETABS software using NBC 105:2020, the results obtained are as follows.

4.1 Maximum Storey displacement in X-direction due to RSA, ULS

The maximum storey displacement of setback at both sides building with and with GFRP shear wall due to RSA, ULS in X-direction, without shear wall (66.932mm) > with GFRP shear wall (40.445mm). The maximum storey displacement is decreased by 39.563% with GFRP reinforced shear wall.. The values of storey displacement in X- direction are tabulated below.

Table 3 Maximum storey displacement in X-direction Due to RSA, ULS.

Storey	Elevation	Without shear wall	GFRP shear wall
	m	mm	mm
Storey 10	30	66.932	40.445
Storey 9	27	63.602	36.514
Storey 8	24	58.573	31.999
Storey 7	21	51.839	27.026
Storey 6	18	43.628	21.722
Storey 5	15	34.321	16.288
Storey 4	12	24.495	10.988
Storey 3	9	15.44	6.325
Storey 2	6	9.107	3.508
Storey 1	3	3.371	1.272
Base	0	0	0

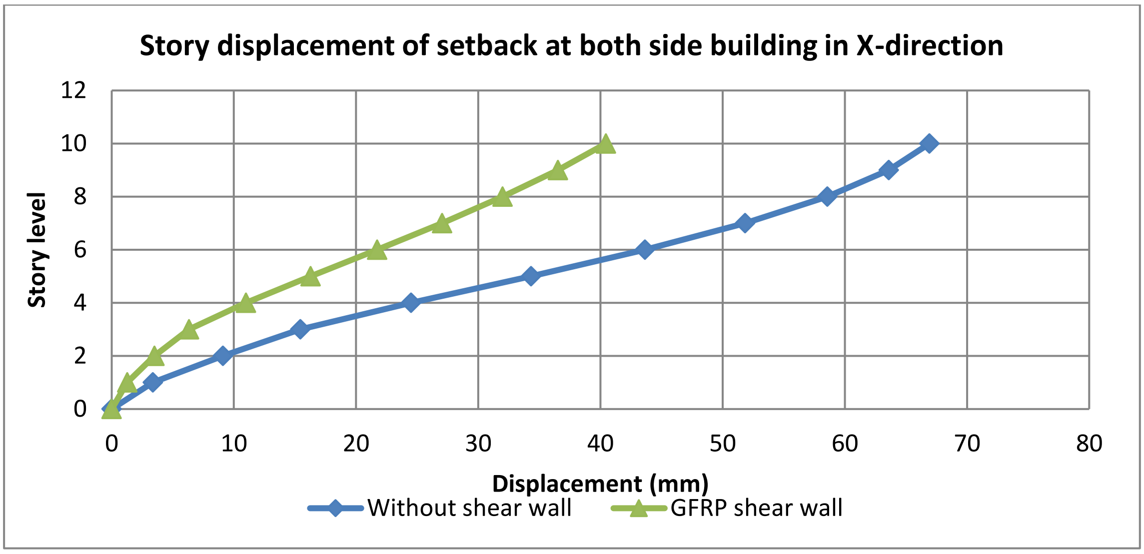


Figure 2 Storey dispacement in X-direction due to RSA, ULS

4.2 Maximum Storey displacement in Y-direction due to RSA, ULS

The maximum storey displacement of setback at both sides building with GFRP shear wall due to RSA, ULS in Y-direction, without shear wall (55.909mm) > with GFRP shear wall (34.671mm). The storey displacement has been decreased by 37.986% with GFRP shear wall. The values of storey displacement in Y-direction are tabulated below.

Table 4 Storey displacement in Y-direction due to RSA, ULS.

