International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 05 | July- 2018 www.irjet.net p-ISSN: 2395-0072

Seismic Response of RC Framed Structures Resting on Sloping Terrain

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Abstract - Earthquakes are really nasty things, when earthquake was happened there was loss of lives, buildings damaged and even collapsed. Buildings constructed on the hilly regions show different structural configuration when compared to buildings constructed on flat ground. Structures on the hill slopes are unsymmetrical hence they grab large amount of shear forces and torsional moments, and also show uneven distribution due to differing column length. Stiffness is more in shorter columns, thus more force will be attracted by the shorter columns and are prone to more damage when subjected to earthquake [1]. This is the main reason for the damage during earthquake. In present study four models with different configurations are analysed using ETABS 2015 and the results in terms of story displacement, story drift, time period, story shear has been compared with step-back and step-back setback buildings and suitable configuration for hilly region has been suggested [2].

***Key Words*:** step-back building, step-back setback building, equivalent static analysis, maximum story displacement, time period, story drift, story shear.

1. INTRODUCTION

Increase in the population leads to shortage of the plain land for the construction and thus it leads to economic development of hilly terrains and hence building design, usage of material for construction and even the construction techniques should be reconsidered. Construction of buildings on sloping ground provides excellent views, natural drainage and also provides additional space from lower floor levels. Slopes are high in case of Himalayan territory, if landslide happens then there will be loss of thousands of lives and property [3]. There is great demand for construction of multi-story buildings on hill slope in and around cities due to real estate development in hilly areas [4].

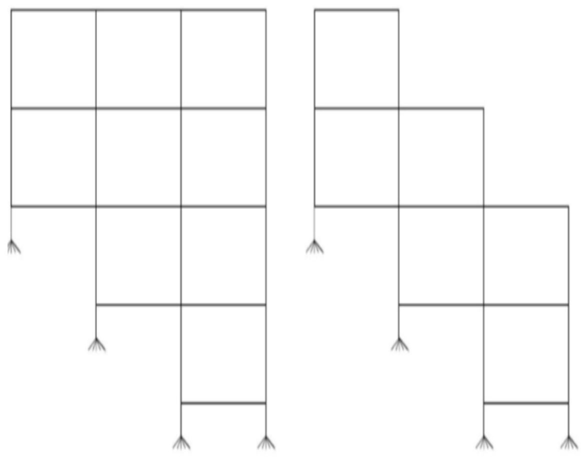
Figure 1: Buildings on sloping ground.

Past earthquakes happened in Sikkim (2011), Doda (2013) and Nepal (2015) caused more destruction of life and property. Earthquake appeared in Mexico city in the year 1985 also caused immense damage [5]. India is mainly divided into four zones depending on the intensity of earthquake (IS 1893 {Part 1}:2002).

1.1 Type of vertical irregularities

At the initial planning stage it is very important to design the configuration of the building resting on the hilly region. Simple configuration which gives the good result can be adopted. Therefore it is very necessary to analyse the 3D behavior of the buildings by using ETABS. There are mainly two types of building configurations on a sloping ground. They are

- Step-back building
- Step-back setback building



(a)Step-back building (b) Step-back setback building

Figure 2: Building configurations on sloping terrain [1], [6].

2. LITERATURE SURVEY

In this study [2] seismic response of 18 analytical models resting along and across the sloping terrain has been investigated using ETABS. Response spectrum method is also used. Shear force produced in the column exactly at foundation level, fundamental time periods, maximum story displacements, story drifts and story shear in buildings are compared with the considered configuration of buildings on sloping terrain. Suitable configuration is suggested. Seismic forces and torsional moments experienced by the step-back setback configuration is less when compared to step-back buildings due to less seismic weight of the structure. It is found that about 45 percent reduction in base shear in case of step-back setback buildings with respect to step-back buildings. According to this paper step-back buildings are more vulnerable to earthquake forces by showing higher story drift and story shear. So in this paper it is concluded that step-back setback buildings are more suitable for hilly terrain when compared to step-back buildings during seismic action.

This study [6] acknowledges about the summary of behavior of structures on the hilly terrain which is correlated to the behavior of structures on the level terrain under the action of seismic force. Majority of studies concluded that the structures on sloping terrain shows higher displacement and base shear when compared to the buildings which rests on flat ground. Damage will be more for shorter columns as it attracts more force during earthquake.

Base shear, time period, story displacement are higher for step-back buildings when it is compared with step-back setback building. Step-back buildings are greatly exposed to earthquake when compared with other configurations. Greater number of bays perform better under seismic condition. Study showed decrease in time period, top story displacement with the increase of number of bays resting on hill slope. Addition of infill wall, shear wall to the structures showed reduced story displacement and story drifts but it might increase the base shear so study suggests that special care has to be considered to reduce base shear.

In this paper [4], analysis of 24 R.C. structures having various configurations like step-back building, step-back setback building, setback buildings are analysed. Study has suggested that step-back setback buildings are more suitable on sloping terrain. From this study it is observed that the short column which is exactly at ground level is severely damaged and hence short column must be specially designed. Force attracted by the setback buildings on plain are less when correlated to step-back setback buildings but study has to be carried out in detail involving economic cost required for levelling sloping ground.

