REVIEW ON SEISMIC ANALYSIS OF MULTISTORIED BUILDING ON SLOPING GROUND

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Abstract - *This is the Review paper studied the combined effects of earthquake-triggered landslides and ground shaking on sloping ground. Sikkim earthquake of September 18,2011 was the first earthquake in India which exposed the RC frame building on hill slopes to ground shaking and performance of such buildings in this rather moderate ground shaking was far from satisfactory. Due to scarcity of flat land in hilly areas, majority of the building is constructed on the hill slopes with regular structural configuration having foundations at different levels. Such buildings pose special structural and constructional problems. Dynamics characteristic of hill buildings (the term has been used in this paper for buildings located on hill slopes) are significantly different in both horizontal and vertical directions, results in center of mass and center of stiffness of a story not coinciding with each other and not being on a vertical line for different floors. When subjected to lateral loads, these buildings are generally subjected to significant torsional response. The various floors of such buildings step backs towards hill slope and at the same time buildings may have setbacks also. Most of the studies agree that the buildings resting on sloping ground has higher displacement and base shear compared to buildings resting on plain ground and the shorter column attracts more forces and undergo damage when subjected to earthquake. Step back building could prove more vulnerable to seismic excitation.*

Keywords: ***Seismic performance, Sloping ground, Step back building, Sikkim Earthquake,***

1. INTRODUCTION

In big cities, construction on sloping land (landslide) is becoming increasingly prevalent due to the unavailability of flat lands. This has created a major challenge for structural engineers with regard to structure design, due to the difficulties encountered during the implementation of projects, both for the structure and the soil.

CONSTRUCTION on sloping land is not subject to any regulations or recommendation in India. However, the landslide is a widespread natural hazard in the world; the threat is similar to an earthquake. If there is a rapid movement of a large mass of earth, it can cause extensive damage to buildings, which exposes people to danger. Moreover, due to the rising rates of population growth in some cities in India, there is a demand to construct buildings with multiple floors. Furthermore, construction on sloping land (landslide) is increasing considered, mainly due to a shortage of available flat lands for building. However, in recent years several studies have been made in this area.

The short, stiff columns on uphill side attract much higher lateral forces and are prone to damage. As per IS 1893: (part 1) 2002, different vertical irregular configurations of buildings have been defined.

1.1 Need of seismic evaluation

- The building may not have been designed and detailed to resist seismic force.
- Lack of timely revisions of codes of practice and standards.
- Many of the existing building are lacking in adequate earthquake resistance because these are not designed according to modern codes and prevalent earthquake resistance practice.
- Different heights of columns are present in building on hilly slopes in a same storey, as a result more forces are attracted during earthquake ground motion by short columns and damage occurs.
- Hill buildings are different from those in plains; they are very irregular and unsymmetrical in horizontal and vertical planes, and torsionally coupled. Hence, they are susceptible to severe damage when affected by earthquake ground motion.

1.2 Significance

It is observed from past earthquakes that the buildings on slopes participate more damage and collapse occurs. This review paper aims to analyse the dynamic characteristics of these type(Fig-1) of buildings.

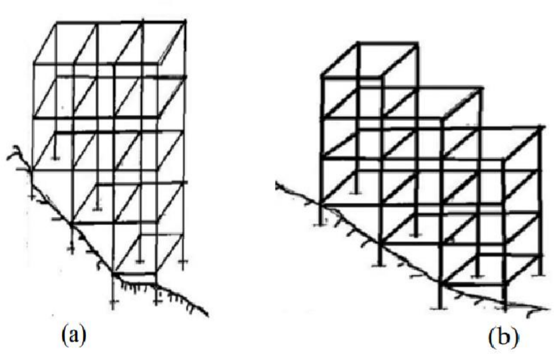


Fig-1 Hill building configuration
(a)Step Back building (b)StepBack & SetBack building

2. Review of Papers on Buildings Resting on Sloping Ground

2.1 Overview

In this review, characteristics of the structures due to the variation of the slope angle are explained. Then the effect of the irregular configurations on vulnerability due to seismic forces is discussed. There are very few researchers who explained the effect of change of sloping angle. No research work is done based on experimental investigation of the structures on sloping ground.

