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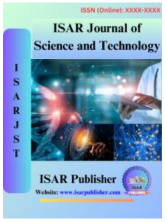

ISAR Journal of Science and Technology

Volume 2, Issue 12, 2024, Page: 23-28

Abbriviate Title- ISAR J Sci Tech

ISSN *(Online)*- 2584-2056

https://isarpublisher.com/journal/isarjst

Seismic Performance of RC Building on Sloping Ground

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Article History

Received: 24.10.2024
Accepted: 15.11.2024
Published: 08.12.2024

Abstract: Result from seismic analyses performed on 4 RC buildings with two different configurations in horizontal and vertical. In vertical like; step back building and step back-set back building and in horizontal symmetrical and unsymmetrical in the terms of bays are presented. Analysis including torsional effect has been carried out by using response spectrum method. The dynamic response properties i.e. fundamental time period, top story displacement and the base shear induced in columns have been studied with reference to the suitability of a building configuration on sloping ground. It is observed that step back-set back buildings are more suitable on sloping ground as compared to step back building.

Keywords: Seismic performance, RC buildings, sloping ground, step back, step back-set back, torsion, response spectrum, base shear.

Cite this article:

Khadka, B., (2024). Seismic Performance of RC Building on Sloping Ground. *ISAR Journal of Science and Technology*, *2*(12), 23-28.

1. Background

Earthquake is the most disastrous due to its unpredictability and huge power of devastation. Earthquakes themselves do not kill people, rather the colossal loss of human lives and properties occur due to the destruction of structures. Building structures collapse during severe earthquakes, and cause direct loss of human lives. Numerous research works have been directed worldwide in last few decades to investigate the cause of failure of different types of buildings under severe seismic excitations. Massive destruction of high-rise as well as low-rise buildings in recent devastating earthquake proves that in developing counties like Nepal, such investigation is the need of the hour. Hence, seismic behavior of asymmetric building structures has become a topic of worldwide active research.

Most parts of Nepal have large scales hilly region, which are categorized under seismic zone V. In this region the construction of multistory RC framed buildings on hill slopes has a popular and pressing demand, due to its economic growth and rapid urbanization. This growth in construction activity is adding increase in population density. While construction, it must be noted that Hill buildings are different from those in plains i.e., they are very irregular and unsymmetrical in horizontal and vertical planes, and torsion ally coupled. Since there is scarcity of plain ground in hilly areas, it obligates the construction of adjacent buildings on slopes.

Kathmandu Valley has been adopting two dominant construction typologies, namely

(i) Unreinforced masonry (URM) construction with masonry units of stone, burnt clay brick or cement blocks, in no, mud or cement mortar, with no earthquake-resistant features; and

(ii) Reinforced concrete (RC) construction with moment frame type configurations;

Of the above two, the second is most prevalent throughout the hills. These RC constructions are mostly non-engineered (i.e., built with no formal engineering inputs) and have emerged in the recent two decades in cities .This observation is valid uniformly for housing as well as critical and lifeline buildings and structures. RC construction across the state in general use hand-mixed concrete based on volume batching, no mechanical vibrator, no control on water-cement ratio, and inadequate curing.

Some photograph of buildings of different configuration on sloping ground is:

2. Literature Review

Birajdar B.G. (2004) presented the results from seismic analyses performed on 24 RC buildings with three different configurations like, Step back building; Step back Set back building and Set back building are presented. 3 –D analysis including torsional effect has been carried out using response spectrum method. The dynamic response earthquake properties i.e. fundamental time period, top storey displacement and, the base shear action induced in columns have been studied with reference to the suitability of a building configuration on sloping ground. It is observed that Step back Set back buildings are found to be more suitable on sloping ground.

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Dr. Vivek Garg and all (2014) studied the seismic analysis of a G+4 storey RCC building on varying slope angles i.e., 7.5° and 15° 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.

3. Objective

To compare the dynamic response of buildings in terms of base shear, fundamental time period and top floor displacement on sloping ground.

To suggested the suitable configuration of building to be used in hilly area or sloping ground.