In this study [1], three dimensional space frame having different configurations like step-back, step-back setback, setback configurations has been examined. Dynamic response of these buildings are compared with other building configurations which involved base shear and top story movement and the most appropriate building configuration is suggested for the hilly regions. Maximum base shear of setback building on level ground found to be lesser when compared to step-back setback buildings. Step-back setback building on sloped ground has less top story displacement, hence step-back setback buildings are suggested for hilly regions.

This study shows that building resting on hilly areas are uneven and are not symmetrical vertically as well as horizontally [7], [8], [9]. These buildings are torsionally coupled so they are more affected by earthquake. Buildings are analysed and designed using ETABS. In this study response of the significance of bracings, shear wall at various locations are examined. This study concluded that the fundamental natural period and joint displacements decreases with the bracings and concrete shear wall.

Vijaya et.al. [10] Showed that buildings up to 9 stories are being constructed without considering the design for gravity loads in the Himalayan region. Results shows that these buildings are more vulnerable to lateral shaking. This paper found that RC buildings with large plan are more susceptible to strong seismic shaking so small plan buildings are efficient along steep slopes.

This paper [11] gives study about Boumerdes 2003 earthquake of north of Algeria which resulted in great damage to buildings and even collapsed. Nonlinear static pushover analysis is handled to check how the framed buildings will behave for future earthquakes. It is concluded from this study that the properly designed frames will perform better under seismic loads.

Seshagiri et al. [12] showed that with the new development there are new structures which will resist seismic forces during future earthquakes. In order to achieve this appropriate design impact is very important. Design force depends on tectonics, topography, geology and it is different for different areas. This paper gives idea about these design forces when the buildings are constructed on hilly areas. Geophysical investigations are carried out to catch shear wave velocity on hill slopes at Himalayan neighbourhood. Specific ground response thus found is compared with codal provisions.

In [13], authors have described that seismic activities are very common in northern India. Proper configuration of building on sloped ground is very necessary due to the unavailability of plain ground. G+6 multi-storeyed building has been analysed with story height of 3.1m on hard strata which is 1.5m below ground level. 26˚, 28˚, 30˚ slope is considered in this study. This study revealed that use of bottom ties gives good response for the structures on sloped terrain. Step-back setback buildings show less story displacement when compared to step-back buildings.

In this [14] study step-back and step-back setback building configuration having G+10 storied RCC building is analysed with slope varying from 10˚ to 30˚.Result from analysis is correlated with the building resting on level ground. ETABS 2015 is used for the analysis. Response spectrum is used. This study shows that the short column is damaged more at the time of earthquake. It has been concluded that the structures on sloping terrain displayed greater displacement and shear force when correlated with structures resting on level land. Base shear found maximum at 20˚ slope when compared to other configurations. Mode period is proportional to mass of the structure. It is observed that there is decrease in story displacement and story acceleration with the increase in slope angle. It showed increase in mode period with the increase in the mass of the structure. Top story showed maximum acceleration and displacement both in the two x and y directions.

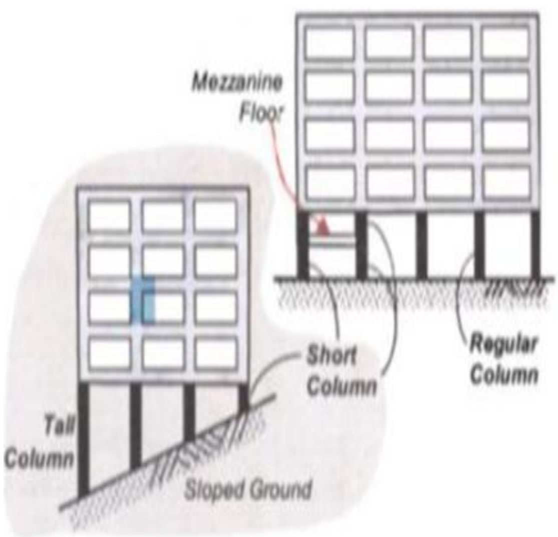


Figure 3: Building framework with short columns [14].

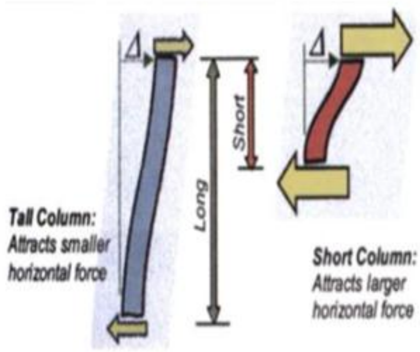


Figure 4: Structural Behaviour of short column with lateral load [14].

In this [15] study, the response of G+3 storied frame structure on the sloping terrain with step-back and step-back setback configuration is analysed using STAD Pro. 16.7˚, 21.8˚, 26.57˚, 30.96˚ sloping angles considered. Response Spectrum analysis performed as per IS 1893 (part 1) 2002. Results showed that short column is affected more during earthquake. Step-back setback building configuration is suggested. Results showed that there is decrease in story displacement with the increase in sloping angle. This study also revealed that approximately around 75% of the majority of the shear force is attracted by the short column. Which resulted in the formation of plastic hinge in short column [16]. This study also shows that base shear is more in longitudinal direction when compared to transverse direction. This paper advised that building height can be increased for 21.8˚ and 26.57˚ which showed less displacement.

Y.Singh et al. [17] examined behaviour of structures on sloped land during Sikkim earthquake in 2011.Sikkim is one of the fastest growing states of India. Dynamic response of buildings resting on slopes is compared with regular buildings resting on flat ground. Linear and nonlinear dynamic analysis exhibited that the stories of downhill buildings at road level are more susceptible to damage during seismic action.

