iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 Issue: XI Month of publication: November 2017

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue XI November 2017- Available at www.ijraset.com

Seismic Analysis of RC Structure in Hill Slope Area

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Abstract: Due to scarcity of flat ground, buildings are constructed in the hill slope. Because of slope in the ground the hill slope building are configured differently than the building in the flat ground. An analytical study was performed to investigate the behavior of buildings on hill slope. Dynamic response of building on hill slope is compared with that of regular buildings on flat ground in terms of fundamental period of vibration, modal mass participation, and deflected shape, torsion in column, column shear, and plastic hinge formation pattern. The seismic behavior of three typical configurations of hill buildings is investigated by performing a linear dynamic analysis and the performance point of these building is obtained by performing a pushover analysis. It is affirmed that the hill buildings have significantly different dynamic characteristics than buildings on flat ground.
Keywords: Hill slope area, Seismic Analysis, Push over Analysis, SAP software

I. INTRODUCTION

A. Behaviour Of Building In Hill Slope

Buildings in hill slope have a typical structural configuration. Subsequent floors in building step back towards the hill slope, resulting in unequal column height in a storey. This causes variation in stiffness both in along and cross-slope directions excitation. Building in hill slope with symmetric plan, when subjected to tremor in cross-slope direction are subjected to torsion due to varying lateral stiffness of uphill and downhill side frames. Due to shift in centre of stiffness and centre of mass at each floor level, the torsion behaviour in these building is more complex than the building on the flat ground. Building in hill slope with symmetric plan, when subjected to tremor in along-slope direction are not subjected to torsion, but the shorter columns on uphill side of a storey attract more lateral force, which are usually higher than their capacity and may result in shear failure. Steep slopes/vertical cuts is the another common type of structural configuration that is found on hills. Where, the foundations of this building are provided at two levels. These buildings are also subjected to severe torsional irregularity in cross-slope direction, and the short columns on the uphill side which attracts more lateral force under along-slope excitation.

II. ANALYTICAL STUDY

In the present study a three dimensional space frame analysis is carried out on a 6 storey RC frame building with three different hill configurations. To compare the behaviour, a 6 storey building resting on flat ground having the same plan as the hill building were also considered. The first building(Type A) is stepping back at every floor level on the slope, up to 4 storey and has two storey above road level. The second building (Type B) is stepping and setting back at every floor level. The third building (Type C) is steeping back at fourth floor level only and two storeys above road level. The 6 storey regular building is labeled as (Type D) rests on the flat ground. The plan and elevation of different building configuration are shown in figures below.

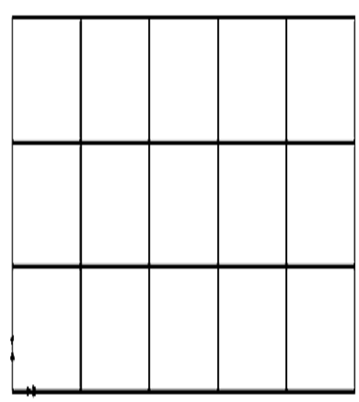

Fig 1. Plan of the building

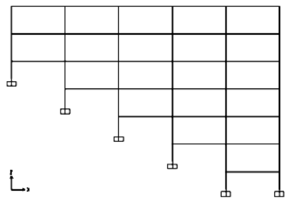

Fig 2. Elevation of Type A Building

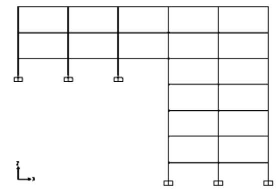

Fig 3. Elevation of Type B Building

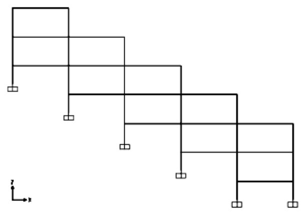

Fig 4. Elevation of Type C Building

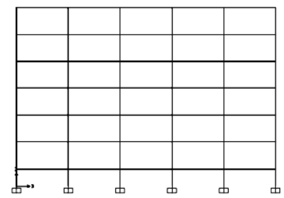

Fig 5. Elevation of Type D Building

The typical storey height is taken as 3.1 m and the depth of footing below ground level is taken as2 m for all the building, assuming rock is available at that depth. The cross sections of beams and column is kept uniform as 250mm × 450mm and 500mm × 500mm respectively; the thickness of the slab is taken as 150mm. The in-plane rigidity of floor slabs has been simulated using rigid diaphragm constraints. The foundations have been considered fixed.