2.2 Review

2.2.1 Chandrasekaran and Rao (2002);investigated analysis and the design of multi- storied RCC buildings for seismicity. Reinforced concrete multi-storied buildings are very complex to model as structural systems for analysis. Usually, they are modeled as two-dimensional or three-dimensional frame systems are in plane and slope with different angles 5°, 10°, and 15°. Analyze multistoried buildings in the country for seismic forces and comparing the axial force, shear force, moment, nodal displacement, stress in beam and support reaction compared too current version of the IS:1893– 2002 to the last version IS:1893-1984.

2.2.2 Birajdar and Nalawade (2004); studied **"seismic performance of buildings resting on sloping ground"**. They considered twenty four RC building frames with three different configurations as Step back building, Step back Set back building and Set back building situated at a slope of 27 degree with the Horizontal. They studied the seismic response of buildings with varying storey level ranging from 4 to 11 (15.75m to 40.25m), consist of three bays along slope direction and one bay across slope, located in seismic zone III. They carried out 3D analysis including torsional effect by using Response spectrum method. They observed that their is a linear increase in the value of top storey displacement and fundamental time period as the height of building increases. From comparison they found that, this increase in top storey displacement and fundamental time period as the height of step back building increases is higher than step back set back building, as shown in Figure 2(a) and Figure 2(b). From their study it is observed that the shear force in the column towards extreme left is significantly higher as compared to rest of the columns, in case of step back building it is found to be 55-250% more than step back set back building. Thus they conclude that extreme left column at ground level, which are short are the worst affected and step back building could prove more vulnerable during seismic excitation than other type of configuration. They observed in step back buildings, the uneven distribution of shear force in the various frames suggests development of torsional moment due to static and accidental eccentricity.

2.2.3 Y. Singh and phanigade (2011): Both of them presented a paper **"Seismic behavior of buildings located on slopes"**, in this report study made on different configuration of the buildings on slopes, and also study made on dynamic response of the building by comparing buildings on slopy ground as well as regular building on flat ground in terms of fundamental period of vibration, storey drift, column shear, seismic behavior of two typical configurations of buildings which is located on sloping ground is analysed using linear and non-linear time history analysis.

2.2.4 Ravikumar C. M et al (2012); focused on the **"study of performance of irregular configuration of RC buildings".** In which they studied vertical irregularities of buildings such as geometric irregularity and buildings resting on sloping for which two types of configurations were considered as buildings resting on sloped ground in X-direction and buildings resting on sloped ground in Y-direction. All buildings consist of 5 bays in X-direction and 4 bays in Y-direction with 3 storey located in severe zone V. The performance of these buildings was studied by linear analysis using code IS 1893 (part-1) 2002 and Nonlinear analysis using ATC 40. They observed that the vulnerability of sloping ground buildings was found to be remarkable which attracts large force to deform moderately. Base shear of building on hill slope was found to be 6019.2 kN, which was around 25-55% more than other buildings and also displacement was found to be 83.4 mm which was moderately higher than other buildings. They found that the performance goal was not achieved of sloping ground buildings in X-direction and in Y-directions this was achieved after collapse point. Thus they conclude that the buildings resting on sloping ground are more vulnerable to earthquake than the buildings resting on plain ground.

2.2.5 Nagargoje and .Sable et al (2012); studied **"seismic performance of buildings on hill slope"**. They carried out 3D space frame analysis to study dynamic response of the buildings, in terms of base shear and top floor displacement. A parametric study was carried out on thirty-six buildings with three configurations as step back, step back set back and set back buildings located in seismic zone III. B.G.Biradar and S.S.Nalawade (2004) studied seismic performance of hill buildings by considering story level up to 11, however in this paper the study is carried out by considering story level ranging from 4 to 15 (15.2 m to 52.6m). They found that the story displacement of step back buildings is quite high as compared to step back –set back buildings. They observed that the base shear induced in step back set back buildings is higher in the range of 60 and 260% than set back building. They suggested step back set back buildings may be favored on sloping ground.

