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Seismic Response of Buildings Resting on Hill Slope

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Abstract

Due to the scarcity of flat lands and rapid growth in population, residents are obligated to shift towards hill slope for shelter risking their lives. The buildings situated in hilly areas are much more vulnerable than plain area due to presence of mass irregularities, stiffness irregularities and geometric irregularities, hence susceptible to severe damage when subjected to seismic action. In this study, behavior of step back and step back-set back building under slope of 34 degrees are studied under variation of number of storey from 7 to 9 and their response is compared with plain area building. The analysis is performed to determine the impact of variation of storey's number of building situated at sloping ground on time period, base shear, top storey displacement, performance level and column shear forces and torsion of structure.

Keywords

Base Shear, Top storey displacement, Torsion, Performance point, Fundamental Time period

1. Introduction

1.1 Background

Construction of multistory buildings on sloping ground is problematic in earthquake-prone countries like Nepal. Residents are forced to seek shelter on hill slopes due to a paucity of flat lands and increasing population development, endangering their lives. It has presented structural and earthquake engineers with numerous issues in designing and analyzing structures in slant areas. Excavating slopes and converting them to plains requires both time and money, diminishing the natural beauty of landscapes, despite the fact that humans desire to do so for housing and building[1]. While designing such structure, it must be taken into consideration that structures on slopes are not similar to those in plain land because, they are irregular and unsymmetrical. Such buildings also have high mass irregularity and stiffness variation on storey wise. As a result, the center of both, mass and rigidity do not coincide on several floors causing twist of structures during seismic quakes[2]. With these scenarios in mind, it's important to look into the seismic responses of buildings with varying numbers of stories in order to develop earthquake-resistant structures and prevent them from collapsing, saving lives and property.

1.1.1 Configuration of Building in Hilly Terrain

Arrangement of the buildings on hilly area depends upon structural and architectural arrangement of buildings. Depending upon the arrangement of bays and slope fundamentally there are two prominent types of configurations:

- **Step back type of configuration:** The building configuration in which horizontal plane remains same but on the lower part it will maintain slope as per terrain or topography of the area. In these type of buildings the foundation of different grid columns are at different level so that there is stiffness variation and mass irregularity (i.e.top floor level has higher mass and stiffness than ground floor) along storey-wise.

- **Step back-set back type of configuration:** In this building configuration the structure is arranged in stepping pattern in which the horizontal plane is not remains same along with lower part of the structure. In these type of structure the foundation level of different grids columns are at different level and also top storey are not at same level so that there is variation of mass and stiffness (i.e. middle floor has high mass and stiffness than ground floor) along different storeys.

1.1.2 Effect of Soil Structure Interaction (SSI) on Sloppy Area Buildings

Soil-structure interaction is defined as a process in which the response of the soil to seismic forces influences the motion of the structure, and the structure's motion influences the response of the soil. Under the effect of soil structure interaction, the response values of the building exposed to seismic analysis are greater than the response values derived from seismic analysis of a building with a fixed base. In case of Sloppy area buildings it was found that the base shear value, time period, performance level is decreases on considering SSI on analysis. Similarly the top storey displacement and torsion forces are increased with consideration of SSI[3]. Hence on analyzing above scenarios it is very important to consider the effect of soil structure interaction so in this study buildings are analyzed by considering SSI with help of Gazettes(1991) empirical equations[4].

1.2 Need of This Work

• It is observed from past record that although Nepal is an earthquake prone hilly area, the constructions were not realized to be earthquake resistant. So that on recent earthquake 2015 April, lots of people lost their lives, many became homeless and infrastructures were demolished including monuments[5].

Figure 1: Damages on Buildings During to Sikim Earthquake

• In hilly area, there is presence of high irregularity in mass as well as stiffness so that there high possibility of large damages such as in Sikkim earthquake.As a result, when earthquake ground motion occurs, they are vulnerable to catastrophic damage.
• Short columns which stiffness is very high, are found in buildings resting on hilly slopes in the same storey. As a result, short columns attract more forces during earthquake ground motion, causing damage.
• In context of Nepal, there is lack of revised codes and standard also no mention about response of sloppy area building as a result of which most of buildings have inadequate earthquake resistant and vulnerable to earthquake.
The above mentioned issues inspired me to carryout this study.

