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Seismic Performance of Step Back Buildings

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Abstract
The construction of the building on plain ground has now been limited due to the urbanization, scarcity of the land, limited space and the high value of the land. In Nepal, the construction practice of non-engineered structures under the supervision of semi-skilled workers without the guidance of professional structural design is dominant. Such structures were found to be highly susceptible to damage during earthquakes. In order to prevent loss of life and improve the overall quality of these structures, a set of pre-engineered guidelines called Mandatory Rule of Thumb (MRT) has been developed for use by semi-skilled workers. The NBC 205:2012 codes provide the ready to use guidelines for detailing of low-rise RC concrete buildings without masonry infill wall. Based on the construction practice on the hilly area people are still using MRT guidelines to construct in the slope ground. In this study 4 storey and a 3-storey step back building resting in 40 degree slope constructed using MRT guidelines and their response is compared with the plain ground building. Modelling and analysis are carried out using the finite element-based software ETABS V 19.0. Different seismic performance parameters such as base shear, story drift, time period, top storey displacement are evaluated using equivalent static method and the response spectrum analysis. From the analysis it is found that the step back building has less base shear and time period than the building in the plain which results in less top storey displacement. Pushover analysis is performed to evaluate the behavior of the buildings. It is found that for the demand of 0.35g the building in the plain and the building in the slope constructed using the MRT guidelines does not meet the life safety criteria for both 3 storey and 4storey building.

Keywords
Step back buildings, Seismic performance, Nonlinear static analysis, Interstorey drift,Time period, Soil Structure Interaction(SSI)

1. Introduction

1.1 Background

Nepal lies in seismically active region in the boundary between Eurasian plate and the Indian Plate. Many earthquakes from higher magnitude to lower magnitude occur in this region. The structures built in such regions are very vulnerable to earthquakes. The 2015 Gorkha earthquake has caused damage to many infrastructures and many people lost their life. Loss of life was not due to earthquakes but due to the damage of weak structures caused by earthquakes. Building constructed in the hilly area or on an inclined ground behaves differently than the buildings in the plain ground under the seismic excitation. The building in the slope has irregularities in both the horizontal and in the vertical plane. The analysis of the buildings needs to be more focused as compare to the building in the plain ground. Such buildings have mass and stiffness varying on the vertical as well as in horizontal plane resulting in the eccentricity in the building, and demands the torsional analysis, in addition to the lateral force under the action of the earthquakes.However in Nepal, still the construction practice of non engineered structure without the guidance of professional structural design is dominant.Based on the construction practice on the hilly area people are using MRT guidelines for the construction on the sloping ground which can be vulnerable during the seismic excitation. Different types of building configuration can be adopted on the slope area depending upon the structural and architectural needs. There are mainly two well known types of configurations for the sloping ground:

- Step back configuration
- Set back and step back configuration

1.2 Rationale of the study

Nepal is a developing country and still the practice of the MRT guidelines is dominant in the rural areas. The MRT guidelines provides the ready to use guideline for the detailing of the low-rise RC buildings. The guidelines provide a minimum structural safety and needs certain requirement to be used. The MRT guidelines are intended for low-rise reinforced concrete buildings, up to three stories in height, with foundations at a uniform level and a regular geometry. Despite this, in many rural hilly areas, construction practice is done following these guidelines in slope ground. The purpose of this research is to study the behavior of step back building constructed using MRT guidelines under the seismic excitation and compare the results with the building on a plain ground. It could be useful for determining the vulnerability of a building on a slope ground. The main objective of the study is

- To study the seismic performance (Fundamental time period, top storey displacement,inter-storey drift, performance point) of the RC step back building constructed on the sloping ground.

The specific objective of the study are:

- To perform code based design check of building constructed on slope detailed as per MRT guidelines.
- To study the seismic performance of low rise RC step back building constructed as per MRT on a sloping ground and compare it with the building on the plain ground.
- To determine the life safety performance demand of the building.
- To compare the seismic response of buildings with and without incorporating SSI effects.

1.3 Limitation of the Study

The study is carried out to obtain the response of low rise RC step back building constructed as per the MRT guidelines.The failure of slope is not considered.The effect of the infill wall is also not considered during the study. The study is limited to the considered building.Further analysis can be carried out with the variation in geometry, story height, number of bays and on different slope angle.

2. Literature review

Different literatures related on the seismic performance of the building resting on the slope, comparative study of the building on plain ground and sloping are studied to carry out this research. The reviewed literatures are explained as below:

Chaitrali et al (2014) Performed a response spectrum analysis method on a G+6 multistoried buildings resting on a different slope angle of a ground. Step back and step back set back building configuration are studied using the response spectrum method accordingly to the IS1893-2000. From the study they concluded that set-back configuration building show less base shear, top story displacement and time period than that of setback building and the plain ground. Bottom ties should be connected up to the short column [1].