Storey	Elevation	Without shear wall	GFRP shear wall
	m	mm	mm
Storey 10	30	55.909	34.671
Storey 9	27	53.559	31.505
Storey 8	24	49.697	27.793
Storey 7	21	44.343	23.648
Storey 6	18	37.711	19.175
Storey 5	15	30.091	14.539
Storey 4	12	21.897	9.964
Storey 3	9	14.779	6.036
Storey 2	6	8.789	3.365
Storey 1	3	3.273	1.227
Base	0	0	0

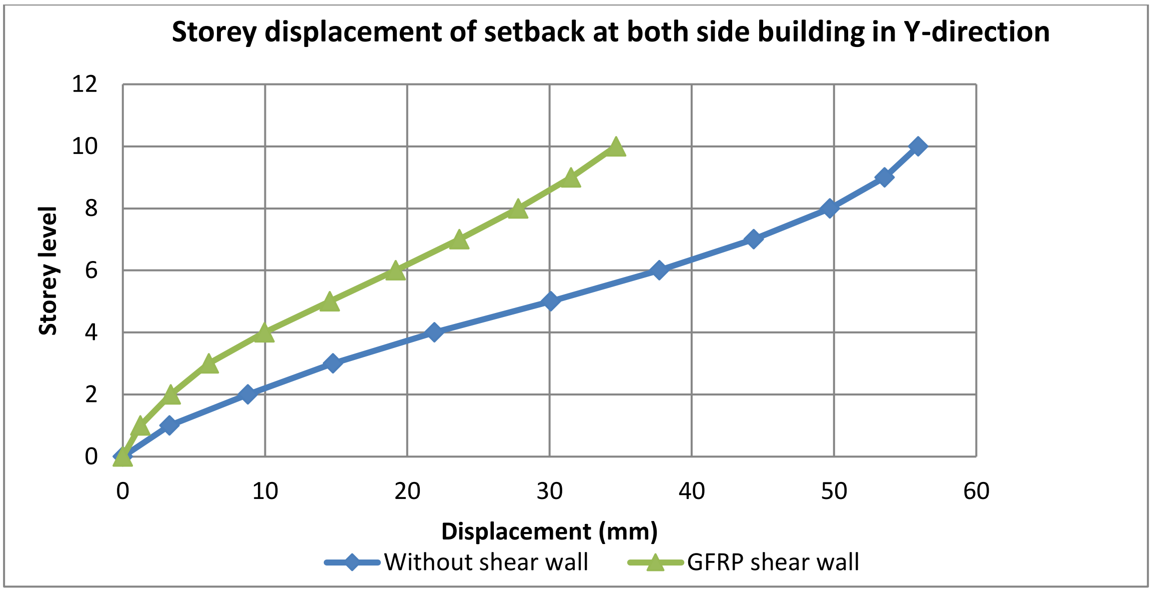


Figure 3 Storey diaplacemnt in Y-direction due to RSA, ULS

4.3 Maximum storey drift in X-direction due to RSA, ULS

The maximum storey drift of setback on both sides of the building in the X-direction is due to RSA, without shear wall (0.003282) > with GFRP shear wall (0.001812). The storey drift is decreased by 44.789% with GFRP reinforced shear wall. The values of storey drift in X-direction are tabulated below.

Table 5 Storey drift in X-direction due to RSA, ULS.

Storey	Elevation	Without shear wall	GFRP shear wall
Storey 10	30	0.00111	0.00131
Storey 9	27	0.001677	0.001505
Storey 8	24	0.002244	0.001658
Storey 7	21	0.002737	0.001768
Storey 6	18	0.003103	0.001812
Storey 5	15	0.003282	0.001767
Storey 4	12	0.003023	0.001554
Storey 3	9	0.002133	0.000939
Storey 2	6	0.001912	0.000745
Storey 1	3	0.001124	0.000424
Base	0	0	0