1.3 Scope of This Work

Three alternative types of structures varying from 7 to 9 storey (21 m to 27 m height) on which first two types are on sloppy area and third type on plain area under the effect of earthquake load, are subjected to 3D space frame analysis. Equivalent static, response spectrum and pushover analysis are carried out to find out response of three selected buildings, in the form of base shear, fundamental time period, ground level column's shear force, torsion and top floor displacement and comparison is done. Finally, a building configuration suitable for mountainous hilly terrain is suggested. The main focus of this study is to find out response of buildings under variation of storey.

1.4 Objectives of Study

To evaluate seismic response (Fundamental time period, Base shear, Top storey displacement, performance point, column shear and torsion) of various reinforced concrete buildings on slope under variation of stories' number by seismic coefficient method, response spectrum method and push over analysis.

1.5 Limitation of Study

This study is done only to find out the response of step back, step back-set back buildings on hill slopes and plain area buildings under variation of stories' number and this study does not include detail study about effect of SSI on seismic performance of buildings and also does not include detail comparative study on effect of considering and without considering SSI on above mentioned buildings. So all types of model are analyzed under variation of storey only under consideration of SSI as per Gazettes (1991) i.e. buildings with fixed base are not analyzed.

2. Methodology

Structural analysis can be done in a variety of ways, including linear, nonlinear, static, and dynamic

methods. When the structural is regular in shape, has a regular stiffness and mass, and is also smaller in size, the linear static and dynamic approaches are appropriate. The lateral forces in the dynamic analysis technique are based on the parameters of the building's natural vibration modes, which are defined by the distribution of mass and stiffness over height. The magnitude of base shear is determined on the basis of the fundamental period in the equivalent lateral force technique, and forces are distributed according to a codal provision formula that is only applicable to conventional buildings.While on pushover analysis, the buildings are pushed on one direction on step by step and corresponding base shear and hinge formation are recorded. Here the buildings are analyzed by three methods as follows.
a. Seismic Coefficient Method
b. Response Spectrum Analysis
c. Push Over Analysis.
As per figure 2 in the seismic coefficient method, the

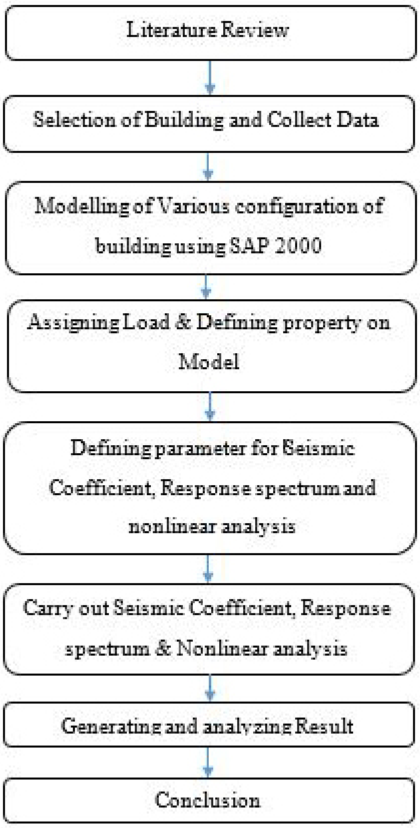

Figure 2: Overall methodology

base shear ratio is calculated according to NBC 105:2020 and then calculated coefficient is applied on SAP 2000 and seismic forces are applied along x and y direction. Similarly, in Response spectrum method the spectrum is generated according to codal provision of NBC 105:2020 and generated spectrum is applied on SAP 2000, and analysis is done. While in Pushover analysis, the hinges on beam and columns are defined based on ASCE 41:13 code. The structure is being pushed up to 500mm in multiple steps and corresponding base shear Versus displacement curve is generated and finally the performance point for different configuration is find out.