Dhoke & Rehman (2018)studied seismic performance on setback buildings with symmetrical and unsymmetrical arrangement of setback using Response spectrum method. Commercial building with G+11 storey building is considered having plan dimension 24m x 24m with storey height3.1m. Different types of shear wall at a different position is considered under the 9 model. Shear wall and cross bracings are found to be very effective in reducing the forces in the columns and is observed that there is significant reduction in the member forces, and lateral drift demand [2].

Birajdar and Nalawade (2004) performed the seismic analysis of 24 RCC building with three different configurations i.e step back, step back set back and set back building. The 27 degree slope of the ground is considered for the study. The response spectrum method was used to perform the 3 dimensional study including the torsional effect. The fundamental time period, base shear action induced in column and the top storey displacement was studied for the different configuration of the building and is concluded that for the sloping ground step back set back are more suitable [3].

Dangol and Motra (2021)studied the behavior of step back and step back-set back building under slope of 34 degrees with the variation on the storey from 7 to 9 .The different response parameter such as time period, base shear, top storey displacement, shear force on column are computed and is compared with the same storey building on the plain area. Push over analysis is performed and displacement and the base shear and the performance point is determined for each model. The study also incorporated the effect of the Soil structure interaction using the spring support. They concluded that the base shear, top storey displacement of the plain area building is higher than that of building on the slope. Also the performance of building is decrease with increasing number of stories in sloppy area [4].

Dangi and Akhtar (2019) assessed seismic evaluation of G+6 story rectangular building with and without a shear wall on various sloping terrain of 15, 30 and 45 degree. The Response Spectrum analysis is performed using the software SAP2000. Three different position of shear wall are used for the study. The results showed that shear wall at periphery is effective in resisting lateral loads whereas shear wall at corners is effective for countering axial loads. Lateral displacement and member forces reduced whereas base shear and axial force increases due to the shear wall in the building [5].

Zaidi, Naqvi, and Ibrahim (2020) studied the soil interaction effect of a 4-storey building resting on a three different hill slopes 0, 15 and 27 degree. The building is modelled and analyzed using the SAP 2000 software. A non-linear static push over analysis is performed out and the important seismic performance results in terms of base shear and displacement at the performance point are determined and comparison is done with the fixed base and flexible base model. With the increment of the slope angle base force value of the building increases but the displacement decreases. It is observed that the response of the structure reduces to a much significant amount when the effect of soil-structure interaction(SSI) is considered and the consideration of the SSI effect is found to be beneficial [6].

Debbarma and RG (2019) perform a effect of hill slope angle variation on the building resting a slope along with the effect of the soil structure interaction. They analyzed a five storied building at a slope angle of 0, 15, 30 and 45 degree using ETABS for linear analysis and SAP 2000 for nonlinear analysis. Response of the structure is calculated on the basis of different seismic parameters such as base shear, displacement. With the increase in the slope angle the time period of the modal increases whereas the base shear, displacement of the modal decreases. Also they concluded that with the consideration of the effect of the SSI the time period, displacement of the modal increase as compared to the fixed base [7].

3. Methodology

Different literatures related to the scope of the research were reviewed to gain the knowledge in the theoretical background and the rational of the study. The research objectives are set up. The low rise RC step back residential building in a slope with the certain dimensions, floor height is selected. Structural modelling of step back building and the building in the plain ground were modelled using the finite element software ETABS V 19. The different seismic performance parameter such as fundamental time period, top storey displacement, interstorey drift, base shear are determined by equivalent static analysis and the response spectrum analysis method. Further the nonlinear static push over analysis of the different model were performed to obtain the push over curve and the performance point on the required seismic demand. The bilinear idealized curve based on the FEMA 356 was obtained from the push over curved to determine the yield and the ultimate displacement of the building. Different parameters obtained from linear and nonlinear analysis of building of different configuration are compared. Conclusion and recommendation are drawn from the analysis of results.

3.1 Soil Structure Interaction

Soil structure interaction is defined as the complex interaction between the structure and the underlying soil in which the response of the soil to the ground motion influences the motion of the structure and the motion of the structure influence the response of the soil. SSI effects are categorized as inertial interaction effects, kinematic interaction effects. When considering the SSI, building subjected to the seismic excitation tends to have a higher response value as compared to the response value obtained from a building with the fixed base. This is due to the dynamic interaction between the building and the underlying soil amplifies the seismic forces and the deformations experienced by the structure. So to obtain the more accurate response of the building subjected to the earthquake it is important to analyze the effect of the soil structure interaction. For modeling soil-structure interaction problem, equivalent spring are used and the structure is modeled with vertical, horizontal and rotational springs at its base, representing the effects of soil flexibility at soil-foundation interface. The spring stiffness and the damping constants are obtained and assigned to the spring properties. Static foundation stiffness in case of surface foundation are calculated using the Gazetas Foundation Engineering Handbook 1991 [8].

