Seismic performance of hill buildings−A review

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Abstract— **The buildings situated on hill slopes in earthquake prone areas are generally irregular, torsionally coupled . Hence, susceptible to serve damage when affected by earthquake ground motion. Such buildings have mass & stiffness varying along the vertical & horizontal planes, resulting the center of mass & center of rigidity do not coincide on various floors, they demand torsional analysis, in addition to lateral forces under the action of earthquakes. This study compels with a review of studies on the seismic behavior of buildings resting on sloping ground. It is observed that the seismic behavior 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.**

Index Terms— **Seismic performance, soil interaction, Sloping ground, Step back building, step back-set back building.**

INTRODUCTION

The scarcity of plain ground in hilly areas compels construction activity on sloping ground resulting in various important buildings such as reinforced concrete framed structures resting on hilly slopes. Since, the behavior of buildings during earthquake depends upon the distribution of mass and stiffness in both horizontal and vertical planes of the buildings, both of which vary in case of hilly buildings with irregularity and asymmetry due to step-back and step back-set back configuration. The presence of such constructions in seismically prone areas makes them exposed to greater shears and torsion as compared to conventional construction. In order to highlight the differences in behavior, this may further be influenced by the characteristics of the locally available foundation material. Current building codes including IS: 1893 (Part 1): 2002 suggest detailed dynamic analysis of these types of buildings on different soil (hard, medium and soft soil) types. To assess acceptability of the design it is important to predict the force and deformation demands imposed on structures and their elements by severe ground motion.

REVIEW OF PAPERS ON BUILDINGS RESTING ON SLOPING GROUND

Prabhat Kumar, , Ashwani Kumar and A.D Pandey, studied seismic performance of buildings on hill slope with soil interactions, their study has been conducted on eight representative step back structures. The foundation media has been idealized by equivalent uncoupled springs and the response spectrum analysis has been also conducted by considering seismic ground motion in the longitudinal and transverse directions. The buildings whose floors step back towards the hill slope and top floor level is different for each particular storey of building is considered for modeling and analysis. The slope of the ground is taken as 27^0 with horizontal. These types of buildings are unsymmetrical in one direction (Y-direction) while it is symmetrical in other direction (X-direction). The torsional behavior of these type of buildings will therefore change from floor to floor, making a three dimensional analysis more or less essential for assessment of response.

From which they conclude that vertical static displacements and horizontal dynamic displacements in X and Y direction increases with increase in the foundation flexibility with respect to the fixed base displacements. The shear forces due to static analysis in all the interior and shorter exterior columns at ground level are higher than those obtained from a fixed base analysis.

Prabhat Kumar, Ashwani Kumar and A.D Pandey studied seismic behavior of buildings located on slopes**.** They consider the fact that hilly regions in the northern part of India are also the most seismic prone areas it becomes imperative to critically assess the behavior of such structural forms as are prevalent in the region. They carried out Dynamic analysis (Response Spectrum Analysis) has been taking into account of ground profile; the structural forms, .i.e., two step-back (3 storey 3 bay & 4 storey 4 bay) and two step-back-set-back (3 storey 3 bay & 4 storey 4 bay) buildings are compared to get the better configuration for the slope topography. The dynamic analysis of structures can be carried out by two methods, Response Spectrum Method and Time History Method. The Response Spectrum Method consists of determining the response in each mode of vibration and then superimposing the responses in various modes to obtain the total response. The seismic analysis of all buildings was carried out by Response Spectrum Method in accordance with IS: 1893 (Part 1): 2002. A response spectrum for hard soil sites is shown in Figure5. From that study it is observed that ground columns in exterior columns of Step-Back Buildings 3 storey 3 bays and Step-Back Set-Back 3storey 3 bays and F5 of Step-Back Buildings 4 storey 4 bays and Step-Back-Set-Back Building 4 storey 4 bays which are stiffer attract more shear forces. Due to irregularity or asymmetry there are induced shear forces in X-direction when the dynamic analysis is carried out in Y direction because of torsion in columns having higher values and comparable with respect to shear forces observed during dynamic analysis when carried out in X direction, and no induced shear force in Y direction when dynamic analysis is carried in X direction.