III. SEISMIC INPUT

To compare the dynamic behaviour of building on hill slope under various seismic excitations. A linear dynamic analysis was performed for a set of five ground motions taken from a strong motion database of Pacific Earthquake Engineering Research Centre (http://peer.berkeley.edu/smcat/) were tabulated in the Table. The time histories are scaled using wavelet transform to match the response spectrum of Indian Seismic Zone V as shown in Fig.

Table.1 Earthquake record used in analysis

S.No	Earthquake	Event	Magnitude	PGA [g]	PGV [cm/sec]	PGD [cm/sec]
1	Imperial Valley	14/06/53	-	0.006	0.4	0.06
2	Morgan Hill	24/04/84	M6.2	0.212	12.6	2.1
3	Loma Prieta	18/10/89	M6.9	0.294	14.6	4.66
4	Northridge	17/01/94	M6.7	0.511	63.7	21.18
5	Chi Chi	20/09/99	M7.6	1.157	114.7	31.43

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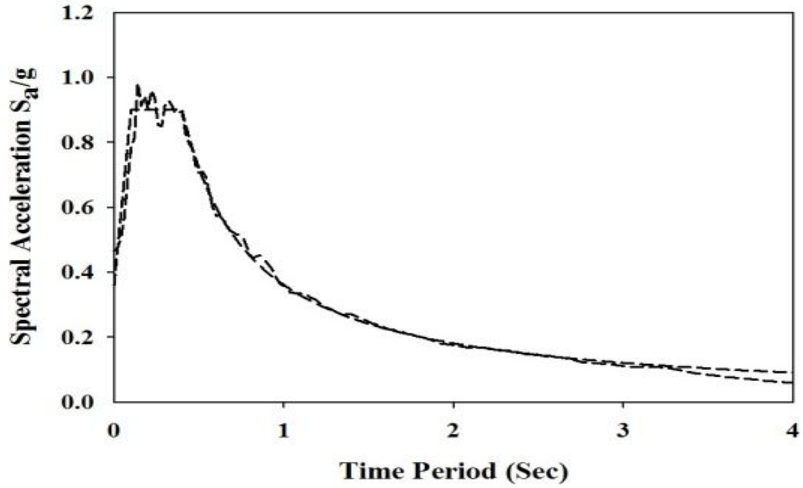

Fig 6. Indian code response spectrum for seism zone IV and matched response spectrum of a typical scaled time history

IV. MODAL ANALYSIS

Fundamental periods and modal mass participation ratio in the first three modes are shown in the Table for all three building configurations.

Table 2. Fundamental period and Modal Participation Mass Ratio for three different building along X-Direction

Mode	Type A		Type B		Type C		Type D	
	Time Period Sec	Modal Participation Mass Ratio P_k	Time Period Sec	Modal Participation Mass Ratio P_k	Time Period Sec	Modal Participation Mass Ratio P_k	Time Period Sec	Modal Participation Mass Ratio P_k
1	0.531	51.92	0.407	31.21	0.456	43.12	1.337	75.43
2	0.191	33.9	0.167	48.95	0.351	39.42	0.41	10.17
3	0.146	9.45	0.141	13.23	0.154	1.77	0.218	4.41

Table. 3. Fundamental period and Modal Participation Mass Ratio for three different building along Y-Direction

Mode	Type A		Type B		Type C		Type D	
	Time Period Sec	Modal Participation Mass Ratio P_k	Time Period Sec	Modal Participation Mass Ratio P_k	Time Period Sec	Modal Participation Mass Ratio P_k	Time Period Sec	Modal Participation Mass Ratio P_k
1	0.808	55.02	0.402	51.92	0.57	52.24	1.311	75.46
2	0.428	10.61	0.362	2.05	0.41	10.57	0.401	10.21
3	0.303	12.38	0.253	17.28	0.365	18.25	0.215	4.38

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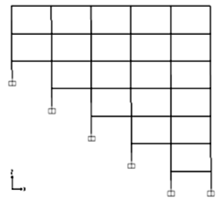
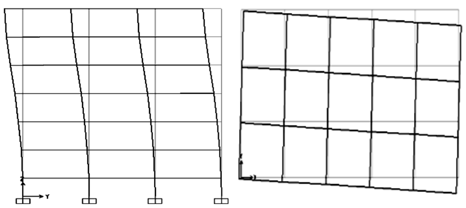
Due to irregularity of configurations, the cumulative mass participation in fundamental mode for buildings on slopes is much lower than the regular building. The fundamental mode shapes of these three building is shown in Fig.