3. METHODOLOGY

Analysis of step-back and step-back setback buildings resting on the sloped terrain is done using ETABS 2015.Seismic parameters like maximum story displacement, time period, story drift and story shear are calculated.

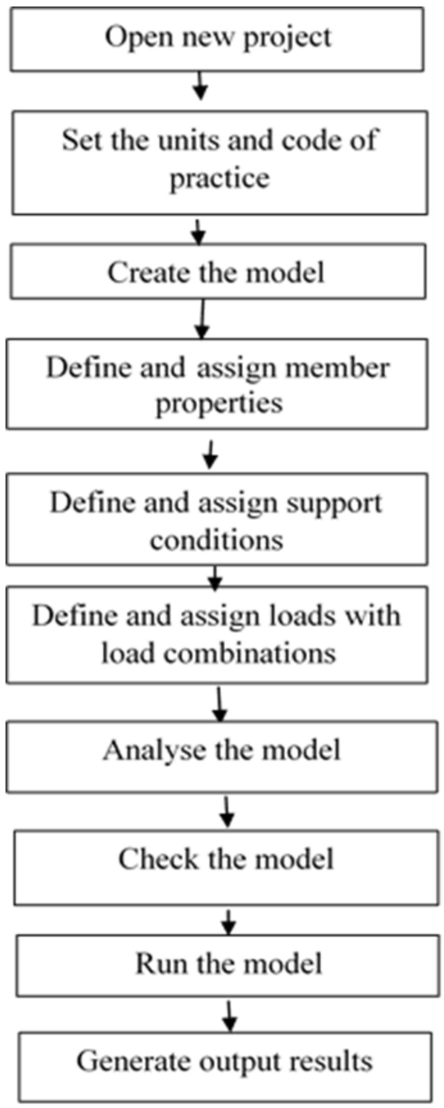


Figure 5: Flow Chart of Methodology.

4. STRUCTURAL MODELLING

All models possess similar geometrical and material properties besides the same ground inclination. Floor height is taken as 3m. Spacing in X direction is taken as 6m and spacing in Y direction is taken as 5m. Slab thickness is taken as 125 mm for all the models. Beam with dimension of 300X500 mm and 400X400mm column size are considered. Live load of 3kN/m^2, Floor finish 1kN/m^2, wall load of 11.5kN/m, M25 grade of concrete, Fe415 grade of steel are considered. Poison's ratio is taken as 0.2 for the modelling. Fixed type of joint has been assigned along all three directions.

Seismic parameters are assumed as per IS 1893 (Part 1). Special Moment Resisting Frame type of building with Response reduction factor R taken as 5. Seismic zone V is assumed with zone factor (Z) 0.36. Importance factor (I) is taken as 1.5 for important building. Soil below the foundation is assumed as medium soil.

Table 1: Preliminary data considered for all building configuration.

Title	**Description**
Type of the building	SMRF
Occupancy	Residential building
Floor height	3m
Spacing in X direction	6m
Spacing in Y direction	5m
Beam size	300X500mm
Column size	400X400mm
Slab thickness	125mm
Live load	3kN/m^2
Floor finish	1kN/m^2
Concrete grade	M25
Poison's ratio	0.2
Grade of steel	Fe415

Table 2: Seismic parameters.

Title	**Description**
Seismic Zone	V
Zone factor, (Z)	0.36 from IS 1893 (Part 1) 2002 ANNEX E
Importance factor, (I)	1.5 (important building) from IS 1893 (Part 1) 2002,table 6 of IS 1893 (Part 1) 2002
Response reduction factor, (R)	5 for SMRF, Table 7 of IS 1893 (Part 1)2002
Soil type	Medium soil

4.1 Type of building configurations considered for the analysis

Two models of 5 bays and two models of 7 bays with step-back and step-back setback configurations are modelled using ETABS. Fixed type of support is assigned for all the models resting on sloping ground. Equivalent Static Analysis is done using ETABS. Seismic parameters like time period, maximum top story displacement, story shear and story drift for both X and Y directions are determined and results are compared with step-back buildings and step-back setback buildings. Building configurations are mentioned below.

5 bays

- 5 bays step-back buildings
- 5 bays step-back setback buildings

7 bays

- 7 bays step-back buildings
- 7 bays step-back setback buildings

4.1.1 Modelling of 5 bays step-back buildings:

RC framed structure. This building configuration has G+4 floors. Story height is taken as 3m.

