

# **Seismic response of RCC step back and step back - set back building on hill slope**

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## **ABSTRACT**

The construction done in the hilly regions is more vulnerable seismically, in contrast with the structures built in flat terrain. Structures developed in hilly areas are typically uneven in both horizontal and vertical directions. A frame building on hill slopes is the only possible choice to accommodate the increasing demand for residential and commercial buildings. The response spectrum method (RSM) is carried out in this analysis, and two different building configurations, i.e., step back and step back-set back with X and Y directions, are evaluated. The current study looked at G+9 structures with different slope angles, such as 7.5°, 15°, 22.5° and 30°. The dynamic methods to perform analysis of the structure of buildings on a hill slope with various configurations are studied i.e. with and without bracing building in seismic zone V. The characteristic parameters such as storey stiffness and storey displacement on buildings will be determined and analysed for the different structures on the sloping ground.

All 16 models were analysed using ETABS v18. Three dimensional space frame analysis is carried out for four different configurations such as step back buildings with bracings at corner of the building, step back buildings without bracings, step back and set back building with bracings at corner of the building, step back and set back building without bracings. The maximum storey stiffness and storey displacement for the step back and step back-setback buildings with and without bracing are at 15° and 30°, respectively, compare with bracing buildings, the value in step back & step back set back building drastically decreases, resulting in the stability of the building.

*Keywords: Seismic Response, Earthquake, Slope, Bracing, ETABS v18, Step back, Step back & set back.*

## **1. INTRODUCTION**

The northern regions of India, have a significant number of sloping landscapes. Due to the mountainous terrain in the north and northeast regions of India also in the southern regions of Rajasthan (Udaipur). There is a high demand for the construction of multi-storey RCC buildings on hill slopes, driven by economic growth and fast urbanization in these hilly areas. Even today, it is in the process of colliding with the influence of climate change in various regions of the country, with the maximum area being more prone to earthquakes (Rao *et al.*, 2020). The shortage of flat land in mountainous places, construction activity on sloping ground is required, resulting in a variety of important buildings such as reinforced concrete framed hospitals, colleges, hotels, and offices resting on hilly slopes. Since the behavior of buildings during earthquakes is determined by the distribution of mass and stiffness in both the horizontal and vertical planes of the building, both of which vary in the case of hilly buildings with irregularity and asymmetry caused by step back and step back-set back configuration (Kumar and Paul, 1996). Previous studies of earthquakes in hill regions, such as Uttarkashi (1991), Chamoli (1999), Sikkim (2011), Doda (2013), and others, demonstrate that buildings with varied heights of columns within the same level were the most sensitive to earthquake damage (Reshi and Singh 2022).

There are two main types of structures commonly found in these regions: step-back structures and set-back structures. Step-back structures. Indian seismic codes, IS 1893 (Part 1):2016 page no. 22, have progressively reduced stories towards the base of each bay while maintaining the same roof level. On the other hand, set-back structures do not have a uniform roof level. Step-back and set-back buildings are architectural design Strategies commonly used in seismic regions to enhance the structural integrity and seismic performance of tall buildings.

Compared to standard structures, both of these types of developments in seismically inclined terrain are exposed to greater shear and torsion forces, this can have an effect on their performance during an earthquake. One of the challenges with step-back buildings is that the shorter columns on the uphill side attract higher lateral forces, which can lead to the failure of these columns. The stiffness and strength characteristics of the walls play a crucial role in determining how much lateral load is shared by the structure (Birajdar *et al.* 2004). Studied various configurations of step-back and set-back buildings using different seismic analysis approaches such as the Response Spectrum Method (RSM).

Numerous research projects have been conducted around the world in recent decades to examine the causes of the failure of various types of buildings during strong seismic excitations (Patel *et al.*, 2018). Geological features are very significant in some areas due to the increased demand for space, certain buildings must now be built without altering the existing geological profile. Multi-storey construction on sloping terrain can significantly minimize foundation costs (Vaidya *et al.*, 2015). The seismic waves that arrive at an area on the earth's surface are the consequence of complicated superposition, which causes unstable motion and ground shaking (Dangi and Akhtar, 2019).

These designs try to reduce the effects of wind loads and seismic forces on the building by including setbacks or terraces at various heights. Different step-back and set-back building configurations with various seismic analysis techniques to evaluate their performance. This technique is frequently used to predict how earthquake-prone structures will react. It involves a range of vibrational periods. The spectrum, which is produced using ground motion information, contains details regarding the displacement of the building and storey stiffness etc.

## 2.LITERATURE REVIEW

Singh & Gade (2011) investigated that, according to a dynamic analysis of a building at a 45-degree slope and vertical cuts with varying heights for a group of five ground movements from the Pacific earthquake engineering research center database, the floor at road level was most vulnerable to damage if downhill structures occur. Step back structures were vulnerable to severe torsional impacts, and the pattern of inter-storey drifts in the upper three stories of a sloping ground structure was equal to that of a three-storey regular structure. As a result, the pattern of inter-storey drifts differs from building to building. The findings of the analytical analysis were supported by observations of the damage pattern during the Sikkim earthquake, which likely corroborated the ground floor's brittleness and torsional impacts in step back buildings. [1]

Kumar et al. (2012) studied vertical irregularities, such as geometric irregularities and buildings resting on sloping ground, for which two types of configurations were considered: buildings resting on sloped ground in the x-direction and buildings resting on sloped ground in the y-direction. They observed that sloping ground buildings were extremely fragile, attracting huge forces that deformed them significantly. The base shear of a building on a steep slope was estimated to be 6019.2 kn, which was around 25–55% larger than that of other buildings, and displacement was determined to be 83.4 mm. Which was moderately greater than other structures. They observed that the performance target of sloping ground constructions in the x-direction was not met, but it succeeded after the collapse pointed in the y-direction. As a result, they conclude that structures on sloping terrain are more vulnerable to earthquakes than buildings on flat ground. [2]

Halkude et al. (2013) studied on buildings resting on sloping terrain with various numbers of bays and hill slopes were subjected to seismic evaluation. They investigated the variation of time period, base shear, and top storey displacement in relation to variation in the number of bays along slope direction

and hill slope angle in various configurations, such as step-back and step-back-set-back buildings, which had 4–11 storeys and 3-6 bays in the x-direction. They investigated one bay along the y-axis with slopes of 16.32°, 21.58°, 26.56°, and 31.56°, with the horizontal in seismic zone iii. Base shear increases with the number of storeys in all configurations, and step-back buildings had larger values of time period and displacement than step-back-set-back buildings. Step-back building frames on sloping terrain were undesirable, but if an instrument to regulate the significant displacement was given, they may have been used. When comparing various arrangements, it was discovered that the base shear of step-back buildings was greater than that of step-set-back buildings.[3]

Jagdish and Tejas (2013) studies on 15 storeys steel building with steel bracing system in wind loading 33 m/s. the plan dimension of the building is 45mX15m and height of the storey is 3m. member selected for models steel structure are beam ISMB600, column ISMC400 bracing ISA200X200X12. In this study base shear, displacement and building weight are observed for a without bracing and with X,K, diagonal and V bracings. The results shown that maximum deflection control with X system with maximum weight of structure. [4]