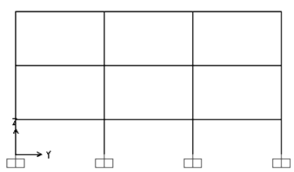


(a)



(b)

Fig 7.Fundamental mode shapes of Type A configuration along (a) X-Direction (b) Y-Direction



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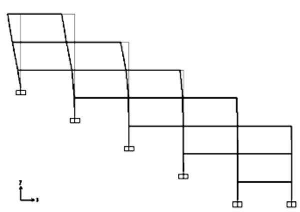
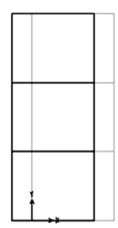
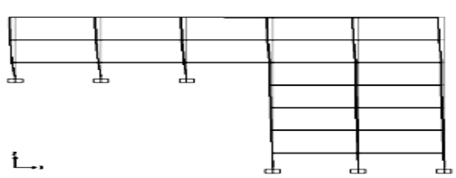


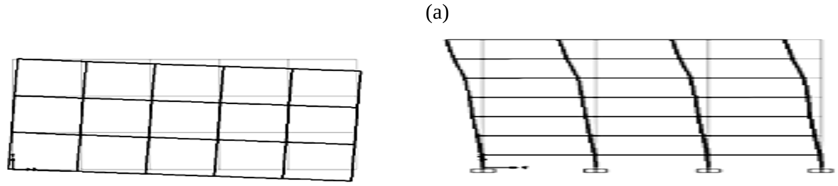


(b)

Fig 8. Fundamental mode shapes of Type B configuration along
(a) Y-Direction (b) X-Direction



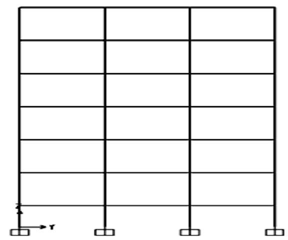
(a)



(b)

Fig 9. Fundamental mode shapes of Type C configuration along (a) X-Direction

(b) Y-Direction



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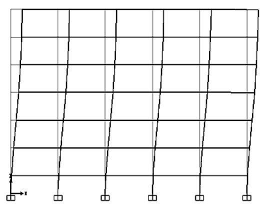
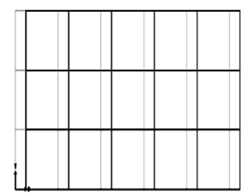




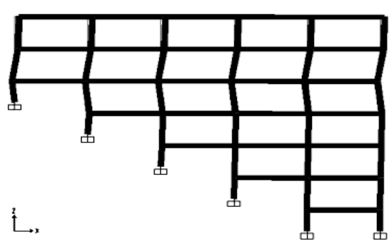
(b)

Fig 10. Fundamental mode shapes of Type D configuration along (a) Y-Direction (b) X- Direction

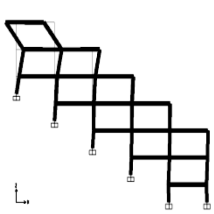
Fundamental time period of Type B and Type D building show a signs of translational mode along X direction. However, Type A and Type C building exhibit torsional mode.

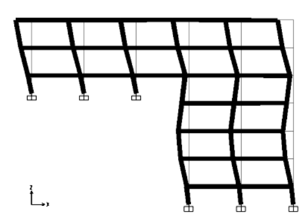
V. LINEAR DYNAMIC RESPONSE

The deflected shapes of Type A, Type B and Type C building due to excitation along X direction is shown in Fig. Due to high rigidity of short column, it is observed that there is no significant lateral displacement in the bottom four storeys of Type A building. The deflected shape of the Type C building is similar to a vertical cantilever propped at 4 floor level. Due to reduction in stiffness at the top storey of the Type B building, the deflection increases. Further, in Type A and Type B configuration, the entire storey shear below fourth floor level is resisted by short columns. In case of Type C configuration both the column in the bottomstorey and the column in fifth and sixth storey are subjectedto the maximum forces. The variation of column forces in hill buildings is extremely different than that of a regular (Type D) building.