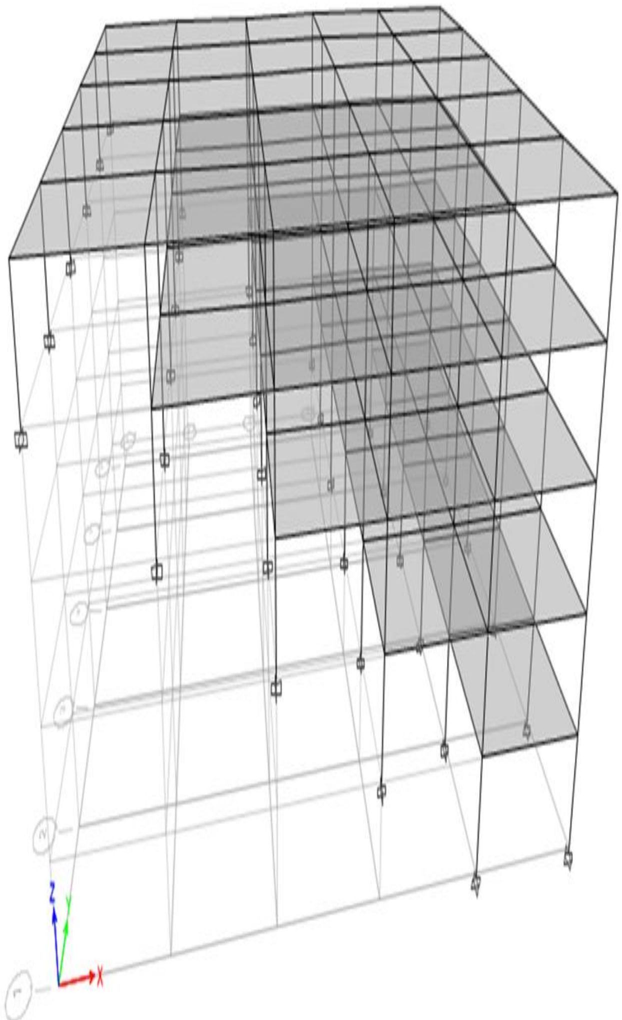


Figure 6: Elevation of 5 bays step-back building.

Figure 7: Rendered view of 5 bays step-back building.

4.1.2 Modelling of 5 bays step-back setback buildings:

RC framed structure. This building configuration has G+6 floors. Story height is taken as 3m.

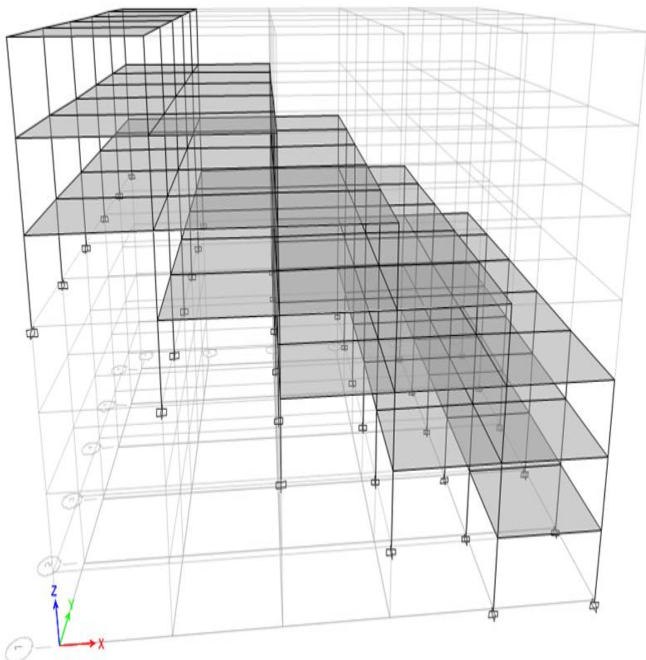


Figure 8: Elevation of 5 bays step-back setback building.

Figure 9: Rendered view of 5 bays step-back setback building.

4.1.3 Modelling of 7 bays step-back buildings

RC framed structure. This building configuration has G+6 floors. Story height is taken as 3m.

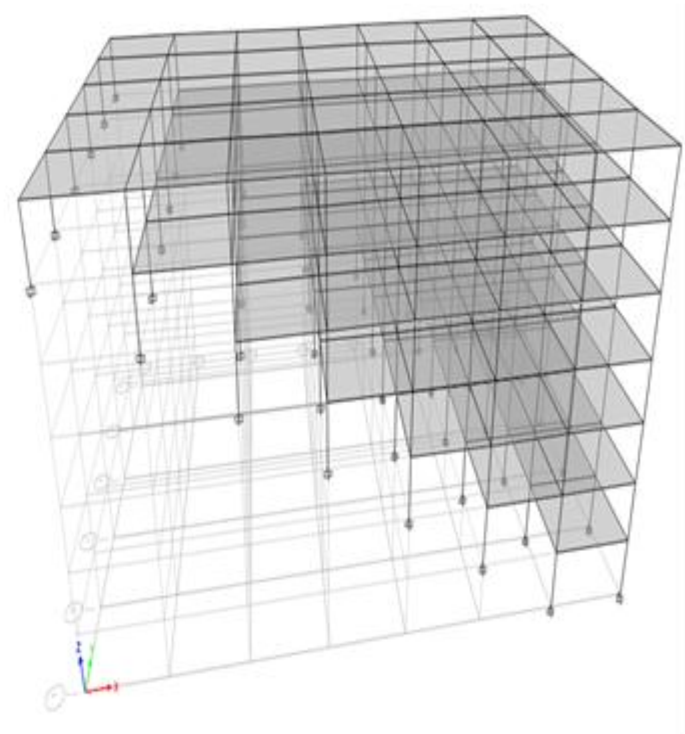


Figure 10: Elevation of 7 bays step-back building.

Figure 11: Rendered view of 7 bays step-back building

4.1.4 Modelling of 7 bays step-back setback buildings

RC framed structure. This building configuration has G+9 floors. Story height is taken as 3m.

