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A Study on Seismic Response of RCC Buildings on Hill Slopes Using STAAD.Pro

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Abstract: The majority of India's hilly regions are prone to earthquakes. A building on a steep slope is distinct from other structures. That is to say, structures that are to be constructed on hilly terrain have a higher risk factor of falling prey to seismic activities as compared to their counterparts built on a rather plainer terrain. The numerous floors/storeys of such a structure step back towards the hill slope, and buildings may also have setbacks. As such, the column of a hill structure sits at different heights on the angle of the terrain; its analysis differs from that of buildings on level ground. The current study looked at G+3 and G+4 structures with different slope angles, such as 0^0, 7.5^0, 15^0, 22.5^0, and 30^0. Both Step back and Step back & set back types of building configurations have been studied in this paper. The earthquake forces are calculated according to IS: 18932002; the structures are situated in seismic zone IV, with a damping ratio of 5%. Linear Static and Linear Dynamic methods were employed to conduct the seismic study. To investigate the influence of shifting column heights in the ground level due to sloping ground, a 3-dimensional analytical model of building plan was created and the same was studied using the structural analysis application "STAAD.Pro." To quantify the effects of diverse sloping terrain, response parameters like top storey displacement, base shear, shear in bottom storey column, and time period were thoroughly studied. It has been discovered that short columns on the elevated side of the terrain/slope experience a greater shear force as compared to columns of increased height on the lower side of the terrain. Under earthquake stresses, Step back & Setback structures showed better resilience to seismic forces as compared to Step back buildings. Step back setback buildings have substantially lower base shear and top floor displacement than setback buildings on sloping land.

Keywords: Earthquake, Slope, STAAD.Pro, Step back, Step back & set back

I. INTRODUCTION

Large areas of mountainous terrain in the north and northeast of India are classified as seismic zones IV and V. Construction of multi-story RCC (reinforced cement concrete) buildings on hill slopes is in high demand due to economic growth and fast urbanisation in hilly regions. Buildings on hilly terrain differ from those on flat ground in that they are quite uneven and asymmetrically proportioned along the horizontal and vertical planes, as well as torsionally coupled, whereas those on flat ground are usually regular and symmetrical, and thus free of torsional moment. Construction activity on sloping land is compelled by a paucity of flat ground in hilly areas. When subjected to earthquake ground vibrations, structures that have been built in masonry with mud/cement mortar especially with no conformity to seismic code regulations have proven dangerous, resulting in loss of life and property. Amounting to inclining economic growth and the causal rapid urbanization in hilly topography, construction of multi-story RC framed structures on hill slopes has a pressing demand. The past studies of earthquakes in hill regions such as in Uttarkashi (1991), Chamoli (1999), Sikkim (2011), Doda (2013) etc. shows that the buildings with different height of columns within same storey were most vulnerable to be damaged by earthquake. Initial analytical data suggested that the columns on the comparatively elevated side of the slope i.e., short columns underwent higher shear forces as compared to the longer columns which are situated on the lower side of the slope due to 'short column effect'. With the development of various structure software, this problem attracts the major attention in analysing and by extension designing of structures on hill slopes.

The present study is concerned with analysing seismic behaviour of step back buildings and step back & set back buildings on different hill slopes. In such buildings column of different heights in same storey are usually observed. In this study two methods that are Equivalent static method and Response spectrum method are employed to study the seismic response of structures on hill slopes using STAAD.Pro software. STAAD.Pro is a very useful software developed by Research Engineers International in 1997. As proving the software very useful, hence it has grown over the course of 20 years and is continually supervised by a top-tier rank industry steering council. STAAD.Pro is the industry standard for static, dynamic, P-delta, non-linear, buckling, and cable analysis.

It includes building regulations for numerous countries such as United States, the United Kingdom, Canada, France, Australia, Spain, Germany, Norway, Finland, India, Sweden, China, the Eurozone, Denmark, Japan and the Netherlands, among others. Moreover, with passing time more countries are getting added to the list. It also enables to work with a variety of materials, including wood, steel, cold-formed steel, concrete, and aluminium. Users/engineers have constructed anything from home structures to skyscrapers to tanks to bridges to tunnels during the last 2 decades. The features like powerful graphics, text, and spreadsheet interfaces offer engaging and interactive model construction, modification, and analysis, allowing complex models to be created fast and simply. The current study looked at G+3 and G+4 structure simulations with different slope angles, such as 0^0, 7.5^0, 15^0, 22.5^0, and 30^0. Both types of building configurations 'step back' and 'step back setback' were analysed. It was discovered that short columns on the elevated side of the slope experience a greater shear force than vertically higher columns on the lower side. Under earthquake stresses, step back setback structures showed better tolerance to seismic damage than step back buildings.