4. Finite Element Modelling and Analysis

4.1 Building Configuration

Low-rise RC residential step back buildings resting on a sloping ground of 40 degrees and on a plain ground which are designed as per the NBC 205:2012 MRT guidelines is studied. The height and length of building are arranged in particular pattern and the size of the bays is at 3.6m x 3.6m x 3.0m as shown in Figure 1 The considered building configuration are labelled as S4 and S3 for 4storey and 3storey step back building resting on a slope and P4 and P3 for the building on plain ground which is tabulated in Table 1. All the buildings have 2 bays along X direction (across the slope) and 3 bays along y direction (along slope). The size of the column and beam and the reinforcement detail are as per the MRT 205 guidelines.The section of the step back building and the plain area building are shown in Figure 2 and Figure 3.

4.2 Building Modelling and Analysis

All the buildings are modelled as a bare frame using ETABS V 19 finite element software. Beam and column are modelled as frame elements and the slab is modelled as an area element.The considered soil for the study is soft soil. The specification of the buildings are in Table2. The soil under the foundation is represented with the link elements which

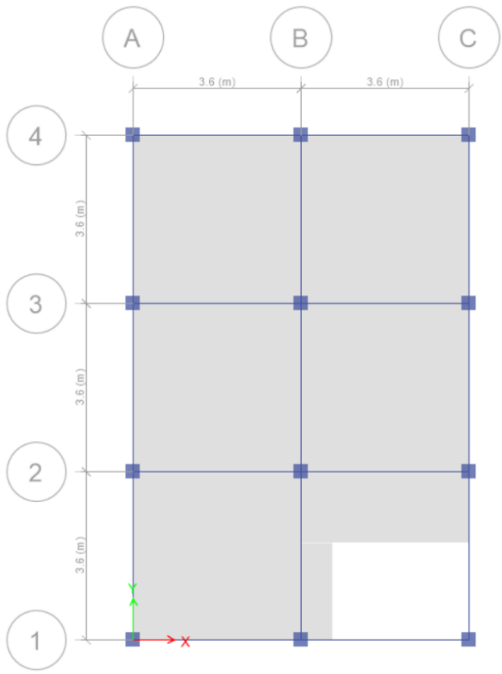
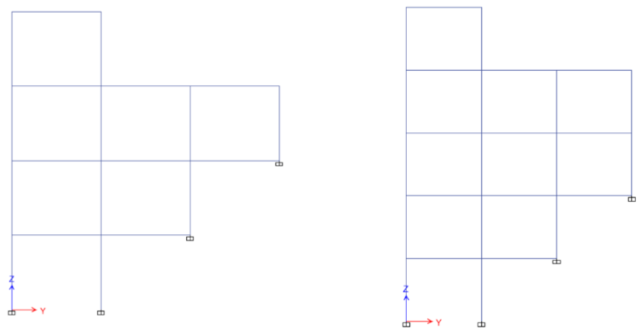
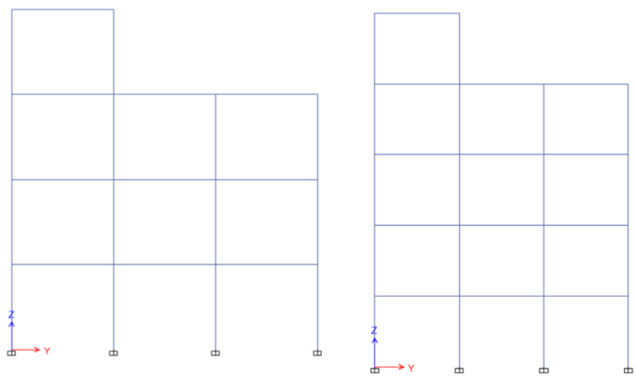


Figure 1: Typical Plan of Building



S3 S4

Figure 2: Step Back Building



P3 P4

Figure 3: Plain area Building

Table 1: Building Configuration

Model Building	Column Size	Beam Size
S4,S3	300mm x 300mm	230mm x350mm
P4,P3	300mm x 300mm	230mm x350mm

Table 2: Specification of Buildings

Title	Specification
No. of bays in X direction	2
No.of bays in Y direction	3
Size of bays	3.6m
Storey Height	3m
Seismic Zone	III
Zone Factor	0.35
Ductility Factor(Ru)	4
Overstrength Factor(˙)	1.5
Building Type	Residential
Damping Ratio	5%
Structure type	RC Moment Resisting Frame
Soil Type	Soft Soil
Concrete Grade	M20
Steel Grade	Fe500
Angle of Slope	40 degree
Wall load	11KN/m
Wall load with opening	8KN/m
Live load	2KN/m^2
Floor Finish load	1.5KN/m^2
Lateral Earth Pressure	0KN/m^2 at top and 74.45KN/m^2 at bottom

accounts for the three degree of freedom in the translation and three degree of freedom in the rotation. The properties of equivalent static spring for individual isolated footing are calculated and are modified for dynamic case using dynamic stiffness modifiers [8].Table3 and Table4 shows the properties of the equivalent spring. For the calculation of the stiffness constant and the damping constant, shear modulus, poison ratio, and shear wave velocity used are 13500KN/m^2, 0.4, 100m/s respectively[9].Half-length of footing and half breadth of footing are 1.2m.