2.2.6 Singh et al (2012); studied **"seismic behavior of buildings located on slopes"** .An analytical study is carried out on buildings considered, by using linear and nonlinear time history analysis. They considered 9 storey buildings, which include step back building at a slope of 45 degree with the horizontal, a RC frame located on steep slope /vertical cut which was not considered in previous studies, in which foundations are provided at two levels, at base downhill and at the road level, to compare the behaviour, they considered buildings resting on flat ground with and 9 storeys. All buildings are located in seismic zone IV, consist of seven bays along slope and 3 bays across the slope. They have analysed buildings for a set of five ground motions, as shown in Table 1, which is taken from strong motion database of pacific Earthquake Engineering Research Centre. It is observed that, in all buildings on sloping ground, storey shear is resisted by short column. The effect of torsion irregularity in the building configuration can be represented by the ratio of maximum to average inter story drifts (Δmax/Δavg) in a storey. From which they observed that, in step back building torsion is observed in all storeys denoted as SI. Whereas torsion is observed in only top storeys of building located on vertical cut denoted as SII, as shown in Figure 3. They conclude that the step back buildings are subjected to significant torsional effects under cross slope excitation. They also studied the inter storey drifts in the top three storeys of all buildings from which they observed that the inter storey drifts in the top three storey of hill building are quite close to those in the 3 storey regular building and the pattern of inter storey drifts of a storey building differs from other buildings.

2.2.7 Jitendra Babu et al (2012); carried out **"pushover analysis of various symmetric and asymmetric structures constructed on plain as well as sloping ground subjected to various kinds of loads"**. They considered various structures in plan symmetry and also asymmetry with different in bay sizes in mutual direction. On sloping ground they considered a 4 storey building in which they have taken one storey above ground level which is situated at a slope of 30 degree with the horizontal. They found that the short column lies in the severity level beyond collapse prevention (CP) from pushover analysis, they obtained displacement and base shear for asymmetric sloping ground as 104X10-3 m and 2.77 x 103 kN respectively. Based on results they developed pushover curves with displacement on X-axis and Base shear on Y-axis and have given comparison between various cases they considered. They observed that the Base shear resisted for maximum displacement up to failure limit by symmetric structure is 70% and by asymmetric sloped building is 24% more than base shear resisted by asymmetric building on plain ground. They conclude that the structure with vertical irregularity is more critical than a structure with plain irregularity.

2.2.8 Sreerama and Ramancharla (2013); Studied on **"Dynamic characteristics of the buildings on flat ground differ to that of buildings on slope ground as the geometrical configurations of the building differ horizontally as well as vertically"**. observed that recent earthquakes like Bihar-Nepal (1980), Shillong Plateau and the Kangra earthquake killed more than 375,000 people and over 100,000 of the buildings got collapsed. Due to this irregularity the centre of mass and the centre of stiffness does not coincide to each other and it results in torsional response. The stiffness and mass of the column vary within the storeys that result in increase of lateral forces on column on uphill side and vulnerable to damage. In their analysis they took five G+3 buildings of varying slope angles of 0, 15, 30, 45, 60° which were designed and analysed using IS-456 and SAP2000 and further the building is subjected and analysed for earthquake load i.e., N90E with PGA of 0.565g and magnitude of M6.7. They found that short column attract more forces due to the increased stiffness. The base reaction for the shorter column increases as the slope angle increases while for other columns it decreases and then increases. The natural time period of the building decreases as the slope angle increases and short column resist almost all the storey shear as the long columns are flexible and cannot resist the loads.

2.2.9 Halkude et al (2013); focused on **"seismic analysis of buildings resting on sloping ground with varying number of bays and hill slopes"**. They studied the variation of time period, base shear and top storey displacement with respect to variation in number of bays along slope direction and hill slope angle. To study the seismic behaviour they considered different configurations, as step back building which are in the range of 4 to 11 storey and consist of varying bays of 3 to 6 in X-direction .They have not studied the seismic behaviour by varying bays along Y-direction, thus they considered one bay along Y-direction, situated at varying slopes of 16.32°, 21.58°, 26.56° and 31.50° with the horizontal located in seismic zone III .It is observed that, in all configurations, base shear increases with increase in number of storey , increases with increase in number of bay and decreases from lower angle to higher angle of slope. when compared between different configurations, base shear of step back building is found to be higher than step set back building. They observed that the time period increases with increase in number of storey in all configurations, in step back building time period increases with increase in number of bays, which is a reverse case in step back set back building in which time period decreases with increase in number of bay and in all configurations time period decreases with increase in hill slope showing minor change in time period. In all configurations it is observed that the top story displacement increases with increase in number of storey, displacement is nearly alike for 3 bay and 4 bay, But, it decreases considerably from 4 to 5 bay and further increases for 6 bay, with respective to hill slope, they found that the top storey displacement decreases with increase in hill slope showing lower value for higher slope .Thus they conclude that the step back frames produce higher base shear, higher value of time period and higher value of top storey displacement as compared to step back set back frames. Also they conclude that greater no of bays are observed to be better under seismic excitation, as number of bays increase time period and displacement decreases.