II. LITERATURE REVIEW

Birajdar and Nalawade (2004) observed and analysed the effect of seismic forces and behaviour of structures lying on hill slopes. The duo examined twenty-four reinforced cement concrete building models in three distinct configurations: Step back, Step back & set back, and set back. All of these case studies were performed while keeping the slope angle of the ground constant i.e., 27-degrees with the Horizon. They observed and analysed the seismic response of structures in seismic zone III with varied storeys ranging from 15.75m to 40.25m along the slope direction, and one bay across the slope. They used the Response spectrum approach to provide a 3D study that included the torsional impact. They observed that with a longitudinal increase of a structure, an inevitable increase of the magnitude of top storey displacement and fundamental time period takes place in a linear fashion. According to their findings, the shear force in the column to the extreme left is much larger than in the rest of the columns. In the case of step back buildings, it is 55-250 percent more than in step back set back buildings. As a result, they believe that short extreme left columns at ground level are the worst impacted, and that step back buildings may be at a higher risk to seismic excitation than Step back & set back buildings. The unequal distribution of shear force in the different frames found in step back structures support the formation of torsional moment owing to static and accidental eccentricity. Y. Singh et al. (2011) investigated the behaviour of RCC frame structures on hill slopes when subjected to five different ground vibrations. Four different sorts of building configurations (Type S-I, Type S-II, Type P-III, and Type P-IV) were analysed. Type S-I' had three stories above the road level and stepped back at every floor level on a 45° slope up to six floors. The 'Type S-II' only had three storeys above road level and stepped back at the sixth storey level. 'Type P-III' and 'Type P-IV' were assigned to the 9 and 3 storeyed normal structures on level land, respectively. All of the structures were in seismic zone IV, with seven bays along the hill and three bays across the slope. The structures were examined for a set of five ground movements selected from the Pacific Earthquake Engineering Research Centre's strong motion database. According to the study, all storeys of 'Type S-I' buildings were highly susceptible to torsion, while as in case of Type S-II building model only the top story was exposed to torsion. The study concluded that the step back buildings under the cross excitation are highly susceptible and prone to considerable torsional effects and while investigating the inter-storey drifts in the top 3 storeys of buildings constructed over hill slopes, it was found that the inter storey drifts are very similar to those in the three-story regular building. Sable et al. (2012) also investigated the seismic behaviour of structures on sloped terrain. The study explored the dynamic reaction of structures by analysing 3D space frames. The structures examined belong to seismic zone III with three distinct configurations: 'step back', 'step back & set back', and 'set back'. A total of 36 structures were examined in order to determine the dynamic reaction. The storey levels ranging from 4 to 15 in mind (15.2 m to 52.6m) were investigated. It was found that the largest base shear is produced in step back-Set back buildings and the least in Setback buildings on flat ground based on their findings. They also concluded that the top story displacement of step back building is highly considerable than step back and set back structures on sloping land. Hence it was found that step back and set back buildings are better choice on hill slopes. Rayyan-Ul Hassan and H.S. Vidyadhara (2013) investigated the effects of earthquakes on six different models resting on flat and sloping surfaces, including bare frame, building with first soft storey and other storeys with brick infill wall, and building with first soft storey and other storeys with brick infill and also provided with shear wall at corners. The horizontal number of bays was preserved at 4, with a total of 12 floors, and all structures located in seismic zone V. These building models were analysed using Response spectrum, Equivalent static and Pushover analysis. Based on Equivalent static analysis it was found that building with upper brick infill storeys and building with upper brick infill storeys and shear wall at corners had almost 79.15% and 89.27% less longitudinal displacement respectively as compared to simple bare frame on sloping ground. When Response spectrum analysis was brought in, these displacements were almost 50.95% and 73.97% less, respectively. Therefore, they concluded that the presence of brick infill and shear wall reduces lateral displacement considerably.

It was also concluded that, as compared to a bare frame model, a structure with upper brick infill storeys and shear walls at corners had more base-shear. They discovered that a structure with higher brick infill storeys and shear walls at corners has less spectral displacement and roof displacement than a bare frame model based on Pushover analysis. As a result of the Equivalent static analysis, Response spectrum analysis, and Pushover analysis, they have concluded that the existence of an infill wall and a shear wall effectively reduces the building's lateral displacement.