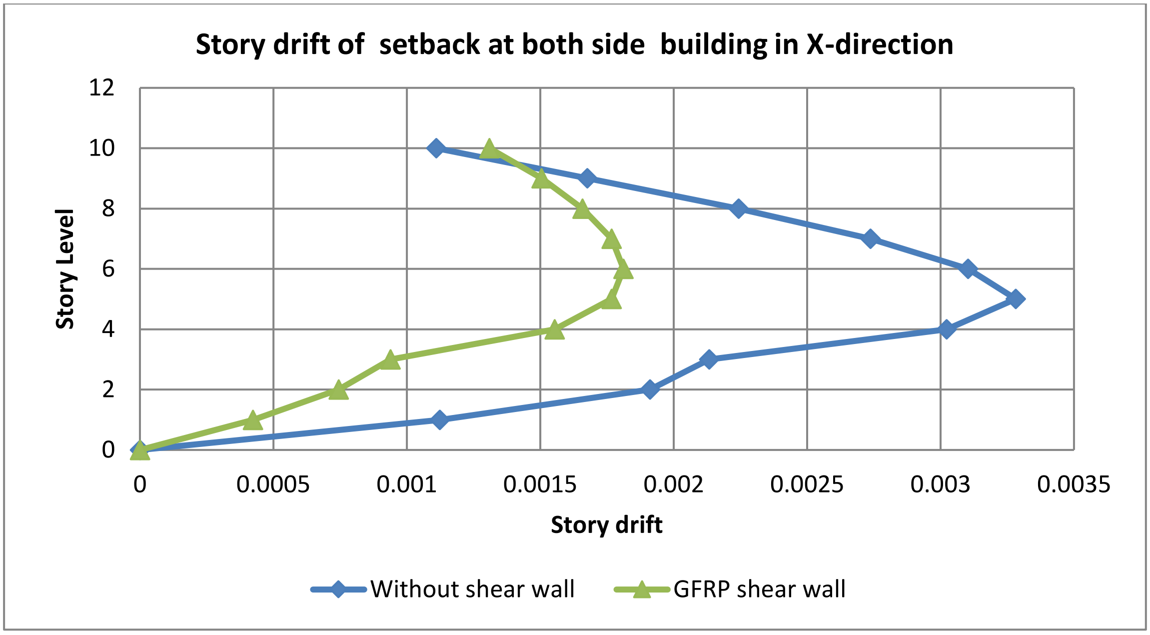


Figure 4 Storey drift in X-direction due to RSA, ULS.

4.4 Maximum storey drift in Y-direction due to RSA, ULS

The maximum storey drift of setback on both sides of the building in the Y-direction is due to RSA, without shear wall (0.002731) > with GFRP shear wall (0.001545). The storey drift is decreased by 43.427% with GFRP reinforced shear wall .The values of storey drift in the Y-direction are tabulated below.

Table 6 Storey drift in Y-direction due to RSA, ULS.

Storey	Elevation	Without shear wall	GFRP shear wall
Storey 10	30	0.000821	0.001055
Storey 9	27	0.001295	0.001238
Storey 8	24	0.001785	0.001382
Storey 7	21	0.00221	0.001491
Storey 6	18	0.00254	0.001545
Storey 5	15	0.002731	0.001525
Storey 4	12	0.002609	0.001373
Storey 3	9	0.001997	0.00089
Storey 2	6	0.001839	0.000713
Storey 1	3	0.001091	0.000409
Base	0	0	0

