Pushover Analysis of a RC Building Resting on Sloping Ground

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Abstract

Several past earthquakes study suggest that earthquake have had a significant impact on the network system as well as considerable catastrophic effects on human life, buildings, bridges and economy. Hilly buildings are more susceptible to severe damage under lateral forces (earthquake ground motion) as compared to buildings in plains, as they are irregular and unsymmetrical in horizontal and vertical planes and torsionally coupled. Past earthquakes like Kangra (1950), Tokachi-Oki-Japan(1968) and Uttarkashi-India(1991) have proved that the buildings located near the edge of stretch of hills or sloping ground suffered severe damages. In this paper, the seismic behaviour of a G+4 Reinforced Concrete (RC) building is being compared considering two conditions viz. (i) resting on plain terrain and (ii) resting on sloping ground. The seismic design of the building has been performed as per IS 1893 (Part I): 2016 and the ductile detailing provisions have been considered as per IS 13920: 2016. The modelling and analysis of the buildings have been done in ETABS. Plastic hinges have been assigned to the frame elements to incorporate the nonlinear behaviour. A nonlinear static pushover analysis has been performed for the buildings and the capacity curve and ductility demand have been determined. It has been observed that there is a change in the dynamic characteristics and increase in the vulnerability along with variation in ductility demand of the buildings resting on slope. The results obtained from the present study will help in evaluating the seismic performance and risk of failure of the hilly buildings.

Keywords. RC building; pushover; ductility; seismic; performance.

1. INTRODUCTION

The rapid urbanization and economic growth in hilly region has accelerated the real estate development, as an impact of this population density increased enormously in hilly region, which leads to the construction of multi-storeyed buildings on sloping ground [1]. The scarcity of plain terrain compels the construction activities to be done on sloping ground [2]. Varied configurations of buildings in hilly areas results the buildings to be highly irregular and asymmetric, due to the variation in mass and stiffness distributions on different vertical axis at each floor [3,4]. In this study the main focus is the comparison of the seismic behaviour of a G+4 RC building having two different conditions viz. (i) resting on plain terrain and (ii) resting on sloping ground [6]. All the seismic design considerations are being considered as per the IS 1893 (Part I) [5]: 2016 and the ductile detailing provisions have been considered as per IS 13920: 2016 [7]. The modelling and analysis of the buildings have been done in ETABS [10]. Models are being compared on the basis of their time periods, mass participation ratios, base shear, column forces, storey drifts, capacity curve and ductility demand [8,9,11]. The results obtained from the present study will help in evaluating the seismic performance of the hilly buildings.

2. OBJECTIVES OF WORK

- To study the comparison of the seismic behaviour of a G+4 RC building having two different conditions viz. (i) resting on plain terrain and (ii) resting on sloping ground on the basis of their time periods, mass participation ratios, base shear, column forces, storey drifts.
- A nonlinear static pushover analysis has been performed for the different models and the capacity curves and ductility demands have been determined.

3. DESCRIPTION OF BUILDING

Plan area- 16m X 16m	Number of storey-5
Height of bottom story- 4m and all other stories- 3m	Total height of building- 16m
Cross-section of the column- 300mm X 300mm	Cross-section of the beam- 230mm X 300mm
Thickness of the slab- 150mm	Grade of Concrete- M25
Grade of Steel- HYSD500	Weight density of brick - 20kN/m^3
Roof Live load- 1.5kN/m^2	Live load- 3kN/m^2
Sloping ground angle-15^o	

SEISMIC DATA

Seismic zone-V	Zone factor-0.36
Importance factor-1	Response reduction factor-5
Function damping ratio- 0.05	Soil type- II (Medium Soil)

4. MODELLING

MODEL 1: G+4 Reinforced Concrete (RC) building resting on plain terrain. (Figure 1)

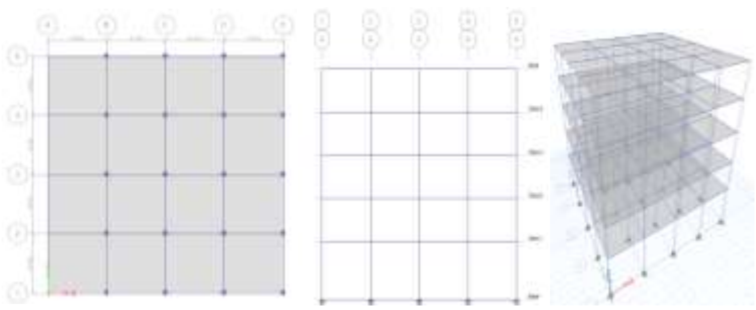


Figure 1. Plan, Elevation and 3D (Model 1)

MODEL 2: G+4 Reinforced Concrete (RC) building resting on sloping ground with one extra slab at the plinth level so that the space can be utilized (Figure 2).