3. Building Configuration, Modelling and Analysis

Three types of buildings (i.e.configurations) are considered in this study, two of which are on sloped ground at a 34-degree angle and the third on a flat area. The first type is step back buildings, second is step back-set back buildings and third is plain area building. The depth of foundation is taken as 1.5 m

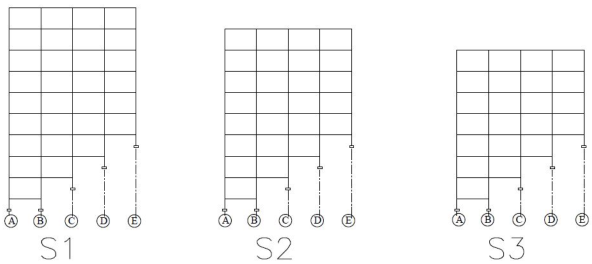

Figure 3: Step Back Building

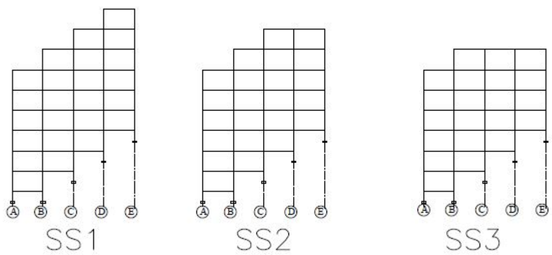

Figure 4: Step-Set Back Building

and soil type is considered as of Kathmandu valley. The step back buildings taken for analysis are as shown in figure 3 which are labeled as S1 to S3 for 9 to 7 storey, similarly step back-set back configuration of buildings are shown in figure 4, are labeled as SS1 to SS3, according to height of building. Also, plain area buildings are designated as P1 to P3 for storey number from 9 to 7. All the buildings have three bays along y direction (across slope) and four bays along x direction (along slope). The structural properties and

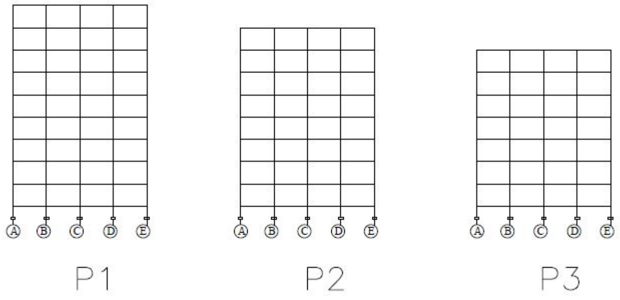

Figure 5: Plain Area Buildings

material properties are taken based on past research work.

Table 1: Sizes of Beam and Column

Building Configuration	Column size	Beam size
Step Back	0.3*0.9m, 0.36*0.9m	0.35*0.7m
Step Back and Set Back	0.3*0.9m, 0.36*0.9m	0.35*0.7m
Plain Area	0.55*0.55m	0.35*0.7m

Here the sizes of column and beam for sloppy area building are taken in rectangular shape in order to reduce eccentricity and stiffness irregularity so that there will be at least 65% mass participation on first three modes and also helps to reduce failure of members. Similarly, for plain area buildings square shape column are taken as it increases the performance of buildings and also helps to reduce eccentricity along with reduction of stiffness irregularity.