Ajay k sreerama and Pradeep k ramancharla studied seismic performance of buildings on hill slope , they studied the behavior of a G+3 building on varying slope angles i.e., 15°,

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30°, 45° and 60° is studied and compared with the same on the flat ground. Building is designed as per IS 456 and later subjected to earthquake loads. In this study it was observed that as the slope angle is increasing, building is becoming stiffer. Two types of analyses were conducted viz., lateral load analysis and incremental dynamic analysis. It was observed from the initial results that the columns on the higher side of the slope i.e., short columns were subjected to more shear force then longer columns on the lower side. From Figure 1 column 1 is observed to have base reaction reduced to zero as slope angle increase because of long column effect. Finite element method is used to study the static behavior where as Applied Element Method (AEM) is used to perform incremental dynamic analysis. Figure 2 shows the Stiffness degradation of whole structure as well as the effective stiffness of bottom storey of the structure with respect to the increase of slope An increase in mass of a building increass its natural period. Buildings are with same plain size, column sizes but with different columns length at bottom (Figure 3). This study helps us to understand the significant difference between the seismic behaviors of building on slopes to building on flat surface and also, the natural period of building depends on the distribution of mass and stiffness along the building Figure 6 shows the resulting capacity curves for the five cases. As the slope angle increases, it is observed that the short column resist almost all the storey shear since other columns are flexible and tend to oscillate. A hinge mechanism is formed near the shorter column zone and is damaged earlier as the slope angle increases. From the linear static analysis it is observed that the Shorter Columns is observed to take more loads since shorter columns are stiffer and hence has more stress carrying capacity. and from figure no 4 we can observe the response of building on 60° and 30° slope is observed to have maximum displacement when compared to that of others. To understand the expected damage of the structures of varying time periods, fragility curves are plotted. Equation used to calculate the damage of the structure as in figure no 5.

Sujit Kumar, Dr.Vivek Garg, Dr.Abhay Sharma. Studied seismic analysis of a G+4 storey RCC building on varying slope angles i.e., 7.5^0 and 15^0 is studied and compared with the same on the flat ground. The seismic forces are considered as per IS: 1893-2002. The structural analysis software STAAD Pro v8i is used to study the effect of sloping ground on building performance during earthquake. Seismic analysis has been done using Linear Static method. The analysis is carried out to evaluate the effect of sloping ground on structural forces. The horizontal reaction, bending moment in footings and axial force, bending moment in columns are critically analyzed to quantify the effects of various sloping ground. It has been observed that the footing columns of shorter height attract more forces, because of a considerable increase in their stiffness, which in turn increases the horizontal force (i.e. shear) and bending moment significantly. Thus, the section of these columns should be designed for modified forces due to the effect of sloping ground. The present study realised the need for proper designing of structure resting on sloping ground. Comparison of critical axial forces Fx (kN) and bending moment Mz (kN-m) in columns for various ground slopes as shown in table 1, also in fig.7 to 10 shows that camparison of critical horizontal reactions in footing and columns on plain and sloping ground (7.5 degree, 15 degree) buildings

From which they conclude that the critical horizontal force and horizontal moment increases with the ground slope. However the vertical reaction in the footing remains same as for the different ground level .Critical bending moment for column increases with slope 15 degree compare to plain ground. However critical force may same as for different ground slope.