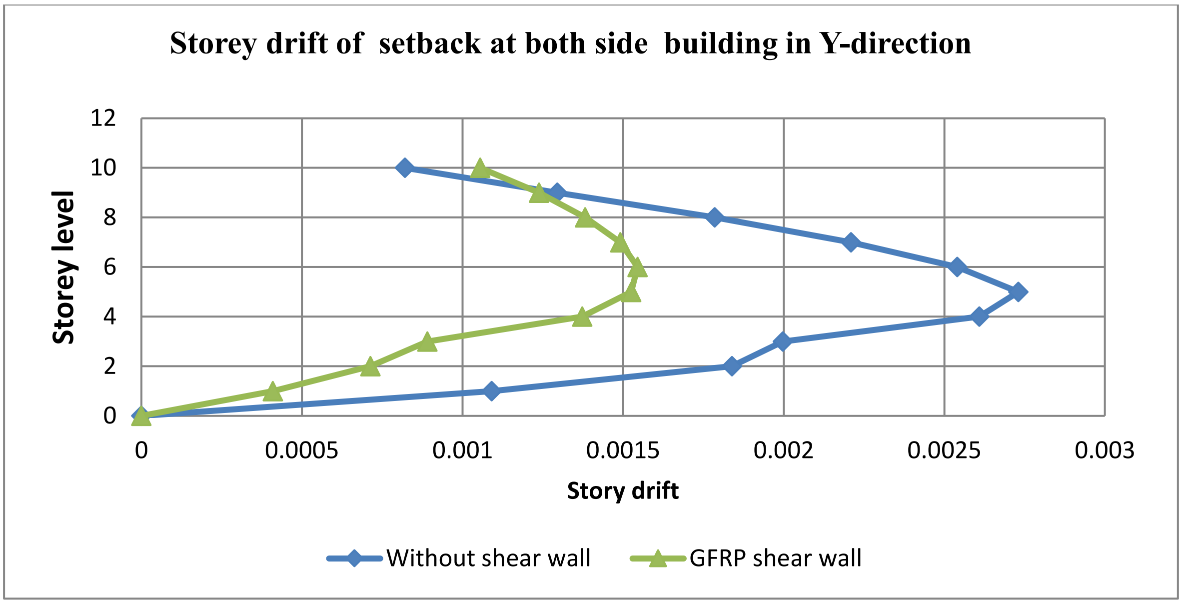


Figure 5 Storey drift in Y- direction due to RSA, ULS.

4.5 Maximum storey Stiffness in X-direction due to RSA, ULS

The maximum storey stiffness of setback on both sides of the building in X- direction due to RSA, with GFRP shear wall (24118522.84KN/M) > without shear wall(9349082.6KN/M). The building with the GFRP reinforced shear wall is stiffer than without shear wall. The values of storey stiffness in X- direction are tabulated below.

Table 7 Storey stiffness in X- direction due to RSA, ULS.

Storey	Elevation	Location	Without shear wall	GFRP shear wall
	M		KN/M	KN/M
Storey 10	30	Top	1629515.9	1397277.755
Storey 9	27	Top	2299518	2555786.629
Storey 8	24	Top	2484528.1	3333149.806
Storey 7	21	Top	2559739.4	3898527.242
Storey 6	18	Top	2627459.6	4402934.539
Storey 5	15	Top	2755709	4981663.647
Storey 4	12	Top	3182385.6	6046753.232
Storey 3	9	Top	4610999.5	10298483.9
Storey 2	6	Top	5337556.1	13474408.25
Storey 1	3	Top	9349082.6	24118522.84
Base	0	Top	0	0