2.2.10 Prashant D and Jagadish Kori G (2013); studied **"seismic response of one way slope RC frame building with soft storey"**. In this paper study is focused on the behaviour of buildings situated on sloping ground with and without infill wall, the influence of infill wall on buildings situated on sloping ground is presented. Nonlinear static pushover analysis is carried out on 10 storey buildings which include bare frame without infill wall and other model with infill wall including a soft storey building on sloping ground. All buildings consist of 5 bays along slope direction situated at a slope of 27 degree with the horizontal, located in seismic zone III. Building frame system considered is

SMRF. They observed that the time period of bare frame model is found to be 1.975 sec which is almost 96-135% more than other models with presence of infill wall. Thus, they conclude, this higher value of natural period in bare frame compared to infill frame ultimately results in underestimation of design base shear in bare frame model on sloping ground. The abrupt changes in the slope profile indicates stiffness irregularity, they observed that the displacement in bare frame model is found to be more because of reduced stiffness compared to other models with infill wall. They found that the base shear of infill models is almost 250% more compared to bare frame. It is concluded that the formation of plastic hinges is more in bare frame model and soft storey building compared to fully infilled fames. In this paper study is concentrated on variation of stiffness due to presence of infill wall and soft storey on sloping ground.

2.2.11 Rayyan-Ul Hassan et al (2013); carried out **"seismic analysis of earthquake resistance multi-storey multi bay RC frame"**. They studied the seismic behaviour of bare frame model, building with first soft storey (infill wall in upper storeys) with presence of both infill and shear wall at corner position for which they used 4 bay twelve storey building situated at a slope of 1:1/3 located in seismic zone V. These buildings have been analysed using Equivalent static, Response spectrum and Pushover analysis. Based on Equivalent analysis results they noted that their is reduction in displacement of models with infill and shear wall at corners with respect to bare frame model by almost 79.15% and 89.27% respectively in longitudinal direction and from Response spectrum analysis which are almost 50.95% and 73.97% respectively. Hence they conclude that the presence of brick infill and shear wall reduces lateral displacement considerably. It is observed that there is increased base shear in building with shear wall when compared to bare frame model.As per IS 1893 part (1) 2002 code, the permissible inter storey drift is limited to 0.004 times the storey height. In this study they found that all buildings considered are within permissible drifts, however the inter storey drifts of bare frame model on sloping ground found to be relatively higher compared to buildings with infill wall and shear wall, From pushover analysis, it is observed that the spectral displacement and Roof displacement of bare frame is higher than building with shear wall at corner. Thus they conclude that the presence of infill wall and shear wall influences the overall behaviour of structures when subjected to lateral forces by effectively reducing large joint displacements found in bare frame, which was also concluded in study done by Mohammad Umar Farooque patel and Prashant D etal.

2.2.12 SUJIT KUMAR et al (2014); Studied on **"effect of sloping ground on structural performance of RCC building under seismic load".** work deals with study of behavior of sloping ground building frames considering different inclination (7.5^0, 15^0) under earthquake forces. The comparison of sloping ground and plane ground building under seismic forces is done. Here G+ 4 storey is taken and same live load is applied in three the buildings for its behavior and comparison. The framed buildings are subjected to vibrations because of earthquake and therefore seismic analysis is essential for these building frames. The fixed base system is analyzed by employing in three building frames in seismic zone IV by means of STAAD Pro. Software. The response of three the building frames is studied for useful interpretation of results. Hence they concluded that the critical horizontal force and bending moment in footing increases significantly with increase in ground slope and the critical bending moment in the column increases significantly for sloping ground(15^0) compared to plane ground.