Prabhat Kumar, Sharad Sharma and A.D. Pandey studied is to investigate the peculiar seismic behavior of hill buildings. The analysis has been conducted for ground motion in two orthogonal directions to assess the level of vulnerability. Comparison of the foregoing has been made with the response of structure with rigid foundation (fixed base). Results highlight the deviation of design forces from conventional structural forms with equal column heights; the ratio of vertical displacements under static loads for flexible soil supports is always greater than the fixed base displacements. They conclude that ratio of displacements for medium to soft soil indicates the redesigning of foundation to limit the displacements up to acceptable values in practice. The horizontal dynamic displacements also shows similar trend. The ratio of shear forces in all the interior frame columns and sloping down exterior frame (Frame 4) columns for flexible soil media under static loads are less than or almost the same with respect to fixed base structure. The exterior frame columns (Frame 1) which are stiffer attract more shear forces as compared to other sloping down frame columns. But in case of dynamic analysis (X-Y Direction), the shear force ratio of ground columns shows lower values as compare to other sloping down frame columns with increasing building height, indicating a trend contradictory to the ratios for static analysis

Pandey A.D, Prabhat Kumar, Sharad Sharma studied seismic soil structure interaction of buildings on hill slopes, they study the static pushover analysis and Response spectrum analysis (RSA) have been conducted on five building i.e. three step back buildings and two step back set back buildings with varying support conditions. These buildings have been analyzed for different soil conditions (hard, medium and soft soils) idealized by equivalent springs. The response parameters, i.e. total base shear (V), displacement from pushover analysis ($\delta_{\text{performance point}}$), displacement from RSA ($\delta_{elastic}$) and response correction factor (R') have been studied with respect to fixed base analysis to compare the effect of soil springs. In general it is found that response reduction factor decreases with increasing time period, but is expected to be constant beyond a certain value of time the hinges in the columns reached the collapse prevention level directly after the immediate occupancy level and jumping the life safety zone**.** The sequence of formation and hinge patterns of step back and set back step back buildings are shown in Figure no 11and also figure 12 shows that the sequences of formation and Hinge patterns of shortest column frame

From that study it is observed that in Step- back set- back buildings, the value of the displacement at performance point, δ_{pp} is always greater than elastic displacement for all types of support. However, in Step back buildings this is valid perfectly in X direction, but for Y direction this is valid up to only two storey and two bays for hard soil. For the adopted building configurations, as the value of time period T increase the value of correction factor R' decreases. Pushover analysis for type of irregularity considered requires modification reference number.

Prashant D, Dr. Jagadish Kori G performed on the building situated on hill slope (27° with horizontal) to bring out effect of soft storey on the response of structure. They studied performance based seismic evaluation of building models namely: bare frame, soft storey, fully infill buildings with unreinforced masonry infill for G+9 storeys located in seismic zone V, constructed on medium soil are considered. Masonry infill is modeled as equivalent diagonal strut and hinge properties as per FEMA 356 are assigned to beams, columns and equivalent diagonal struts. It is observed that the natural periods obtained from the code are less than that of analysis results and their variation is shown in Fig.13.The base shear of the infilled models increases with the increase in stiffness of the building models.. Variations of base shear of various models are shows in Fig no14. As per Clause: 7.11.1 of IS: 1893 (Part 1): 2002 the storey drift for RC building is limited to 0.004 times the storey height, that is 0.4% of storey height in Fig.15. The seismic vulnerability of building is assessed by carrying out non-linear static pushover analysis at IO, LS and CP performance levels. The lateral displacement profiles for the models are shown in Fig. 16. Comparative study is made by comparing the values of natural time period, base shear, lateral displacement; storey drift and also the performance of building are checked at their respective failure modes and target displacement.

From the study it is concluded that, the plastic hinges are more in case of bare frame model, where the stiffness of walls are neglected and also the plastic hinges are more in the soft storey building when it is compared with full infill or corner infill models. This is because of lack of stiffness in the ground storey of the building. The lateral displacements of the soft storey shows the abrupt change which indicates the stiffness irregularity due to soft storey mechanism and increases vulnerability towards seismic forces where as the models in which the stiffness of walls is neglected or full infill is considered have shown the smooth displacement profile.

table no .1 camparison of critical forces in footing for different ground slope for various analysis

Forces/ Component	Plane Ground		Sloping Ground (7.5°)		Sloping Ground (15°)		Comparison of various analysis	
	1		2		3		2/1	3/1
	Footing No.	Value	Footing No.	Value	Footing No.	Value		
Horizontal Reaction Fx (kN)	12	68.47	11	145.68	11	195.29	2.13	2.85
Vertical Reaction Fy (kN)	13	863.25	14	868.05	14	873.72	1.01	1.01
Bending Moment Mz (kN-m)	14	139.77	11	226.38	11	275.97	1.61	1.97

