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A Comparative Study of the Seismic Performance of RC Buildings with Vertical Irregularity Using RC and GFRP Shear Walls

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Abstract

As per seismic studies, vertical irregular RC buildings show major weakness in earthquake areas. Regarding structural behaviour, geometry breaks increase side forces during ground shaking. Moreover, this study actually examines how G+10 RC buildings with setback irregularities perform during earthquakes, focusing on RC and GFRP shear walls. The study definitely determines which type of shear wall works better for these irregular building shapes. Moreover, a total of 4 models with different setback configurations were developed in ETABS software. Further, Response Spectrum Analysis was used to find the peak responses when the structure itself experiences seismic forces. The critical setback configuration was identified, and the optimum shear wall location was taken at corners only from the earlier study. As per the critical cases, a comparative study was conducted regarding conventional RC shear wall and GFRP reinforced shear wall. Both types were compared to find the differences. Results show that the RC shear walls actually made buildings much stiffer and reduced displacement by up to 42.324% and drift by up to 47.708%. GFRP shear walls definitely reduced displacement by up to 39.569% and drift by up to 44.798%, but RC walls actually handled more base force because they were stiffer. The findings highlight the trade-offs between RC and GFRP shear walls and provide practical insights into selecting an appropriate shear wall in irregular high-rise buildings.

Keywords

Vertical irregularity, GFRP, Storey displacement, Storey drift, Storey stiffness, Base shear

1. Introduction

There are many destructive earthquakes that have been reported in the historical record throughout the world. To human lives and properties, an earthquake is an unpredictable large natural hazard. Nepal hosts an earthquake-prone South Asian country [1]. An earthquake results from a sudden energy release in the Earth's crust, generating seismic waves that move in the direction of the surface. Such events can have significant impacts on developmental procedures and, in some cases, even bring progress to a standstill [2]. Buildings with standardised and regular layouts are often not so practical in today's urban surroundings. Non- rectilinear sites, aesthetic requirements and intended functions normally impose a more complicated building plans and elevations [3].

These irregular elevation buildings are vertical irregular (setback) buildings. Setback is one of the vertical irregularities which we see in urban areas. Setbacks in the building are provided not only for aesthetic reasons, but also to comply with the floor area ratio as per building byelaws restrictions. A setback is provided where there are space constraints and closer proximity to the building is required, and also for the light for visuals [4]. The safety of these structures has become an important concern, as their non-uniform configurations can heighten the risks associated with earthquake events [5]. This can be prevented by providing a shear wall at the optimum position in the building. Shear walls are parts of a structure that resist two principal forces: a) in-plane shear forces and b) in-plane bending caused by momentum developed as a result of such shear forces. [6]. A study of G+9 storey RC frame using Response Spectrum Analysis in STAAD PRO revealed that time period of the building decreases as the frequency increases and using shear wall reduced lateral displacement, shear force and base shear by up to 50%, 20% and 50%, respectively [7]. In their study of G+7 multi-storey building, the authors used a shear wall of a thickness of 230 mm, observing that such thickness provides significantly to displacement, drift control and stiffness [8]. So, in this study, shear wall thickness will be taken 230mm. A study that focused on Performance of Reinforced concrete shear wall in a dual structural system, the study evaluated the shear wall in corner shows better performance than other locations in reducing displacement and drift, including 150mm to 400mm shear wall thickness in tall building [9]. A study of 10-storey irregular building using Response Spectrum Analysis in ETABS, the study showed that shear walls are resistant to lateral forces and the shear wall reduced 50% of displacement [10]. The RC shear walls are the most common being used despite being corrosive in nature. Recently, the composite alternative GFRP has gained attention due to its light weight and non-corrosive in nature [11]. 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 (SiO_2) monomers. Such glass fibre impregnated with an alkaline design, glass fibre reinforced polymer (GFRP) bars are made [12]. A recent study shows that the GFRP-reinforced shear walls demonstrated good strength, deformation capacity, energy dissipation, and also exhibited recoverable and self-centering behavior up to allowable drift limits[13]. In case of temperature, GFRP bars are more sensitive [14]. The RC shear walls and GFRP shear walls shows similar behavior in term of displacement and energy dissipation [15] and achieve acceptable levels of lateral drift as compared to the RC shear walls [16]. GFRP bars are lightweight, strong, and non-corrosive according to ACI 440.1R-06[17], GFRP reinforcing bars are available which are shown in Figure 1.

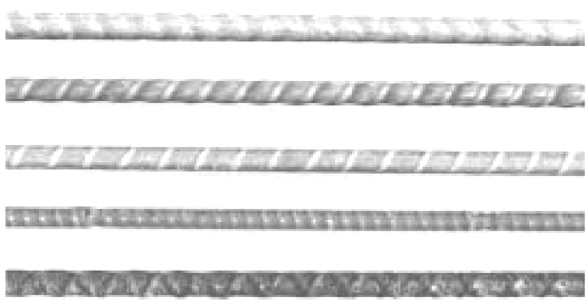


Figure 1: GFRP reinforcing bars (ACI committee 440.1R-06, 2006)

Although less research work has been conducted on the vertical irregular building with the shear wall, there is no comprehensive study comparing RC shear walls and GFRP reinforced shear walls in the setback buildings, creating a gap in current knowledge. Setback structures are more susceptible to seismic forces than ordinary structures, and setback arrangements are particularly critical due to sudden mass and stiffness discontinuities. Setback structures can be made very stiff and stable against seismic forces by using shear walls. Reinforced concrete (RC) shear walls have been the most common choice in the past, but their heavy self-weight and susceptibility to corrosion are serious drawbacks. In the last few years, glass fibre–reinforced polymer (GFRP) has also been a suitable alternative material possessing high strength-to-weight ratio and corrosion resistance. Conducting comparative research of RC and GFRP shear walls in setback buildings is therefore of theoretical and practical interest in structural engineering. This type of research can determine relative weaknesses and strengths of each system, guide decision-making for material and structural selection, and ultimately result in safer, more efficient and sustainable building design. This study focuses on comparative study of RC and GFRP shear walls in setback buildings. A finite element model was developed using ETABS, and RSA analysis was conducted based on the NBC and IS codes. However, there are several limitations to this study; uniform shear wall thickness throughout the height was taken. Nonlinear material behaviors such as concrete cracking, steel yielding, and the brittle failure of GFRP were not captured.

The objectives of this study are to identify the critical configuration of a building from selected structural shapes and to compare the effectiveness of reinforced concrete (RC) and glass fiber–reinforced polymer (GFRP) shear walls in setback buildings.

2. Methodology, Modeling and Analysis

This research aims to conduct a comparative study between RC shear walls and GFRP shear walls in setback buildings. The analysis was carried out using ETABS 2020 software, following the provisions of NBC: 105:2020. (G+10) storey building with four different setback configurations was considered. Amongst these, the setback on both sides was identified as the most critical configuration. Based on the recommendation of Suwal & Khawas[9] the optimum location of shear walls was taken at the corners of the building. The Response Spectrum analysis method was adopted to assess the seismic response of the structures under lateral forces. The methodology followed in this study can be summarised as follows:

1. Problem identification following a through existing literature review.
2. Four setback configurations such as (i) setback at half (50%), (ii) setback at two positions (55%), (iii) setback on both sides (30%) and (iv) setback on four sides (45%) were modeled on the ETABS 2020 software.
3. Amongst these, the setback on both sides was identified as the critical configuration by performing RSA.
4. The critical configuration was modelled on ETABS with RC shear walls and GFRP shear walls placed at the corners.
5. The seismic response of the models was evaluated using the Response Spectrum Analysis.