III. METHODOLOGY

In this study seismic analysis of two building configurations namely step back buildings and step back & set back buildings on different sloping grounds have been carried out by using different parameters such as number of bays, angle of sloping ground, number of stories etc. Seismic response of four and five storey step back and step back & set back buildings resting on different ground slopes were analysed by linear static method as well as response spectrum method. Concrete grade M25 has been assumed to be homogenous and isotropic. The Poisson's ratio of concrete is taken as 0.17 and the steel grade Fe250 is taken.

A. Geometrical Properties

All the models taken have same material properties and resting on sloping grounds of 7.5°, 15°, 22.5°, 30°, and same resting on flat ground (0°). The bay width in horizontal X-direction and horizontal Z-direction are same and equal to 4 meters. The 1st 2nd & 3rd storeys are of the same height of 3.5 meters. Also, column and beam size are taken as 0.4m × 0.4m. As all buildings are resting on sloping ground, the height of columns of ground storey are different, the columns on lower side are long columns, while as columns on higher side are short columns. The slab thickness is assumed to be 120mm.

B. Seismic parameters and loads

The seismic parameters used for dynamic analysis of all models are assumed as per IS 1893(Part 1):2002. The buildings were analysed for seismic zone IV with damping 5%. The importance factor, 'I' is taken as 1.5 and response reduction factor 'R' is taken as 5 for special RC moment-resisting frame (SMRF). Also, the soil is taken as medium soil.

The total dead load and seismic weight of the building has been calculated while as imposed load is taken as 3 KN/m^2 for a typical residential building.

C. Building Configurations Under Study

In the present study, the following building configurations are considered for analysis:

1) Four storey Step Back buildings for angles 0°, 7.5°, 15°, 22.5° & 30°.
2) Five storey Step Back buildings for angles 0°, 7.5°, 15°, 22.5° & 30°.
3) Four storey Step Back and Set Back buildings for angles 0°, 7.5°, 15°, 22.5° & 30°.
4) Five storey Step Back and Set Back buildings for angles 0°, 7.5°, 15°, 22.5° & 30°.

IV. RESULTS AND DISCUSSIONS

A. General

As mentioned earlier, the motive of present research is to analyse and understand the structural behaviour of the two structural models i.e., Step back buildings and Step back & Setback buildings resting on varying ground elevations under the action of seismic forces.

B. Tabulated Results and Discussions of Analytical Study

The research is conducted on two types of buildings, namely, setback buildings and step back & setback buildings with varying storey counts on varying slopes. A four and five storey step back building and step back & set back building resting on ground slopes 7.5°, 15°, 22.5°, 30 ° and same resting on flat ground (0°) was analysed by linear static as well as dynamic method (response spectrum method). The bay width in horizontal X-direction and horizontal Z-direction are same and equal to 4 m. The 1st, 2nd and 3rd storey are of the height 3.5 m each. As buildings are resting on sloping ground, the height of columns of ground storey is different. The column on higher side is short column while the column on lower side is long column. The buildings were analysed for seismic zone IV and damping 5%. In table number I-VIII, the analytical measurements for fundamental time period, base shear, top storey displacement, and ground storey column shear are presented.

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1) *Linear Dynamic Response of a Four Storey Step Back & Set Back Building (G+3):* Following table shows the variation of fundamental time period, base shear, bottom storey column shear and top storey displacement with respect to increase in angle of ground slope for a four-storey step back building analysed using response spectrum method.

TABLE I
Effect Of Sloping Ground On Four Storey Step Back Building

Ground Slope Angle in Degrees	Fundamental Time Period (Sec)	Base Shear (Kn)	Short Column Shear (Kn)	Long Column Shear (Kn)	Top Storey Displacement (mm)
0	0.45	450.3	83.5	83.5	10.1
7.5	0.50	460.9	270.4	20.9	11.515
15	0.62	421.2	283.57	5.96	10.95
22.5	0.78	388.1	295.98	2.3	10.56
30	0.89	361.4	304.3	1.14	10.38

It is observed that as the angle of ground slope is increasing, the base shear value is decreasing except that for 0° slope for which base shear is less than 7.5°. This table also shows that the top storey displacement for building on flat ground is minimum while the top storey displacement at angle 7.5° is maximum. For angle of slope more than 7.5° the top storey displacement is decreasing. Also, this can be seen that the shorter column carries more loads since shorter column is stiffer and hence has more stress carrying capacity. Long column is observed to have shear to reduced very low as slope angle increase because of long column effect. The shear force on ground storey columns of building on flat ground is uniform.

2) *Linear Dynamic Response of a Four Storey Step Back & Set Back Building (G+3):* Following table shows the variation of fundamental time period, base shear, bottom storey column shear and top storey displacement with respect to increase in angle of ground slope for a four-storey step back & set back building analysed using response spectrum method.