Suresh and Arunakanthi (2014) Investigating in hilly regions, construction faces limitations due to local topography, leading to varied column heights and inconsistent structures. This results in higher torsion and shear during seismic activity. Research shows that step-back and set-back building frames perform better than step-back frames. However, when bracings are added to step-back frames, their performance surpasses both step-back and set-back frames. Seismic analysis reveals that dual-system structures, comprising shear walls or bracing frames, handle lateral forces based on their stiffness. Step-back frames without bracings experience higher base shear compared to other frames. They also exhibit wider time periods and greater top-storey displacement. However, they are more susceptible to seismic impact compared to other layouts and induce more torsion. Step-back frames, if recommended, need construction that addresses increased moments in columns caused by earthquakes. [5]

Vaidya et al. (2014) studies behaviour of the building on sloping ground for various shear wall positions as well as the effectiveness of shear walls on sloping ground. Model 1 was a frame-type structural system, while the remaining three were dual-type (shear wall-frame interaction) structural systems with three different shear wall placements. Sap 2000 finite element software was used for response spectrum analysis. Evaluated the building's performance in terms of displacement, storey drift, and maximum forces in columns. The roof displacement for model iii was reduced by up to 43.62% when compared to model 1 and essentially 43.38% when compared to model. Storey drift was stronger for shear wall frame interaction systems than for frame-type structural systems on other sides of the structure; this could be because of stiffness inconsistencies. [6]

Brunesi et al. (2016) investigated the braced frame behaviour in super-tall mega-braced structures with outriggers and belt trusses in their lateral force-resisting systems (LFRS). A modelling procedure is outlined for an open-source FE code to simulate these structures' inelastic dynamic response under large displacements. Extracting thirty- and sixty-storey planar frames from 3D reference buildings, the research emphasizes strength over ductility in these high-rise constructions. Bracing systems and outrigger belts effectively limit inter-storey drifts and second-order effects, with peak inter-storey drifts predicted at two-thirds of the structure's height. The outrigger arms cause visible changes in displacement and acceleration profiles due to their significant stiffening effect. In-plane rotation of outriggers minimally affects central columns but transfers high extra loads (up to 40%) to lateral columns. Compressive force profiles show discontinuities at outrigger belts, highlighting their critical role in these super-tall structural systems. These findings emphasize the importance of outriggers and bracing systems in mitigating seismic effects and maintaining structural integrity in high-rise buildings. [7]

Daniel et al. (2016) carried out an experimental study compared the dynamic behaviour of hill and regular buildings during earthquakes. Hill buildings were found less flexible due to stiffness differences, with regular buildings on flat ground being 1.33 to 2.07 times more flexible. Further, certain configurations showed higher flexibility in hill buildings. A 6-storey RC frame analysis highlighted differences in torsional forces during earthquakes between hill and regular buildings in seismic zone IV. Linear static and dynamic methods were employed for seismic research. [8]

Misal and Bagade (2016) studied the performance of two different types of buildings, such as step-back buildings without bracings, with different configurations of buildings ranging from G+8, G+10, and G+12 resting on sloping ground. Storey shear for first stories step back without bracings and step-set building frames is less than step back with bracing frames. The maximum torsion is generated at the G+12-storey building. Time period and displacement are both established maximums in regular buildings. Hence, step-back building frames without bracings on sloping ground are not desirable. However, it may be adopted by providing a bracing system to control displacements. The maximum torsional moment for step-set and regular buildings on plain ground frames is less than that for step-back with bracings and step-back without bracing frames. As the number of storeys increases, the time period and top-storey displacement also increase. Step back frames with bracings give less displacement compared with step back frames without bracings and also step and set back frames.

Imran and Rajesh (2017) studied compared the performance of various building configurations on sloping and flat ground. Step-back buildings without bracings exhibited higher storey shear compared to those with bracings, with the maximum torsion observed in G+12 buildings. Regular buildings showed maximum time period and displacement. Step-back structures without bracings on sloping ground proved undesirable, but could be made viable with a bracing system. Step-set and regular buildings on plain ground experienced lower torsion compared to step-back designs. As storeys increased, time period and displacement also rose. Step-back buildings with bracings displayed lesser displacement than those without, and compared to step-set structures. [9]

Joseph et al. (2017) investigated the G+14 storey with different slopes of ground was presented. ETABS 2015 software was used for modelling and analysis of the structure. The seismic response of the building changes with the inclusion of braces in the structure. Base shear increases with the inclusion of braces. The value of maximum base shear increases in braced structures as compared to unbraced structures. This is due to the increased stiffness of the building from the addition of braced members. Due to the inclusion of bracing, the stiffness of the building increases; hence, vibrations caused by earthquakes reduce, thus reducing joint displacement of the structure. The displacement of a building without bracing is greater than that of a building with single diamond bracing. And the displacement of single-diamond bracing is greater than that of cross-bracing. The displacement of the building with cross (X) bracing shows the least displacement. As the slope increases, displacement also increases. As the slope increases, storey drift also increases. [10]

Mohammad et al. (2017) carried out an experimental study in assessed seismic performance by altering hill building heights and lengths geometrically across 18 analytical models. Seismic forces were applied along and across hill slopes, using the response spectrum method. Step-back buildings notably increased Fundamental Time Period (FTP) in the across-slope direction (0.575 sec to 1.089 sec). Dynamic analysis revealed time period variations (0.575 sec to 0.695 sec) differing from empirical calculations (0.543 sec to 1.026 sec). Top-storey displacement ranged from 28.37 mm to 15.57 mm, showing deviation in lateral stresses. Ground column shear forces (18.89 kN to 105.24 kN) mirrored step-back layouts. Step-back structures experienced a 45% lower base shear, more drift, and heightened vulnerability to seismic stress compared to set-back buildings. The slope direction impacted shear and drift differences, ranging from 10.19% to 51.54%. Shear concentrated in mid-heights and increased with model length, showing up to a 299.92 kN difference between set-back and step-back buildings. [11]

Patel et al. (2018) studied the structural analysis initiatives E-tabs examined the impacts of various column heights on ground floors due to sloping ground and the effects of shear walls at different positions during earthquakes. Seismic analysis was performed using linear static and linear dynamic methods, and the results were evaluated using pushover analysis. Analysed buildings on sloping terrain using six different models, and the performance of buildings on sloping terrain was found to show increased vulnerability of the structure with the creation of column hinges at the base level and beam hinges at each storey level at the performance point. [12]

Sindhurashmi and Shankar (2018) investigated the buildings on flat ground and hill slopes, noting unsymmetrical hill structures faced increased shear forces and torsional moments with uneven column length distribution. Step-back designs displayed longer mode durations except the initial mode. Step-back setbacks showed lower maximum storey displacement in the y direction but greater

values in the x direction for top stories. They also exhibited reduced storey shear and drift compared to traditional step-backs, suggesting improved stability in various directions. [13]

Dangi and akhtar (2019) studied the behaviour of 6-storey structure on sloping ground, exploring impacts of shear walls at 15°, 30°, and 45° angles. Results showed significant seismic improvement with shear walls, reducing lateral displacement and member forces. Maximum displacement occurred at 45° without shear walls, indicating increased risk with steeper slopes. Shear walls notably increased base shear, with the highest at 45°, similarly affecting axial forces. [14]

