Comparative Analysis of Seismic Performance of R.C Building Resting on Plain and Sloping Ground

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Abstract - *Hilly areas buildings are required to be constructed on sloping ground due to scarcity of the plain ground. The buildings are irregularly situated on hilly slopes in earthquake prone areas like northeast region of India. These buildings are poorly damaged when subjected to earthquake ground motions and resulted in loss of life and property. Since these buildings are unsymmetrical in nature, hence attract large amount of shear forces and torsional moments, and show unequal distribution due to varying column lengths. In present study, different patterns of buildings which are located in hilly area have been modeled and analyzed using ETABS software based on finite element analysis. A parametric analytical study has been carried out, in which buildings resting on plain and sloping ground are geometrically varied in length and width. In this project total four analytical models of Plain ground building, Sloping ground buildings with 15 degree, 25 degree, 35 degree slopes.*

Key Words**: Hill buildings, Response spectrum method, Plain building, Fundamental time period**

1. INTRODUCTION

Now a days, rapid construction is taking place in hilly areas due to scarcity of plain ground. As a result the hilly areas have marked effect on the buildings in terms of style, material and method of construction leading to popularity of multi-storeyed structures in hilly regions. Due to sloping profile, the various levels of such structures towards the hill slope and may also have setback also at the same time. Vibrations which causes disturbance in the earth's surface induced by waves generated inside the earth are termed as earthquakes.

It is well known that earthquake ground motions results primarily from the three factors, namely, source characteristics, propagation of waves and local site conditions. When an earthquake of certain magnitude strikes a structure, they induce motions in the structure which depends upon the structure's vibration characteristics and the location of structure. If a lightweight flexible building is constructed on a foundation which is very stiff, assumption is that the input motion at the base of the structure is same as free field motion. If a huge and rigid structure rests on a relatively soft foundation, the motion at the base of the structure will be different from free-field motion.[1]

Structure subjected to seismic/earthquake forces are always vulnerable to damage and if it occurs on a sloped building as on hills which is at some inclination to the ground the chances of damage increases much more due to increased lateral forces on short columns on uphill side and thus leads to the formation of plastic hinges. Structures on slopes differ from those on plains because they are irregular horizontally as well as vertically. In north and northeastern parts of India have large scale of hilly terrain which falls in the category of seismic zone IV and V. In the work, a parametric study has been buildings resting on sloping ground are geometrically varied in length width and height. Total four analytical models are analyzed using Response Spectrum Method. Analysis results in terms of modal time period, diaphragm acceleration, diaphragm displacement, maximum bending moment, storey shear and storey drifts. At end, the suitability of different geometry of buildings resting on sloping ground has been suggested.[8]

2. GEOMETRICAL PROPERTIERS

All the models have same geometrical and material properties, and rest on the different inclination of ground which is 15 degree, 25 degree and 35 degree . The geometrical properties of the structural elements in the models with designation of different model types. The inter-storey height is taken as 3.1 meters and foundation depth is 1.9 m in all the buildings. The thickness of the slab at all floors in all the models is considered as 125 mm. Since, the models are varied in length along and across the slope, their heights will also be varied accordingly, variation in length of configurations along the slope is carried out from five bays (5 m each). The length of building types, across the slope is altered from two bay (5 m each) to five bays of same length at one bay at a time by keeping the same number of bays along slope and number of storeys in the structure.

2. 1 Modeling of Buildings

The building is modeled using the finite element software ETABS Version 16.2.0. The analytical models of the building include all components that influence the mass, strength, stiffness and deformability of structure. The building structural system consists of beams, columns, slab, walls, and foundation. The non-structural elements that do not significantly influence the building behavior are not modeled. Beams and columns are modeled as two noded beam element with six DOF at each node. The floor slabs are assumed to act as diaphragms, which insure integral action of all the vertical load resisting elements and are modeled as four nodded shell elements with six DOF at each node. Shear wall is modeled by using shell element. In the modeling, material is considered as an isotropic material.