3.1 Database for Soil Structure Interaction

Soft soil is used for soil structure interaction. The foundation soil is modeled with link element considering three degree of freedom along translation and three degree along rotation. The stiffness and damping constants are calculated using empirical equations from Gazettes 1991. Shear modulus and Poisson's ratio values of soft are referred from Japan Nepal Urgent Collaborative Projects regarding the April 2015 Nepal earthquake [6] which is as follows:
Shear Modulus (G)=13875KN/m2
Poisson's ratio=0.3
Half Length of footing =2m
Half Breadth of Footing=2m

Table 2: Specification of Building

Title	Specification
Seismic Zone	III
Zone Factor	0.35
Ductility Factor (Ru)	4
Over-strength factor (Ωu)	1.5
Building Type	Ordinary -1
Damping Ratio	5%
Structure Type	Reinforced Concrete Moment Resisting Frame
Soil Type	Soft
Concrete Grade	M25 and M30
Steel Grade	500fy
Beam Span Length	4.5m
Angle of Slope	34 ∘
Live Load	2 KN/m2
Wall load	9KN/m
Partition Wall load	1KN/m2
Floor Finish Load	1.5 KN/m2
Beam Span Length	4.5m on both X and Y dir
Lateral Earth pressure	0 KN/m2 at top, 48.96KN/m2 at bottom
Floor height	3 m
Depth of Foundation	1.5m

Using above specified footing size, shear modulus

Table 3: Stiffness Constant and Damping Constant

Constant	Value (KN/m or KNs/m)
Kx	156093.75
Ky	140484.38
Kz	167980
Krx	532800
Kry	492840
Krz	792318
Cx	606.96
Cy	485.57
Cz	985.32
Crx	109.21
Cry	116.49
Crz	121.09

and Poisson's ration as specified, the stiffness constants and damping constant are calculated using empirical equations [4]

3.2 Torsional Moment due to Accidental Eccentricity

The accidental eccentricity for analysis is taken as 0.1 times the floor plan dimension perpendicular to the direction of seismic force. According to code, results from response spectrum were normalized by multiplying with a base shear ratio,=Vb/VB, where Vb is the base shear calculated by equivalent static method and, VB is the base shear by response spectrum, if Vb is greater than VB.

3.3 Load Combinations

The load combination for carrying out analysis are based NBC 105:2020 [7] which are as follows.

For Parallel System
1.2DL+1.5LL
DL+0.3LL+Ex
DL+0.3LL-Ex
DL+0.3LL+Ey
DL+0.3LL-Ey
For Response Spectrum
DL+0.3LL+Rx
DL+0.3LL+Ry

4. Results and Discussion

4.1 Time Period

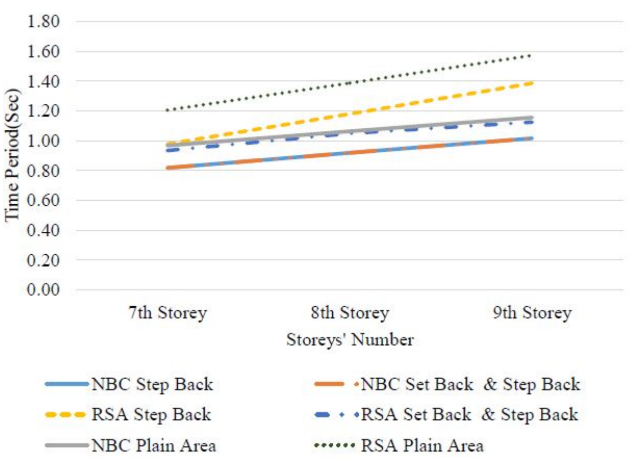

Figure 6: Comparison of Time period

On plotting the time period of three different configured buildings, it was found that the time period of plain area building are higher than step back-set back building and step back building by 39% and 17% respectively on response spectrum analysis, while on equivalent static analysis the plain area building have almost double time period than sloppy area building. It is due to higher seismic weight, higher geometrical plan and also due flexible foundation on plain area building. Similarly, step back building have about 23% higher time period than step back-set back building because step back building have higher vertical geometrical irregularity and mass irregularity. The above chart also shows that time period of step back buildings are increasing by 10-20%, in Step back-set back buildings are increasing by 7-12% and in plain area buildings it is increasing by 9-13%, under increment of storeys due to increase in height,seismic weight and flexibility of structure on increasing number of storey. Further more from above graph it was found that the rate of increase of time period is high in both step back and plain area buildings than step back-set back buildings.