Table 3: Values of Stiffnesses after application of Embedment Correction Factors and Dynamic Stiffness Modifiers

Degree of Freedom	Dynamic Stiffness
Translation along z-axis	150782.593KN/m
Translation along y-axis	142724.522KN/m
Translation along x-axis	142724.522KN/m
Torsion about z-axis	48924.082KN-m/rad
Rocking about y-axis	27569.363KN-m/rad
Rocking about x-axis	30211.4341 KN-m/rad

Table 4: Values of Dashpot Coefficients

Degree of Freedom	Dashpot Coefficient
Translation along z-axis	9080.322KN-s/m
Translation along y-axis	7860.177KN-s/m
Translation along x-axis	860.177KN-s/m
Torsion about z-axis	926.776KN-ms/rad
Rocking about y-axis	2786.011KN-ms/rad
Rocking about x-axis	2765.665KN-ms/rad

4.3 Non linear Analysis

A nonlinear static analysis known as a Pushover analysis of the structure was performed in order to get the pushover curve along x direction and y direction using FEM software ETABS 2019. Plastic hinges are assigned in both end of beam and column at a distance of 10% of the length of the member. Dead nonlinear, Push X and Push Y load cases were defined in order to define the initial hinge formation on the beam and column. The bilinear idealization of the obtained push over curve is carried out based on FEMA356:2000. From the idealized push over curve the yield displacement and the ultimate displacement are obtained.Using the obtained yield displacement and ultimate displacement the different damage state for the each structure is defined[10]. The capacity function and the corresponding damage state for the different building is shown in Table5.

Table 5: Damage state

Capacity Function	Damage State
D_1=0.7d_y	Slight Damage (IO)
D_2=1.5d_y	Moderate Damage (LS)
D_3=0.5(d_y+d_u)	Extensive Damage (CP)
D_4=d_u	Complete Damage

5. Results and Discussion

The analysis of buildings is carried out using the different methods. After analysis, different seismic parameters such as fundamental time period, base shear, top story displacement, inter storey drift, and performance level are calculated and presented below.

5.1 Time Period

The time period of the building on the plain ground is higher than that of step back building which can be seen in Figure4. This implies the building on the plain ground sway more slowly under the earthquake excitation and have a longer time period of vibration are more flexible. The fundamental time period of the 3 storey step back building decreases by 30.06% compared to the three story plain area building and for the 4 storey step back building it get decrease by 25.41% as compared to the four storey plain area building.

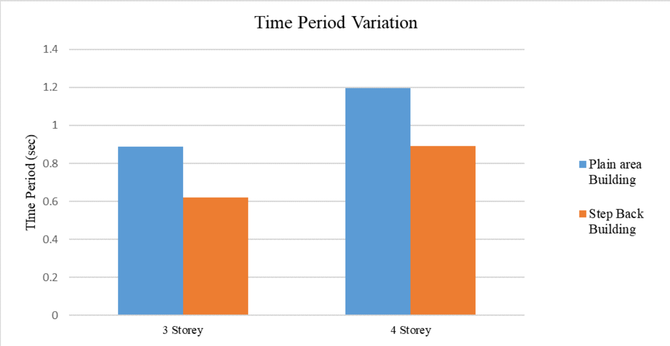


Figure 4: Time period Comparison

5.2 Base shear

Table 6: Base Shear Variation

Model Building	Base shear(KN)
P3	445.110
S3	400.011
P4	599.37
S4	573.31

The base shear of the building (Table6) in the plain ground is more than the building in the slope for both 3 storey and 4 storey building. For the building in the slope the seismic weight of the building decreases with the increase in slope which results in the decrease in the base shear as comparison to the building in the plain.

5.3 Storey Displacement

From the Figures 5,6,7,and 8 the displacement in the plain ground building is more compared to the step back building in both across and along the slope direction. The plain area building have high base shear and time period which makes the building flexible causing high displacement. The column is fixed at a different height level due to the slope ground which decrease the effective flexural height and increase the stiffness due to which displacement decreases. In step back building, the top story displacement is higher across the slope direction than along the slope direction for both 4 storey and 3 storey buildings.

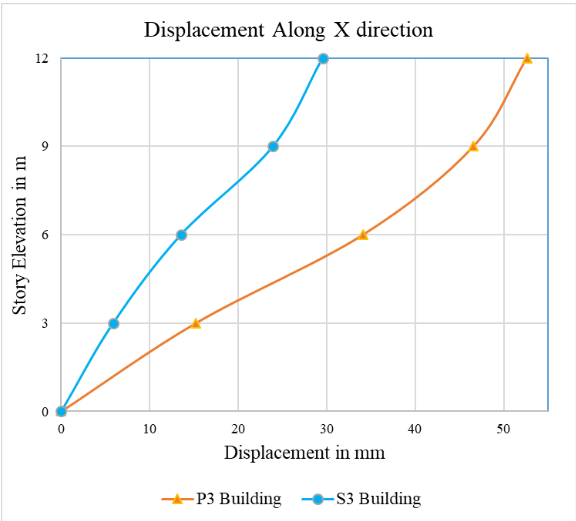


Figure 5: Storey Displacement of a 3-storey Building across slope

The top storey displacement obtained from the response spectrum analysis is higher than the equivalent static analysis. For the step back building (S4) the top storey displacement increase by 30% in X direction and 56% in Y direction when performing RSA. However, for the same storey building in the plain the top storey displacement increases only by 16% in X direction and 1% in Y direction. So for the building in the slope it is necessary to use the Response spectrum analysis to obtain the better response of the building.