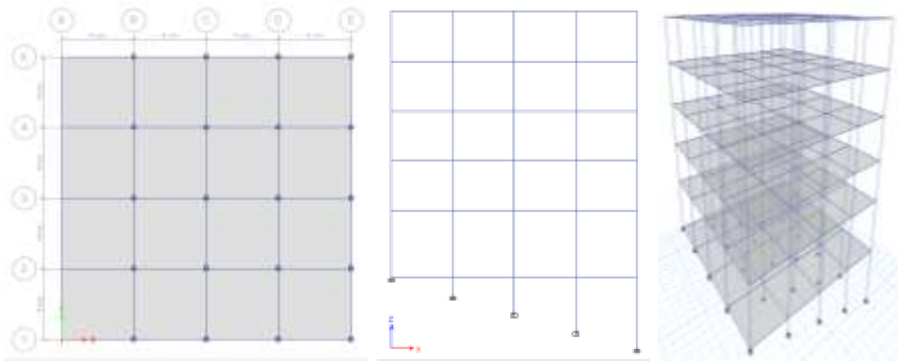


Figure 2. Plan, Elevation and 3D (Model 2)

5. ANALYSIS AND RESULTS

5.1. Time Period

Building acts as an inverted pendulum and has been considered as lumped mass system. One lumped mass get increased with increase in the storey. When earthquake occur building start vibrating under forced vibration and when earthquake completes then building vibrates as free vibration and vibrates at natural frequency. The time required to complete one complete cycle of oscillation when it was disturbed and left free is called natural time period. Natural time period is inverse of natural frequency. It depends on mass and stiffness of the building. Time period for Model 1 and Model 2 is presented in Table 1.

$$\mathbf{Tn = 2\pi\sqrt{m/k}}$$

Table 1. Time period for model 1 and model 2

Mode	Time Period(sec)	
	Model 1	Model 2
1	1.124	1.58
2	1.124	1.578
3	0.984	1.397
4	0.354	0.492
5	0.354	0.491
6	0.311	0.437

5.2. Mass Participation Ratio

The percent of structural mass that is participating in a given direction and mode is known as the mass participation ratio. The ration for Model 1 and Model 2 is given in Table 2 and 3 respectively.

Table 2. Mass participation ratios for model 1

Mode	UX	UY	RZ
1	0.894	0.00001354	0
2	0.00001354	0.894	0
3	0	0	0.8958
4	0.0805	0.00001162	0
5	0.00001162	0.0805	0
6	0	0	0.0794

Table 3. Mass participation ratios for model

Mode	UX	UY	RZ
1	0.0075	0.893	0.0088
2	0.9017	0.0075	0.00000429
3	0.00004003	0.0086	0.9011
4	0.0021	0.0688	0.0002
5	0.0692	0.0021	0
6	0.000004542	0.0005	0.0705

5.3. Base Shear

The total amount of shear acting in a lateral direction on all the storeys of a building is known as the Base Shear of the building. Base shear plays a crucial role while selecting the type of foundation. Stronger foundations are required when the base shear of a building is as high as compared to low base shear. The following expression is used for the calculation of base shear:

$$\mathbf{Vb = Ah} \times \mathbf{W}$$

Where Ah= Design horizontal seismic coefficient for structure.

W= Seismic weight of the building.

Table 4. Base shear for model 1 and model 2

Model	Base Shear	
	X-direction (kN)	Y-direction (kN)
Model 1	468.65	468.65
Model 2	240.64	238.13

5.4. Column Forces

Comparison of forces on 5 exterior columns of both the models is presented in Table 5.