2.2.13 Mohammad Umar Farooque etal (2014); focused on **"performance study and seismic evaluation of RC building on sloping ground"**. They studied the behaviour of RC frame on sloping ground with the presence of shear wall with different positions at centre and at corner and given the performance of structures with shear wall on sloping ground. A parametric study was carried out on eight storey building which includes a bare frame, building with shear wall at centre and at corner position located in seismic zone III. To give comparison they considered models on plane ground. All buildings consist of 5 bays in both directions. Seismic analysis has been done using linear static, Response spectrum analysis and evaluated using pushover analysis. Based on Equivalent static analysis, they found that the buildings with shear wall at centre and at corner have 41.4%, 61.5% respectively less displacement and based on Response spectrum analysis, these buildings have 23.6%, 38.1% less displacement as compared to the bare frame model on sloping ground. From which they conclude: as the buildings resting on sloping ground has higher displacement, the presence of shear wall reduces the lateral displacement considerably. Performance point determined from pushover analysis is the point at which the capacity of structure is exactly equal to the demand made on the structure by the seismic load. Based on state of structures at performance point, they observed that the spectral displacement of building on hill slopes have 114%-179% higher than building model on plain ground in longitudinal direction and also the plastic hinge formation is more in bare frame model, building with presence of shear wall on sloping ground when compared to the building on plain ground, which proves that the buildings on hill slopes are more vulnerable than other buildings. Hence, they conclude that the performance of buildings on hill slopes suggests an increased vulnerability of the structure with formation of column hinges at base level and beam hinges at each story level at performance point. Previous papers have not considered the presence of shear wall to study the seismic behavior of hill slope buildings.

2.2.14 Shivanand.B, H.S.Vidyadhara (2014); Studied on **"Design Of 3d Rc Frame On Sloping Ground"**.The buildings resting on hill areas have to be configured differently from flat ground. Hill buildings are different from those in plains; they are very irregular and unsymmetrical in horizontal and vertical planes, and torsionally coupled and hence susceptible to sever damage when affected by earthquake. The floors of such buildings have step back towards the hill slope and at the same time setback also. In this study 3D analytical model of 12 storied building have been generated for symmetric and asymmetric case. Building models are analyzed and designed by ETABS software to study the effect of influence of bracings, shear wall at different positions. Seismic analysis done by linear static (ESA), linear dynamic (RSA) and non-linear static Analysis (Pushover Analysis). They observed that Fundamental natural period decreases when effect of bracings and concrete shear wall is considered and the displacements are found to within the limit in linear static method, linear dynamic and non-linear static analysis. Hence they concluded that The Setback Stepback on Sloping ground possesses relatively less displacements when compared to StepBack buildings on Sloping ground & Plain Ground and ,The performance of the buildings on sloping ground suggests an increased vulnerability of the structure with formation of column hinges at base level and beam hinges at each story level at performance point.

2.2.15 G. Suresh, E. Arunakanth et al (2014); Three dimensional space frame analysis is carried out for two different configurations of buildings ranging from 8 to 10 storey resting on sloping and plain ground under the action of seismic load by using Etabs software. And also considering bracing system to step back building configuration. Dynamic response of these buildings, in terms of base shear, fundamental time period and displacement is presented, and compared within the considered configuration as well as with other configurations. At the end of suitable configuration of building to be used in hilly area is suggested.

2.2.16 R. B. Khadiranaikar and Arif Masali (2014); This study summarizes the knowledge in the **"seismic response of buildings on hill slopes"**. The dynamic response of the structure on hill slope has been discussed. A review of studies on the seismic behaviour of buildings resting on sloping ground has been presented. It is observed that the seismic behaviour of buildings on sloping ground differ from other buildings. The various floors of such buildings step backs towards hill slope and at the same time buildings may have setbacks also. Most of the studies agree that the buildings resting on sloping ground has higher displacement and base shear compared to buildings resting on plain ground and the shorter column attracts more forces and undergo damage when subjected to earthquake. Step back building could prove more vulnerable to seismic excitation.

2.2.17 Prasad Ramesh Vaidya et al (2015); This study investigates the **"seismic performance of shear wall building on sloping ground"**. The main objective is to understand the behaviour of the building on sloping ground for various positions of shear walls and to study the effectiveness of shear wall on sloping ground. The performance of building has been studied with the help of four mathematical models. Model one is of frame type structural system and other three models are of dual type (shear wall-frame interaction) structural system with three different positions of shear walls. Response spectrum analysis is carried out by using finite element software SAP 2000. The performance of building with respect to displacement, story drift and maximum forces in columns has been presented in this paper.

2.2.18 S. K. Deshmukh, Farooq. I. Chavan (2015); The aim of study is to analyze the RCC building sloping ground ,as such building are different from those in plains, they are irregular variation along the vertical and horizontal planes. The Experimental method used over here for seismic analysis is linear static method for seismic analysis of G+6 storey plain building as well as inclined building. In these case the analysis of structure is carried out computationally by using STAAD.Pro Initially plain they are very irregular and unsymmetrical in horizontal and vertical planes and subjected to torsion and twisting forces, this leads to, severe damage when subjected by Earthquake ground motion due to mass and stiffness building G+6 storey with plan dimension of 20m x 9m has been analyzed which is later on compared with analysis of similar building resting on sloping ground.