4. Need of Study

Nepal has large scale of hilly region, which are categories under seismic zone IV and V. In this region the construction of multistory RC buildings on hill slopes. While construction, it must be noted that Hill buildings are different those in planes i.e. they are very irregular and unsymmetrical in horizontal and vertical planes, torsion ally coupled. Hence, they are susceptible to severe damage when affected by earthquake ground motion. Past earthquake have proved that buildings located near the edge of stretch of hills or sloping ground suffered severe damages. Moreover, sloping ground buildings may result in increase of torsional effect along the adjacent building. Such buildings have mass and stiffness varying along the vertical and horizontal planes so that the center of mass and center of rigidity do not coincide on various floors. This requires torsional analysis; in addition to lateral forces under the action of earthquakes. The investigation presented in this research aimed at predicting the seismic response of adjacent RC buildings of different plinth level with different configuration on sloping ground.

5. Building Configurations

In the present study, two buildings (i.e. configurations) are considered, which are resting on the sloping ground. The first one is step back building and another is step back-setback building. The slop ground is 27 degree with horizontal, which is neither too steep or nor to flat. Geometric Properties of Building are given in table.

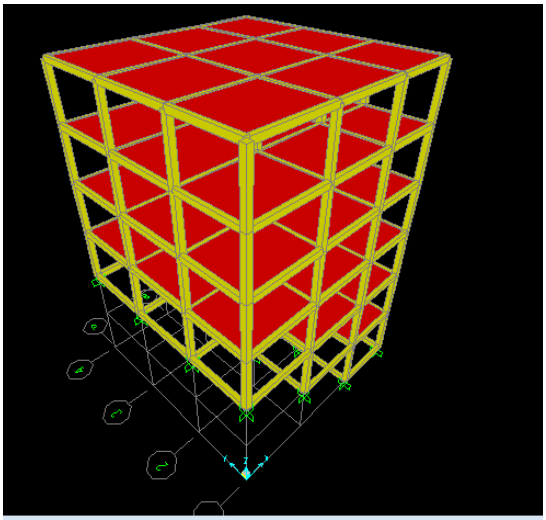

Figure 1 3-D Model of Building in Sloping Ground

Table 1: Geometrical Properties of Building Model

Building configuration	No of Bays/ No of storey	Size of column	Size of beam	Dimension of Buildings along X & Y Direction
Step back building 1	3 bays(both) /6	12’ * 12’	9’ * 12’	X-dir. - 14’+14’+12’ Y- dir. - 14’+14+12’
Step back set back Building 1	3bays(both)/6	12’ * 12’	9’ * 12’	X-dir. - 14’+14’+12’ Y- dir. - 14’+14+12’
Step back builings 2	2 bays(x –dir) 3 bays (y-dir)/5	12’ * 12’	9’ * 12’	X-dir. - 14’+14’ Y- dir. - 14’+14+12’
Step back set back building 2	2 bays(x –dir) 3 bays (y-dir)/5	12’ * 12’	9’ * 12’	X-dir. - 14’+14’ Y- dir. - 14’+14+12’