6. Comparative analysis was performed between RC and GFRP shear walls in terms of storey displacement, storey drift, stiffness and base shear.
7. Results were interpreted, and conclusions were drawn based on the comparative findings.

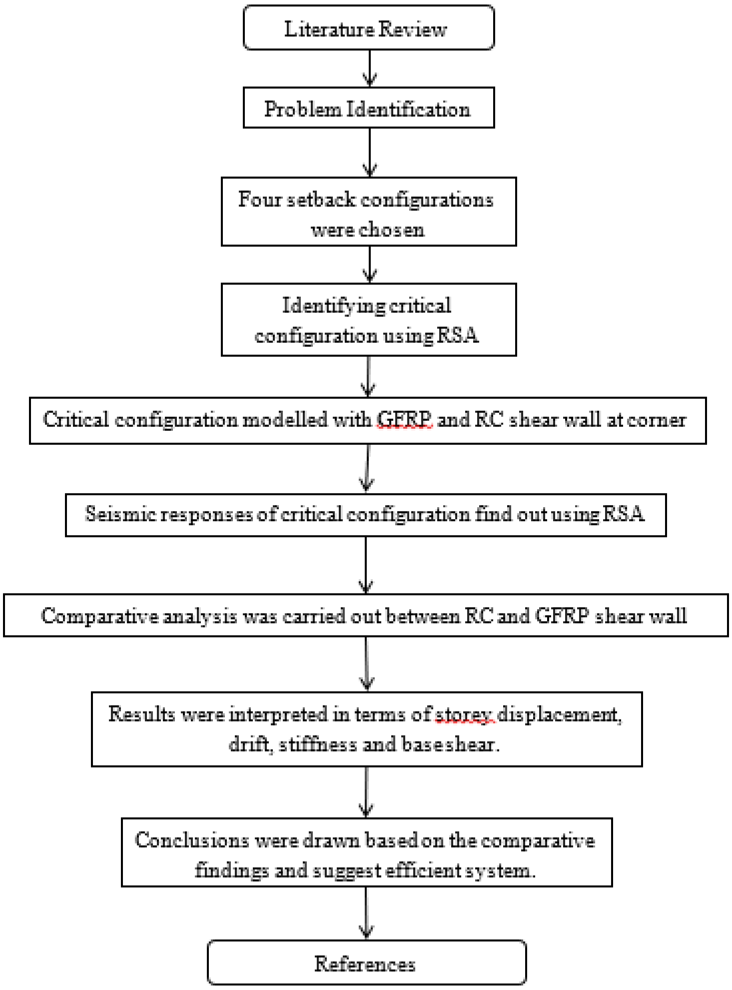


Figure 2: Methodological Flow Chart.

2.1 Configuration building

The building model taken for this study, a G+10-storey building having 9 bay x 9 bay configuration with a 4m center-to-center column distance, measures 36m x 36m in plan dimension, and all the building configurations have taken same dimensions to enable a controlled comparison of structural performance under varying configurations and is shown in Table 1.

Table 1: Sections and material properties

Description	Values	Description	Values
Storey	G+10	Zone factor (Z)	0.35
Grade of concrete	M25	Important factor (I)	1.25
Grade of steel	HYSD-500	Response reduction factor	5

Storey height	3 M	Lift load at top	10 KN/m^2
Column size	800x800 M	For material Glass fiber	According to ACI committee 440.1R-06,2006
Beam size	650x750 M	Density	2100 Kg/M^3
Slab thickness	125 MM	Modulus of elasticity	50000 Mpa
Wall thickness	230 MM	Coefficient of thermal expansion	6x10^{-6} 1/C
Shear wall thickness	230 MM	Tensile strength	483-1600 Mpa
Partition and parapet wall thickness	115 MM	Minimum yield strength	360 Mpa
LL, floor	3 kN/m^2	Minimum tensile strength	483 Mpa
LL, roof	1.5 kN/m^2	Expected yield strength	395.64 Mpa
Floor finish	1 kN/m^2	Expected tensile strength	530.82 Mpa
Soil type	D		

Four setback-shaped building configurations were considered in this study to examine the structural behavior under different geometric irregularities. The selected configurations include: (i) a building with a setback at mid-height, representing a 50% reduction in plan area; (ii) a building with setbacks introduced at two different elevations, resulting in a 55% plan area reduction; (iii) a building with symmetrical setbacks on both sides, each accounting for a 30% reduction; and (iv) a building with setbacks on all four sides, corresponding to a 45% reduction in plan area. These configurations were selected to represent common setback patterns observed in urban buildings and are illustrated in Figure 2. Figure 3 illustrates the ground floor plan of the building.