(a)





(b) (c)

Fig 11. Deflected shapes of building due to excitation along X direction (a) Type A; (b) Type B; (c) Type C

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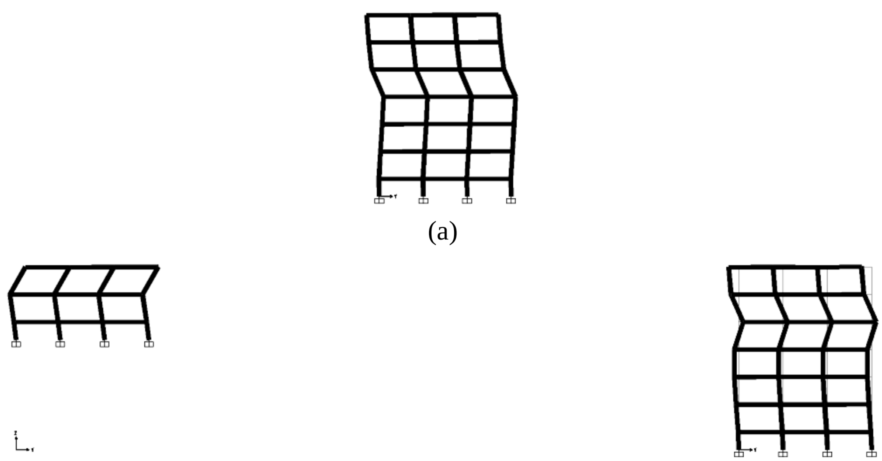
(a) (b)

(c) (d)

Fig 12. Variation of column shear along the height of the building due to excitation along X-direction: (a) Type A; (b) Type B; (c) Type C; (d) Type D configuration

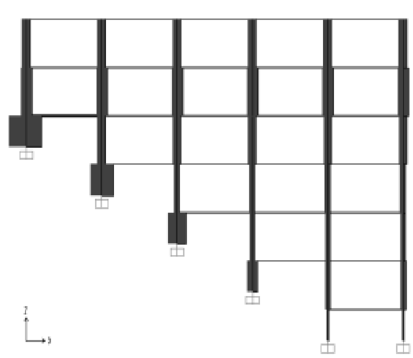
The deflected shape of the hill building configurations (Type A, Type B and Type C) due to excitation along Y direction is shown in Fig. The variation of torsional force along height of the building due to excitation along Y direction is shown in Fig. for the purpose of comparison. A similar pattern is observed for column shears, where the columns of the top three storeys in hill building configurations have much higher shears than the storey below when compared with the corresponding columns in the regular (Type D) building.



(a)

(b) (c)

Fig 13. Deflected shapes of building due to excitation along Y direction (a) Type A; (b) Type B; (c) Type C



(a)

(b) (c)

Fig 14. Variation of torsional force along height of the building due to excitation along Y- direction: (a) Type A; (b) Type B; (c) Type C

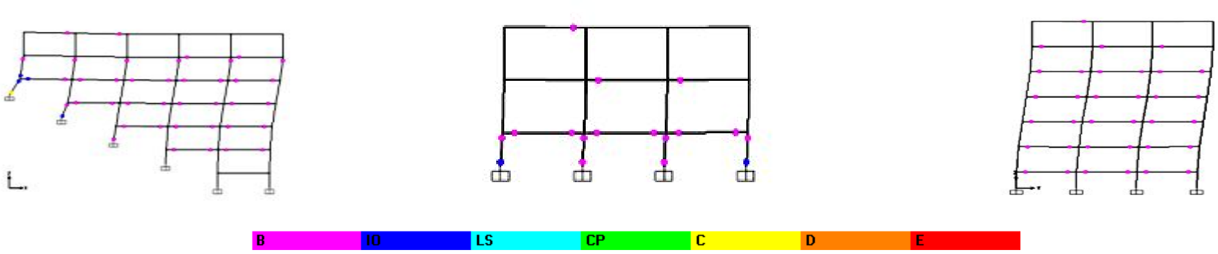
(a) (b)

(c) (d)

Fig 15. Variation of column shear along the height of the building due to excitation along Y-direction: (a) Type A; (b) Type B; (c) Type C; (d) Type D configuration