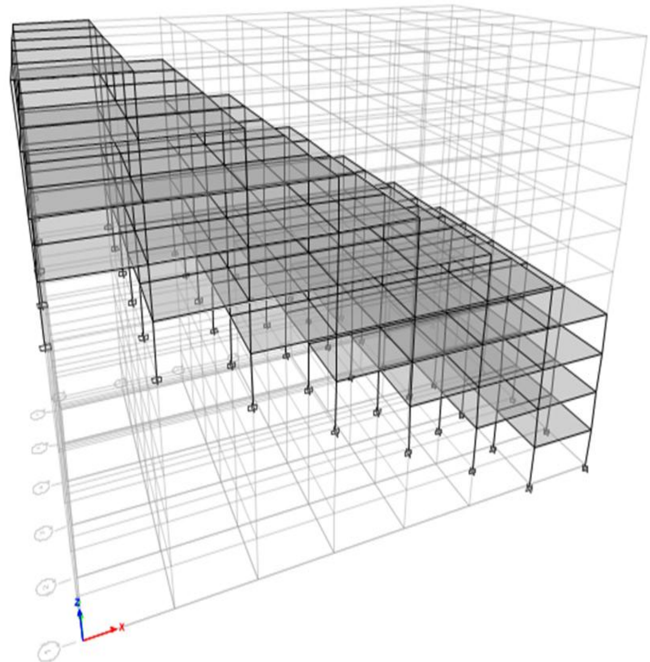


Figure 12: Elevation of 7 bays step-back setback building.

Figure 13: Rendered view of 7 bays step-back setback building.

5. RESULTS AND DISCUSSIONS

Results in terms of seismic parameters like time period, maximum top story displacement, story shear and story drift for both X and Y directions are determined and results are compared with step-back buildings and step-back setback buildings.

5.1 Time period

Figure 14 and 15 shows variation of time period for different modes of step-back setback building and step-back building.

5.1.1 Time period for 5 Bays

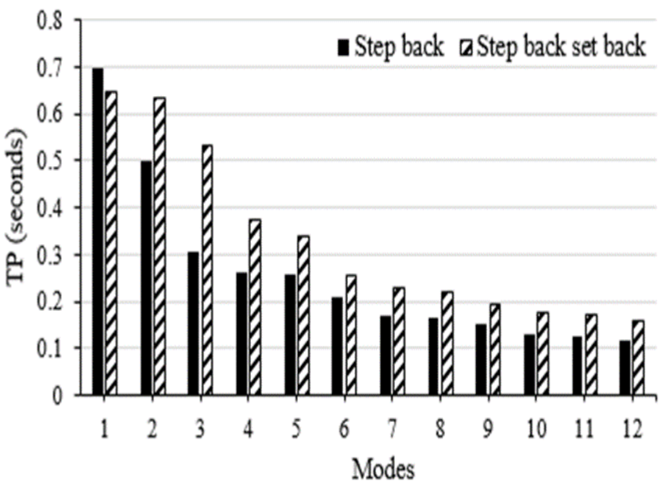


Figure 14: Comparison of variation of time period (TP).

From the above figure it is observed that step-back setback building shows greater time period for all the modes excluding the 1st mode when compared with the step-back building.

5.1.2 Time period for 7 Bays

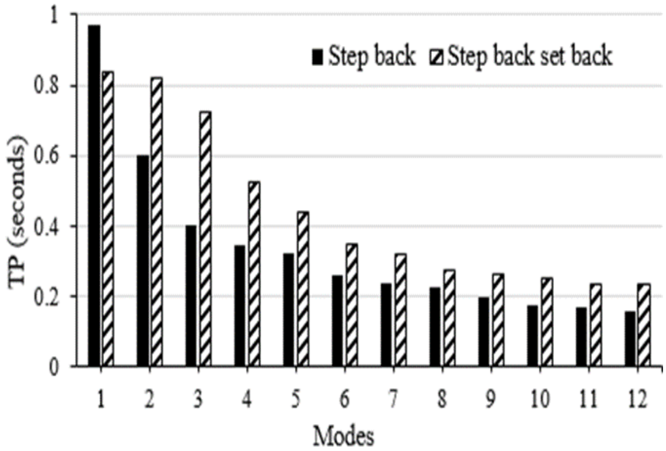


Figure 15: Comparison of variation of time period (TP).

From the above figure it is observed that step-back setback building show greater time period for all the modes excluding the 1st mode when compared with the step-back building.

5.2 Maximum story displacement

Figures 16 to 19 shows variation of lateral displacement of various stories with respect to ground for step-back setback building and step-back building.

5.2.1 Maximum story displacement for 5 bays - X direction

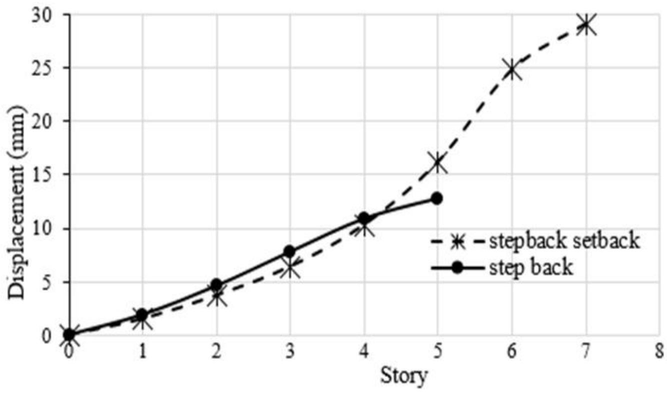


Figure 16: Comparison of variation of maximum storey displacement in X direction.