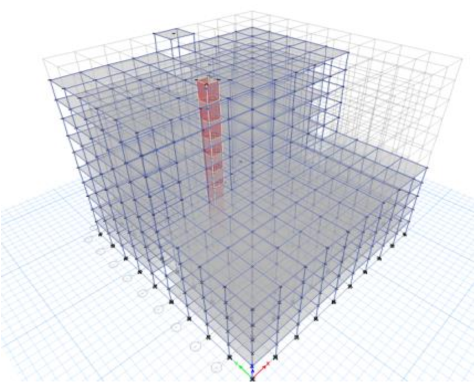


Figure 2a: Setback at half (50%) building

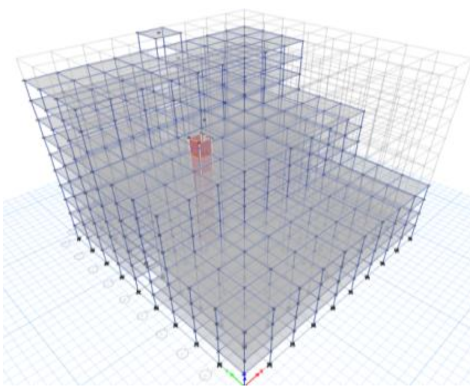


Figure 2b: Setback at 2 positions (55%)building

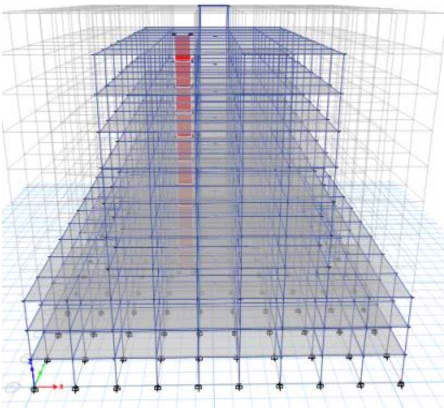


Figure 2c: Setback on both sides (30% both sides) building

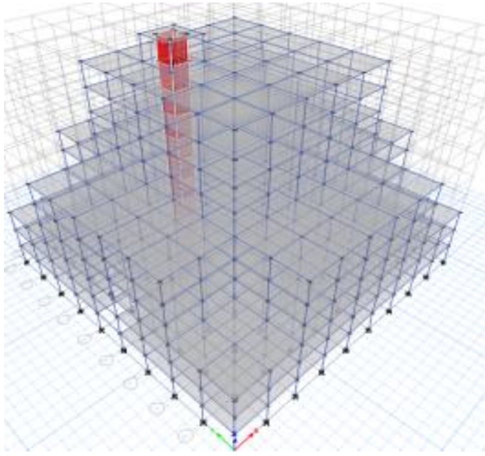


Figure 2d: Setback on four sides (45%) building

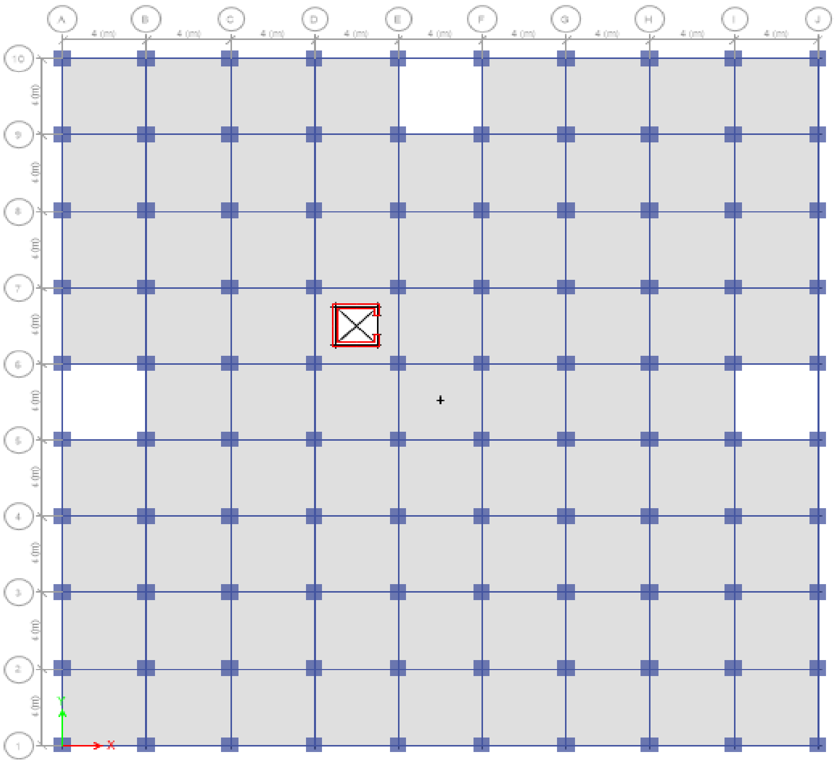


Figure 3: Plan of Ground Floor of the Building

2.2 Modelling and Procedure

The following modelling procedure is undertaken to prepare finite element models for structural analysis using Response Spectrum Analysis.

a) Four setback buildings with different configurations, such as (i) setback at half (50%), setback at 2 positions (55%), (iii) setback on both sides (30%) and (iv) setback on four sides (45%) are modelled using finite element software (ETABS 2020).

b) Column and beam are modelled as two nodes and 6 degree of freedom at each node. Slab and RC shear walls are modelled as thin shell elements, whereas GFRP shear walls are layered type, having 4 nodes and 6 degree of freedom at each node. The properties of GFRP bars are taken from ACI committee 440.1R-06, 2006.

c) Load due to self-weight is modelled as dead load and staircase loads are modelled as both dead load and live load.

d) Earthquake load is considered in both X and Y directions with the following details: Soil type D, Seismic zone factor (Z) = 0.35, Importance factor (I) = 1.25 and Response Reduction factor = 5.

e) Load combinations and mass source are defined and formulated as per NBC: 105 2020 and IS456:200.

f) Response Spectrum as per NBC: 105:2020 is loaded and fixed the scale factor to match base shear with equivalent static and a model validated with theoretical period.

g) In this study, Response Spectrum Analysis (RSA) was selected instead of the nonlinear analysis method because RSA is widely accepted in international and national seismic design codes, including NBC: 105:2020. The present study aims to investigate elastic behavior of structures, especially storey displacement, drift, stiffness and base shear, in order to evaluate the effectiveness of RC and GFRP shear walls. The building taken for this study is G+10 storeys with setbacks, which falls under range where RSA can provide accurate prediction seismic behaviour and the primary objective of this study is to compare the seismic performance of RC and GFRP shear walls rather than evaluate localised material nonlinearity.

Figure 4 shows the plan layout of the building with setbacks on both sides and shear walls at the corners to improve lateral stiffness and torsional resistance, while Figure 5 presents the three-dimensional view highlighting the vertical discontinuities due to setbacks and the continuity of corner shear walls for enhanced seismic performance and structural stability.