2.2.19 A. S. Swathi et al. (2015); Studied on **"Seismic Performance of Buildings on Sloping Grounds"**.In hilly areas buildings are built on sloping grounds. When the hilly areas come under the seismic zones, these buildings are highly vulnerable to earthquakes. This is due to the fact that the columns in the ground storey are of different heights in such a way that column in one end is a short column and column in other end is a long column. Along with this if the building has an open ground storey, the seismic vulnerability is further increases. This paper deals with the comparison of seismic performance of soft storey building on sloping grounds and soft storey building retrofitted with shear wall. The aim of the paper is to check if the seismic performance of the structure is improved when it is retrofitted with shear wall.

2.2.20 Narayan Kalsulkar, Satish Rathod (2015); Generally, building frames are analyzed for gravity loads in vertical direction and lateral loads like earthquake load and wind load in lateral direction. The analysis of structure depends on idealization of geometry of structure and idealization of load system on the structure. The behavior of buildings during earthquake depends upon the distribution of mass and stiffness in both horizontal and vertical planes of the buildings. General behavior is shattered when the structure has irregularities. These kinds of irregularities are especially seen in hilly regions, where the structure rests on the sloping ground. In the present study, the response spectrum method is carried out on the type of structure that rests on the sloping ground. Building frames which occurs in hilly regions are narrowed down to two basic formats such as step back frames and step back-set back frames and dynamic responses have been studied for various building configuration.

2.2.21 Nagarjuna, Shivakumar B. Patil et al (2015); The structures are generally constructed on level ground; however, due to scarcity of level grounds the construction activities have been started on sloping grounds. There are two types of configuration of building on sloping ground, the one is step back and the other is step back setback. In this study, G+ 10 storeys R.C.C building and the ground slope varying from 10o to 40o have been considered for the analysis. A comparison has been made with the building resting on level ground (setback). The modeling and analysis of the building has been done by using structure analysis tool ETABS, to study the effect of varying height of the column in bottom storey and the effect of shear wall at different position during the earthquake. The results have been compared with the results of the building with and without shear wall. The seismic analysis was done by linear static analysis and the response spectrum analyses have been carried out as per IS: 1893 (Part 1): 2002. The results were obtained in the form of top storey displacement, drift, base shear and time period. It is observed that short column is affected more during the earthquake. The analyses showed that for construction of the building on sloping ground the stepback setback building configuration is suitable, along with shear wall placed at the corner of the building.

2.2.22 Paresh G. Mistry et al (2016); Studied on **"Seismic Analysis of Building on Sloping Ground Considering Bi-Directional Earthquake"**. They work on building on plain ground, setback with stepback building and stepback building with 10 storey on sloping ground(200) all buildings modeled in zone-V is modeled in SAP-2000 software. The size of beam is 300 mm x 450 mm and the size of column is 450 mm x 450 mm. The slabs are considered as 125 mm thickness. Necessary meshing is given to the slab to transfer slab load to the adjacent beams. The external wall thickness is 230 mm and internal wall thickness is 115 mm. The slabs are loaded with floor finish of 1.5 KN/m2 and live load of 3 KN/m2. Terrace water proofing is 1 KN/m2. Storey height is 3 m. In this case 90% of total seismic mass is covered in 12 modes. Setback with stepback and Stepback building are modeled on 20 degree slope and grade of steel id Fe-415. They observed that the Base shear increases by 20 % if earthquake is applied to some angle compared to right angle. Hence they concluded that the values of base shear are higher for time history analysis compare to response spectrum analysis and the values of axial force and moments are higher for time history analysis compare to response spectrum analysis.