TABLE II
Effect Of Sloping Ground On Four Storey Step Back & Set Back Building

Ground Slope Angle in Degrees	Fundamental Time Period (Sec)	Base Shear (Kn)	Short Column Shear (Kn)	Long Column Shear (Kn)	Top Storey Displacement (mm)
0	0..38	274	53	53	98
7.5	0.40	284.5	167.7	12.9	10
15	0.45	263.5	274.9	5.6	9.1
22.5	0.55	246.3	294.3	2.1	8.6
30	0.67	232.8	273.7	0.9	8.1

It is seen from the table II that as the angle of slope increases, the fundamental time period of building also increases but the base shear decreases. The maximum top storey displacement is for building resting on ground slope of 7.5° and minimum storey drift is for building resting on 30° ground slope

It can be observed by comparing table I and table II that the values of fundamental time period, base shear, bottom storey column shear and top storey displacement for step back set back buildings are much lower than that for step back buildings.

3) *Linear Dynamic Response of a Five Storey Step Back Building:* Following table shows the variation of fundamental time period, base shear, bottom storey column shear and top storey displacement with respect to increase in angle of ground slope for a five-storey step back building analysed using response spectrum method.

TABLE III
Effect Of Sloping Ground On Five-Storey Step Back Building

Ground Slope Angle in Degrees	Fundamental Time Period (Sec)	Base Shear (Kn)	Short Column Shear (Kn)	Long Column Shear (Kn)	Top Storey Displacement (mm)
0	0.6	539	99	99	16
7.5	0.64	497.8	274.3	21.2	16.1
15	0.76	465.5	303.7	6.4	16
22.5	0.93	432.2	327.2	2.5	15.6
30	1.1	408	340.6	1.3	15.5

It is seen from the table III that as the angle of slope increases, the fundamental time period of building increases but the base shear decreases. Maximum top storey displacement is observed when building rests on 7.5° ground slope, and minimum top storey displacement is found when building rests on 30° ground slope.
By comparing the results of table I and III, it is observed that the values of fundamental time period, base shear, bottom storey column shear and top storey displacement for four storey Step back buildings are much lower than that for five storey Step back buildings.

4) *Linear dynamic response of a five-storey step back & set back building (G+4):* Following table shows the variation of fundamental time period, base shear, bottom storey column shear and top storey displacement with respect to increase in angle of ground slope for a five-storey step back & set back building analysed using response spectrum method. It is seen from the table IV that as the angle of slope increases, the fundamental time period of building increases but the base shear decreases. It is also observed by comparing the results of table I and table IV that the values of fundamental time period, base shear and bottom storey column shear for five storey Step back set back buildings are lower than that for a four-storey step back buildings.

TABLE IV
Effect Of Sloping Ground On Five Storey Step Back & Set Back Building

Ground Slope Angle in Degrees	Fundamental Time Period (Sec)	Base Shear (Kn)	Short Column Shear (Kn)	Long Column Shear (Kn)	Top Storey Displacement (mm)
0	0.48	376	74	74	14.2
7.5	0.49	349.5	206.7	15.9	13.1
15	0.56	329.1	305.3	6.3	12.5
22.5	0.69	309.5	293	2.2	11.8
30	0.83	293.1	294	1	11.4

5) *Linear static response of a four-storey step back building (G+3):* Following table shows the variation of fundamental time period, base shear, bottom storey column shear and top storey displacement with respect to increase in angle of ground slope for a four-storey step back building analysed using equivalent static method.

TABLE V
Effect Of Sloping Ground On Four Storey Step Back Building

Ground Slope Angle in Degrees	Fundamental Time Period (Sec)	Base Shear (Kn)	Short Column Shear (Kn)	Long Column Shear (Kn)	Top Storey Displacement (mm)
0	0.48	450.4	67.5	67.5	11.5
7.5	0.55	460.9	191.3	14.8	12
15	0.61	421.2	236	5	11.1
22.5	0.68	388.36	250.7	2	10.2
30	0.75	361.4	250.7	1	9.6

It is seen from the table V that as the angle of slope increases, the fundamental time period of building increases but the base shear decreases except that for 0° slope for which base shear is less than that for 7.5° slope. Since the value of response acceleration coefficient decreases as the angle of slope increases and hence the value of base shear is decreasing with increase in angle of slope.
By comparing the results of table V and table I it is observed that the values of fundamental time period for step back buildings by dynamic method is more than that by equivalent static methods and also the shear force in bottom storey columns obtained by dynamic method is more than that for static method.