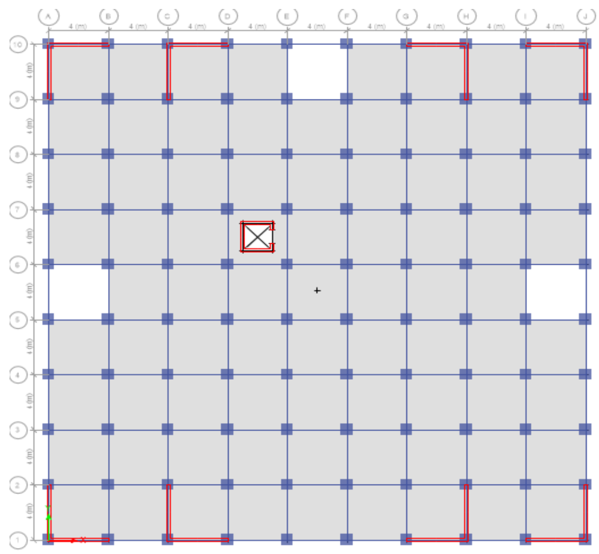


Figure 4: Plan of setback on both sides building with shear wall at corners

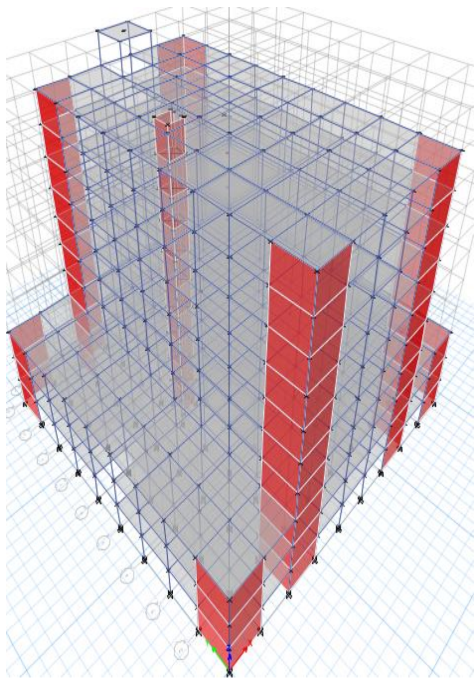


Figure 5: 3D of setback on both sides building with shear wall at corners

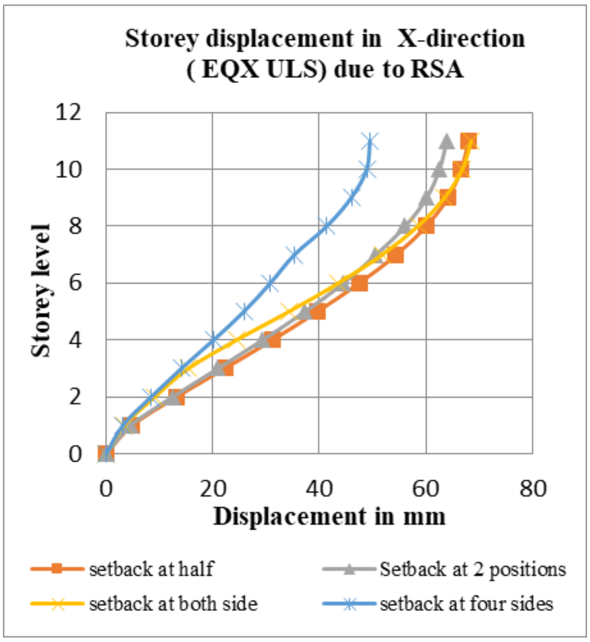
3. Result and Discussion

After modelling of different setback configurations, such as (i) setback at half, (ii) setback at 2 positions, (iii) setback on both sides, and (iv) setback on four sides on ETABS 2020, Response Spectrum analysis is carried out to find out the critical configuration. The analysis results are presented below.

3.1 Seismic parameters result of four setback configurations due to RSA, ULS

3.1.1 Maximum storey displacement

From Figure 6, the maximum storey displacement of normal type building due to RSA, setback on both sides shows maximum displacement in X direction, and setback at half shows in Y-direction. Setback on both sides produces a non-uniform but planar symmetric reduction of stiffness that produces lateral flexibility along the aligned axis. The resulting misalignment between center of stiffness and center of mass increases torsional coupling causes to dominate the elastic displacement response [18]. A half-setback introduces plan asymmetry: unilateral loss of stiffness and resulting mass offset both concentrate flexibility and raise effective eccentricity in the direction of setback. That asymmetry raises the modal contribution and dynamic amplification in the orthogonal axis (here, the Y-direction), and hence the peak displacement is in the Y-direction under RSA [19].



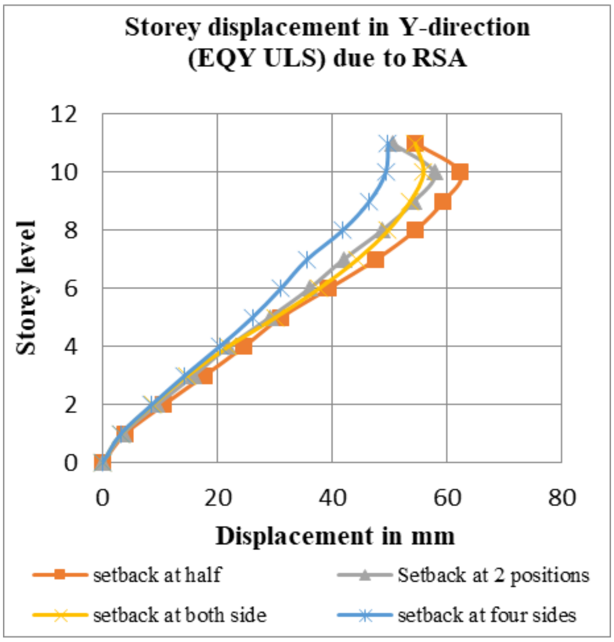


Figure 6: Storey displacement in the X- and Y- directions obtained from response spectrum analysis (RSA)

3.1.2 Maximum storey drift

Setback on both sides shows the maximum drift in X-direction and setback at half in Y-direction shown in figures 7 and 8. The setbacks are imposed symmetrically on both sides; the stiffness of the building reduces uniformly along the X-axis. This uniform reduction leads to increased lateral flexibility in the X-direction with increased storey drifts along the X- axis. Setback at half has a setback only along the Y-axis that creates asymmetrical distribution of stiffness, results in asymmetrical flexibility in the Y-direction and provides higher drift in the

Y- direction.

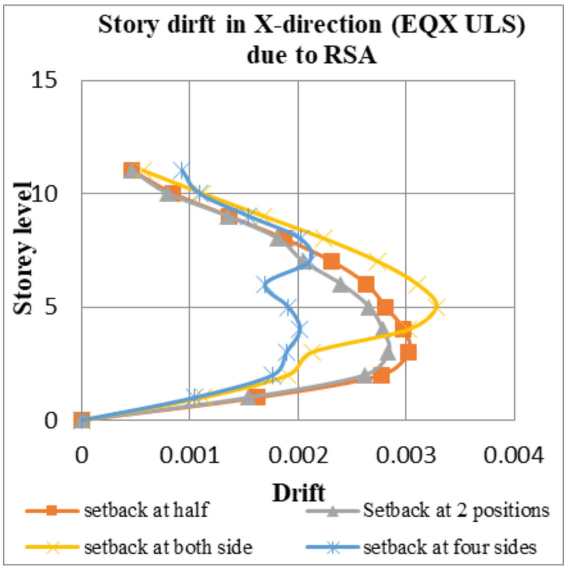


Figure 7: Storey drift in X-direction due to RSA

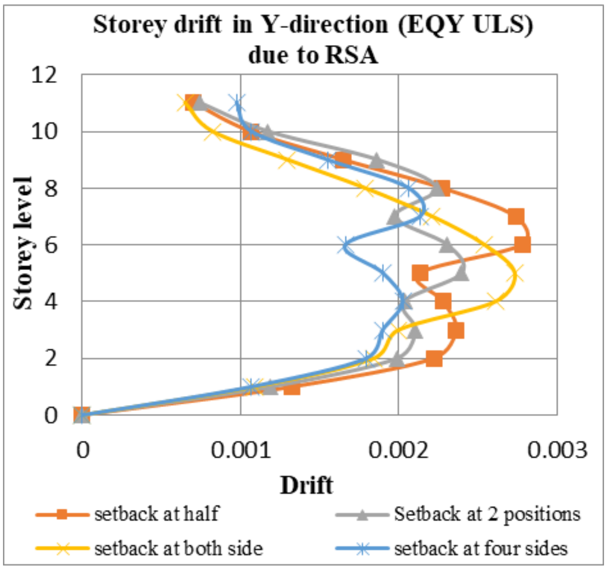


Figure 8: Storey drift in Y-direction due to RSA

3.1.3 Maximum Storey Stiffness

In figures 9 and 10, the setback on all four sides exhibit maximum stiffness because setback introduced on all sides equally, the reduction in plan area and stiffness is distributed uniformly around the building's perimeter. This results in a more symmetric distribution of lateral load resisting elements in all the directions that provided the structural system retains more continuity and redundancy, as result, stiffness is relatively higher. The Setback on both sides exhibits minimum stiffness. In setback on both sides building setback are on two sides, there is a loss in symmetrical plan area and lateral load resisting elements. As a result, stiffness is relatively lower on the setback on both sides buildings [20].