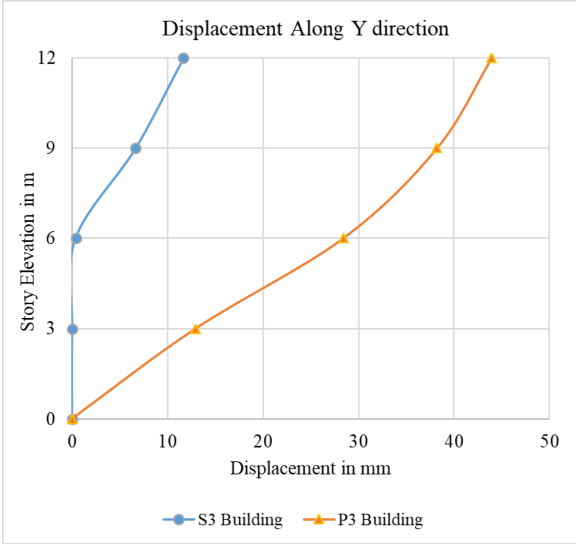


Figure 6: Storey Displacement of a 3-storey Building along slope

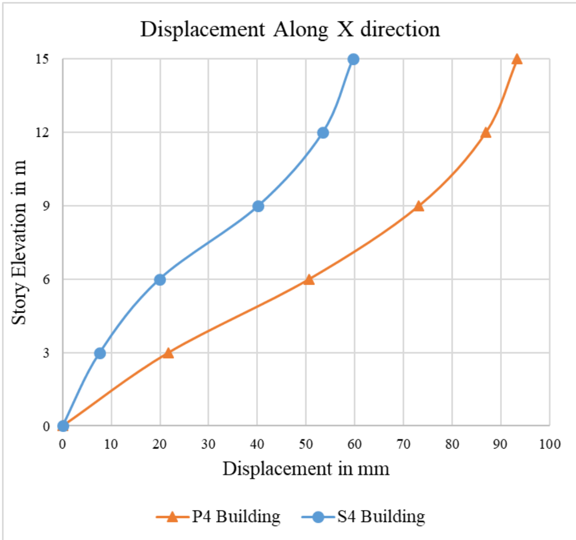


Figure 7: Storey Displacement of a 4-storey Building across slope

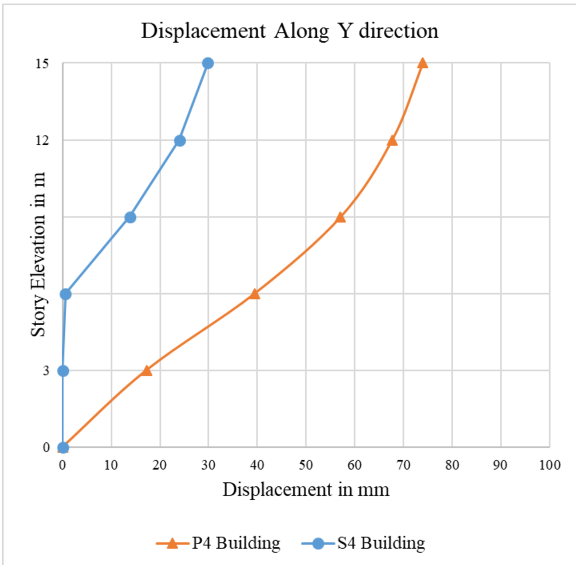


Figure 8: Storey Displacement of a 4-storey Building along slope

5.4 Interstorey Drift

The inter-story drift for different buildings model is shown in the Figure 9,10,11,and 12. For the 3-storey building the interstorey drifts are within the allowable value permitted by NBC 105:2020 for both ULS and SLS. But for the 4 storey buildings the interstorey dtift exceeds the allowable value in case of regular building and slope building. The maximum interstorey drift is found in the second story. The maximum interstorey drift for four story step back building exceed by 10.94% of allowable value(ULS) recommended by NBC 105 across the slope direction and is within the allowable value along the slope direction. For four storey plain building, the interstorey drift exceed by 53.84% across the slope direction and 18.67% along the slope direction.