Table -1: Configuration of Buildings

Building Configuration	Parametric Variation	Column Size(mm)	Beam Size(mm)
Plain Ground building	5 bays (G+6)	400 x 400	300 x 500
15 degree slope building	5 bays (G+6)	400 x 400	300 x 500
25 degree slope building	5 bays (G+6)	400 x 400	300 x 500
35 degree slope building	5 bays (G+6)	400 x 400	300 x 500

2.2 Seismic Loading and Parameters

The seismic parameters considered in dynamic analysis of all the models are assumed as per IS 1893 (Part 1): 2002. The hill buildings are assumed to be in Zone V with the peak ground acceleration value of 0.36g. The importance factor, I is taken as 1.5 (for important building). Also, the response reduction factor R taken as 5 for SMRF system of the buildings. The soil strata beneath the foundation is assumed as medium soil.

The gravity and imposed loads are taken as per IS 875 (Part 1 and 2): 1987, self-weight of the structure is calculated and imposed load is assumed to be 3 kN/m2 for a typical residential building. Since, the lateral load due to earth pressure on foundation columns does not take part in the seismic weight of the structure, thus its effect is neglected in the analysis to observe only the effect of lateral forces due to seismic loads.

2.3 Response Spectrum Method

Response spectra are curves plotted between maximum response of SDOF system subjected to specified earthquake ground motion and its time period (or frequency). Response spectrum can be interpreted as the locus of maximum response of a SDOF system for given damping ratio. Response spectra thus helps in obtaining the peak structural responses under linear range, which can be used for obtaining lateral forces developed in structure due to earthquake thus facilitates in earthquake-resistant design of structures.

Usually response of a SDOF system is determined by time domain or frequency domain analysis, and for a given time period of system, maximum response is picked. This process is continued for all range of possible time periods of SDOF system.

2.4 Codal Provisions (Dynamic Analysis)

Dynamic analysis should be performed to obtain the design seismic force, and its distribution to different levels along the height of the building and to various lateral load resisting elements, for the following buildings:

Regular buildings- Those are greater than 40 m in height in zone IV, V and those are greater than 90 m height in zones II,III, and irregular buildings-All framed buildings higher than 12m.

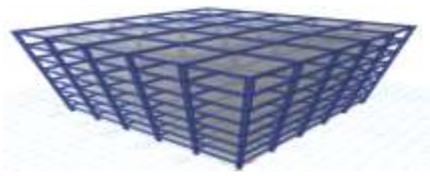

Fig -1: 5 Bay building resting on plain ground

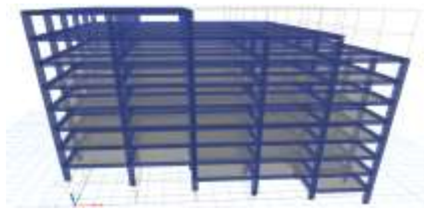

Fig -2: 5 Bay building resting on 15 degree slope

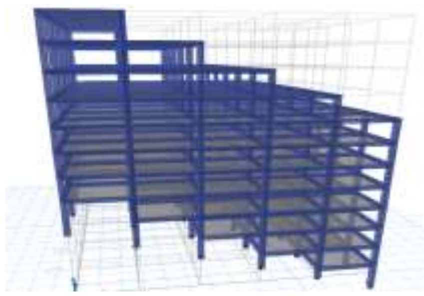

Fig -3: 5 Bay building resting on 25 degree slope

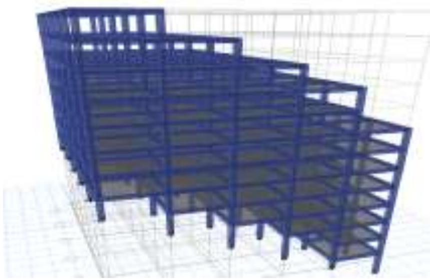

Fig -4: 5 Bay building resting on 35 degree slope

3. RESULT AND DISCUSSION

3.1 Modal Time Period

Table -2: Modal Time Period in 1st Mode

Building Type	Modal Time Period in 1st mode
Building on Plain Ground	1.079
Building on 15 degree slope	1.106
Building on 25 degree slope	1.212
Building on 35 degree slope	1.123