6) *Linear static response of a four-storey step back set back building (G+3):* Following table shows the variation of fundamental time period, base shear, bottom storey column shear and top storey displacement with respect to increase in angle of ground slope for a four-storey step back & set back building analysed using equivalent static method. It is seen from the table VI that as the angle of slope increases, the fundamental time period of building increases but the base shear decreases except that for 0° slope for which base shear is less than 7.5°. The top storey displacement of step back set back buildings is decreasing as the angle of ground slope is increasing. By comparing the results of table II and table VI it is observed that the fundamental time period for step back set back buildings obtained by response spectrum method is less than that by equivalent static method. It is due the fact that static method does not account the Set back action on buildings and depends only on height of building.

TABLE VI
Effect Of Sloping Ground On Four Storey Step Back & Set Back Building

Ground Slope Angle in Degrees	Fundamental Time Period (Sec)	Base Shear (Kn)	Short Column Shear (Kn)	Long Column Shear (Kn)	Top Storey Displacement (mm)
0	0.483	274	41	41	10.3
7.5	0.547	284.1	117.5	9	9.8
15	0.61	263.4	146.7	3	8.4
22.5	0.68	246.2	158.3	1.2	7.2
30	0.75	232.8	160.8	0.56	6.5

7) *Linear static response of a five-storey step back building (G+4):* Following table shows the variation of fundamental time period, base shear, bottom storey column shear and top storey displacement with respect to increase in angle of ground slope for a five-storey step back building analysed using equivalent static method.

TABLE VII
Effect Of Sloping Ground On Five-Storey Step Back Building

Ground Slope Angle in Degrees	Fundamental Time Period (Sec)	Base Shear (Kn)	Short Column Shear (Kn)	Long Column Shear (Kn)	Top Storey Displacement (mm)
0	0.59	539.7	81	81	18
7.5	0.65	498	206.9	16	17.2
15	0.7	465.6	261	5.5	16.3
22.5	0.77	432.3	280.9	2.2	16.1
30	0.84	408.2	283.5	1.1	14.7

It is seen from the table VII that as the angle of slope increases, the fundamental time period of building increases but the base shear decreases. The top storey displacement of step back buildings is decreasing as the angle of ground slope is increasing.
By comparing the results of table V and VII it is observed that the values of fundamental time period, base shear, bottom storey column shear and top storey displacement for four storey Step back buildings are much less than that for five storey Step back buildings.

8) *Linear static response of a five-storey step back & set back building (G+4):* Following table shows the variation of fundamental time period, base shear, bottom storey column shear and top storey displacement with respect to increase in angle of ground slope for a five-storey step back & set back building analysed using equivalent static method. It is seen from the table VIII that as the angle of slope increases, the fundamental time period of building increases but the base shear decreases. The top storey displacement of step back buildings is decreasing as the angle of ground slope is increasing. By comparing the results of table IV and table VIII it is observed that the fundamental time period for step back set back buildings obtained by response spectrum method is less than that by equivalent static method. It is due the fact that static method does not account the Set back action on buildings and depends only on height of building. The base shear values obtained by dynamic methods after multiplying by base shear ratio are same as that by static method The bottom storey column shear for step back set back buildings obtained by response spectrum method are more than that by equivalent static method. The top storey displacement by static method is comparatively same as that by response spectrum method. By comparing the results of table VII and table VIII it is observed that the values of base shear, bottom storey column shear and top storey displacement for step back set back buildings is very less than that for step back buildings.

TABLE VIII
Effect Of Sloping Ground On Five Storey Step Back & Set Back Building

Ground Slope Angle in Degrees	Fundamental Time Period (Sec)	Base Shear (Kn)	Short Column Shear (Kn)	Long Column Shear (Kn)	Top Storey Displacement (mm)
0	0.59	380	57	57	15.8
7.5	0.65	347.9	144	11	13.7
15	0.7	329.2	183.8	3.8	12.1
22.5	0.77	309.56	199.4	1.5	12.1
30	0.84	292.8	203	0.73	9.8

C. Graphical Representation for Analytical Results

Following graphs shows the variation of fundamental time period, base shear, bottom storey column shear and top storey displacement with respect to increase in angle of ground slope for step back buildings and step back & set back buildings analysed using response spectrum method and equivalent static method.