Table 5. Column forces in exterior columns of model 1 and model 2

Column	Model 1			Model 2		
	P (kN)	M_2 (kN-m)	M_3 (kN-m)	P (kN)	M_2 (kN-m)	M_3 (kN-m)
1	334.7348	46.137	46.7623	342.7071	51.1434	58.0688
2	611.6728	44.2977	57.172	810.923	38.466	23.2983
3	609.6403	44.3312	56.4659	818.2662	41.7977	20.6865
4	607.8509	44.4752	56.8283	820.5263	38.5937	17.6855
5	334.7239	46.4941	53.8438	443.8706	31.4064	15.9027

5.5. Storey Drift

As we have discussed in this paper, the building acts as a spring mass system. In which the floor level acts as a mass and the columns impart stiffness to the structure. When a seismic load acts on the structure, each mass vibrates differently depending on the location and amount of its mass value. The relative displacement between two adjacent storeys is known as storey drift. Storey drift for Model 1 when response spectrum in X and Y-direction is presented in Figure 3 and Table 6 and in Figure 4 and Table 7 respectively. Storey drift for Model 2 when response spectrum in X and Y-direction is presented in Figure 5 and Table 8 and in Figure 6 and Table 9 respectively.

For Model 1

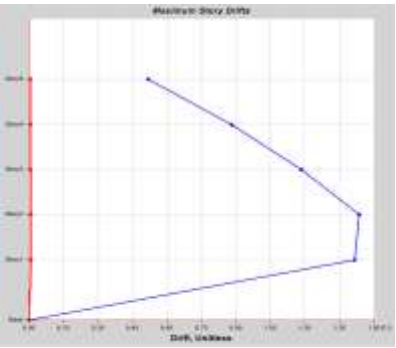


Figure 3. Storey drift for model 1 when response spectrum in X-direction

Storey	Elevation	Location	X-Dir	Y-Dir
	M			
Roof	16	Top	0.000518	0.000008
Storey4	13	Top	0.000882	0.000008
Storey3	10	Top	0.001185	0.000007
Storey2	7	Top	0.001434	0.00001
Story1	4	Top	0.001415	0.000009
Base	0	Top	0	0

Table 6. Storey drift values for model 1 when response spectrum in X-direction

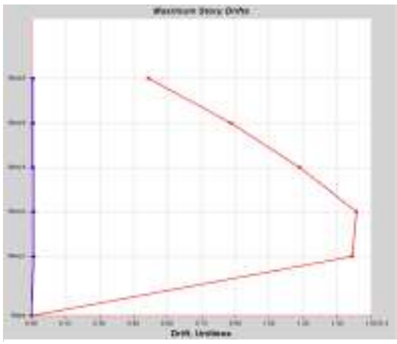


Figure 4. Storey drift for model 1 when response spectrum in Y-direction

Story	Elevation	Location	X-Dir	Y-Dir
	M			
Roof	16	Top	0.000008	0.000518
Story4	13	Top	0.000008	0.000882
Story3	10	Top	0.000007	0.001185
Story2	7	Top	0.00001	0.001434
Story1	4	Top	0.000009	0.001415
Base	0	Top	0	0

Table 7. Storey drift values for model 1 when response spectrum in Y-direction

For Model 2

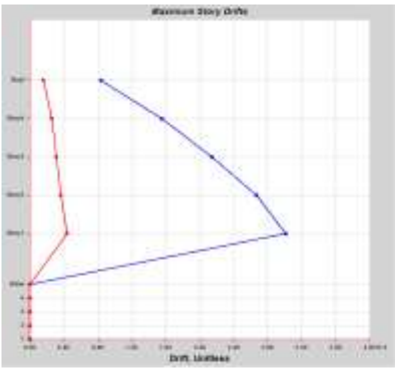


Figure 5. Storey drift for model 2 when response spectrum in X-direction

Storey	Elevation	Location	X-Dir	Y-Dir
	M			
Roof	20.288	Top	0.000833	0.00016
Storey4	17.288	Top	0.001553	0.000259
Storey3	14.288	Top	0.002142	0.000312
Storey2	11.288	Top	0.002668	0.000364
Storey1	8.288	Top	0.003011	0.000441
Base	4.288	Top	0	0
4	3.216	Top	0	0
3	2.144	Top	0	0
2	1.072	Top	0	0
1	0	Top	0	0