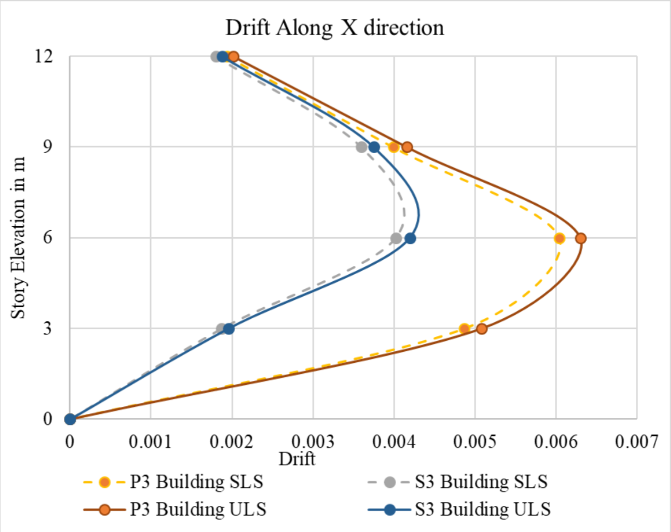


Figure 9: Inter Storey Drift of a 3-storey Building across slope

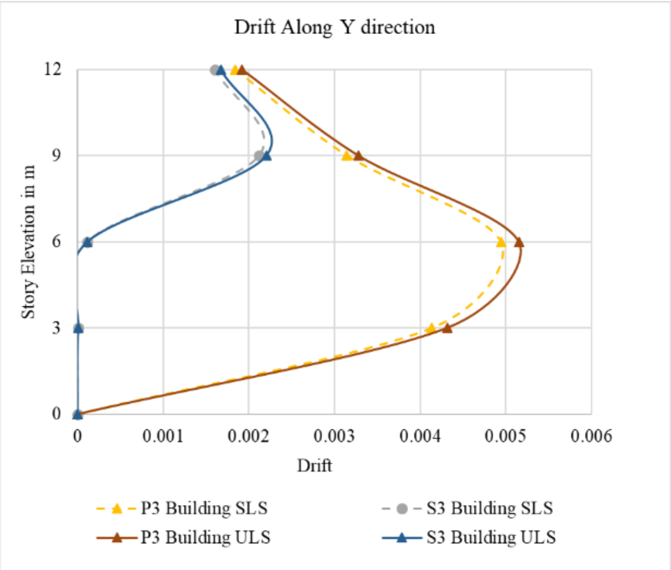


Figure 10: Inter Storey Drift of a 3-storey Building along slope

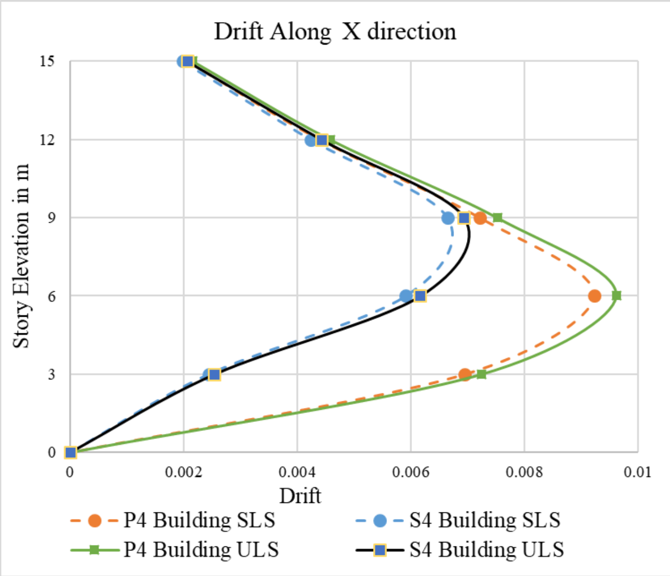


Figure 11: Inter Storey Drift of a 4-storey Building across slope

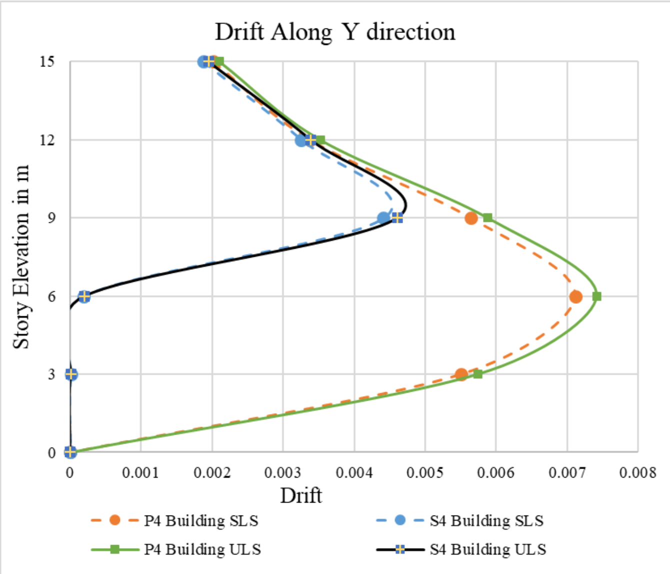


Figure 12: Inter Storey Drift of a 4-storey Building along slope

5.5 Design Check

The size of the frame elements is provided as per the MRT guidelines for both 3 and 4 storey building. The reinforcement is also assigned as per the MRT guidelines .However, the MRT guidelines are only applicable to buildings up to three stories with regular geometry on flat ground. The design check of the building is done to ensure it meets the requirements. In the case of S4 model building 3 beam fails in shear and most of the column does not satisfy the Column Beam Capacity ratio. For the P4 model building 26 beam fails in shear. For the S3 model building all the concrete frame pass for the given reinforcement details however some of the column exceeds the CBC ratio. For the P3 model building all the concrete frame pass which is necessary as the MRT guidelines is applicable for up to 3 storey regular building. The reinforcement provided as per MRT guidelines also meets the requirements for construction of the buildings on slope up to three stories in height.