Table 2: Geometrical Properties of Building Model

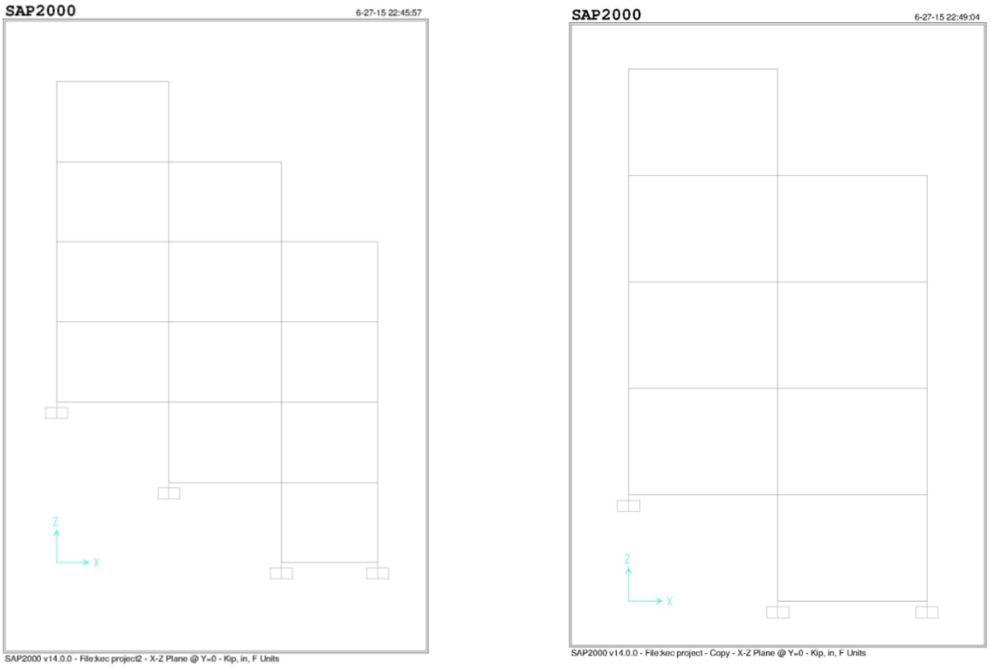

Figure 2: Model of step back-set back Building

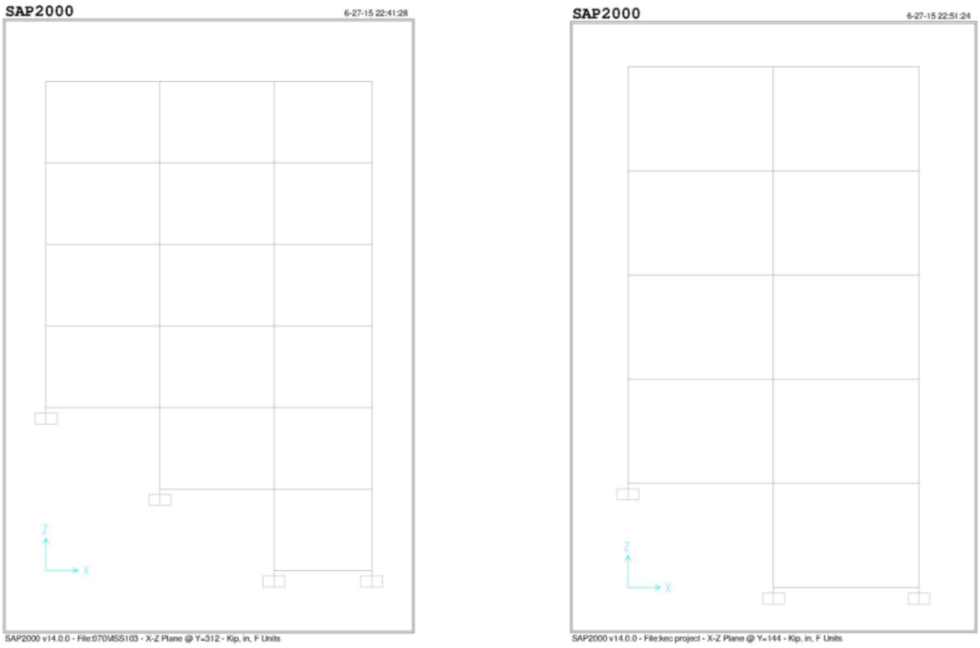

Figure 3: Model of Step back building

6. Method of Analysis

The analysis based on the following assumptions.

i. Material is homogenous, isotropic and elastic.

ii. The value of modulus of elasticity and Poisson's ratio are 25000N/mm^2 and 0.20, respectively.

iii. Secondary effect P-Δ, shrinkage and creep are not considered.

iv. The floor diaphragms are rigid in their plane.

v. Axial deformation in column is considered.

vi. Each nodal point in the frame has six degree of freedom, three translation and three rotations.

vii. Torsional effect is considered as per IS: 1893 (I)-2000.

7. Response Spectrum Analysis (RSA)

The seismic analysis of all buildings carried out by response spectrum method by using IS: 1893 (I)-2000, including the effect of eccentricity (static + accidental). The other parameters used in seismic analysis are, seismic zone (V), zone factor 0.36, importance factor 1.0, 5% damping and response reduction factor

5.0, presuming ordinary moment resistant frame for all configurations and height of buildings.