From the above figure it is observed that the step-back setback building shows lesser storey displacement till 4th storey when compared with the step-back buildings but the storey displacement increases in the 5th floor when compared with the step-back building.

5.2.2 Maximum story displacement for 5 bays - Y direction

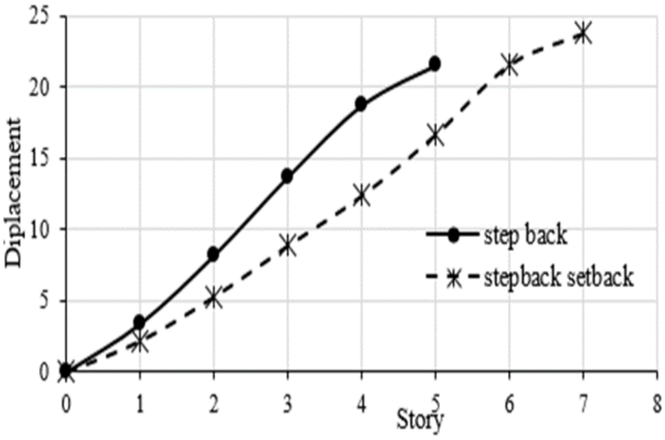


Figure 17: Comparison of variation of maximum storey displacement in Y direction.

From the above figure it is observed that the step-back setback building shows lesser storey displacement in all the floors when compared to step-back building.

5.2.3 Maximum story displacement for 7 bays - X direction

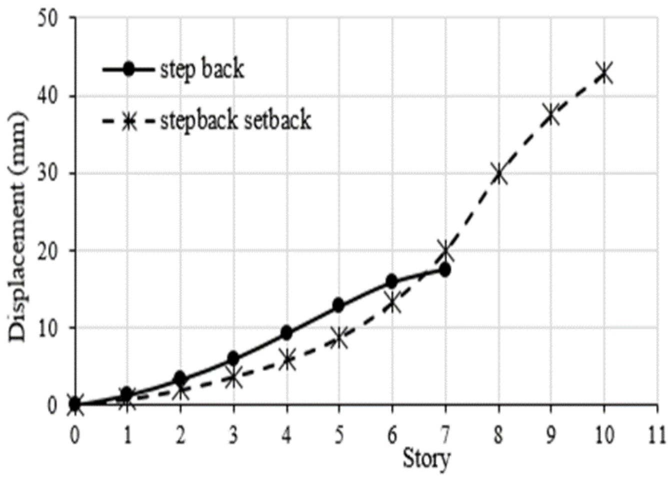


Figure 18: Comparison of variation of maximum storey displacement in X direction.

From the above figure it is observed that the step-back set back building shows lesser storey displacement till the 6th storey when compared with the step-back buildings but the storey displacement increases in the 7th story when compared with the step-back building.

5.2.4 Maximum story displacement for 7 bays - Y direction

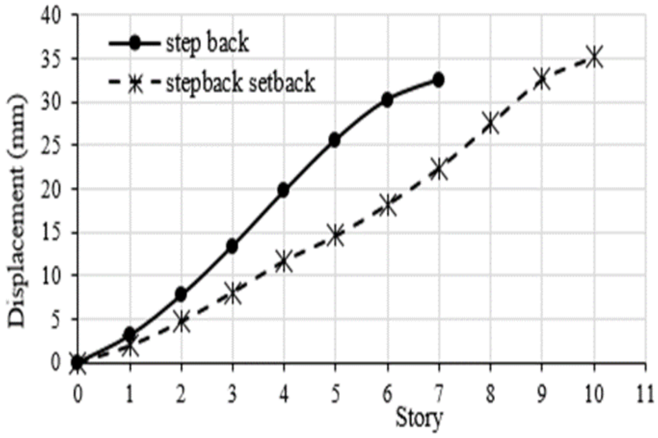


Figure 19: Comparison of variation of maximum storey displacement in Y direction.

From the above figure it is observed that the step-back setback building shows lesser storey displacement in all the floors when compared to step-back building.

5.3 Story shear

Figures 20 to 23 shows variation of story shear for various floors of Step-back setback building and step-back building.

5.3.1 Story shear for 5 bays - X direction

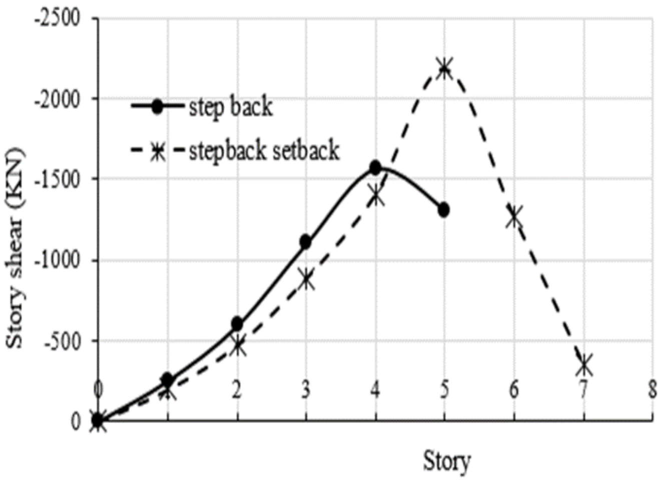


Figure 20: Comparison of variation of story shear in X direction.