4.2 Base Shear

On plotting base shear of three configured buildings, it was found that the plain area building have high base shear value than step back and step back-set back building. The base shear of plain area is 36% higher than step back-set back buildings due to presence of high seismic weight. Similarly step back building

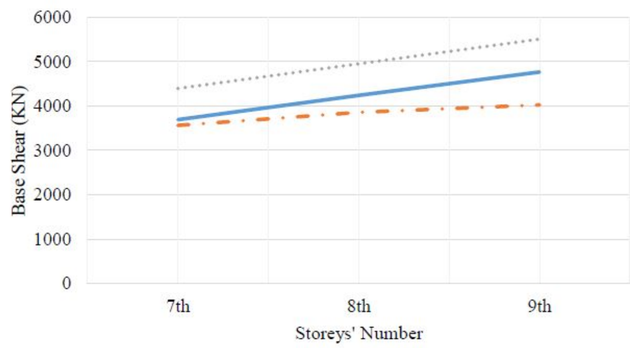

Figure 7: Comparison of Base Shear

have higher value of seismic weight than step back-set back buildings so it has 18% high base shear. Furthermore, the diagram also shows that the rate of increment of base shear in step back buildings are by 12-14%, in step back-set back buildings are by 4-8% and in plain area buildings are by 11-12%, under increment of storeys because on increasing number of storeys, seismic weight of structure also increases. Also the rate of increment of base shear is quite high in step back and plain area building than step back-set back building.

4.3 Performance Point

Table 4: Performance Point (Push x)

Type	Base Shear (KN)	Displacement (m)
S1	6319.633	0.104
S2	6423.432	0.087
S3	6742.726	0.071
SS1	6361.089	0.09
SS2	6612.468	0.081
SS3	6584.957	0.069
P1	7528.825	0.128
P2	6438.23	0.105
P3	6531.989	0.092

On analyzing above table, it can be concluded that the plain area buildings have high value of base shear on pushing structure in x direction (along slope) than sloppy area because plain area building have regular mass and stiffness distribution. On comparing the sloppy area buildings, step back-set back buildings are found to be better on slope area than step back because step back-set back buildings have high base shear value and low spectral displacement on performance point. Similarly, it was found that the increment of storey's reduces base shear by 2% along x direction (along slope) and spectral displacement are increased by 15-20% at the performance of buildings for step back buildings. For step back-set back buildings, there is reduction of base shear by 3% along x direction (along slope) and spectral displacement is increased by 10-15% on increasing number of storey. The reason that step back-set back buildings has higher performance level than step back is in step back there is high geometric and mass irregularity on both horizontal and vertical plane. Hence the results shows that there is reduction of performance level of buildings on increasing number of stories on sloppy area.

4.4 Top Storey Displacement

On plotting the top storey displacement of different buildings it was found that the plain area building have 36% high displacement than step back-set back building as in sloppy area building there is presence of short length column which stiffness is very high so that displacement is low. The step back building have about 30% high displacement than step back-set back buildings. The reason that step back building have high displacement is because of presence of high