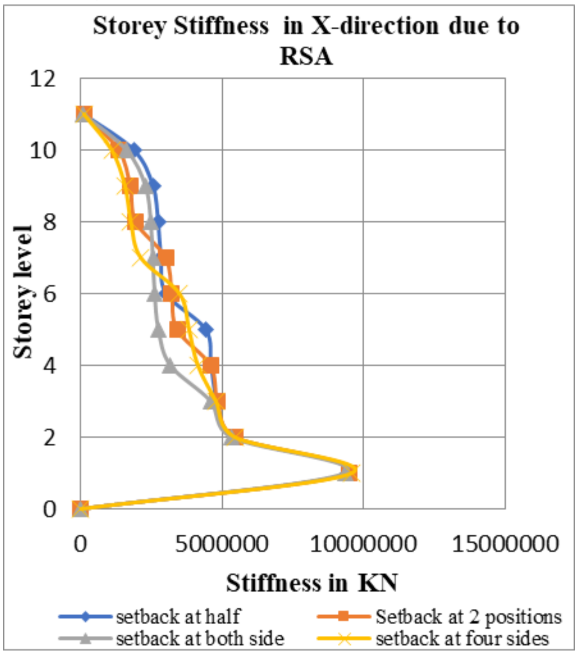


Figure 9: Storey stiffness in X- direction due to RSA

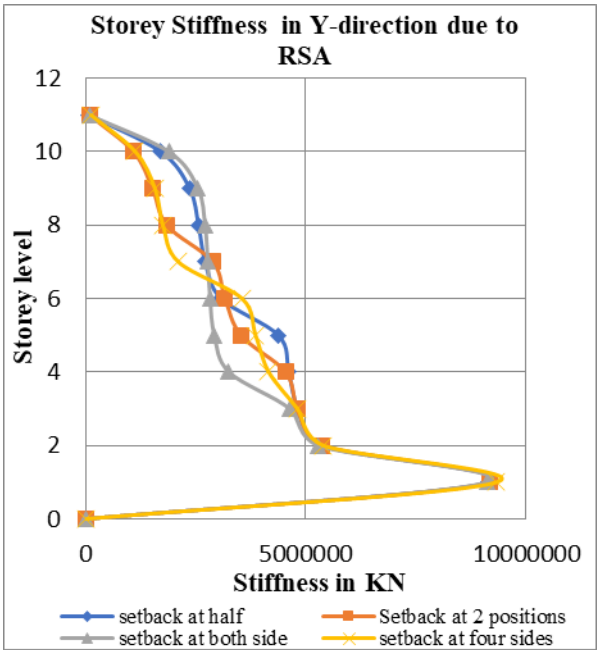


Figure 10: Storey stiffness in Y-direction due to RSA

After analysis of four setback configurations using RSA, the configuration with setbacks on both sides exhibits the maximum lateral displacement and drift in X-direction. Conversely, setback at half in Y-direction as well as setback on four sides shows minimum displacement and drift in both directions. In terms of stiffness setback on both sides shows minimum value, while setback on four sides shows maximum value in both directions, the finding indicates that the setback on both sides is the most critical configuration. Misalignment of center of mass and stiffness, loss of mass and lateral load resisting elements in two directions make setback on both sides building more vulnerable to seismic forces.

3.2 Seismic parameters result of setback on both sides building with RC and GFRP shear walls at corners due to RSA, ULS

The critical setback configuration was found as setback on both sides and then setback on both sides of the building modelled with RC and GFRP shear walls at corners on ETABS. Response Spectrum Analysis was performed to find out seismic response. The analysis results are presented below.

3.2.1 Maximum Storey displacement

From figures 11 and 12, the analysis of maximum storey displacement of setback on both sides building with RC and GFRP reinforced shear walls at corners subjected to RSA under Ultimate Limit State (ULS) conditions in X and Y directions highlights the influence of different shear wall systems. The introduction of GFRP reinforced shear wall reduced the displacement to 40.445mm and 34.671mm, while RC shear wall further reduced it to 38.604 mm and 34.069 mm in X and Y directions respectively. These results correspond to reduction of 39.563%, 37.986% with GFRP shear wall and 42.324%, and 39.063% with RC shear wall in X and Y directions respectively, compared with buildings without shear walls. The additional 2.762% in X-direction and 1.077% in Y-direction reduction achieved with the RC shear wall than the GFRP shear wall is attributed to rigidity and higher stiffness of RC shear wall, which gives higher resistance of against the lateral force. While lighter and high strength-to-weight ratio of the GFRP shear wall exhibits slightly lower stiffness and higher lateral displacement than RC shear wall. An experimental and analytical studies of FRP bar reinforced shear walls have significantly demonstrated, although FRP-reinforced walls significantly mitigate residual deformations and damage, their stiffness is lower than conventional RC shear walls[21]. The corresponding displacement values in X-direction and Y-direction are given in Table 2 and Table 3.

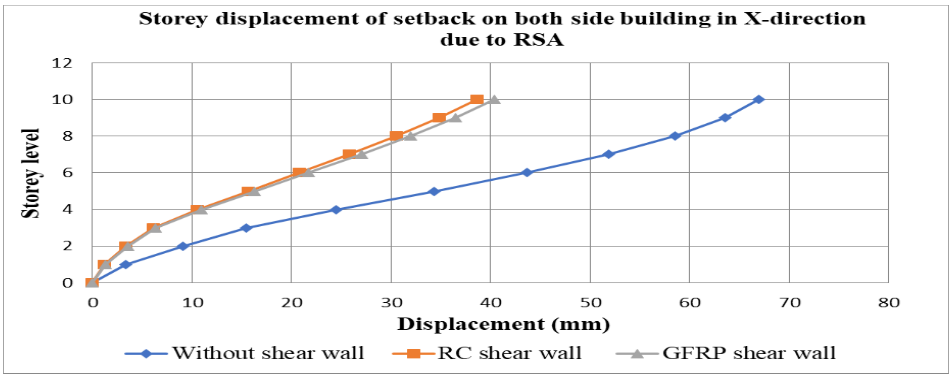


Figure 11: Maximum Storey displacement of setback on both sides building in X- direction due RSA, ULS

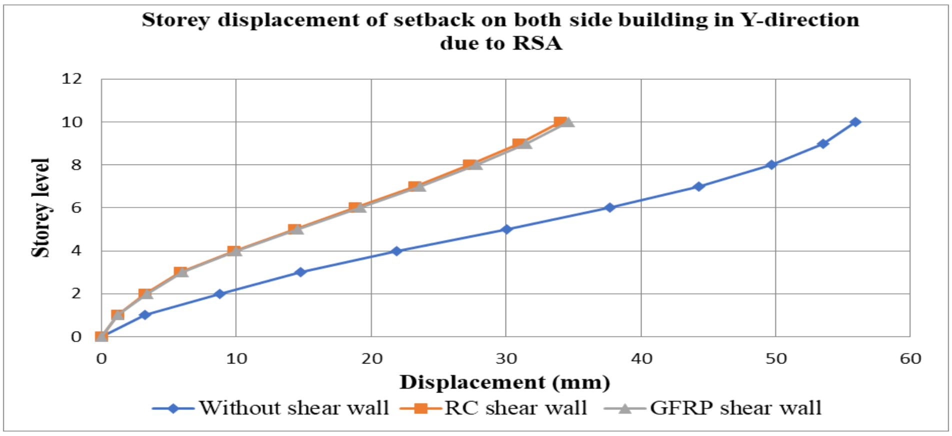


Figure 12 : Maximum Storey displacement of setback on both sides building in Y-direction due to RSA, ULS

Table 2: Maximum storey displacement of setback on both sides building in X- direction due to RSA, ULS

