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Review on Seismic Analysis of Multistoried Building in Hilly Region

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***Abstract:** Due to sloping land and high seismically active zones, designing and construction of multistory buildings in hilly regions is always a challenge for structural engineers. This review paper focuses to establish a review study on the Possible Types of building frame configuration in the hilly region and he behavior of Such building frames under seismic loading conditions, and (3) The recent research and developments to make such frames less vulnerable to earthquakes.*

This paper concludes that the dynamics characteristics of such buildings are significantly different in both horizontal and vertical directions, resulting in the center of mass and center of stiffness having eccentricity at point of action and not vertically aligned for different floors. When such frames are subjected to lateral loads, due to eccentricity it generates torsion in the frame. Most of the studies agree that the buildings resting on slanting ground have higher displacement and base shear compared to buildings resting on plain ground and the shorter column attracts more forces and undergoes damage when subjected to earthquake.

***Keywords:** Building frame configuration, Seismic behavior, Dynamic characteristics, Response spectrum analysis, time history analysis.*

I. INTRODUCTION

Construction on sloping land in hilly regions is becoming increasingly prevalent due to the unavailability of flatlands. This has created a major challenge for structural engineers with regard to structure design, due to encountered difficulties during the implementation of projects, both for the structure and the soil. Construction on sloping land is not subject to any Indian standard codes in India. However, Hilly regions are prone to landslides, 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 the structures. 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 is increasingly considered, mainly due to a shortage of available flatlands for building.

The necessity of seismic studies for building in hilly region -

1) Hill buildings are very irregular and unsymmetrical in horizontal and vertical planes. Hence, they are susceptible to damage whenaffected by earthquakes.
2) The building may not have been designed and detailed to resist seismic force which will result in huge disaster outcomes, when subjected to an earthquake.
3) Many of the existing buildings are lacking in adequate earthquake resistance. Seismic studies can assist in retrofitting andrepairing the old building and historical conservation.

II. REVIEW

A. *The Possible Types of Building Frame Configuration in the Hilly Region.*

After reviewing several papers which deal with the structural studies under seismic loads. Authors find two common terminologies (type of building in the hilly region) : they are step back and set back set building models. (refer figure -1 a&b)