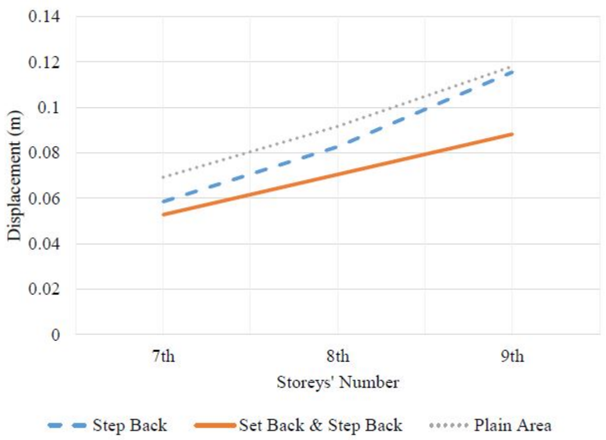

Figure 8: Top Storey Displacement Along Slope by Seismic Coefficient Method

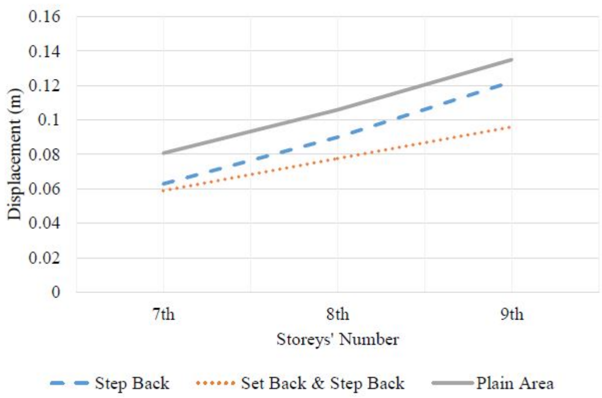

Figure 9: Top Storey Displacement Along Slope by Response Spectrum Method

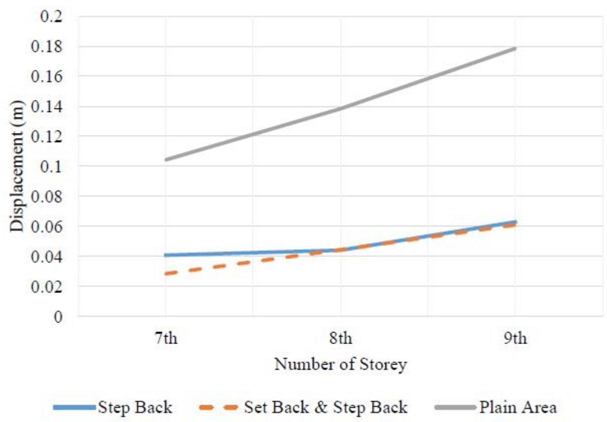

Figure 10: Top Storey Displacement Across Slope by Seismic Coefficient Method

vertical irregularities. Furthermore, the above diagram also shows that the top storey displacement is increasing with increase in number of storeys such as in step back buildings by about 40%, in step back-set

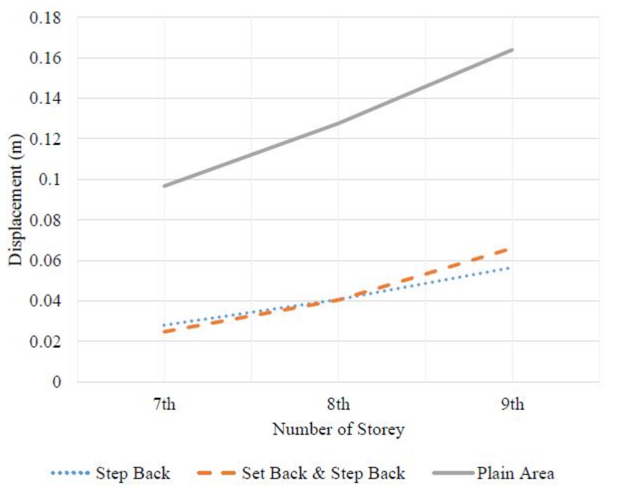

Figure 11: Top Storey Displacement Across Slope by Response Spectrum Method

back buildings by 33-25% and in plain area buildings by 28-32% along slope direction. whereas in across slope it was increasing by about 48%, 37-56%,28-32% in step back, step back-set back and plain area buildings respectively. The reason behind the increment on top storey displacement under increment of storey are increase in height and flexibility of structure. Similarly rate of increment of displacement in plain area and step back buildings are quite higher than step back-set back buildings.