5.6 Pushover Analysis Results

Pushover analysis is performed for assessing the behavior of the structure to observed the sequence of yielding and crack formation in the building. The capacity curve was obtained as a result of the pushover analysis. The push over curve slope within the elastic range[13,14,15,16] show the stiffness of the step back building is higher than the building in the plain ground. The push over curve in Y direction has large slope. This is due to the column fixed in the different level due to sloping ground which increase the stiffness in Y direction(Along the slope).From the push over curve the ultimate displacement of plain ground building along the slope is higher than that of step back building whereas the ultimate displacement of the step back building is higher across the slope direction. The ultimate base shear of step back building is higher than the regular building.

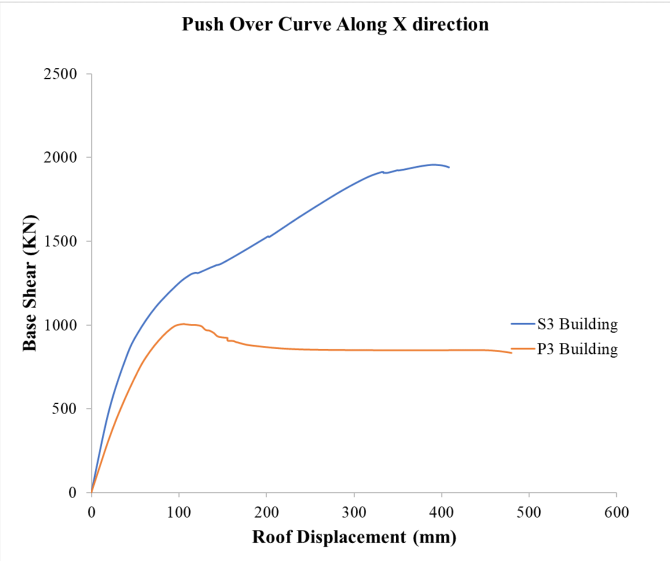


Figure 13: Pushover curve of a 3-storey Building across slope

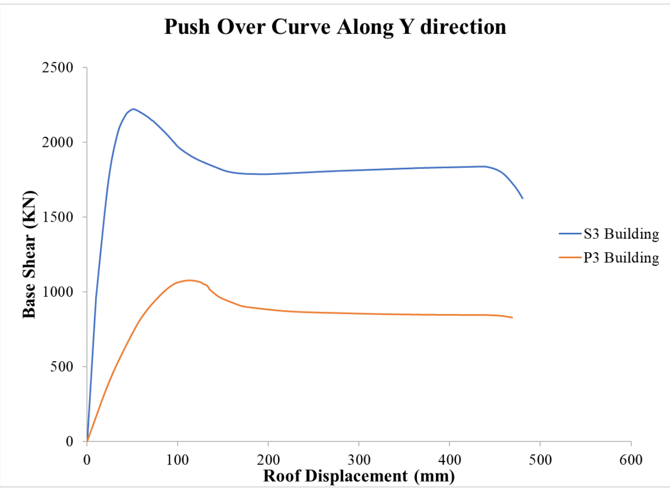


Figure 14: Pushover curve of a 3-storey Building along slope

Bilinearization of pushover curve is done as per FEMA 356 from where yield and ultimate displacement is obtained which are used to determine the displacement at different performance level. The yield and the ultimate displacement for all the model is obtained and the corresponding displacement at the various performance level is determined. The performance point for the 0.35g demand as per the FEMA440 is shown in Table 7. For the 0.35g demand, the