2.2.23 Likhitharadhya Y R et al (2016); Studied on **"Seismic Analysis of Multi-Storey Building Resting On Flat Ground and Sloping Ground"**. They taken one building configurations are considered, which include buildings situated on plain ground. Number of storey considered for each type of configurations is 10 storeys. Plan layout is kept same for all configurations of building frame. The columns are taken to be square to avoid the issues like orientation. The response spectrum analysis is carried out using the spectra for medium soil as per IS 1893 (Part 1) 2002 for seismic zone V, medium soil and 5% damping. They observed that The sloping ground buildings possess relatively more maximum displacement and shear forces which may give to critical situations than the flat ground. Base shear is maximum at 200 slope compared to other models. Base shear is maximum in X-direction compared to Y-direction for sloping ground building. From the analysis, Mode Period is decrease with increase in slope angle. Mode period is directly proportion to the mass of the structure, the mass of the structure increases, the mode period also increases. From the analysis, Storey displacement is decrease with increase in slope angle. Displacement is maximum at the top story when compared with bottom storeys in all other models along x and y-direction . Hence they concluded that from the analysis, Storey Acceleration is decrease with increase in slope angle. Acceleration is maximum in storey-11 when compared to storey-1 in all other models along x and y-direction.

2.2.24 Shivakumar Ganapati et al (2017); studied on **"pushover analysis of R.C frame structure with floating column on sloping ground"**. They considered model consist of 3 bays with 10 story building, each bay having a dimension of 5m in X direction 5m in Y direction. The story height is kept 3m .the beam size is of 0.3x0.45m and the column size is of 0.6x0.85m.The slab thickness is 0.125m. The building is to be situated in the seismic zone 5 with medium soil. The floor finish 1kN/m2 and live load 3kN/m2are consider and concert grade of M25 and M30 and the grade of steel Fe-500 are assumed for study. These model were analyzed using pushover analysis method in ETABS. They observed that in step back-set back building on sloping ground maximum displacement decreases when compared to step back building on sloping ground without floating column. Hence they concluded that that building with provision of floating column at corner on any floor shows the poor performance compared to other cases. Hence provision of floating columns at corner should be considered as critical case, hence special attention is needed.

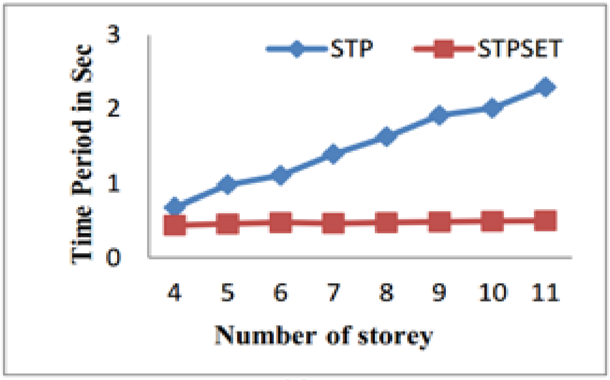
2.2.25 Ravindra Navale et al (2017); Studied on **"Analysis of Unsymmetrical Building Resting on Sloping Ground by Dividing In 2D Frame"**. They considered Following types of structures are analyse as lateral load resisting frame. Column sections of size 230mm×600mm, beam sections of size load, floors finished load 1 KN/m2, live load 2 KN/m2 on all floors earthquake loads as per IS 1893:2002. The damped and undamped frames with different geometrical configurations viz. are taken for the study. Model-1 building on normal terrain Model-2 building on sloping terrain For the seismic analysis of building, the zone factor 'Z' is taken as 0.24 for seismic zone IV, Importance Factor 'I' equal to 1. They observed that bending moment in sloping terrain building is reduces considerable, but tremendously increase at base of building. Hence they concluded that Seismic Performance of building can be improved by providing step up set back columns, which resist input energy during earthquake.

2.2.26 Naveen Kumar S M et al (2017); studied on **"Analysis and Comparison of Step Back RC Frame Building on Sloping Strata and Plain Strata"**. The structures are generally constructed on level ground; however, due to scarcity of level grounds the construction activities have been started on sloping grounds. There are two types of configuration of building on sloping ground, the one is step back and the other is step back setback. In this study, G+ 10 storeys RCC building have been considered for the analysis. A comparison has been made with the building resting on level ground. The modeling and analysis of the building has been done by using structure analysis tool ETAB 2015. The seismic analysis was done by the response spectrum analyses have been carried out as per IS: 1893 (part 1): 2002. The results were obtained in the form of top storey displacement, Storey drift, Base shear and over turning moment. They observed that the Overturning moment is same till story 4 because column height is same , but after story 4 it overturns due to column variation and also overturning moment gradually decreases for step back configuration on sloping ground compare to step back on flat ground for load. Hence they concluded that Base shear is more for sloping strata than plain strata for both D-con 7 and D-con 9 combinations and the over turning moment gradually decreases on sloping ground than compare to flat ground in both D-con 7 and D-con 9.