4.5 Shear Force(V2)

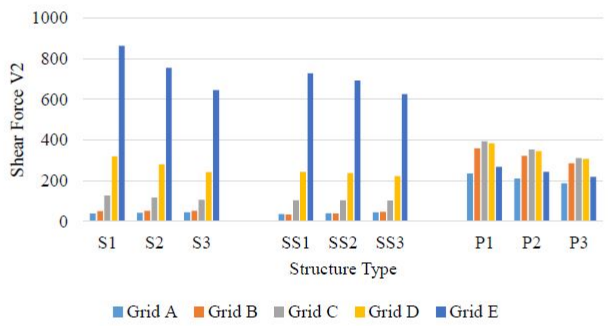

Figure 12: Comparison of Shear Force V2 (KN)

From the chart we can see that Grid E (Top base column) have high value of shear V2 on both sloppy area buildings while the plain area buildings have almost similar shear V2 on all grid. It was also found that the step back buildings have about 18% high shear V2 value than step back-set back buildings.The presence of a significant torsional moment due to static and accidental eccentricity is suggested by the uneven values of shear force in the various grids of columns and this torsion moment is maximum on step back buildings. The shear force V2 is found to be increasing by 14-16%, 5-10%, 10-11% in step back, step back-set back and plain area buildings respectively under the increment of storeys.

4.6 Torsion

From the above graph it can be concluded that the Step back buildings have high torsion value along Grid E (Top base column) than step back-set back building and plain area buildings. It was found that the step back building of 9 storey have torsion of 86.4 KN along Grid E while step back-set back building have 34.45 KN and plain area have 11.77 KN. Here plain area buildings and step back-set back buildings have experienced the less torsional effect than step back buildings due to less stiffness irregularity. Hence Step back-set back is found to have better performance than step back building on sloppy ground. Also the torsion moment are found to increasing by 13-16%, 5-10%, 12-14% in step back, step back-set back and plain area buildings respectively with respect to increase in number of stories. It is due to increase in static and accidental eccentricity under increment of storey.

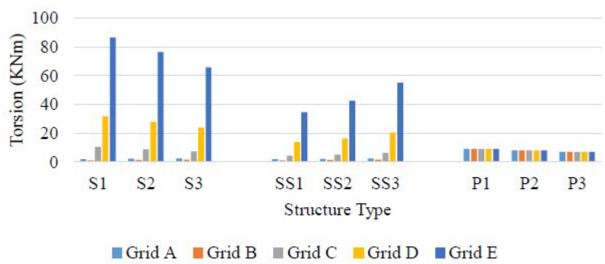

Figure 13: Comparison of Torsion

4.7 Effect of SSI on Performance of Buildings

As the objective of this study is only to find out the response of above three configured buildings under variation of stories i.e this study does not include detail study on effect of SSI on above configured buildings so in this study all the models are only analyzed by considering SSI on the basis of Gazettus(1991) equation. On analyzing the above buildings with SSI as per Gazettus (1991) equations it was found that the time period of building is lower on considering SSI than normally under fixed base. Similarly there is decrease in value of base shear and performance level of buildings on incorporating SSI. Also there is increase in top storey displacement and shear value on considering SSI than normal fixed base case.

5. Conclusion and Recommendation

From the above study the following conclusion are made:
• On analyzing the time period, it can be concluded that plain area building have high time period than step back and step back-set back buildings. Similarly, on sloppy area the step back building have high time period than step back-set back building and this period is increases with increase in number of storey.
• The plain area building have high base shear than sloppy area building. The step back building have high base shear than step back-set back building. The base shear is also increases with increase in number of stories.
• Plain area building have high performance level and step back building have low performance. The performance of building is decrease with increasing number of stories in sloppy area.
• Plain area building have high top storey displacement while step back-set back building have low top storey displacement. The displacement is increases steeply with increase in number of stories in both plain area and step back building while in step back-set back building rate of increment is found to be low.
• The shear force and torsion is maximum along top base column (grid E) column in sloppy area buildings which suggest the effect of short column effect and also these valuses are increases rapidly with increase in number of stories.
• Hence, Step back-set back building are favorable for sloppy area.
• In this study, all three configuration of buildings are analyzed under effect of SSI based on empirical equation only so for finding detail effect of SSI on seismic performance of sloppy area buildings, it is recommended to analyze the buildings under detail soil model and also recommended for detail comparative study on consideration and without consideration of SSI.

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