Phatale and Parekar (2019) studied the dynamic characteristics of hill buildings, which were irregular and unsymmetrical in both horizontal and vertical directions. These irregular variations result in a significant torsional response when subjected to lateral loads. Bracing systems, such as X, V, inverted V, diagonal, and bare frames, can reduce these torsional moments. The analysis of dynamic parameters, such as fundamental time periods, maximum top storey displacements, storey drifts, and base shear, reveals that cross bracing increases frame stiffness and frequency, while inverted V and X bracing provide better results for step-back buildings on sloping ground. [15]

Rao et al.(2019) Investigated 3D models of 5-storey buildings at varied slope angles (15°, 25°, 35°, 45°) using ETABS software. Analysing setback-step back and stepped-back configurations in Zone IV, non-linear static analysis revealed dynamic properties (base shear, roof displacement, drift, stiffness) during ground excitation. Higher slopes showed reduced base shear, time period, and displacement. Results indicated left-side short columns as more vulnerable to shear, urging caution in modelling. Setback-step back models displayed lower displacement compared to step-back configurations. In hilly areas, the setback-step back design, incorporating shear walls or bracings, proved advantageous for structures at smaller angles, emphasizing the need for meticulous modeling and analysis. [16]

Shreyas and Vasudav (2019) investigated the buildings between hilly and level terrains. Hillside structures exhibited varying column heights due to site conditions. Using the response spectrum method, two structure types on slopes were analysed using ETABS v17. Results compared storey displacement, shear, time period, and drift across 18 models on slopes of 15°, 20°, and 25°, and heights of 24m, 27m, and 30m. Step-back frames showed higher storey displacement compared to step-back and set-back frames. Implementing step-back structures reduced storey shear by 30–35%, and 7–10% in storey drift. Higher buildings increased displacement and time period, while slopes decreased maximum displacement. The study recommended optimal configurations for such structures. [17]

Bohara et al. (2021) studied the buildings' behaviour under lateral loading, focusing on step-back structures on slopes. Shear walls, steel, and concrete bracing countered earthquake forces across nine models using ETAB's coding. Response Spectrum Analysis revealed superior performance in corner shear walls and specific concrete and steel bracings. Recommendations highlight the necessity of linear dynamic analysis for precise design in high seismic zones on step-back hillsides, advocating further research into failure mechanisms and nonlinear static analysis. [18]

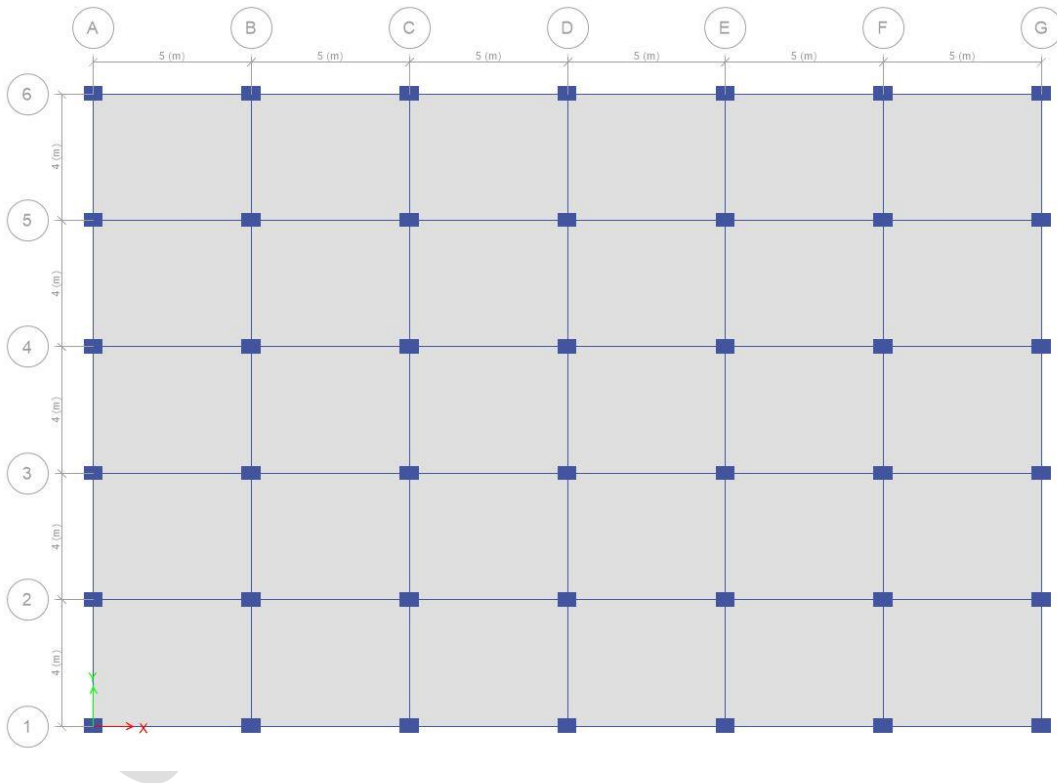
Verma and Dubey (2021) evaluated seismic behaviours in buildings using L-shear walls at corners, C-shear walls at the core, and reinforced concrete-filled steel tube columns in step-back and step-back-setback configurations. Key parameters included base shear, column forces, drift, displacement, and time period. Diagonal strut angles were set at 26.5650 and 44.740 degrees for different wall configurations. The buildings were 30m × 25m, 3.2m per floor, with slanted storeys at 280. Results showed seismic response improvements of 70-80%, base shear increments of 2-3 times, and reduced displacement by 5-7 times with shear walls. However, on inclined ground, taller columns experienced increased bending moments due to reduced height. [19]

Madhav et al. (2022) studied the seismic reaction and dynamic response of structures lying on hill slopes were investigated for step-back and step-back-set-back buildings. Most studies agreed that buildings on sloping terrain had higher displacement and base shear than buildings on flat ground, and the shorter column attracted more pressure and sustained more damage during an earthquake. Step-back buildings may be more vulnerable to seismic excitation than set-back and step-back set-back buildings. [20]

Reshi and Singh (2022) studied G+3 and G+4 buildings with slope angles ranging from 0° to 30° in seismic zone IV. Step-back and set-back configurations were analysed using a 3D model in Staad. Findings revealed that shorter columns on elevated terrain endured higher shear force compared to longer columns on lower terrain. Step-back-set-back structures exhibited superior seismic resistance over step-back designs, attributing lower base shear and top floor displacement to their flexibility in accommodating sloping ground. [21]

### 3. MODELLING AND ANALYSIS

All the models taken have the same material properties and rest on sloping grounds of 7.5°, 15°, 22.5°, and 30°. The bay width in the horizontal X-direction is 5 meters and in the horizontal Z-direction is 4 meters. From the ground to the terrace, the storey height will be the same: 3.0 meters. Also, column and beam sizes are taken according to Table No.1. All buildings rest on sloping ground, and the height of the columns of the ground Stories is different; the columns on the lower side are long columns, while the columns on the higher side are short columns with the bracing used at corner of the building. Took the reference of Indian code IS 1893 (Part I): 2016. Stories with one way slanted at different degrees of sloping ground, with the dimension in the plan as 30m x 20m as shown in Fig. 1. The buildings are designed for the zone V.