1) Linear Dynamic Analysis Results

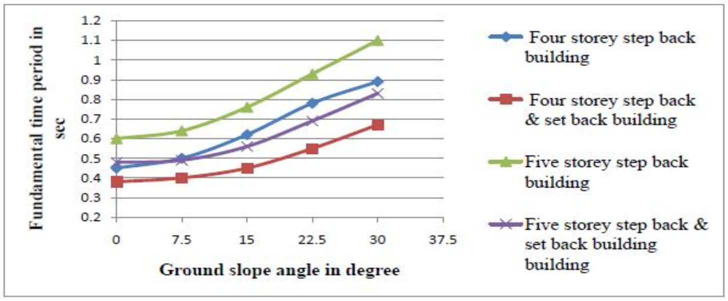

Fig. 1 Variation of fundamental time period with angle of ground slope

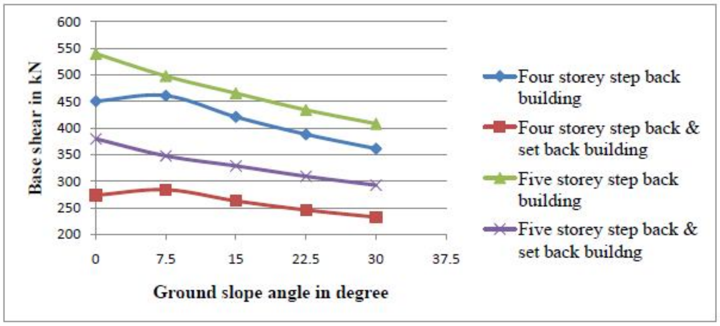

Fig. 2 Variation of base shear with angle of ground slope

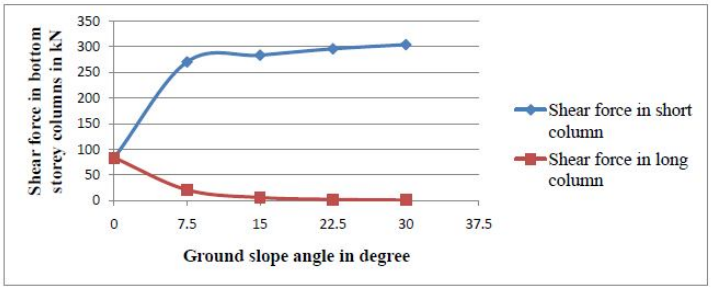

Fig. 3 Variation of bottom storey column shear with angle of ground slope for step back building (G+3)

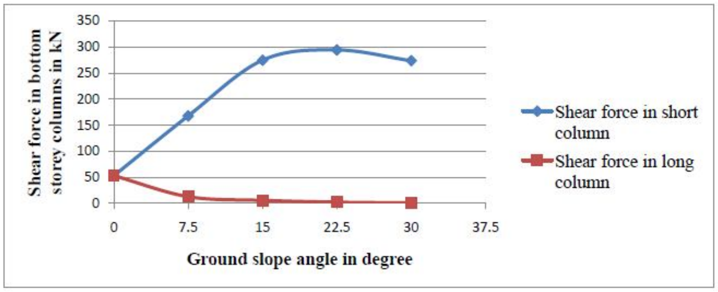

Fig. 4 Variation of bottom storey column shear with angle of ground slope for step back & set back building (G+3)

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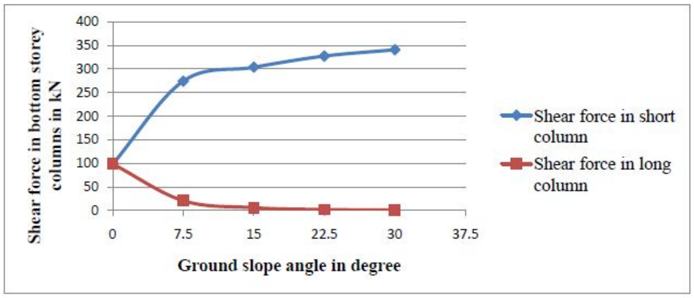

Fig. 5 Variation of bottom storey column shear with angle of ground slope for step back building (G+4)

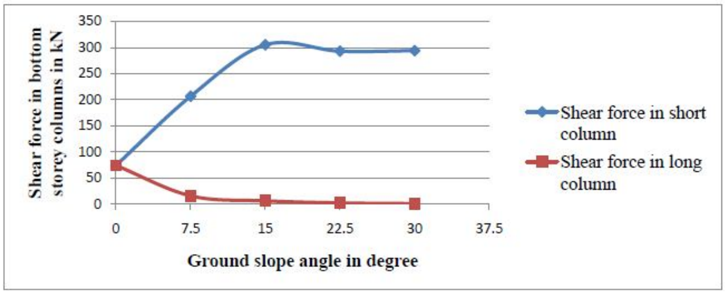

Fig. 6 Variation of bottom storey column shear with angle of ground slope for step back & set back building (G+4)