From the above figure it is observed that the step-back setback building shows lesser storey shear till the 4th story when compared with the step-back building but the story shear increases in the 5th floor when compared with the step-back building.

5.3.2 Story shear for 5 bays - Y direction

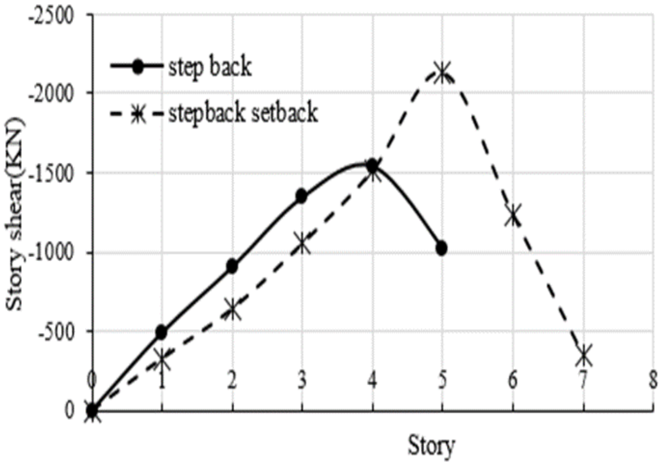


Figure 21: Comparison of variation of story shear in Y direction.

From the above figure it is observed that the step-back setback building shows lesser storey shear till the 4th story when compared with the step-back building but the story shear increases in the 5th floor when compared with the step-back building.

5.3.3 Story shear for 7 bays - X direction

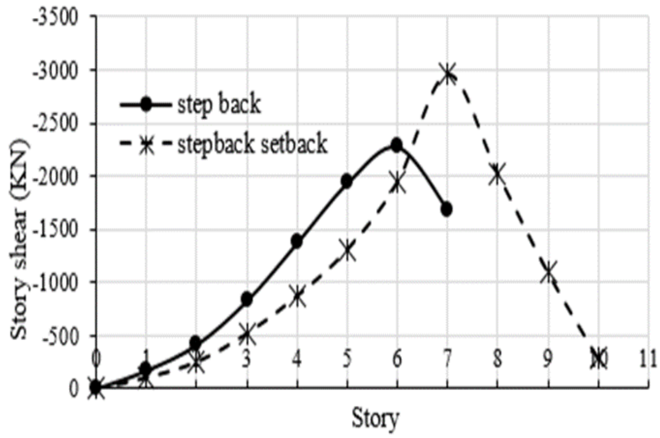


Figure 22: Comparison of variation of story shear in X direction.

From the above figure it is observed that the step-back setback building shows lesser story shear till the 6th story when compared with the step-back building but the story shear increases in the 7th story when compared with the step-back building.

5.3.4 Story shear for 7 bays - Y direction

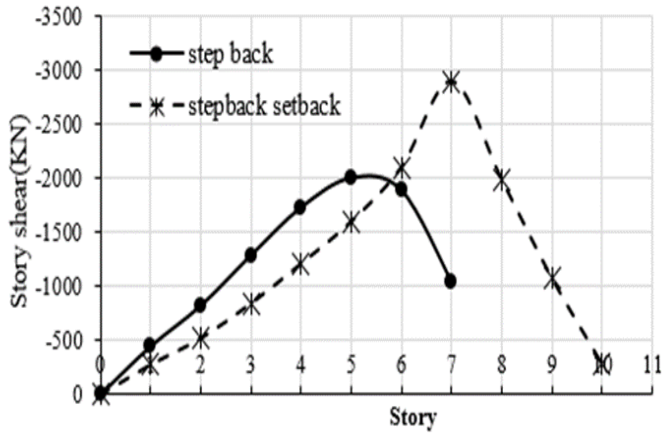


Figure 23: Comparison of variation of story shear in Y direction.

From the above figure it is observed that the step-back setback building shows lesser storey shear till the 5th story when compared with the step-back building but the story shear increases in the 6th and 7th story when compared with the step-back building.

5.4 Story drift

Figures 24 to 27 shows story drift of various floors of step-back setback building and step-back building.

5.4.1 Story drift for 5 bays - X direction

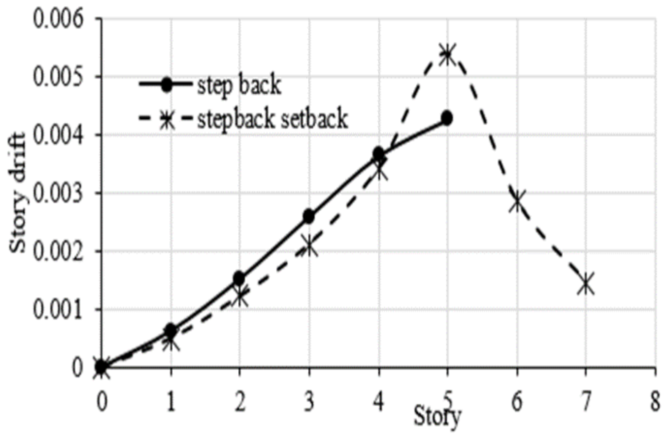


Figure 24: Comparison of variation of story drift in X direction.

From the above figure it is observed that the step-back setback building shows lesser story drift till 4th story when compared with the step-back building but the story drift increases in the 5th story when compared with the step-back building.