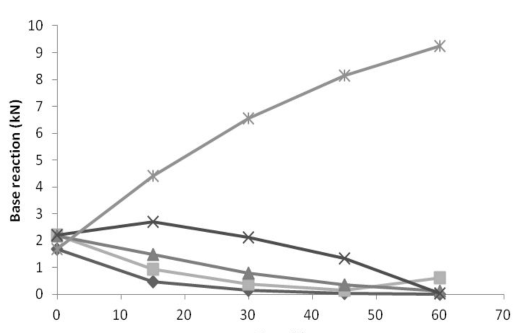

Figure 1: Base reaction Vs Slope

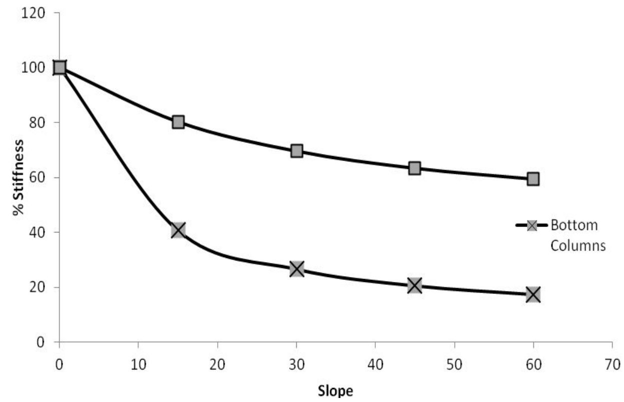

Figure 2: % Stiffness Vs Slope

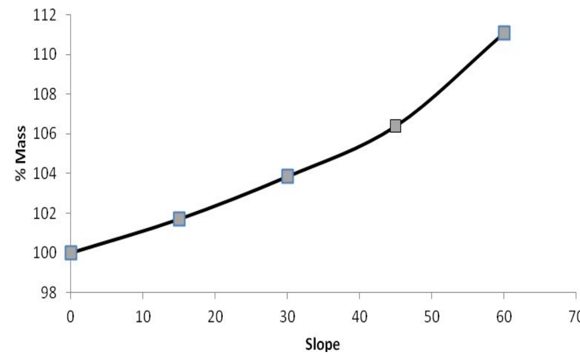

Figure 3: % Mass Vs Slope

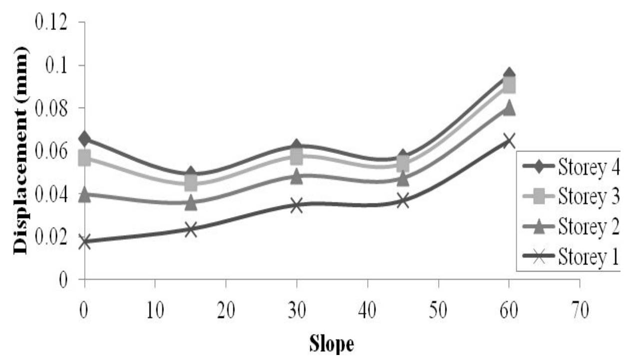

Figure 4: Maximum time history response of each storey

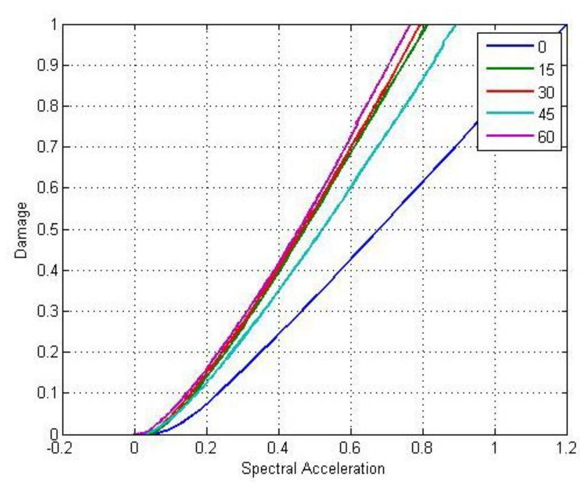

Figure 5: Fragility Curves

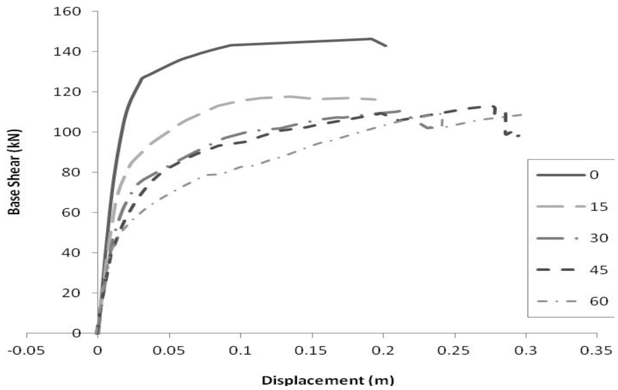

Figure 6: Pushover curves of A, B, C, D and E buildings

CRITICAL FORCES IN footings OF BUILDING FRAME