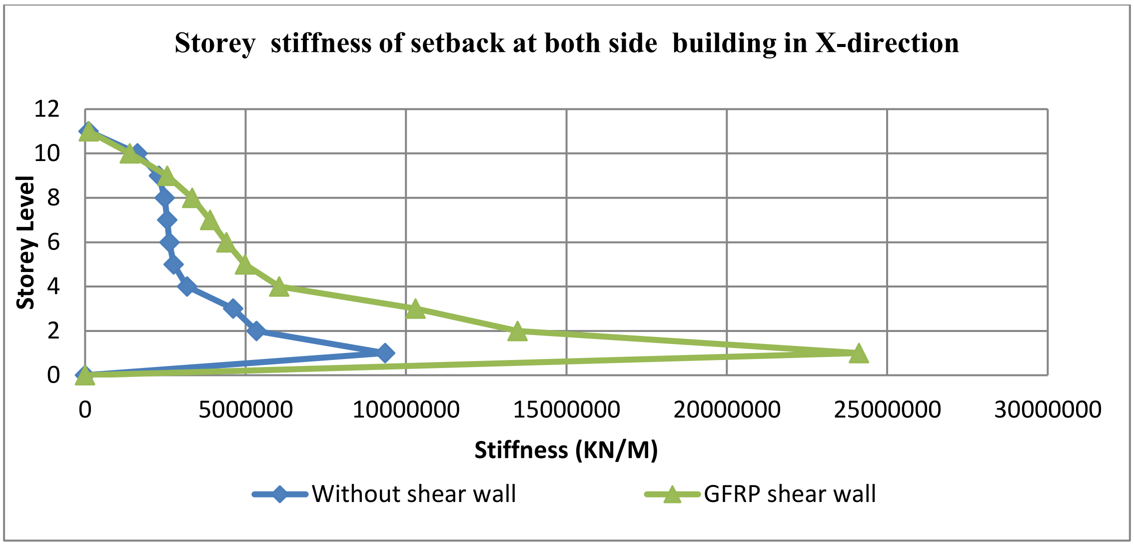


Figure 6 Storey stiffnessin X-direction due to RSA, ULS.

4.6 Maximum storey Stiffness in Y-direction due to RSA, ULS

The maximum story stiffness of setback on both sides of the building in Y- direction due to RSA, with GFRP shear wall (23803451.59KN/M) > without shear wall(9107427.3KN/M). The building is stiffer with the GFRP shear wall than without shear wall. The values of story stiffness in Y- direction are tabulated below.

Table 8 Sotrey stiffness in Y- direction due to RSA, ULS.

Storey	elevation	Location	Without shear wall	GFRP shear wall
	M		KN/M	KN/M
Storey 10	30	Top	1890439.1	1510681.793
Storey 9	27	Top	2542972.3	2727861.259
Storey 8	24	Top	2703987.1	3530443.116
Storey 7	21	Top	2766523	4101137.375
Storey 6	18	Top	2817517.2	4599591.107
Storey 5	15	Top	2914231.9	5161618.184
Storey 4	12	Top	3251738.3	6133975.728
Storey 3	9	Top	4634147	10276924.42
Storey 2	6	Top	5285899.7	13382704.69
Storey 1	3	Top	9107427.3	23803451.59
Base	0	Top	0	0