For each building case, adequate mode (minimum six) were considered, in which, the sum of modal masses of all modes at least 99% of the total seismic mass. The member forces for each contributing mode due to dynamic loading were computed and the modal responses were combined using SRSS method. The design spectrum of IS 1893:2002 was utilized in response spectrum analysis.

Consideration of Torsional Moment due to accidental Eccentricity:

First, the dynamic analyses of buildings without shifting the centre of mass from their locations were carried out. Then the result due to the application of torsional moments at each floor level equal to the lateral force times the accidental eccentricity at that floor were superimposed the results from dynamic analysis. The accidental eccentricity at each floor level was considered equal to 0.05 times the floor plan dimension perpendicular to the direction of seismic force.

As per codal provision, dynamic results were normalized by multiplying with a base shear ratio, $\lambda = V_B/V_{B,}$ where $\bar{V}_B$ is the base shear evaluation based on time period given by empirical equation and, V_B is the shear from dynamic analysis, if $= \bar{V}_B/V_B$ ratio is more than one.

8. Analysis of Results

In all, four buildings have been analyzed for seismic load with an effect of accidental eccentricity. The seismic force was applied in X-direction and Y-direction independently. Important results are presented in the subsequent sections. In the buildings A-A, B-B, C-C & D-D are the gridline of the building along the slope line. This notation is also used for the frame of that gridline.

9. Step Back Buildings:

In this configuration, two buildings have been analyzed.

9.1.1 EQ force in X direction (along the slope line):

The dynamic response of step back building in term of fundamental time period, top storey displacement and base share in columns at ground level is presented in table. The fundamental time period and base share (λ) as per IS: 1893(I)-2002, are evaluated and presented in the same table. It observed that there is linear increase in the value of top story displacement and time period as the height of step back building increases. The fundamental time period time period by dynamic analysis is higher than the values estimated by empirical equation given by IS: 1893(I)-2002. Hence, the value of shear coefficient by dynamic analysis is less than the static method as per IS: 1893(I)-2002.

Though the building plan is symmetrical along the sloping line and the torsional effect including accidental eccentricity is insignificant in x direction, it is observed the shear force in the column towards extreme left is significantly higher as compared to the rest of the columns at ground level for different heights of buildings. Comparatively, in the extreme right columns and adjacent to them (frame D & frame C) at ground level 99% modal masses participate at 34^{th} (total) and equivalent 12^{th} mode of X-direction .

9.1.2 EQ force in Y direction (across the slope line):

Table, shows the dynamic properties of each of the step back building for excitation in Y direction. The effect of accidental eccentricity is substantial when earthquake force is in Y direction. The value of fundamental time period and the top storey displacement in Y direction are substantially higher than the corresponding values when the earthquake force is in X direction. The evaluation of fundamental time period in Y direction as per IS 1983 (l)-2002 is remarkably lower than the values obtained by response spectrum analysis in the same direction. Though the effect of torsional moment is dominant in Y direction, the corresponding normalized values of shear force in extreme left columns (frame A) at ground level are less than the corresponding normalized values obtained for earthquake forces in X direction. From design point of view, it is to be noted that particular attention should be given to the size (strength), orientation (stiffness) and ductility demand of the extreme left column at ground level such that it is safe under worst possible load combinations in X and Y directions. 99% modal masses participate at 10^{th} (total) and equivalent 4^{th} mode of X-direction.

9.2 Step Back Set Back Buildings:

9.2.1 EQ. force in X direction (along the slope line):

The results of dynamic analysis of step back set back buildings are presented in table. It is seen that the evaluation of fundamental time period using dynamic analysis (RSA) in X- direction is slightly lesser than Y-direction. On the other hand it is observed that the value of base shear ratio is higher in X-direction than Y-direction. Observations from table it is indicate that.

i) The columns at extreme left (frame A) attract maximum shear force.

ii) The second last frames to the extreme right are subjected to least shear forces.

iii) 99% modal masses participate at 34^{th} (total) and equivalent 12^{th} mode of X-direction

9.2.2 EQ force in Y direction (across the slope line):

When earthquake force is applied in Y direction, it is observed from Table that.

i) Variation of shear force in all frames is found to be less with compare to set back buildings.

ii) Unlike the behavior due to earthquake force in X direction extreme left frame A is not severely stressed, indicating the lateral forces in Y direction cause in significant effect due to torsion.

iii) The fundamental time period in Y direction by dynamic analysis is not much affected by the height of step back set back buildings, whereas. IS: I 893(I)-2002 predicts the time period value which varies linearly with the height of building.

iii) 99% modal masses participate at 7^{th} (total) and equivalent 3^{rd} mode of X-direction.