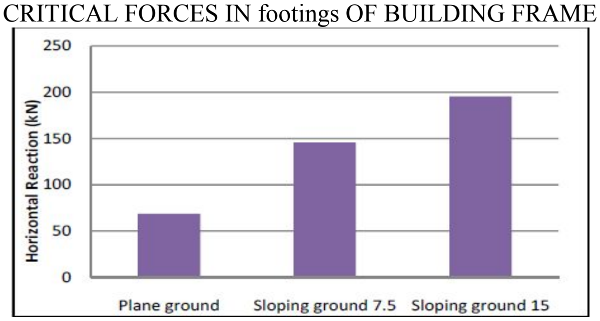

Figure 7: Performance of critical horizontal reactions in footing on plain and sloping ground (7.5 degree, 15 degree) buildings

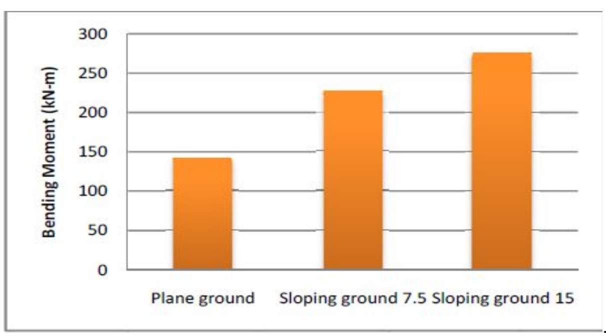

Figure 8: Performance of critical bending moment in footing on plain and sloping ground (7.5^0, 15^0) buildings

CRITICAL FORCES IN COLUMNS OF BUILDING FRAME

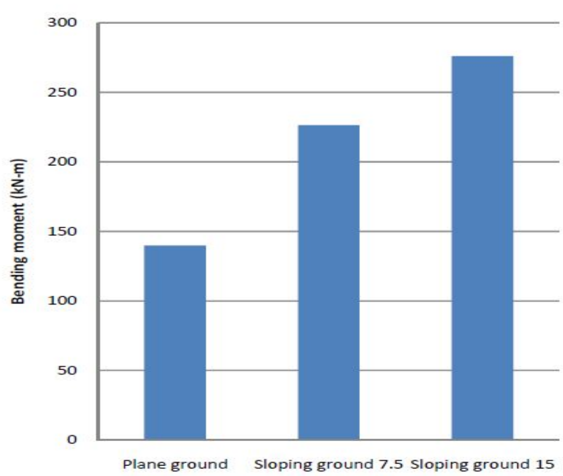

Figure 9: Performance of critical bending moment in column on plain and sloping ground (7.5 degree, 15 degree) buildings