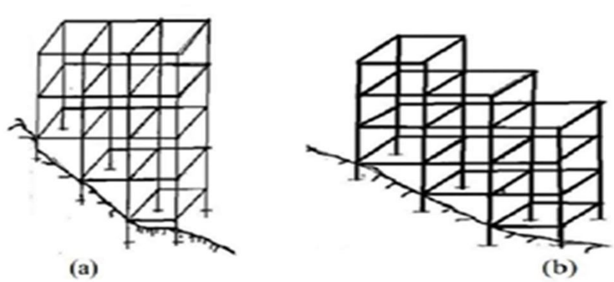

Figure - 1 (a) Step back (b) Setback – step back

B. The Behavior of Such Building Frames under Seismic Loading Conditions.

1) *Birajdar et. al. (1999):* In paper "Seismic performance of buildings resting on the sloping ground". They considered 24 RC building frames in seismic zone III with three different configurations as Step back, Step back Set back and Set back building at 27 degreeslope. They studied the seismic response of buildings' story level ranging from G+4 to G+11, three bays frame along slope and one bay across slope. They carried out analysis by considering the torsional effect by using the Response spectrum method. They observed with increase in building height there is a linear increase in the value of top storey displacement and fundamental time period. Columnstowards the extreme left have higher shear force 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. Paper concludes that extreme left columns at ground level, Short columns are worst affected and step back building could prove more vulnerable during seismic excitation than other types of configuration.
2) *Y. Singh et. al. (2005):* In paper "Seismic behavior of buildings located on slopes", It is a comparative study of the building subjected to different configurations subjected to two different site conditions, first at sloped ground and secondly flat ground. They compared fundamental periods of vibration, storey drift, column shear, seismic behavior of two typical configurations of buildings which are located on sloping ground, which is analysed using linear and nonlinear time history analysis. They concluded that buildings on flat ground are more resilient than buildings at sloped ground.
3) *Ravikumar C. M et al (2010):* In paper "Study of the performance of irregular configuration of RC buildings" studied the vertical irregularities of buildings such as geometric irregularity and buildings resting on X and Y direction slop. All buildings consist of 5 bays in X-direction and 4 bays in Y- direction with 3 storeys located in severe zone V. The performance is studied by linear analysis using code IS 1893 (part-1) 2002 and Nonlinear analysis using ATC 40. They observed that sloping ground buildings are vulnerable and were found to remarkably attract large force deformation. 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 by sloping ground buildings in X-direction and in Y- directions; this was achieved after the collapse point. Thus they conclude that the buildings resting on sloping ground are more vulnerable to earthquakes than the buildings resting on plain ground.
4) *Nagargoje and Sable et al (2012):* In paper "Seismic performance of buildings on hill slope". Dynamic response of the buildings is studied in terms of base shear and top floor displacement. A parametric study was carried out on 36 building models with three configurations as step back, step back set back and set back buildings located in seismic zone III.
5) *Singh et al (2012):* In paper "Seismic behavior of buildings located on slopes". The linear and nonlinear time history analysis was performed on 9 storey buildings, subjected to step back building at a slope of 45 degree with the horizontal and compared with similar building on flat ground. 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, Site located in seismic zone IV is considered. The buildings are seven bays and 3 bays along and across the slope respectively. They have analysed buildings for a set of five ground motions, as shown in Table 1, which is taken from the strong motion database of Pacific Earthquake Engineering Research Centre. This paper concludes that the step back buildings are subjected to significant torsional effects under cross slope excitation.
6) *Jitendra Babu et al (2012):* In paper "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 & asymmetry with different bay sizes in mutual direction. They considered a four-story building on sloping land, with one storey above ground level at a 30 degree angle to the horizontal. From pushover analysis, they discovered that the short column is in the severity level beyond collapse prevention (CP), with displacement and base shear for asymmetric sloping terrain of 104X10-3 m and 2.77 x 103 KN, respectively. They constructed pushover curves with displacement on the X-axis and base shear on the Y-axis based on the results and compared the many situations they investigated. They discovered that by using a symmetric construction, the base shear resisted for maximum displacement up to failure limit is 70%, and by using an asymmetric structure, the base shear resisted for maximum displacement up to failure limit is 80%.
7) *Sreerama and Ramancharla (2013):* In paper "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". Recent earthquakes such as Bihar-Nepal (1980), Shillong Plateau, and the Kangra earthquake killed over 375,000 people and destroyed over 100,000 houses, according to the report. The center of mass and the center of stiffness do not coincide because of this irregularity in building resultingin torsional reaction. Within the storeys, the stiffness and mass of the column varies, resulting in increased lateral stresses on the column on the uphill side, making it subject to damage. They used IS-456 and SAP2000 to

design and analyse five G+3 buildings with varied slope angles of 0, 15, 30, 45, and 60 degrees. The buildings were also subjected to and analyzed for earthquakes. They found that short columns 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 columns resist almost all the storey shear as the long columns are flexible and cannot resist the loads.