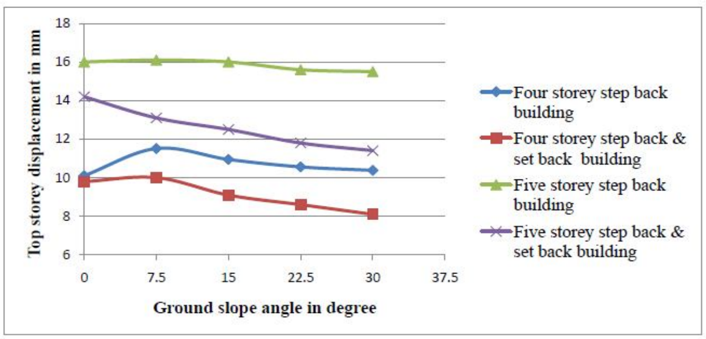

Fig. 7 Variation of top storey displacement with angle of ground slope

2) Linear Static Analysis Results

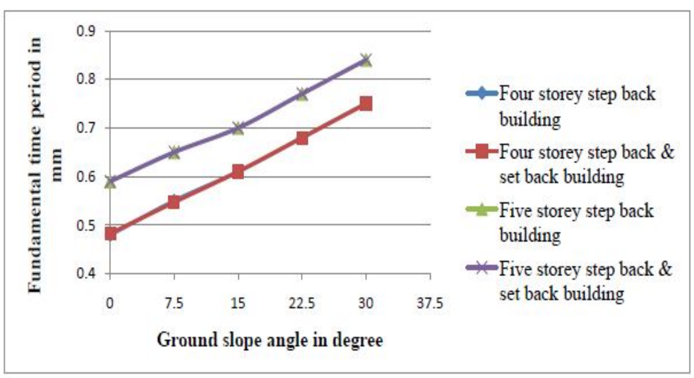

Fig. 8 Variation of fundamental time period with angle of ground slope

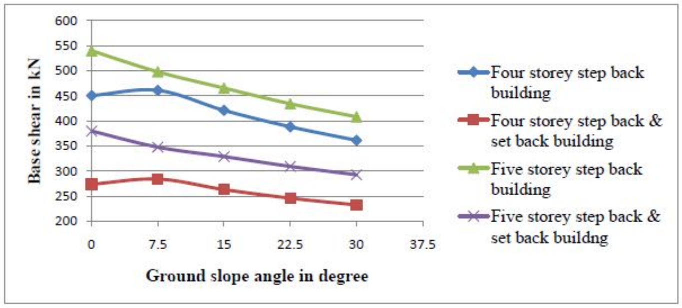

Fig. 9 Variation of base shear with angle of ground slope

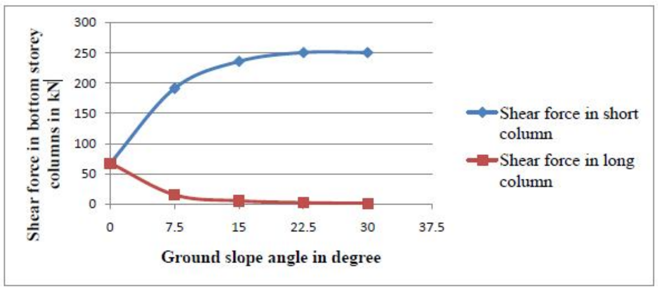

Fig. 10 Variation of bottom storey column shear with angle of ground slope for step back building (G+3)

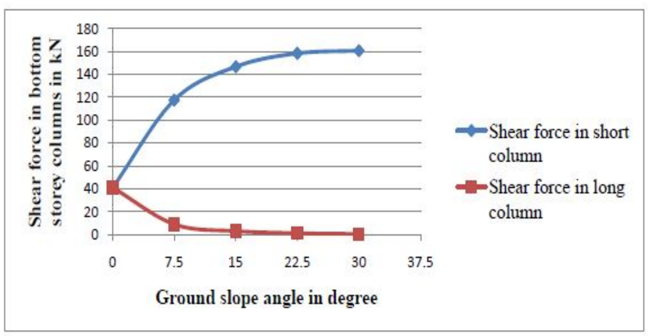

Fig. 11 Variation of bottom storey column shear with angle of ground slope for step back & set back building (G+3)