**Fig. 1** Building configuration

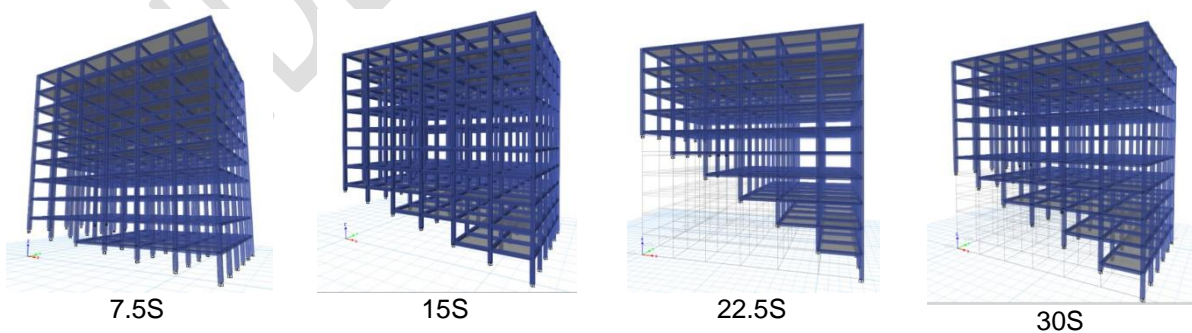
#### 3.1 DETAILED DATA OF BUILDING

**Table 1** The properties adopted for the buildings are as shown

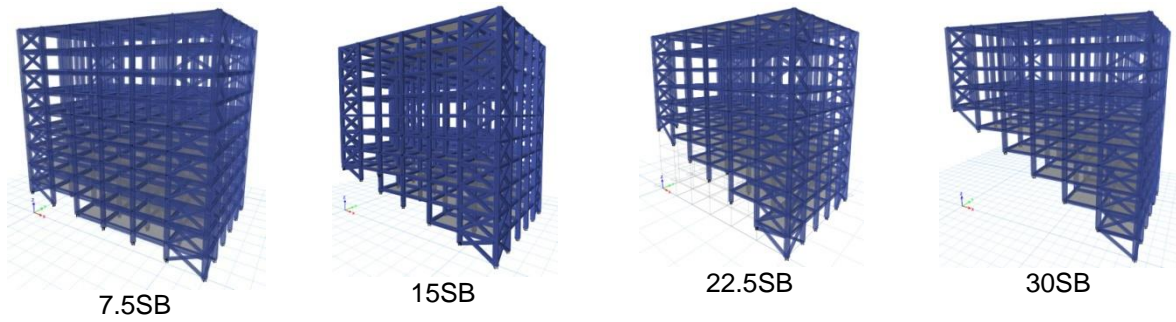
Properties
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Total stories	10 (G+9)
Plan Size	30mX20m
Storey height	3m
Spacing in X direction	5m
Spacing in Y direction	4m
Building used	Office building (SMRT)
Foundation	Isolated Footing
Seismic zone	Zone V
Soil type	Medium Soil
Concrete grade	M25
Steel grade	Fe415
Young's modulus of M25 concrete, E	2.5x10 <sup>4</sup> MPa
Poisson's ratio of concrete	0.2
Density of concrete	25 kN/m <sup>3</sup>
<b>Structural Members</b>	
Thickness of slab	125mm
RCC Beam size	300 x 350 mm
Bracing	300 x 300 mm
RCC Column size	450 x 450 mm and 450 x 600mm
<b>Super imposed Dead Load</b>	
Floor finishes	1.5 kN/m <sup>3</sup>
Wall Load	5.5 kN/m <sup>3</sup>
<b>Live Load</b>	
Terrace	1.5 kN/m <sup>3</sup>
Floor	3 kN/m <sup>3</sup>
Response reduction factor	5
Damping ratio	5%(IS 1893:2016)
Impact factor	1.5
Poisson ratio	0.2

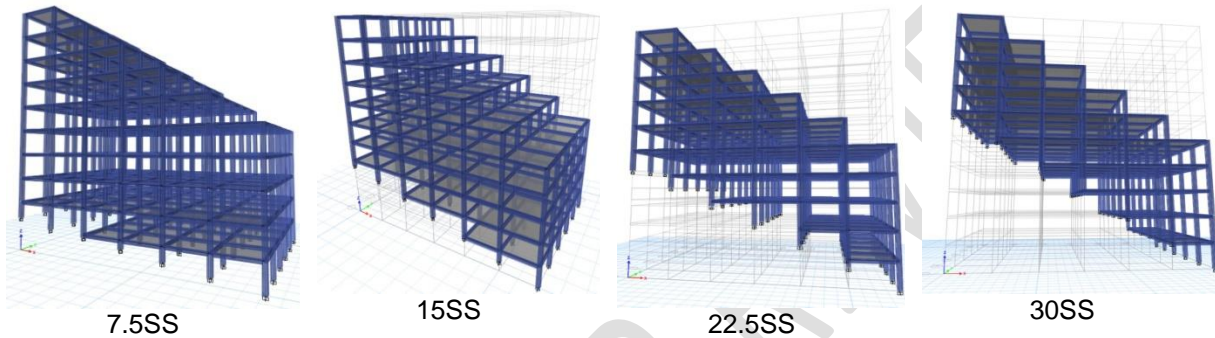
### 3.2 MODEL SPECIFICATIONS OF STEP BACK STEP BACK – SET BACK BUILDINGS WITH AND WITHOUT BRACING



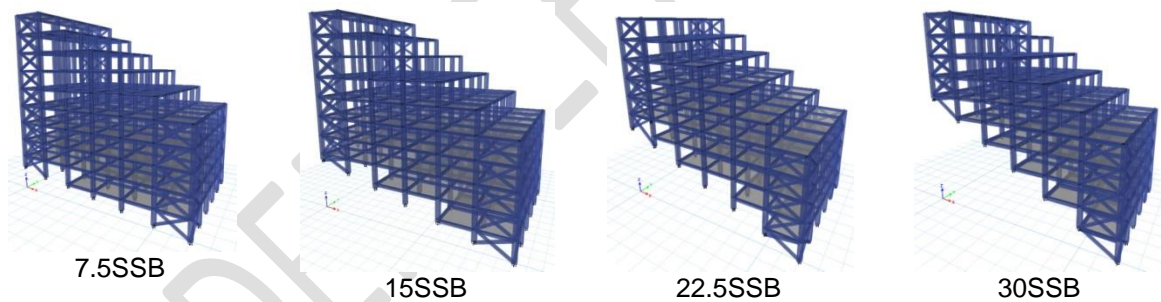
**Fig. 2** Details of the model with different irregularities for step back building



**Fig..3** Details of the model with different irregularities for step back building with bracing



**Fig. 4** Details of the model with different irregularities for step back-set back building



**Fig..5** Details of the model with different irregularities for step back-set back building with bracing

## 4 RESULT & DISCUSSION

### 4.1 Storey Stiffness

The storey stiffness is the total stiffness that is provided inside a storey by its walls and columns. The stiffness variations along the storey heights in RSM seems to be comparable. The RSM, which is most exposed in the case of an earthquake, has an exceptionally low rigidity according to models on the slope. The relative resistance of each level or storey of a building to lateral (sideways) pressures such as wind or seismic activity is referred to as the structures. In plain terms, it refers to how well each level of a building can resist movements or deformations generated by external pressures. A tougher storey will experience less lateral displacement or movement when subjected to the same lateral force as a less stiff one.