Storey	Elevation	Without shear wall	RC shear wall	GFRP shear wall
	M	MM	MM	MM
Storey 10	30	66.932	38.604	40.445
Storey 9	27	63.602	34.887	36.514
Storey 8	24	58.573	30.588	31.999
Storey 7	21	51.839	25.854	27.026
Storey 6	18	43.628	20.803	21.722
Storey 5	15	34.321	15.624	16.288
Storey 4	12	24.495	10.57	10.988
Storey 3	9	15.44	6.09	6.325
Storey 2	6	9.107	3.371	3.508
Storey 1	3	3.371	1.223	1.272
Base	0	0	0	0

Table 3 : Maximum storey displacement of setback on both sides building in Y-direction due to RSA, ULS

Storey	Elevation	Without shear wall	RC shear wall	GFRP shear wall
	M	MM	MM	MM
Storey 10	30	55.909	34.069	34.671
Storey 9	27	53.559	30.974	31.505
Storey 8	24	49.697	27.32	27.793
Storey 7	21	44.343	23.247	23.648
Storey 6	18	37.711	18.854	19.175
Storey 5	15	30.091	14.304	14.539

Storey 4	12	21.897	9.811	9.964
Storey 3	9	14.779	5.88	6.036
Storey 2	6	8.789	3.27	3.365
Storey 1	3	3.273	1.193	1.227
Base	0	0	0	0

3.2.2 Maximum storey drift

The maximum storey drift of Setback on both sides in X and Y directions under RSA is higher in the GFRP shear wall 0.00182, 0.001545 and lower in the RC shear wall 0.001726, 0.001517 respectively as shown in Figures 13 and 14. The introduction of RC shear wall exhibits drift reduction of 47.708%, 44.452%, while GFRP shear wall yields drift reduction of 44.789%, 43.427%. The RC shear wall achieved an additional 2.919% and 1.025% reduction in drift than the GFRP shear wall in X and Y directions, respectively. The reduction in drift can be due to the improvement of lateral stiffness and force resisting capacity provided by shear wall. By enhancing over all lateral load carrying capacity of structure, it reduces storey drift. The RC shear wall has a higher modulus of elasticity and provides higher stiffness than the GFRP shear wall, resulting in comparatively better drift control. The presence of any shear wall in buildings improves load distribution and inter-storey sway by providing a flexural mechanism [22]. The studies of GFRP reinforced shear walls, drift capacity was shown to be comparable to that of RC shear walls, through the elastic portion dominates before degradation set in [23]. The corresponding drift values in X-direction and Y-direction are given in Table 4 and Table 5.

Table 4: Maximum storey drift of setback on both sides building in X-direction due to RSA, ULS

Storey	Elevation	Without shear wall	RC shear wall	GFRP shear wall
Storey 10	30	0.00111	0.001239	0.00131
Storey 9	27	0.001677	0.001433	0.001505
Storey 8	24	0.002244	0.001578	0.001658
Storey 7	21	0.002737	0.001684	0.001768
Storey 6	18	0.003103	0.001726	0.001812
Storey 5	15	0.003282	0.001685	0.001767
Storey 4	12	0.003023	0.001493	0.001554
Storey 3	9	0.002133	0.000907	0.000939
Storey 2	6	0.001912	0.000716	0.000745
Storey 1	3	0.001124	0.000408	0.000424
Base	0	0	0	0

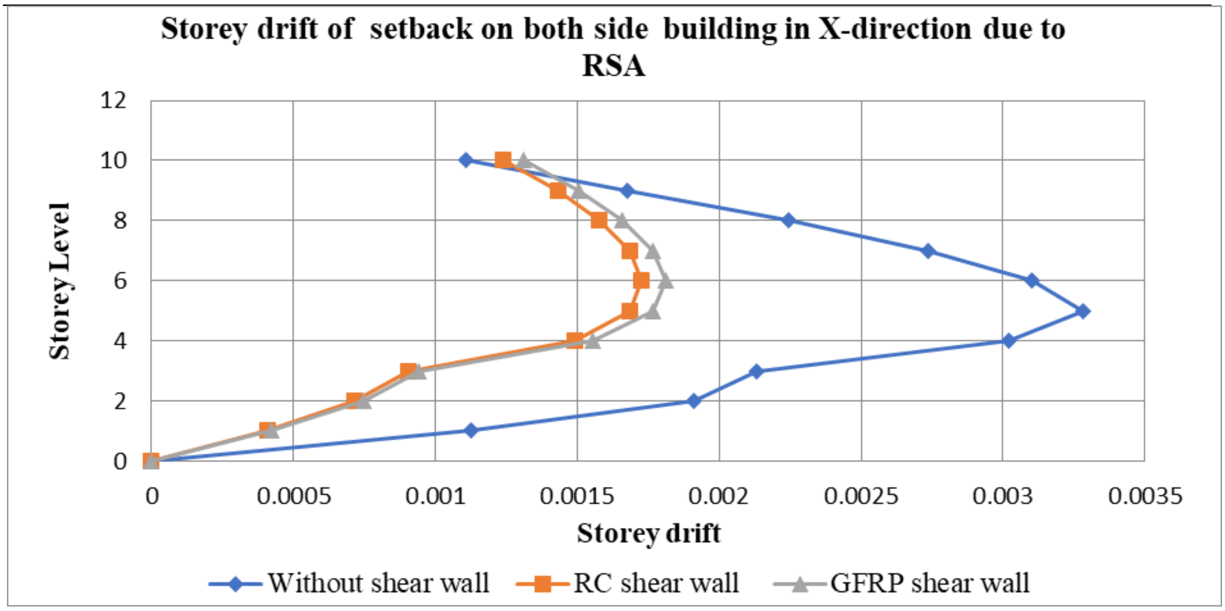


Figure 13: Maximum storey drift of setback on both sides in X-direction due to RSA, ULS

Table 5: Maximum storey drift of setback on both sides in Y-direction due to RSA, ULS

Storey	Elevation	Without shear wall	RC shear wall	GFRP shear wall
Storey 10	30	0.000821	0.001031	0.001055
Storey 9	27	0.001295	0.001218	0.001238
Storey 8	24	0.001785	0.001358	0.001382
Storey 7	21	0.00221	0.001464	0.001491
Storey 6	18	0.00254	0.001517	0.001545
Storey 5	15	0.002731	0.001497	0.001525
Storey 4	12	0.002609	0.001356	0.001373
Storey 3	9	0.001997	0.00087	0.00089
Storey 2	6	0.001839	0.000692	0.000713
Storey 1	3	0.001091	0.000398	0.000409
Base	0	0	0	0