8) *Halkude et al (2013):* In paper "Seismic analysis of buildings resting on sloping ground with varying number of bays and hill slopes' '.The authors of this paper looked at how time period, base shear, and top storey displacement changed as the number of bays along the slope direction and hill slope angle changed. They looked at several layouts, such as step back buildings, which span from 4 to 11 storeys and have 3 to 6 bays in the X-direction, to study the seismic behavior. They did not investigate the seismic behavior of changing bays along the Y-axis, thus they chose one bay along the Y-axis with slopes of 16.32°, 21.58°, 26.56°, and 31.50°, with the horizontal in seismic zone III. Base shear increases with the number of storeys and the number of bays, and decreases from a lower angle to a greater angle of slope in all configurations. When comparing different arrangements, step back buildings have a larger base shear than step set back buildings. They discovered that the time period increases with the number of storeys in all configurations, that the time period increases with the number of bays in step back buildings, that the time period decreases with the number of bays in step back set back buildings, and that the time period decreases with the increase in slop in all configurations. Also they conclude that greater no of bays are observed to be better under seismic excitation, as number of bays increases time period and displacement decreases.
9) *Prashant D and Jagadish Kori G (2013):* In paper "Seismic response of one way slope RC frame building with soft storey". In this paper the behavior of buildings situated on sloping ground with and without infill wall is presented. Nonlinear static thrust analysis is performed on 10-story buildings that include a frame without partition and other models with partition walls, including a soft-story building on a sloping story. All the buildings consist of 5 bays in the direction of the slope, which are located in seismic zone III with an inclination of 27 degrees with respect to the horizontal. The building structure system under consideration is SMRF. They observed that the bare frame model was 1,975 seconds, which is almost 96 135% longer than other models with a bulkhead presence. From this, they conclude that this higher value of the natural period in the shell compared to the infill frame ultimately leads to an underestimation of the basic design shear force in the shell model on sloping terrain. Sudden changes in the profile of the slope indicate an irregularity in stiffness. They observed that the displacement in the model with a bare frame is due more to reduced stiffness compared to other models with a fill wall. They found that the base shear of the infill models is almost 250% higher compared to the bare frames. It is concluded that the formation of plastic hinges is more likely in models with bare frames and soft floors, compared to completely filled frames. In this thesis, the study focuses on the variation of stiffness due to the presence of infill walls and soft projectiles in sloping soils.
10) *Sujit Kumar et al (2013):* In paper "Effect of sloping ground on structural performance of RCC building under seismic load". The paper deals with the investigation of the behavior of buildings with sloping floors taking into account different inclinations (7.50, 150) under seismic forces. The comparison of the construction of sloping floor and floor plan under seismic forces is carried out. Here G + 4 floors are taken and the same payload is used in three buildings for behavior and comparison. Framed buildings are subject to tremors due to earthquakes and therefore a seismic analysis is essential for these building frames. The fixed base system is analyzed using STAAD Pro on three building frames in seismic zone IV. Software. The response of three building frames is examined for a useful interpretation of the results. From this, they concluded that the critical horizontal force and the critical bending moment in the foundations increase significantly with the increase in the slope of the terrain and the critical bending moment in the column for inclined terrain (150) increases significantly compared to the ground level.
11) *G. Suresh, E. Arunakanth et al (2013):* The analysis of the three-dimensional structure is performed for two different configurations of buildings of 8 to 10 floors, which rest on sloping and level ground under the action of seismic loads using the Etabs software. And also think about the bracing system to recover the building configuration. The dynamic reaction of these buildings with respect to basic shear, fundamental time and displacement is displayed and compared within the considered configuration, as well as with other configurations. In the end, a suitable building configuration is suggested for use in mountainous areas.
12) *R. B. Khadiranaikar and Arif Masali (2014):* This study summarizes the findings on the "seismic behavior of buildings on slopes". The dynamic response of the structure to the slope was discussed. An overview of the studies of the seismic behavior of buildings resting on sloping terrain was presented. It is observed that the seismic behavior of buildings on sloping terrain differs from that of other buildings. The different floors of such buildings recede in the direction of the slope, and at the same time, the buildings may also recede. Most studies agree that buildings that rest on sloping ground have higher ground

displacement and shear compared to buildings that are on flat ground, and the shorter column attracts more forces and is damaged in earthquakes. . Regression construction could be more prone to seismic excitation.

13) Nagargoje and. Sableetal(2014); 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 eve lupto11,howeverinthis 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 backset 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.
14) *Chandrasekaran and Rao (2014):* 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 5o, 10o, and 15o. 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.
15) *S.M. Nagargoje and K.S. Sable (2014):* The maximum base shear is induced in Step back Setback building& least in Setback building on levelled ground. Top storey displacement of Step back building is quite high as compared to Step back-Setback building resting on sloping ground. Step back-Set back building may be favoured on sloping ground.
16) *Y. Singh, Phani Gade, D.H. Lang & E. Erduran (2014):* The linear and non-linear dynamic analysis shows that the storey at road level, in case of downhill buildings, is most susceptible to damage. The hill buildings are subjected to significant torsional effects under cross-slope excitation.
17) *G. Suresh, E. Arunakanth et al (2015):* Three dimensional space frame analysis is carried out for two different configurations of buildings ranging from 8 to 10 story resting on sloping and plain ground under the action of seismic load by using E tabs 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.
18) *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 behavior 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.
19) *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.

C. The Recent Research and Developments to Make Such Frames less Vulnerable to Earthquakes.

1) *Prasad Ramesh Vaidya et al (2015):* In paper "Seismic performance of shear wall building on sloping ground". The main objective is to understand the behavior of the building on sloped terrain for different wall panel positions and to study the effectiveness of wall panels on sloped terrain. Construction performance was examined with the help of four mathematical models. Model one is a frame type structural system and the other three models are a dual type structural system (scissor wall frame interaction) with three different positions of shear walls. The response spectrum analysis is performed with the finite element software SAP 2000. In this article, the behavior of the building with respect to displacement, floor drift and maximum column forces was presented.