It is critical in high-rise structures to provide a balanced distribution of stiffness throughout the structure to avoid extreme movements across stories, which could lead to structural concerns or discomfort for citizens.

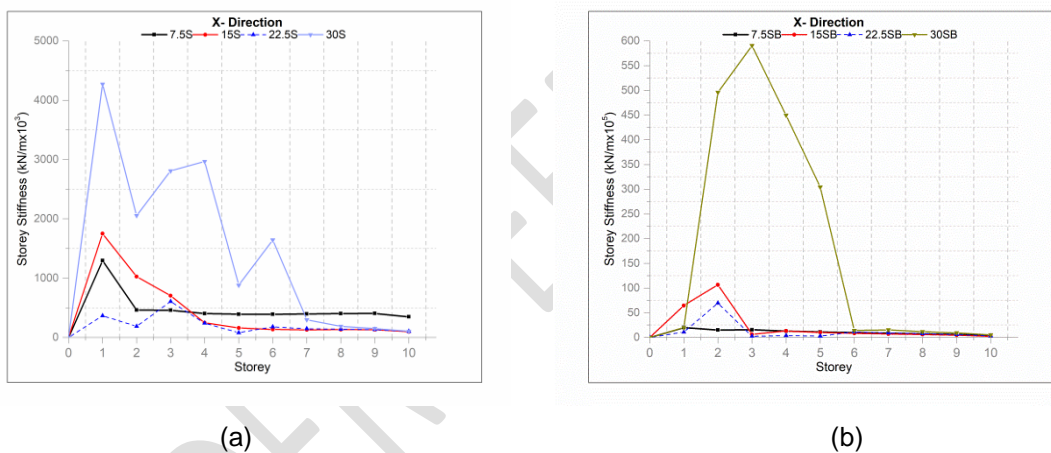
#### 4.1.1 Storey Stiffness for Step Back Building

The storey stiffness in step back building of G+9 storey at 7.5°, 15°, 22.5°, and 30° angles. The result shows the maximum storey stiffness changes from certain storey height and it reduce throughout the structure buildings particularly in both directions, without the use of bracing & with corner bracing. In x & y - direction at particular storeys of the building in zone V, the storey stiffness of the building is same for all different sloping angles.

In X direction the result shows the maximum value in both the cases (with & without bracing) which is  $590 \times 10^5$  kN and  $42.7 \times 10^5$  kN at the 3<sup>rd</sup> and 1<sup>st</sup> storey as compare with three other angles 7.5°, 15° & 22.5°. Which shows that 30° angle has highest value of storey stiffness in step back building.

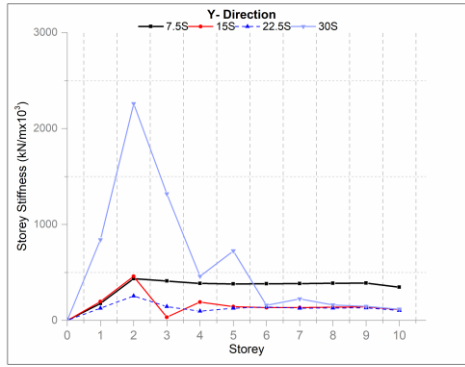
In X direction the result shows the maximum value in both the cases (with & without bracing ) which is  $389 \times 10^5$  kN and  $22.5 \times 10^5$  kN at the 1<sup>st</sup> and 2<sup>nd</sup> storey as compare with three other angles 7.5°, 15° & 22.5°. Which shows that 30° angle has highest value of storey stiffness in step back building.

**Figure 6** shows the variation in storey stiffness for zone V in x - direction with and without bracing. Storey stiffness is maximum at 30° in both the cases. But it reduces by high value as we added bracing to the building. Investigated the storey drift changes at particular storey 3<sup>rd</sup> and 7<sup>th</sup> without bracing and with bracing respectively in the building.

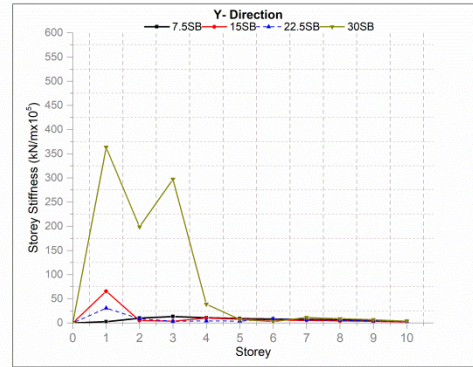


**Fig. 6** Step back building storey stiffness at x – direction (a) without bracing (b) with bracing

**Figure 7** shows the variation in storey stiffness for zone V in y - direction with and without bracing. Storey stiffness is maximum at 30° in both the cases. But it reduces by high value as we added bracing to the building. Investigated the storey drift changes at particular storey 1<sup>st</sup> and 6<sup>th</sup> without bracing and with bracing respectively in the building.



(a)



(b)

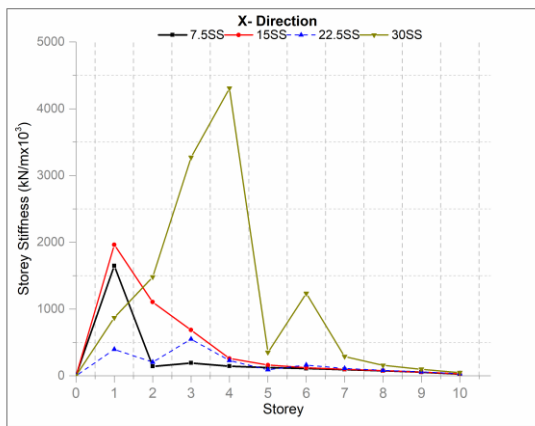
**Fig. 7** Step back building storey stiffness at y – direction (a) without bracing (b) with bracing

#### 4.1.2 STOREY Stiffness For Step Back – Set Back Building

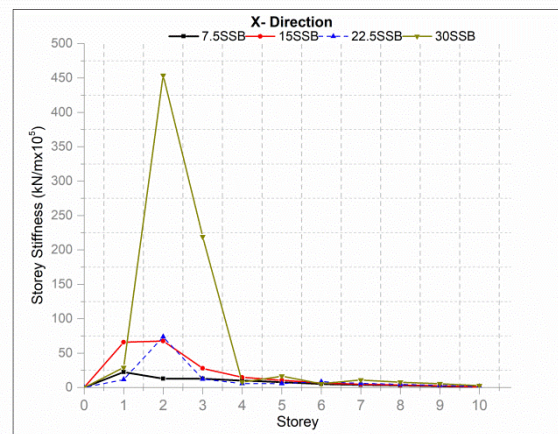
In X direction the result shows the maximum value in both the cases (with & without bracing ) which is  $453 \times 10^5$  kN and  $43 \times 10^5$  kN at the 2<sup>nd</sup> and 4<sup>th</sup> storey as compare with three other angles 7.5°, 15° & 22.5°. Which shows that 30° angle has highest value of storey stiffness in step back building.