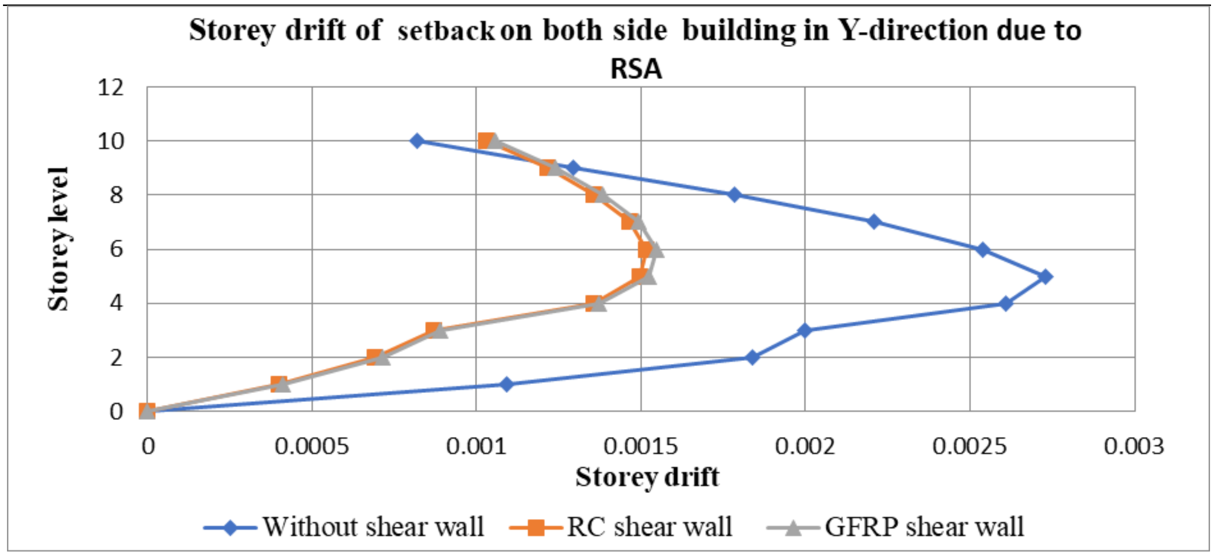


Figure 14 : Maximum storey drift of setback on both sides building in Y-direction due to RSA, ULS

3.2.3 Maximum storey Stiffness

The maximum storey stiffness of setback on both sides of the building in X and Y directions under RSA is higher when using RC shear wall 24208518.5 KN/M, 23935164.4 KN/M respectively, and when introduced GFRP shear wall stiffness decreases to 24118522.84 KN/M in X- direction, 23803451.59 KN/M in Y-directio as shown in Figures 15 and 16. These results indicate that building with the RC shear wall behaves more rigidly than compared to the GFRP shear wall. Studies show that the RC shear wall is stiffer than the GFRP shear wall because of the higher value modulus of elasticity of steel or RC shear wall [11],[24]. The values of storey stiffness in X and Y directions are given in Table 6 and Table 7 respectively.

Table 6: Maximum storey stiffness of setback on both sides building in X-direction due to RSA, ULS

Storey	**Elevation M**	**Location**	**Without shear wall KN/M**	**RC shear wall KN/M**	**GFRP shear wall KN/M**
Storey 10	30	Top	1629515.9	1398134.41	1397277.755
Storey 9	27	Top	2299518	2545433.38	2555786.629
Storey 8	24	Top	2484528.1	3327558.6	3333149.806
Storey 7	21	Top	2559739.4	3897928.09	3898527.242
Storey 6	18	Top	2627459.6	4407486.73	4402934.539
Storey 5	15	Top	2755709	4988249.16	4981663.647
Storey 4	12	Top	3182385.6	6021945.97	6046753.232
Storey 3	9	Top	4610999.5	10306109.4	10298483.9
Storey 2	6	Top	5337556.1	13553000.5	13474408.25
Storey 1	3	Top	9349082.6	24208518.5	24118522.84
Base	0	Top	0	0	0

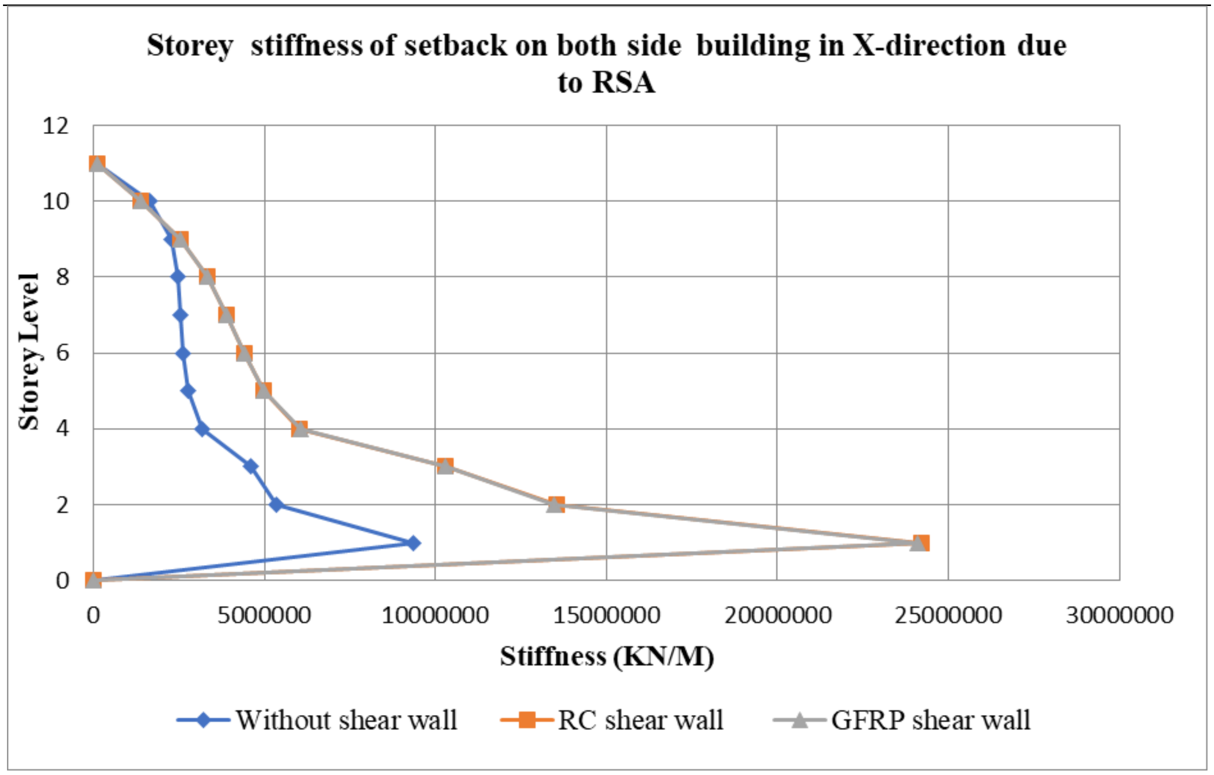


Figure 15: Maximum storey stiffness of setback on both sides building in X-direction due to RSA, ULS

Table 7: Maximum storey stiffness of setback on both sides building in Y-direction due to RSA, ULS

Storey	Elevation	Location	Without shear wall	RC shear wall	GFRP shear wall
	M		KN/M	KN/M	KN/M
Storey 10	30	Top	1890439.1	1512319.12	1510681.793
Storey 9	27	Top	2542972.3	2715927.98	2727861.259
Storey 8	24	Top	2703987.1	3523998.1	3530443.116
Storey 7	21	Top	2766523	4100167.08	4101137.375
Storey 6	18	Top	2817517.2	4604214.31	4599591.107
Storey 5	15	Top	2914231.9	5168775.22	5161618.184
Storey 4	12	Top	3251738.3	6114375	6133975.728
Storey 3	9	Top	4634147	10299668.2	10276924.42
Storey 2	6	Top	5285899.7	13487250	13382704.69
Storey 1	3	Top	9107427.3	23935164.4	23803451.59
Base	0	Top	0	0	0