From design point of view, the uniform section (having constant area of steel and concrete throughout) from bottom to top for extreme left column (frame A), would be sufficient to fulfill the design requirements for different heights of step back set back buildings considered.

Table 3 : Dynamic response of Building

Designation	Orientation	No of storey	Fundamental Time period by RSA	Time period by IS 1893	Maximum Top Storey Displacement	Base shear Ratio	Normalized Value of Shear Force in Column at ground				Remarks
							Frame A-A	Frame B-B	Frame C-C	Frame D-D	
step back building1	X-direction	18.228	0.93	0.663	29.845	1.938	622.7	83.467	0.257	2.657	Along Slope
	Y-direction	18.228	1.07	0.663	37.005	1.908	281.469	172.688	47.507	47.715	Across Slope
step back set back building2	X-direction	18.223	0.792	0.663	25.528	1.774	539.527	70.991	0.257	2.434	Along Slope
	Y-direction	18.223	0.914	0.663	26.873	1.654	259.187	141.206	38.927	38.81	Across Slope
step back building3	X-direction	15.24	0.946	0.578	33.074	2.111	487.41	35.998	37.114		Along Slope
	Y-direction	15.24	0.996	0.578	35.202	2.036	240.917	85.736	87.682		Across Slope
step back set back building4	X-direction	15.24	0.873	0.578	29.238	1.952	447.125	32.947	34.006		Along Slope
	Y-direction	15.24	0.921	0.578	28.505	1.846	242.69	75.996	77.453		Across Slope

Table 4 Base Reaction due to dynamic analysis

Designation	Orientation	No of storey	MX KN-m	MY KN-m	MZ KN-m	Remarks
step back building1	X-direction	18.228	118.5933	7492.293	3300.189	along slop
	Y-direction	18.228	6984.128	110.3231	3918.086	across slop
step back set back building2	X-direction	18.223	41.0507	6111.126	2906.179	along slop
	Y-direction	18.223	5711.067	34.6387	2766.85	across slop
step back building3	X-direction	15.24	159.9704	4502.138	2479.62	along slop
	Y-direction	15.24	4288.019	154.7362	2118.232	across slop
step back set back building4	X-direction	15.24	94.64	3965.081	2302.628	along slop
	Y-direction	15.24	3774.779	40.2236	1688.431	across slop

10. Comparison of Two Configurations

Step back building Vs. Step back Set Back Building:

In Step back buildings: frame A has attracted much higher base shear force than the frames B. C. and D. This uneven distribution of shear force in the various frames suggests development of torsional moment due to static and accidental eccentricity, which has caused profound effect in Step back buildings.

An uneven distribution of base shear in various frames was also observed in Step back —Set back buildings. However, this uneven distribution of shear forces is low to moderate, indicating torsional moments of lesser magnitude under the action of seismic forces Based on the above observations, it can be stated that Step back buildings are subjected to higher amount of torsional moments as compared to Step back Set back buildings and may prove more vulnerable during the seismic excitation. The configuration of Step back Set back building has an advantage in neutralizing the torsional effect, resulting into better performance than the Step back building during the earthquake ground motion, provided the short columns are taken care of in design and detailing.

11. Conclusions

Based on dynamic analysis of two different configurations of buildings, the following conclusions can be drawn.

1) The performance of STEP back building during seismic excitation could prove more vulnerable than step back set back buildings.

2) The development of torsional moments in Step back buildings is higher than that in the

Step back-Set back buildings. Hence, Step back Set back buildings are found to be less vulnerable than Step back building against seismic ground motion.

3) In Step back buildings and Step back-Set back buildings. It is observed that extreme left column at ground level, which are short, are the worst affected. Special attention should be given to these columns in design and detailing.

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