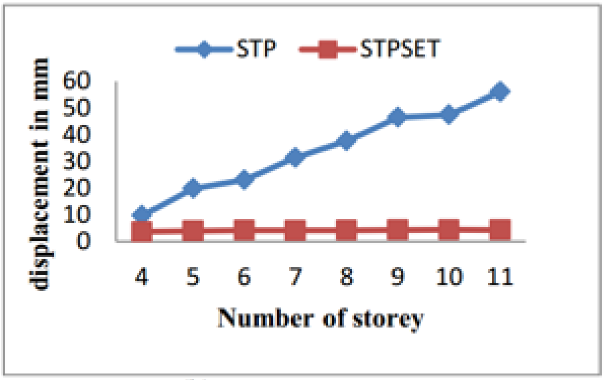
2.2.27 Tamboli Nikhil Vinod et al (2017); studied **"seismic behavior of multi-storied r.c.c. buildings resting on sloping ground and bracing system"**. They considered the only RC framed buildings are considered for the analysis. The buildings considered (8-12 story buildings) without basement, shear wall. The contribution of infill walls are considered as non-integral with RC frames. The out of plane action of masonry walls are neglected in the analysis. The effect of the supporting foundation medium on the motion of structure gives soil structure interaction but this effect may not considered in the seismic analysis for structures supported on rock or rock like materials. The Flexibility of floor diaphragms are neglected and considered as rigid diaphragm. The base of the column is assumed to be fixed in the analysis. Secondary effect P- shrinkage and creep are not considered. The contribution of infill wall to the stiffness was not considered. Loading due to infill wall was taken into account. It is observed that the time period for step back without bracings and with bracings frames and regular building on plain ground are more than step-set back frames. They concluded the story shear for first stories step back without bracings and step-set frames are less than step back with bracings frames and regular building on plain ground.

Table-1 Earthquake records used in the analysis

Events	Magnitude	PGA [g]	PGV [cm/sec]	PGD [cm]
Chi-Chi [1999]	M7.6	0.266	38.331	38.331
Imperial Valley [1979]	M6.5	0.289	19.915	10.97
Northridge [1994]	M6.7	0.249	19.381	6.824
San Fernando [1971]	M6.6	0.33	56.35	60.017
Kobe[1995]	M7.2	0.28	16.369	8.067



(a)



(b)

Fig-2:(a) Variation of Time period
(b) Variation of Displacement

Note: STP=Stepback building STEPSET=Stepback Setback building

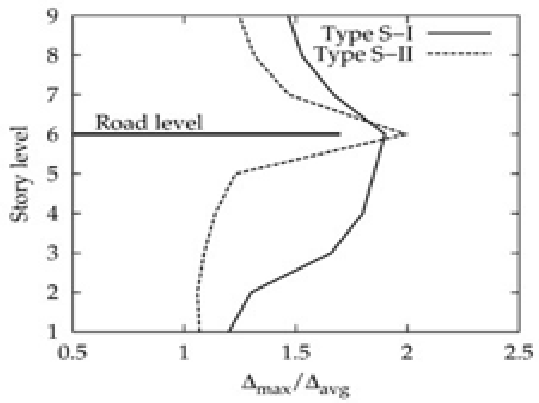


Fig-3: Variation of Δmax/Δavg along height in hill building configurations and due to seismic excitation in cross-slope direction. Note: Type S-I=Step back building.

3. CONCLUSIONS

From the above discussion following conclusions can be made.

1. Step back buildings produce higher base-shear, higher time period, higher top storey displacement compared

to step-back set-back building. During seismic excitation Step-back building could be more damage than other configuration of buildings.

2. It is noticed that, short columns attracts more seismic forces and are worst affected during seismic excitation. From design point of view, special attention should be given to the strength, stiffness and ductility demand of short column.

3. The hill slope buildings are subjected to significant torsional effects, due to uneven distribution of shear force in the various frames of building suggest development of torsional moment, which is found to be higher in step back building.

4. Many researchers suggested as step back set back buildings may be favoured on sloping ground.

5. From the study it is concluded that the presence of infill wall and shear wall influences the behaviour of structure by reducing storey displacement and storey drifts considerably, but may increase the base shear, hence special attention should be given in design to reduce base shear.

6. It is concluded that the greater number of bays are found to be better under seismic condition, as the number of bays increases, time period and top storey displacement decreases in hill slope buildings.

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