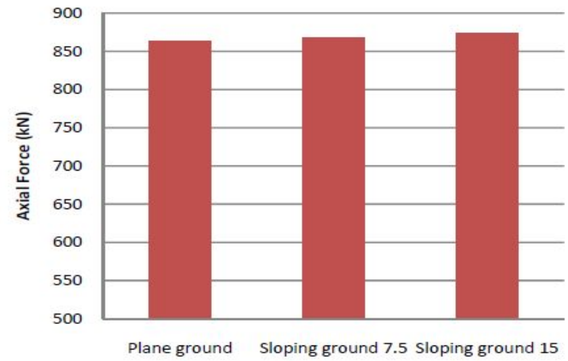

Figure 10: Perfoemance of critical axial force in column on plain and sloping ground (7.5 degree, 15 degree) buildings

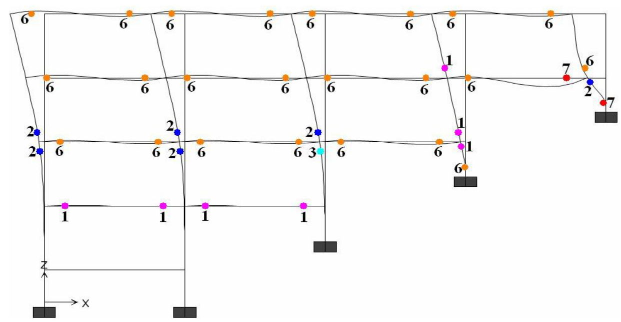

Figure 11: Sequence of formation and Hinge patterns of frame

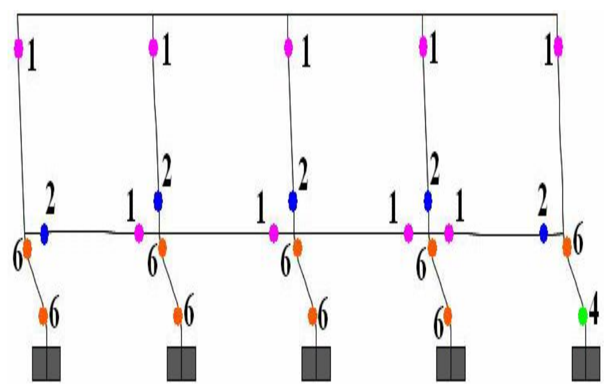

Figure 12: Sequence of formation and Hinge patterns of shortest column frame

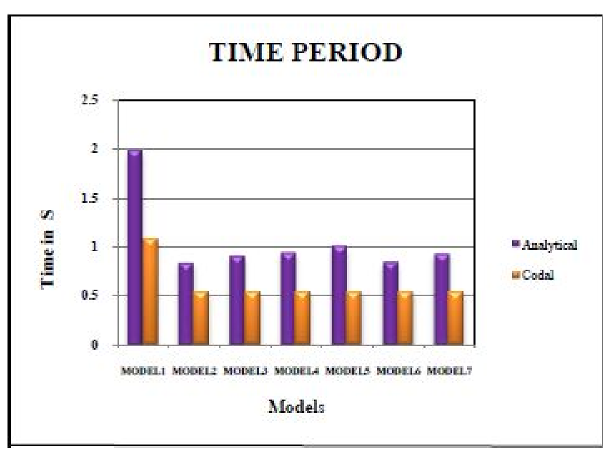

Figure 13: Time Period

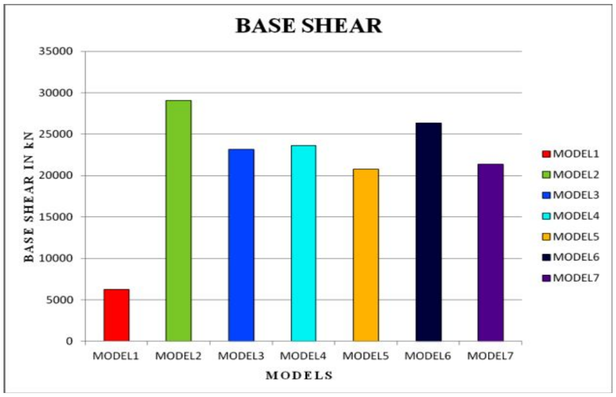

Figure 14: Base Shear

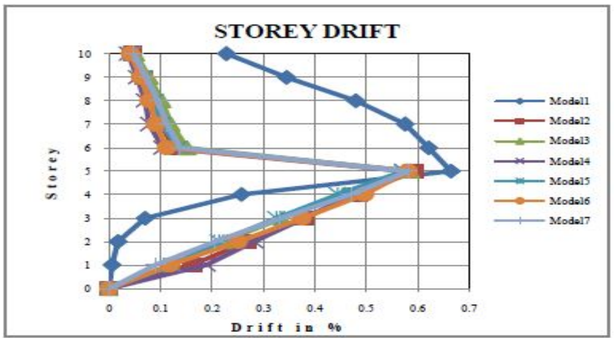

Figure 15:Storey drift

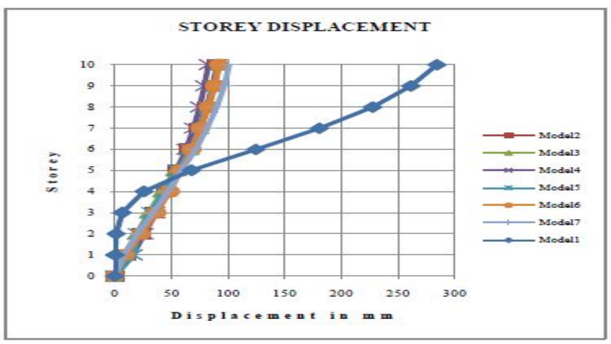

Figure 16:Storey displacement

During the course of this review, it is observed that researchers have studied the seismic behaviour of buildings situated on varying slopes and varying number of bays along slope direction .Some researchers have suggested suitable building configuration on sloping ground. Some researchers have studied the seismic behaviour of hill slope buildings by considering infill wall (soft storey) and Shear wall.

CONCLUSIONS

From the above discussion following conclusions are drawn.

1. Step back buildings produce higher base shear, higher value of time period, higher value of top storey displacement compared to step back set back building. During seismic excitation Step back building could prove more vulnerable than other configuration of buildings.