5.4.2 Story drift for 5 bays - Y direction

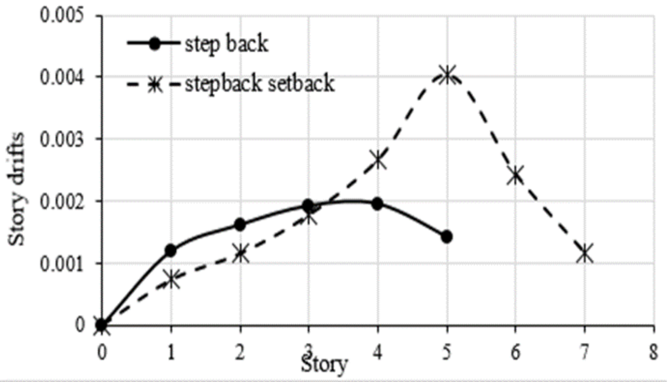


Figure 25: Comparison of variation of story drift in Y direction.

From the above figure it is observed that the step-back setback building shows lesser story drift till 3rd story when compared with the step-back building but the story drift increases in the 4th and 5th story when compared with the step-back building.

5.4.3 Story drift for 7 bays - X direction

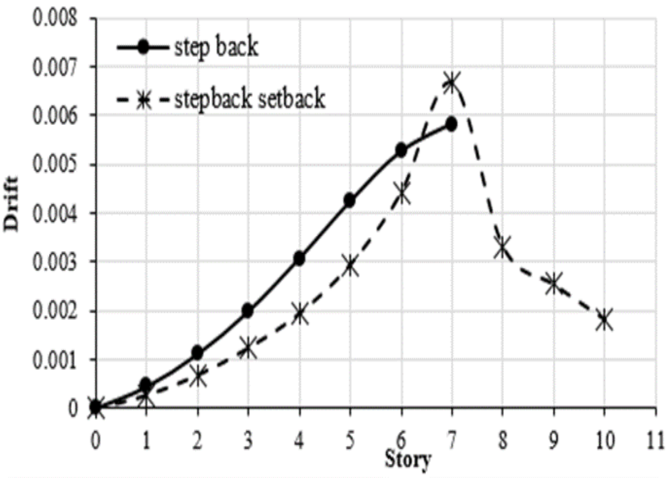


Figure 26: Comparison of variation of story drift in X direction.

From the above figure it is observed that the step-back setback building shows lesser story drift till 6th story when compared with the step-back building but the story drift increases in the 7th story when compared with the step-back building.

5.4.4 Story drift for 7 bays - Y direction

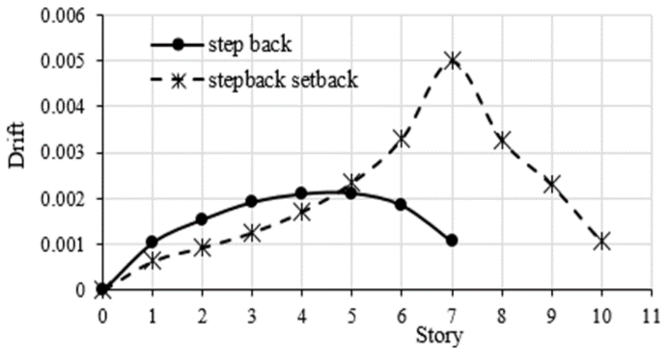


Figure 27: Comparison of variation of story drift in Y direction.

From the above figure it is observed that the step-back setback buildings shows lesser story drift till 4th story when compared with the step-back buildings but the story drift increases in 5th, 6th and 7th stories when compared with the step-back building.

6. CONCLUSIONS

Increase in population leads to unavailability of flat ground for the construction. Modifying sloped terrain into flat land is troublesome which needs both the money and time. So it may be uneconomical. Buildings on the sloped terrain are not symmetrical. They draw large amount of seismic force and are subjected to more damage during earthquake. So it is very necessary to adopt proper configuration of buildings for sloped terrain.

To overcome this problem step-back and step-back setback building configurations are modelled and analysed using ETABS under the action of seismic force. Results are correlated with step-back and step-back setback building configurations as follows

- Both 5 bays and 7 bays step-back setback configuration shows greater time period for all 12 modes except 1st mode when compared to step-back buildings.
- Step-back setback configuration shows lesser value of maximum story displacement for all the stories in Y direction when compared to step-back buildings.
- Step-back setback configuration shows lesser value of maximum story displacement for all the lower stories in X direction when compared to step-back buildings but top stories shows greater value of maximum story displacement.
- Step-back setback configuration shows lesser value of story shear for all the lower stories in both X and Y direction when compared to step-back buildings but top stories shows greater value of story shear.

- Step-back setback configuration shows lesser value of story drift for all the lower stories in both X and Y direction when compared to step-back buildings but top stories shows greater value of story drift.

Proposed step-back setback configuration shows lesser story displacement in the y direction for all the stories when it is compared with step-back buildings. Hence this study advised to adopt step-back setback building configuration in case of hilly terrain.

6.1 Future scope

- Only seismic analysis is considered in the present study. Same study may be expanded for the wind analysis as per BIS 875 part 3.
- In this study all models are analysed using Equivalent Static Analysis. Same study can be extended for the analysis using Response Spectrum Method.
- Same study can be stretched out for the analysis considering bracings and dampers.
- Proposed method of analysis can be used for different dimensions by varying building height and dimension.

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