Table 8. Storey drift values for model 2 when response spectrum in X-direction

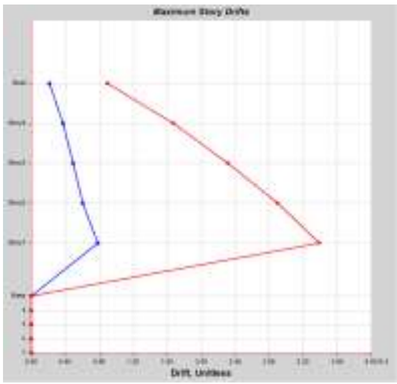


Figure 6. Storey drift for model 2 when response spectrum in Y-direction

Storey	Elevation	Location	X-Dir	Y-Dir
	M			
Roof	20.288	Top	0.000214	0.000895
Storey4	17.288	Top	0.000374	0.001674
Storey3	14.288	Top	0.000489	0.002316
Storey2	11.288	Top	0.000602	0.002897
Storey1	8.288	Top	0.000785	0.003388
Base	4.288	Top	0	0
4	3.216	Top	0	0
3	2.144	Top	0	0
2	1.072	Top	0	0
1	0	Top	0	0

Table 9. Storey drift values for model 2 when response spectrum in Y-direction

5.6. Capacity Curve

The non-linear behaviour of the structure can be shown by the Capacity Curve or Pushover Curve. It is the load deformation curve of the base shear and the horizontal roof displacement of the building. Capacity curve for model 1 when response spectrum in X and Y-direction is presented in Figure 7 and 8 respectively. Capacity curve for model 2 when response spectrum in X and Y-direction is presented in Figure 9 and 10 respectively.