In Y direction the result shows the maximum value in both the cases (with & without bracing ) which is  $389 \times 10^5$  kN and  $61.2 \times 10^5$  kN at the 1<sup>st</sup> storey of building as compare with three other angles 7.5°, 15° & 22.5°. Which shows that 30° angle has highest value of storey stiffness in step back building.

**Figure 8** shows the variation in storey stiffness for zone V in x - direction with and without bracing. Storey stiffness is maximum at 30° in both the cases. But it reduces by high value as we added X bracing to the building. Investigated the storey drift changes at particular storey 2<sup>th</sup> and 4<sup>th</sup> without bracing and with bracing respectively in the building.



(a)



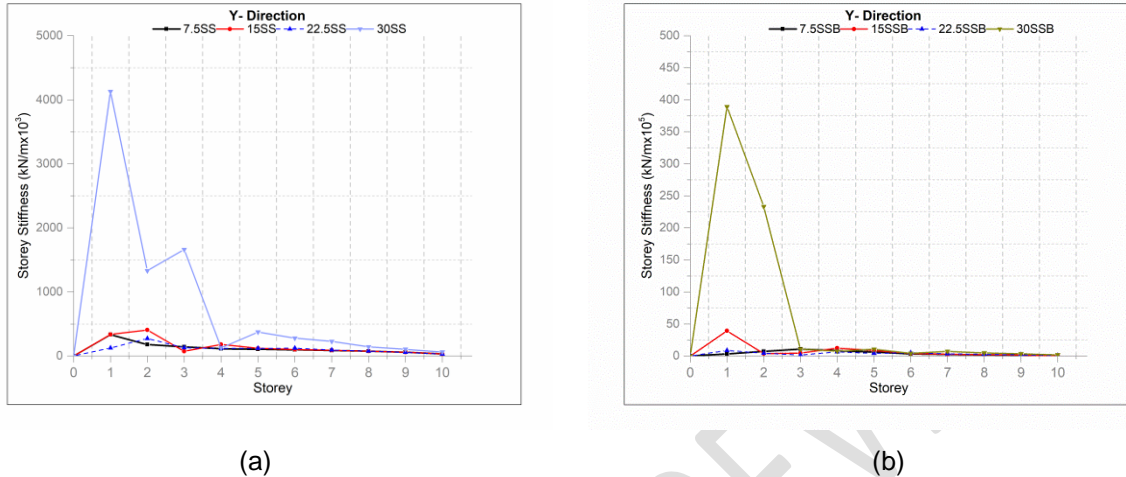
(b)

**Fig. 8** Step back – set back building storey stiffness at x – direction (a) without bracing (b) with bracing

**Figure 9** shows the variation in storey stiffness for zone V in y - direction with and without bracing. Storey stiffness is maximum at 30° in both the cases. But it reduces by high value as we added X

bracing to the building. Investigated the storey drift changes at particular storey 1<sup>st</sup> and 4<sup>th</sup> without bracing and with bracing respectively in the building.

As the floor area decreases the number of members resisting the lateral forces also decreases due to this irregularity the centre of mass and the centre of stiffness does not coincide to each other result in disturbance of storey stiffness and torsional response (Mohammad et al. 2017).



**Fig. 9** Step back – set back building storey stiffness at y – direction (a) without bracing (b) with bracing

## 4.2 STOREY Displacement

The storey displacement is the amount of lateral displacement at any point of the building with respect to its original position. The term "storey displacement" typically refers to the maximum lateral displacement or movement experienced by a building at a particular floor level during an earthquake or other dynamic loading events. This measurement is crucial in assessing the structural integrity and safety of a building.

The maximum displacements at each storey level concerning the ground determined using the response spectrum method for various configurations are displayed in both directions, X and Y. When a force acts in a given direction, displacements are detected in both the X and Y directions to reflect the influence of torsion. The storey displacement is greatest on the top storey and gradually decreases down the structure's height until it is almost non-existent on the bottom floor.

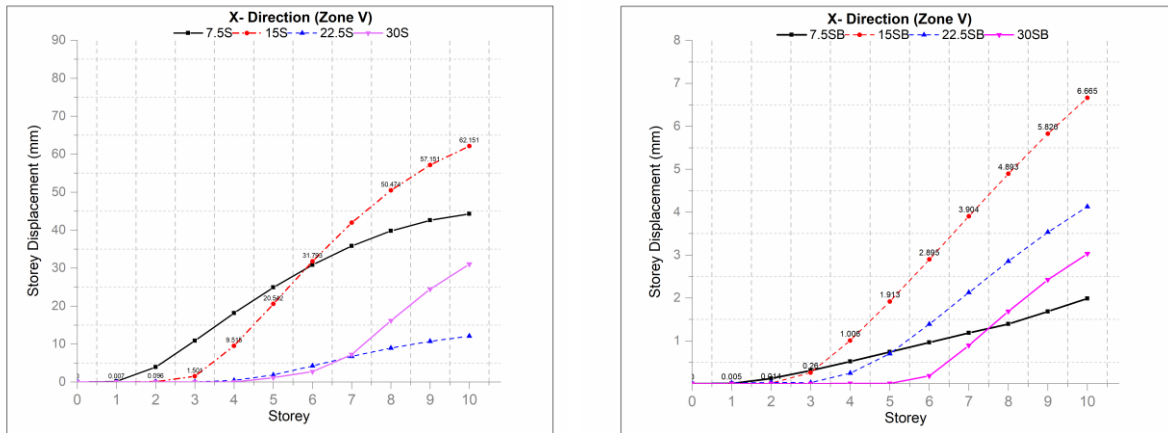
### 4.2.1 Displacement for step back building

The displacement in different zones of a G+9 storey building is examined at 7.5°, 15°, 22.5° and 30° angles. The result indicates that the biggest value is at the 10th storey of the building, indicating that 15° angle in zone V has the highest value of displacement at the top due to seismic. The results demonstrate that zones and hill slopes rise, and maximum storey displacement varies on top of structures in both directions, with and without bracing. If we check in the x and y directions at specific storeys of the building in zone V, the highest displacement is at the 10th level in both directions.

In X direction largest value from all angles is at 15° (with & without bracing) which is 6.66 mm and 62.15 mm at the 10th storey when compared with three other angles 7.5°, 22.5°, and 30° including with bracing which is 1.85 mm, 4.12 mm and 3.03 mm, respectively, as compared without bracing which is 29.52 mm, 12.06 mm and 31.03 mm.

Similarly in Y direction largest value from all angles is at 15° (with & without bracing) which is 6.38 mm and 86.16 mm at the 10th storey when compared with three other angles 7.5°, 22.5°, and 30° including with bracing which is 0.85 mm, 5.23 mm and 5.84 mm, respectively, as compared without bracing which is 35.07 mm, 8.35 mm and 10.9. mm.