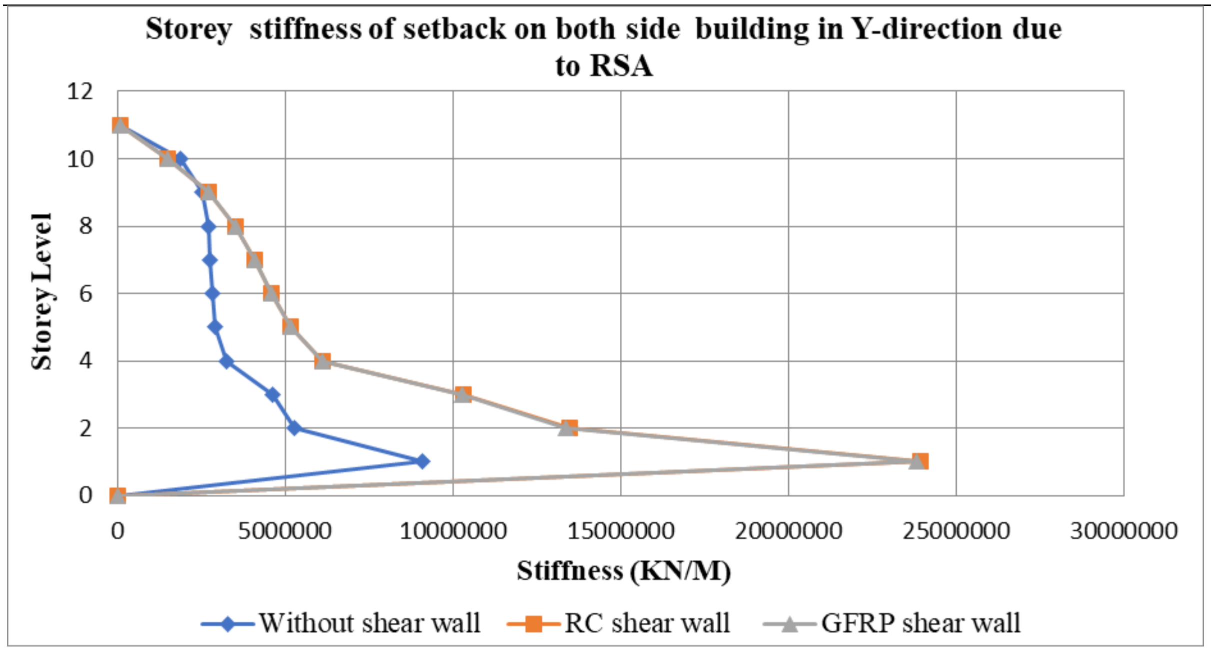


Figure 16: Maximum storey stiffness of setback on both sides building in Y-direction due to RSA, ULS

3.2.4 Maximum base shear

From Figure 17, the results show that base shear is higher for the setback on both sides with the RC shear walls (26985.97 KN) followed by the GFRP shear walls (26973.97 KN) and lowest in the bare frame (26335.29 KN). The presence of shear wall base shear capacity is increased because the shear wall can be attributed to improved lateral stiffness and strength, which results in the structure attracting greater seismic force before yielding. The base shear is slightly higher of RC over GFRP shear wall, which indicates the comparatively higher stiffness and ductility of RC shear walls, which can effectively handle strength in higher level of forces under dynamic loading. In studies of shear walls reinforced with composite materials, the study revealed that while FRP and GFRP reinforcement considerably improve strength and deformation capacity, their stiffness is lower than RC walls, which can slightly reduce forces mobilisation under equivalent condition [11].

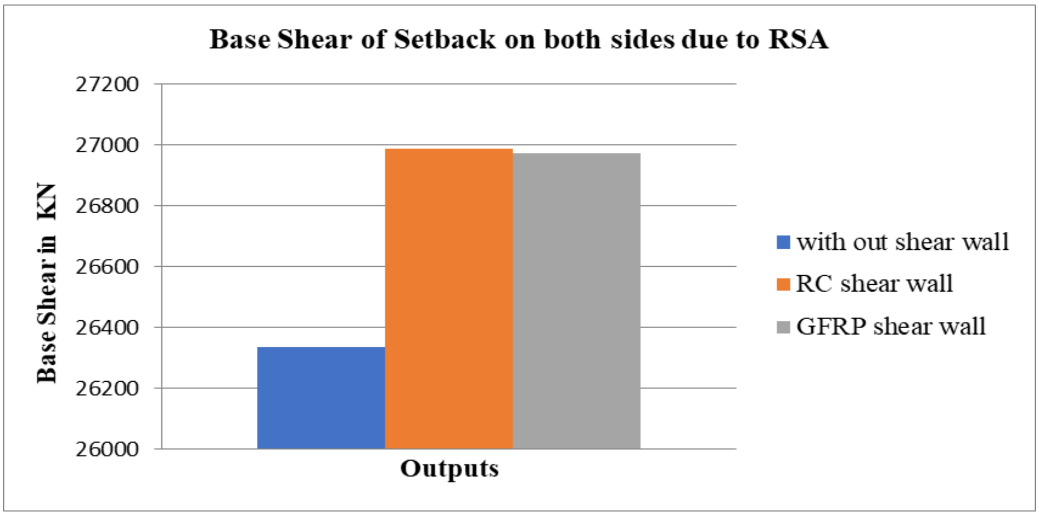


Figure 17: Base shear of setback on both sides building due to RSA, ULS

4. Conclusions

From the results of comparative analysis presented above, it can be concluded that the setback structures with RC shear walls performed better in terms of lateral displacement, storey drift, stiffness and base shear capacity when compared with GFRP shear walls.

- The RC shear wall was reduced by up to 42.324% in displacement, and 47.708% in drift, while the GFRP shear wall achieved reductions of up to 39.563% in displacement and 44.798% in drift. Thus, the RC shear walls an additional reduced 2.72% in displacement and 1.077% in drift compared to the GFRP shear walls.
- Structures with the RC shear walls showed greater stiffness and sustained higher base shear, enabling resistance to higher seismic forces before yielding.
- RC shear walls have comparatively superior performance in terms of displacement, drift control, stiffness and base shear capacity, having their higher modulus of elasticity and greater ductility. While the GFRP shear walls show slightly lower stiffness, and have advantages such as reduced weight and a high strength to weight ratio, which provide lighter foundation requirements and improved durability in a corrosive environment.
- RC shear walls are more suitable in high seismic zones where rigidity and drift limitation are critical and GFRP walls are suitable for light-weight and corrosive environments.

Thus, the study advances knowledge on differentials between RC and GFRP reinforced composite shear wall systems by quantifying seismic performance. Also, it guides engineers to the selective application of RC in critical seismic regions and GFRP in coastal or retrofitting contexts.

This study focused on Response Spectrum Analysis to captured elastic behavior of structures with uniform dimensioned of shear wall configuration, more advanced nonlinear technique like pushover and time history analysis can be used in future research to better understand the inelastic behavior of shear wall system. A more accurate evaluation of structural performance would also be possible by investigating the impact of different shear wall thicknesses along the building height.

Conflicts of interest statement

The authors declare that there are no conflicts of interest related to this work.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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