For Model 1

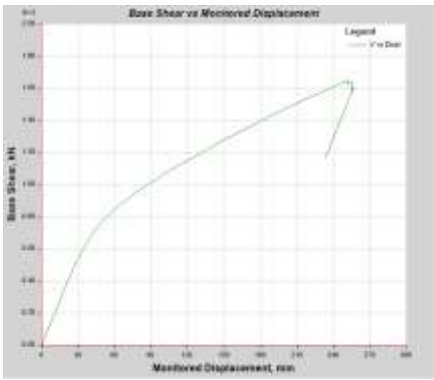


Figure 7. Capacity Curve for model 1 when response spectrum in X-direction

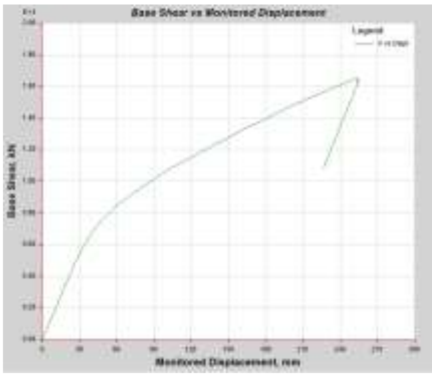


Figure 8. Capacity Curve for model 1 when response spectrum in Y-direction

For Model 2

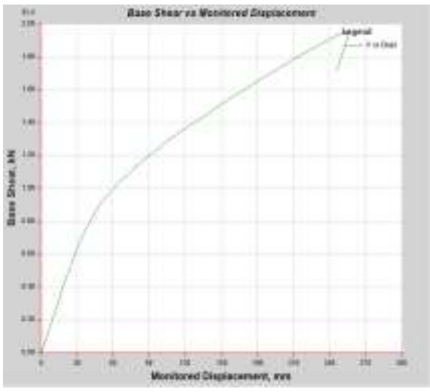


Figure 9. Capacity Curve for model 2 when response spectrum in X-direction

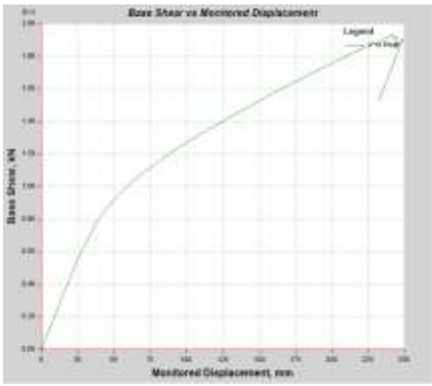


Figure 10. Capacity Curve for model 2 when response spectrum in Y-direction

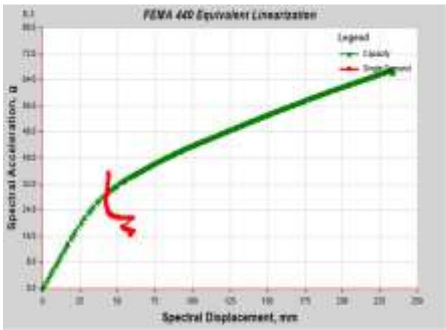
5.7. Performance Point

The intersection point between the capacity spectrum and the demand spectrum at a given damping ratio is termed the Performance Point. It is the maximum inelastic capacity of the structure. Performance point for model 1 when pushover analysis in X and Y direction is presented in Figure 11 and 12 respectively and for module 2 is presented in Figure 13 and 14 respectively.

For Model 1

Point Found	**Yes**	**T secant**	**2.43 sec**
Shear	740.7828 kN	T effective	2.407 sec
Displacement	46.634 mm	Ductility Ratio	1.668543
Sa	0.029309	Effective Damping	0.0686
Sd	42.991 mm	Modification Factor	0.980907

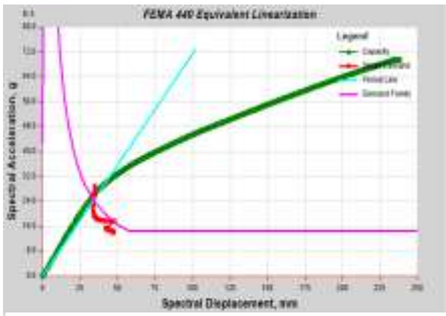
Figure 11. Performance point for model 1 when pushover analysis in X-direction



Point Found	Yes	T secant	2.43 sec
Shear	743.2573 kN	T effective	2.409 sec
Displacement	46.688 mm	Ductility Ratio	1.672114
Sa	0.029313	Effective Damping	0.0688
Sd	43.015 mm	Modification Factor	0.982096

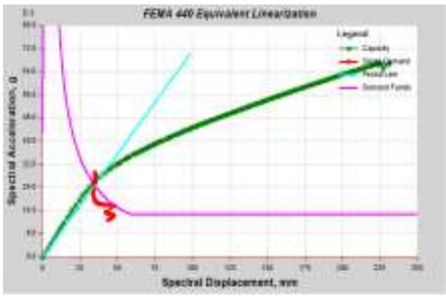
Figure 12. Performance point for model 1 when pushover analysis in Y-direction

For Model 2



Point Found	Yes	T secant	2.305 sec
Shear	756.6875 kN	T effective	2.316 sec
Displacement	37.443 mm	Ductility Ratio	1.519953
Sa	0.026431	Effective Damping	0.0617
Sd	34.873 mm	Modification Factor	1.00973

Figure 13. Performance point for model 2 when pushover analysis in X-direction



Point Found	Yes	T secant	2.323 sec
Shear	770.4671	T effective	2.335 sec
Displacement	37.701	Ductility Ratio	1.567648
Sa	0.025992	Effective	0.0638
Sd	34.843	Modification	1.010133

Figure 14. Performance point for model 2 when pushover analysis in Y-direction

6. Conclusion

In the present paper, the seismic analysis of a G+4 Reinforced Concrete (RC) building has been done considering the building is resting on plain and hilly terrains. The seismic design of the building has been performed as per IS 1893 (Part I): 2016 and the ductile detailing provisions have been considered as per IS 13920: 2016. The following conclusions can be drawn. A. The time period of the building resting on hilly slope is found to be higher than the same resting on plain ground which might be due to additional flexibility because of unsymmetrical configuration in the former case. B. The base shear for the hilly building is found to be lesser than the same resting on plain ground which might be due to increased flexibility in the former case. C. The storey drift is found to be higher in case of hilly terrain building than the building resting on plain ground. However, for both the buildings, the drifts are within the desired limit as per IS:1893-2016 code. D. The ductility demand of the building resting on hilly terrain is higher than the same resting on plain ground which might be due to unsymmetrical configuration in the former case.

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