Figure 10 shows the variation in storey displacement for zone V in x direction with bracing & without bracing. Storey displacement is maximum on top most storey at 15°. Result show with the use of bracing to the building the storey displacement reduces with high margin.



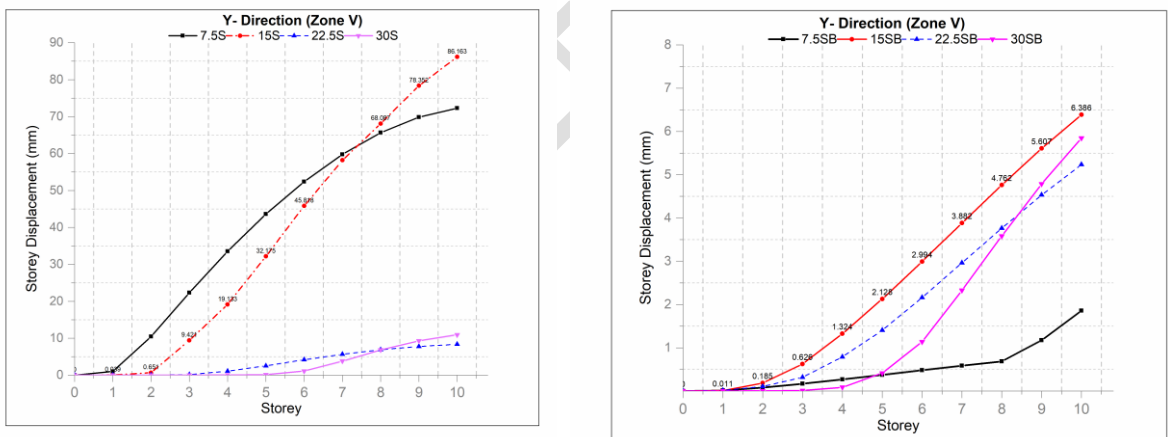
(a)

(b)

Fig. 10 Step back building displacement at x-direction in zone V (a) without bracing

(b) with bracing

Figure 11 shows the variation in storey displacement for zone V in y direction with bracing & without bracing. Storey displacement is maximum on top most storey at 15°. Result show with the use of bracing to the building the storey displacement reduces with high margin.



(a)

(b)

Fig. 11 Step back building displacement at y-direction in zone V (a) without bracing

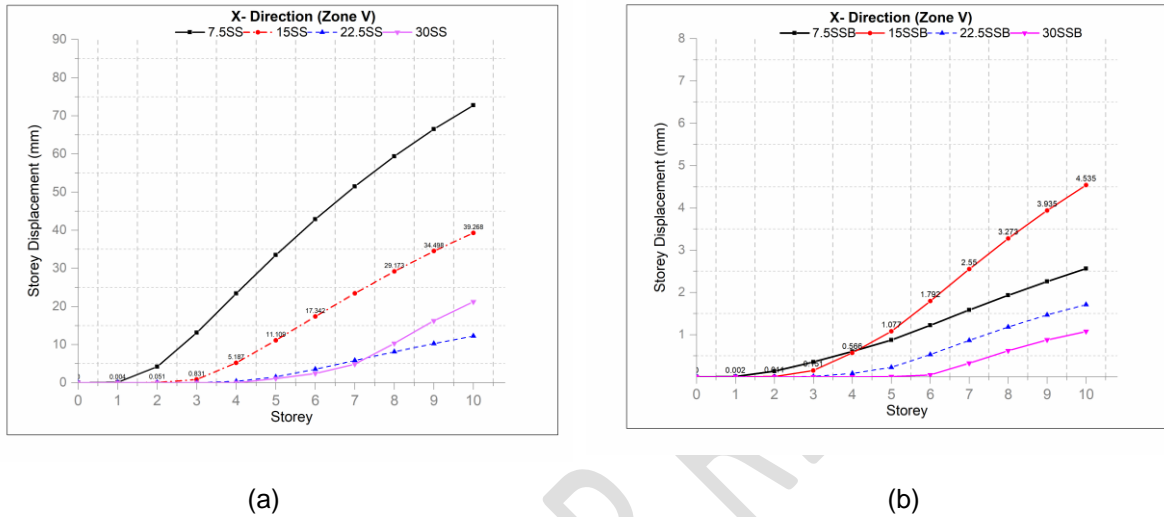
(b) with bracing

#### 4.2.2 Displacement for Step Back – Set Back Building

In X direction largest value from all angles is at 15° and 7.5° (with & without bracing) which is 4.53 mm, 39.26 mm and 2.56 mm, 72.73 mm at the 10th storey when compared with two other angles 22.5°, and 30° including with bracing which is 1.71 mm and 12.22 mm, respectively, as compared without bracing which is 1.07 mm, 21.21 mm.

Similarly in Y direction largest value from all angles is at 15° and 7.5° (with & without bracing) which is 2.79 mm, 6.16 mm and 0.95 mm, 92.44 mm at the 10th storey when compared with two other angles 22.5°, and 30° including with bracing which is 0.62 mm and 4.56 mm, respectively, as compared without bracing which is 0.152 mm, 7.255 mm.

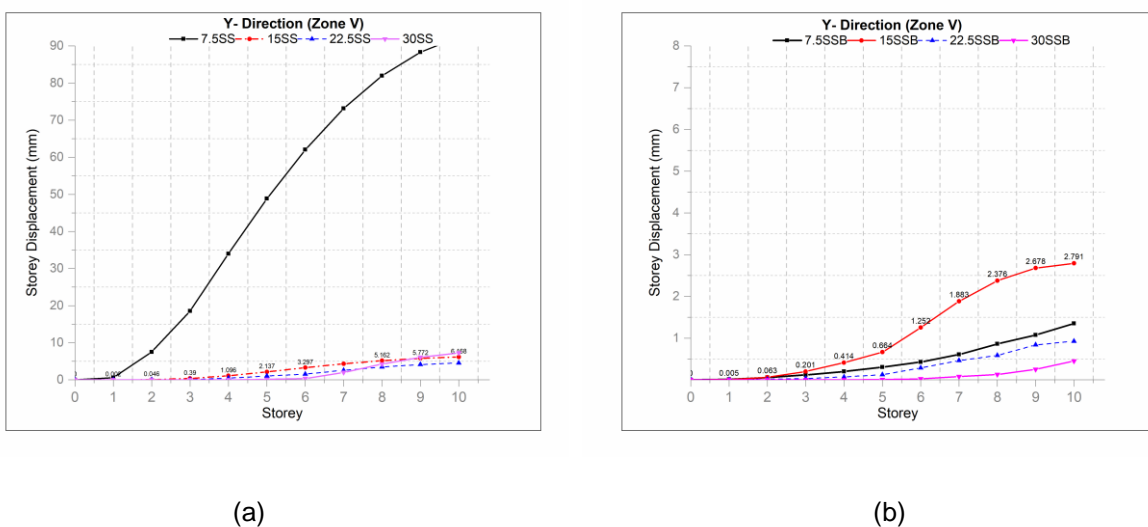
Figure 12 shows the variation in storey displacement for zone V in x direction with bracing & without bracing. Storey displacement is maximum on top most storey at 7.5° without using bracing and 15° with bracing. Result show with the use of bracing to the building the storey displacement reduces with high margin.