2) *S. K. Deshmukh, Farooq. I. Chavan (2015):* The objective of the study is to analyze the sloping floor of the RCC building, since these buildings differ from those of levels, they are irregular variations along the vertical and horizontal planes. The experimental method used here for seismic analysis is the linear static method for seismic analysis of simple 6-story G + buildings as well as sloping buildings. In these cases, the structural analysis is performed mathematically with STAAD. Pro initially flat, they are very irregular and asymmetrical in the horizontal and vertical planes and are subject to torsion and torsion forces, this leads to severe damage in earthquakes due to ground movements. Floor with a floor of 20m x 9m analyzed, which is later compared with the analysis of a similar building on a slope.
3) *A. S. Swathi et al. (2015):* Studied on "Seismic Performance of Buildings on Sloping Grounds". In mountainous areas, buildings are built on sloping terrain. When mountainous areas fall under seismic zones, these buildings are very prone to earthquakes. This is because the pillars on the first floor are of different heights, so the pillar at one end is a short pillar and the pillar at the other end is a long pillar. If the building has an open ground floor, the seismic vulnerability increases even more. This article deals with the comparison of the seismic behavior of buildings with soft floors on hillside properties and buildings with soft floors that have been modernized with wall panels. The objective of the article is to check if the seismic behavior of the structure improves when it is updated with a wall disc.
4) *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 earthquakes 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 occur 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 configurations.
5) *Nagarjuna, Shivakumar B. Patil et al (2017):* Structures are generally erected on level ground; However, due to the lack of flat terrain, construction work began on sloping land. There are two types of building configurations on sloping terrain: one is a step back and the other is a step back. In this study, a 10-storey G + RCC building with a 10 to 40 degree slope was taken into account for the analysis. A comparison was made with the building on level ground (reverse). The building was modeled and analyzed with the ETABS structural analysis tool in order to examine the effects of different column heights on the lower story and the effects of wall panels at different positions during the earthquake. The results were compared with the results of the building with and without wall panels. The seismic analysis was performed by linear static calculation and the response spectrum analysis were performed according to IS: 1893 (Part 1): 2002. The results were obtained in the form of upper floor displacement, drift, base shear and time frame. It is observed that the short pillar is more affected during the earthquake. The analysis showed that the design with a gap and wall panels attached to the corner of the building is suitable for the construction of the building
6) *Shivakumar Ganapati et al (2019):* In paper "Pushover analysis of R.C frame structure with floating column on sloping ground". They considered the 3-bay model with 10-story buildings, each of which measures 5 m in the X direction and 5 m in the Y direction. The floor height is 3 m. The beam size is 0.3 x 0.45 m and the column size is 0.6 x 0.85 m. The slab has a thickness of 0.125 m. The building will be located in seismic zone 5 with a central floor. The floor covering of 1 kN/m2 and the payload of 3 kN /m2 are taken into account and the M-25 and M-30 concert quality and the Fe-500 steel quality are assumed for the investigation. These models were analyzed using the pushover analysis method in ETABS. They observed that when building upside down on sloped terrain, the maximum displacement decreases compared to building upside down on sloped terrain without a floating column. From this, they concluded that buildings with floating columns at the corners of each story performed poorly compared to other cases. Therefore, the provision of floating columns in the corners should be considered a critical case, thus requiring special attention.
7) *Tamboli Nikhil Vinod et al (2020):* In paper "Seismic behavior of multi-storied R.C.C. buildings resting on sloping ground and bracing system". They looked at the only buildings with CR frames that were considered for the analysis. The considered buildings (8-12 floors) without basement, wall panels. The contribution of the infill walls is not considered integral with the RC frames. The unscheduled effect of masonry walls is neglected in the analysis. The influence of the load-bearing foundation medium on the movement of the structure leads to an interaction of the soil structure, but this effect cannot be taken into account in the seismic analysis for structures that rest on rocks or materials similar to the rocks. The flexibility of the soil membranes is neglected and a rigid membrane is considered. The calculation assumes that the base of the column is solid. Side

effect P: shrinkage and creep are not taken into account. The contribution of the infill wall to stiffness was not taken into account. The load of the infill wall was taken into account. The story shear for first stories step back without bracings and step-set frames are less than step back with bracing framesand regular building on plain ground.

III. CONCLUSION

A. Compared to set-bake-set building, Step back buildings produce higher base-shear, higher time period, higher top storey displacement. During seismic excitation Step-back buildings are more prone to damage.
B. The short columns attract more seismic forces and are worst affected during seismic excitation.
C. Special precaution should be given to the strength, stiffness and ductility demanded of a short column.
D. Response of step back buildings under earthquake load is such that it distributes uneven shear force in the frame due to eccentricity, building frame subjects to torsional moment.
E. Many research papers concluded set-back buildings are more favored on sloping ground.
F. The presence of infill and shear wall influences the behavior 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.
G. The greater number of bays are found to be better under seismic condition, as the number of bays increases, time periodand top storey displacement decreases in hill slope buildings.

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