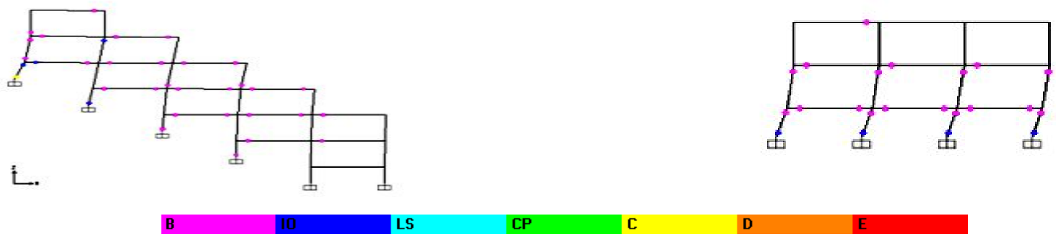
VI. NON-LINEAR STATIC ANALYSIS

The hinge pattern of the Type A, Type B and Type C building configurations, subjected to independent excitation along X and Y directions are shown in the Fig. In Type A and Type B configuration, the entire storey shear below fourth floor level is resisted by short columns resulting in the formation of plastic hinges at these locations (Fig (a) & Fig (a)). However, in Type C configuration both the column in the bottomstorey and the column in fifth storey were subjectedto the maximum forces. Consequently hinges were formed at these locations (Fig (a)). When excited along Y-direction for Type B and Type C configuration hinges are developed both in beams and column. Whereas in Type A configuration when excited along Y-direction, hinges are formed in beams as well as columns (Fig (b)) in the rigid side frame, whereas on the flexible side, the hinges are developed only in beams (Fig (c)). Performance point of the hill building using codal type lateral load pattern is tabulated in Table. It is evident that Type B building can undergo a larger value of displacement when compared to other hill building. Further, in Type A and Type B building it is observed that displacements in both X and Y direction are almost same. Type C building can withstand a larger value of base shear when compared with other hill building.



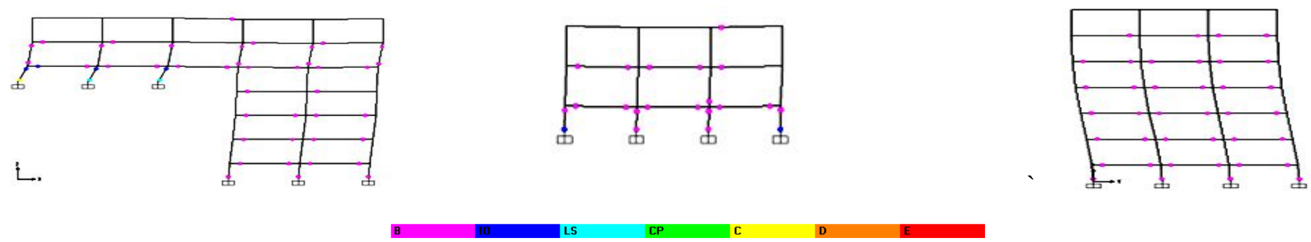
(a) (b) (c)

Fig 16. Hinge pattern of Type A configuration: (a) Along X-Direction; (b) Along Y-Direction (rigid side); and (c) Along Y-direction (flexible side)



(a) (b)

Fig 17. Hinge pattern of Type B configuration: (a) Along X-Direction; (b) Along Y-Direction



(a) (b) (c)

Fig 18. Hinge pattern of Type C configuration: (a) Along X-Direction; (b) Along Y-Direction (rigid side); and (c) Along Y-direction (flexible side)

Table 4.Performancepoint of hill building models using Codal type lateral load pattern

Building Configuration	Displacement mm	Base Shear kN	Displacement mm	Base Shear kN
	X-Direction		Y-Direction	
Type A	2.220	929.699	2.524	1060.251
Type B	4	1446.117	5.206	948.149
Type C	3.217	1926.995	3.924	1457.332

VII. CONCLUSION

The behaviour of hill buildings differs significantly from the regular buildings on flat ground. The hill buildings undergo torsional effects when excited along Y-Direction. When excited along X-Direction the varying heights of columns cause stiffness irregularity, and the short columns resist almost the entire storey shear. The pushover analysis in hill building shows that in case of downhill building the storey above the road level is more susceptible to damage.

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