**Fig. 12** Step back – set back building displacement at x-direction (a) without bracing (b) with bracing

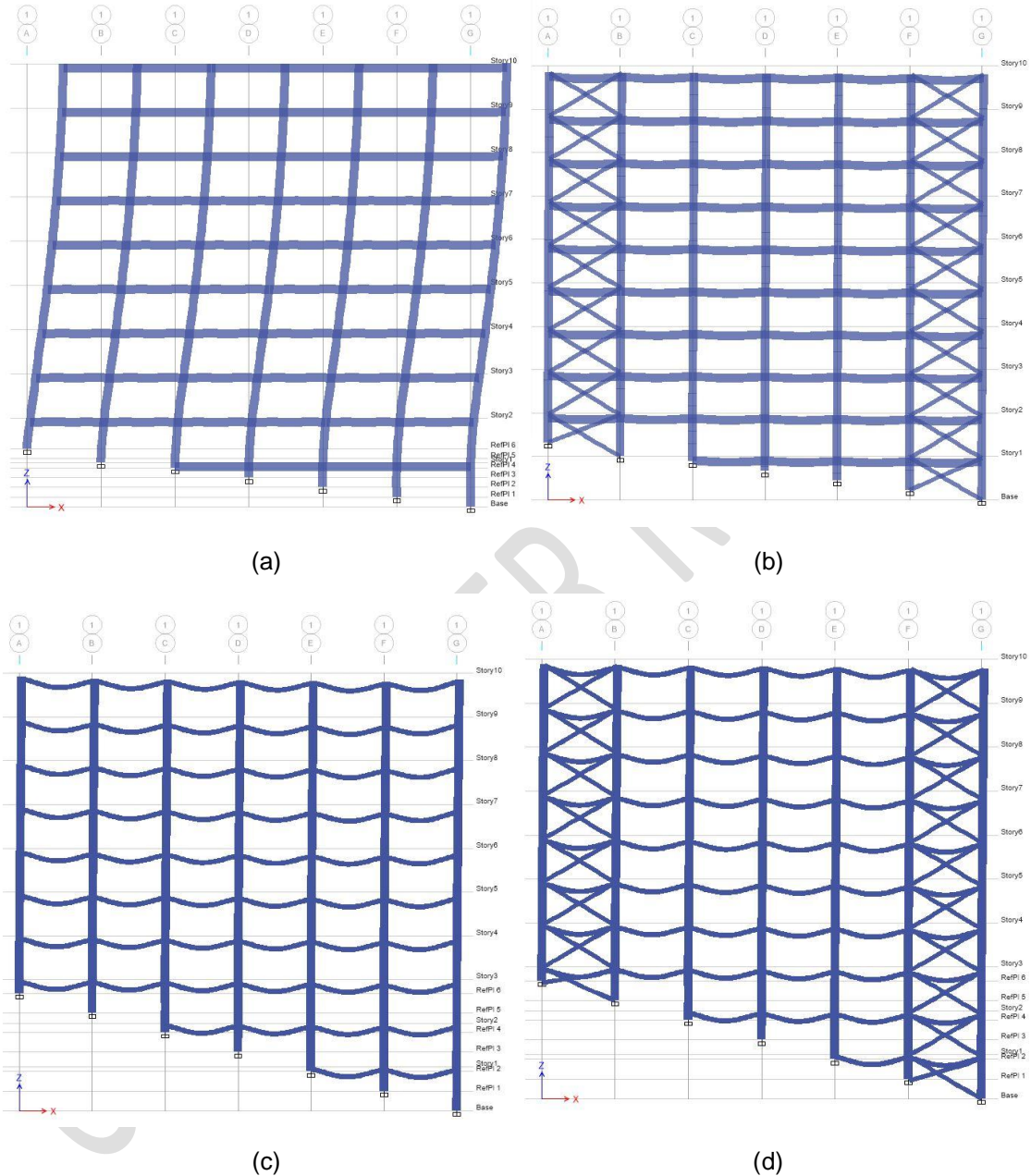
Figure 13 shows the variation in storey displacement for zone V in y direction with bracing & without bracing. Storey displacement is maximum on top most storey at 7.5° without using bracing and 15° with bracing. Result show with the use of X bracing to the building the storey displacement reduces with high margin.

Results were obtained in the form of top storey displacement. It is observed that short column is affected more during the earthquake. The analysis showed that for construction of the building on hill slope the step back and step back-set back building configuration is suitable (Dangi and Akhtar 2019).



**Fig. 13** Step back – Set back building displacement at y-direction (a) without bracing (b) with bracing

Figure 14 shows the deflected shape of G+9 structure with bracing & without bracing of step back building in zone V for x & y direction. Storey displacement is maximum on top most storey at 7.5° without using bracing and 15° with bracing. Result show with the use of X bracing to the building the storey displacement reduces with high margin.



**Fig. 14** Deflected shapes of hill sloped building at (a) 7.5S and (b) 7.5SB (c) 15S and (d) 15SB

## 5. CONCLUSION

A massive number of have a look at and studies tasks, as well as many building codes, have conveyed the problem of vertical irregularities in building. The seismic reaction of the two configurations of constructing on slopes and building on sloping terrain consider into studied by Response spectrum analysis. The following are the conclusions reached from the preceding investigation. The performance of step back and step back-set back building compared with & without bracing fundamentally and unrepeated about a structure laying on sloping ground. To determine true

behaviour, a response spectrum analysis of a three-dimensional model of complex structures such as hill buildings with & without bracings is performed.

The concept of step back and step back-set back buildings has gained significant attention due to the architectural and environmental advantages. These architectural methods, which strategically role setbacks or lessen floor in a building's structure, have some of advantages, together with advanced air flow, improved aesthetics, and expanded power efficiency. The improvement of sustainable architecture and concrete design may be helped via investigating the ability future applications of step back and step back-setback building as a thesis subject matter.

The following conclusions can be drawn based on results obtained:

- The displacement in X and Y (across and along) direction of regular building on levelled ground is minimum and as hill slope increases it is maximum at 15° in step back and step back & step back-setback. The addition of bracing in the building will results in the drastic reduction of lateral displacement of the building thereby, in turn, assures the safety of the structures.
- Structure are subjected to bracing on corner of buildings with the hill slopes, the value decreases affects the overall behaviour of the structures.
- As the number of stories increases, displacement of both step back and step back & step back-set back building increases.
- In step back building, result shows as the hill slope increases the storey stiffness increases to maximum at 30° and bracing is used the storey stiffness decreases due to base shear of the building. In step back & step back set back building the maximum stiffness is at 7.5° & shifted to 15° with bracing due to reduction of structure.
- As the storey height rises, displacement increases with the increase in height which causes storey drift. Hill slope 15° has the utmost drift value in step back as compared to 7.5° and 15° for the step back & step back set back building the ground slope is minimum than the storey drift value will be increase but as we add bracing the storey drift value starts decreasing for all the hill slopes.
- The building with bracing results in decreased value of storey stiffness, storey displacement helps in moving towards the safety of the building.

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