2. It is observed that, short columns attracts more forces and are worst affected during seismic excitation. From design point of view, special attention should be given to the size (strength), orientation (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.

REFERENCES

[1]Prabhat Kumar, Ashwani Kumar and A.D Pandey "Influence of soil structure interaction in seismic respose of step back setback building" Paper No. C012

[2]Prabhat Kumar, Ashwani Kumar and A.D Pandey "Comparison of Seismic Response of Buildings on Slopes" National Conferance On Emerging Trends In Engineering Science & Technology (NCETEST-2014) March 29th -30th, 2014

[3]Ajay Kumar Sreerama, Pradeep Kumar Ramancharla "Earthquake behavior of reinforced concrete framed buildings on hill slopes" *international Symposium on New Technologies for Urban Safety of Mega Cities in Asia* (*USMCA 2013*)

[4]Sujit Kumar, Dr.Vivek Garg, Dr.Abhay Sharma "Effect of sloping ground on structural performance of rcc building under seismic load" ISSN: 2348-4098

[5]Prabhat Kumar, Sharad Sharma and A.D. Pandey" Influence of soil-structure interaction in

[6]seismic response of step-back buildings" Paper No. C013

[7]Pandey A.D, Prabhat Kumar, Sharad Sharma" Seismic soil structure interaction of buildings on hill slopes" International journal of civil and structural engineering. volume 2, no 2, 2011 ISSN 0976 – 4399

[8]IS: 1893 (Part 1). (2002). 'Criteria of Earthquake Resistant Design of Structures', Fifth revision. BIS New Delhi.

[9]Prashant D, Dr. Jagadish Kori G "Seismic response of one way slope rc frame building with soft storey" Issue 3, Vol.5 (September 2013. ISSN 2249-6149