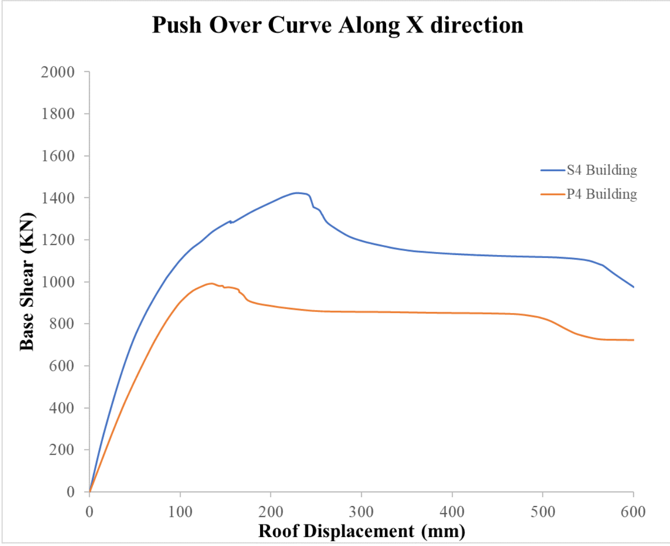


Figure 15: Pushover curve of a 4-storey Building across slope

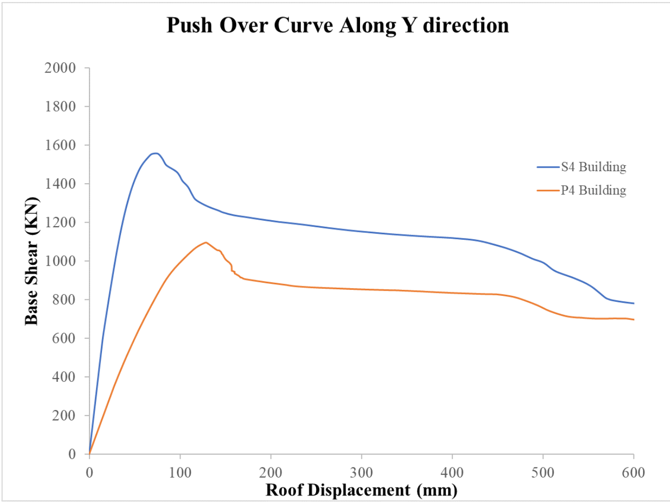


Figure 16: Pushover curve of a 4-storey Building along slope

building in the plain and the building in the slope does not meet the life safety criteria for both 3 storey and four storey building. The demand is reduced to meet the performance of all buildings to the Life safety criteria.

Table 7: Displacement at various performance level across the slope direction (X direction)

Building Model	Yield Displacement(dy) mm	Ultimate Displacement (du) mm	Damage State Displacement (mm)		
			IO	LS	CP
P3	50.86	105.6	35.602	76.29	78.23
S3	57.796	389.456	40.4572	86.694	223.626
P4	73.02	133.82	51.114	103.42	109.53
S4	65.016	227.022	45.5112	97.524	146.019

Table 8: Life safety demand requirements

Building Model	Demand(g)	Performance point
P3	0.136	72.82mm
S3	0.245	85.60mm
P4	0.125	103.20mm
S4	0.144	97.25mm

The Table 8 shows the life safety capacity performance point of the step back building and the building in the plain ground. The reinforcement requirement as per the MRT guidelines does not provide the life safety of the building for the capacity of 0.35g.Hence the demand is determined to meet the performance point at the life safety. It is seen that 3 storey building can have life safety performance point at a higher demand as compared to the 4 storey building. Also, the step back building has a life safety performance at a higher demand as compared to the same storey plain ground building.

5.7 Effect of Soil Strucutre Interaction

The time period of all the building model increases when considering the soil structure interaction. For the three storey step back building the time period of the building increase by the 11.11% and by 8.857% for the four storey step back building compared to the fixed base building model. For the plain ground building the time period increase by 7.658% and 10.033% for the three storey and four storey building respectively. This increase in the time period of the building is due to the interaction between the foundation and the soil, which adds to the structure's resistance to lateral deformation. The building's natural period of vibration lengthens as a result.After accounting the soil structure interaction the maximum displacement of a building increased, primarily as a result of the softening impact of soil.The increase in the top storey displacement when considering the effect of SSI is higher across the slop direction. The displacement can be lower in the Y direction and higher in the X direction, for instance, if the soil is stiffer in the Y direction than the X direction.

6. Conclusion

Building construction in hilly region still follows the MRT guidelines. Slope building perform differently than the building in the plain ground. From the comparative study between the 4 storey and 3 storey building in the plain and sloping ground constructed as per the MRT guidelines the following conclusions are made:

- The size and the reinforcement provided as per MRT guidelines meets the design strength requirements for construction of the buildings on slope up to three stories in height however the beam column capacity ratio is not satisfied. For a 4 storey building in both plain and slope ground numbers of beam fails in shear.

- The top storey displacement is more in plain ground as compared to the step back building. In step back building, the top story displacement is higher in across the slope direction than along the slope direction for both 4 storey and 3 storey buildings.

- The consideration of the effect of the soil structure interaction increase the flexibility of the building which ultimately increase the fundamental time period and the storey displacement of the building.

- The ultimate displacement from pushover curve of plain ground building along the slope is higher than that of step back building whereas the ultimate displacement of the step back building is higher across the slope direction. The ultimate base shear of step back building is higher than the regular building which is due to the support at the different story level and these supports takes the significant portion of the horizontal force.

- For the 0.35g demand the building in the plain and the building in the slope does not meet the life safety criteria for both 3 storey and four storey building. For 0.245g the S3 and for 0.136g the P3 building model, the performance point is at the life safety criteria. For 0.144g demand the S4 and 0.125g P4 building model have their performance point in the Life safety point. This conclude the slope building can meet the life safety performance in more demand as compared to the same storey plain ground building.

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