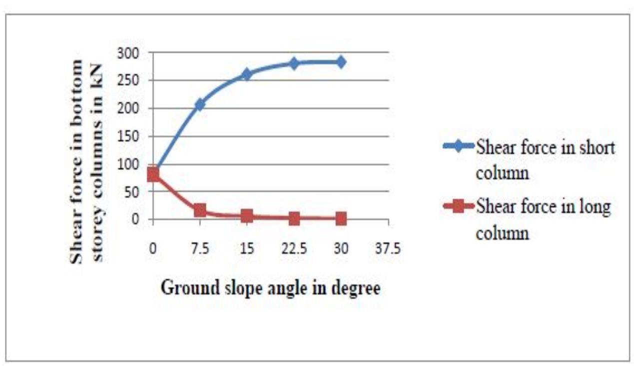

Fig. 12 Variation of bottom storey column shear with angle of ground slope for step back building (G+4)

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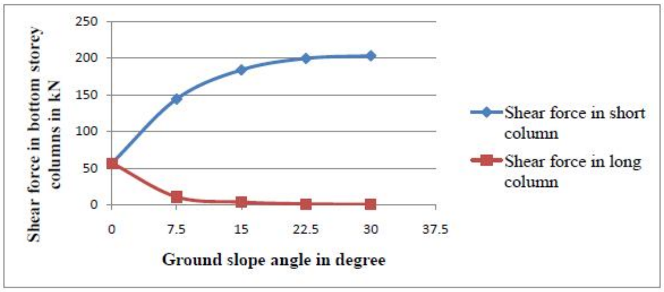

Fig. 13 Variation of bottom storey column shear with angle of ground slope for step back & set back building (G+4)

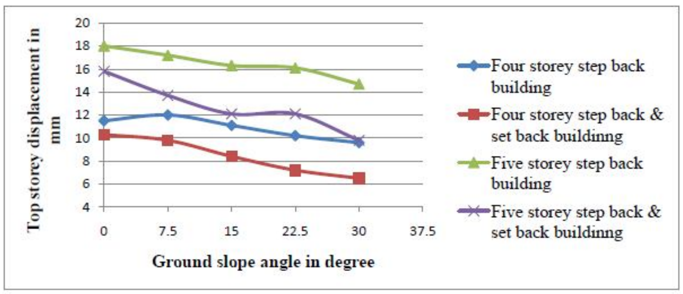

Fig. 14 Variation of top storey displacement with angle of ground slope

V. CONCLUSION AND FUTURE WORK

Large numbers of analysis and research studies along with various building codes have tackled the concern surrounding the effects of vertical irregularities in buildings. In order to obtain the design lateral force distribution, various building codes suggest methods like elastic response spectrum or elastic time history analysis; moreover, the said codes also supply the criteria so as to classify the vertically irregular buildings. The major portion of these aggregated studies tends to focus and study only the 'elastic response'. Majority of the analytical studies that have been undertaken have dealt with investigating irregularities of two kinds found i.e., those in set-back and soft and/or weak first storey buildings. Although most of the studies agree on the increase in drift demand for the tower component of the Set-back buildings, nevertheless the studies have reached upon dissimilar conclusions regarding the Set-back building models.

From the data revealed by the seismic analysis for the structures while experimenting with different loading combinations, the following conclusions are drawn:

1) As the ground slope increases, fundamental natural period of vibration increases but base shear almost decreases. That means ground slope is directly proportional to fundamental natural period of vibrations but inversely proportional to the base shear.
2) The step back building frames give higher values of time period as compared with the step back & set back building frames.
3) Step back building frames produce higher base shear as compared with step back & set back building frames.
4) In step back and step back & set back frames; it is observed from results that short columns which are on higher side of sloping ground are subjected to very high shear forces as compared to long columns and hence targeted attention is the utmost requirement while designing these short columns.
5) As the slope angle increases, it is observed that the short column resists almost all the storey shear since other columns are flexible and tend to oscillate.
6) The step back building frames give higher values of top storey displacement as compared with step back & set back building frames.
7) As the number of stories increases, fundamental natural period of both step back and step back & set back building increases.
8) As the number of stories increases, base shear of both step back and step back & set back building increases.
9) As the number of stories increases, top storey displacement of both step back and step back & set back building increases.

10) During the event of a seismic event, the structural integrity of step back frames have a higher potential of sustaining damage as compared to step back & set back building frames. Therefore, step back building frames on sloping ground are not favourable. However, it may be adopted, provided a system to control the large displacement is adopted.

The future study can be carried out by considering the stiffness of brick infill walls and by varying the number of bays in X or Y direction with various lateral load resisting systems in the structure analysis methods like Time history analysis or Push over analysis can be carried out to get more accurate results.

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