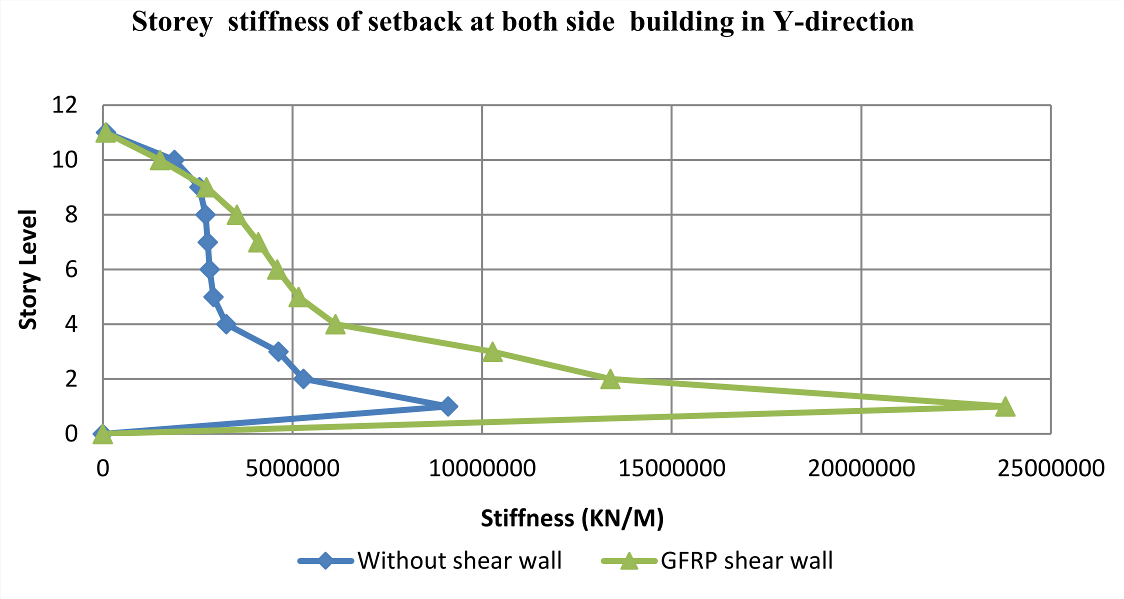


Figure 7 Storey stiffness in Y-direction due to RSA, ULS.

4.7 Maximum base shear due RSA, ULS

The maximum base shear was shown by setbacks on both sides building with with GFRP shear wall (26973.97KN) >, without shear wall (26335.29KN). The base shear is increased by 2.42% with GFRP reinforced shear wall. The base shear diagram is shown below.

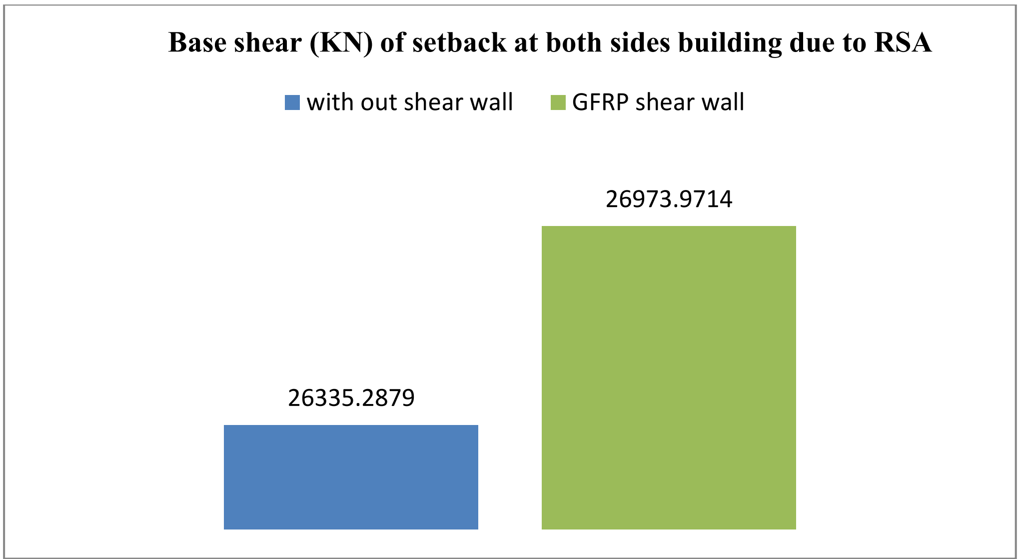


Figure 8 Base shear due to RSA, ULS.

5. Conclusion

After completion of analysis of setbacks on both sides, the building with GFRP reinforced shear wall at Corner results were presented above. From the observation of the results presented above, it can be concluded that setbacks on both sides' buildings with the GFRP shear wall performed better than without shear wall.

1. Setback at both sides building with GFRP shear wall at optimum position which is at corner, the maximum percentage of decrease of displacement showed by setback at

both sides with GFRP shear wall 39.52% in X- direction and 37.98% in Y-direction. The maximum percentage of decrease of drift with GFRP shear wall 44.79% in X-direction and with 43.43% in Y-direction. The maximum stiffness with GFRP shear wall is 24118522.844 KN/M in both X and Y-direction. The percentage of increase of base shear values with GFRP shear wall 2.42%.

2. GFRP shear wall showed better performance in terms of controlling displacement, drift and providing higher stiffness, making them more suited for seismic resistance in setback building.

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