3.2 Storey Drift

The floor wise lateral storey drift are tabulated below

Table -3: Building on plain ground

Story	Load Case/Combo	Direction	Drift
Terrace	SPEC X Max	X	0.000931
Story7	SPEC X Max	X	0.001663
Story6	SPEC X Max	X	0.002249
Story5	SPEC X Max	X	0.002719
Story4	SPEC X Max	X	0.003107
Story3	SPEC X Max	X	0.003398
Story2	SPEC X Max	X	0.003324
Story1	SPEC X Max	X	0.001397

Table -4: Building on 15 degree slope

Story	Load Case/Combo	Direction	Drift
Terrace	SPEC X Max	X	0.001079
Story9	SPEC X Max	X	0.00153
Story8	SPEC X Max	X	0.002114
Story7	SPEC X Max	X	0.002725
Story6	SPEC X Max	X	0.003228
Story5	SPEC X Max	X	0.003639
Story4	SPEC X Max	X	0.003908
Story3	SPEC X Max	X	0.004044
Story2	SPEC X Max	X	0.001798
Story1	SPEC X Max	X	0.000831

Table -5: Building on 25 degree slope

Story	Load Case/Combo	Direction	Drift
Additional Story 2	SPEC X Max	X	0.00127
Additional Story 1	SPEC X Max	X	0.001725
Terrace	SPEC X Max	X	0.002062
Story9	SPEC X Max	X	0.002374
Story8	SPEC X Max	X	0.002747
Story7	SPEC X Max	X	0.003264
Story6	SPEC X Max	X	0.003811
Story5	SPEC X Max	X	0.007757
Story4	SPEC X Max	X	0.006357
Story3	SPEC X Max	X	0.002647
Story2	SPEC X Max	X	0.001511
Story1	SPEC X Max	X	0.0009

Table -6: Building on 35 degree slope

Story	Load Case/Combo	Direction	Drift
Additional Story 5	SPEC X Max	X	0.001279
Additional story 4	SPEC X Max	X	0.001836
Additional story 3	SPEC X Max	X	0.002139
Additional story 2	SPEC X Max	X	0.002432
Additional Story 1	SPEC X Max	X	0.002829
Terrace	SPEC X Max	X	0.002918
Story7	SPEC X Max	X	0.003352
Story6	SPEC X Max	X	0.002284
Story5	SPEC X Max	X	0.005846
Story4	SPEC X Max	X	0.004063
Story3	SPEC X Max	X	0.002672
Story2	SPEC X Max	X	0.001611
Story1	SPEC X Max	X	0.001086

3.3 Diaphragm Centre of Mass Displacement

The floor wise lateral diaphragm centre of mass displacement are tabulated in table 7 to 10 for both models i.e. building on plain and sloping ground. Also a graph is plotted taking floor level as the abscissa and the displacement as the ordinate for both models in both the longitudinal and transverse direction.

Table -7: Building on plain ground

Story	Diaphragm	Load Case/Combo	UX	UY
Terrace	D1	SPEC X Max	54.604	54.604
Story7	D1	SPEC X Max	52.174	52.174
Story6	D1	SPEC X Max	47.54	47.54
Story5	D1	SPEC X Max	41.033	41.033
Story4	D1	SPEC X Max	32.919	32.919
Story3	D1	SPEC X Max	23.447	23.447
Story2	D1	SPEC X Max	12.959	12.959
Story1	D1	SPEC X Max	2.655	2.655

Table -8: Building on 15 degree slope

Story	Diaphragm	Load Case/Combo	UX	UY
Terrace	D1	SPEC X Max	65.395	66.285
Story9	D1	SPEC X Max	62.9	63.867
Story8	D1	SPEC X Max	58.919	59.921
Story7	D1	SPEC X Max	53.058	54.145
Story6	D1	SPEC X Max	45.17	46.374
Story5	D1	SPEC X Max	35.524	36.872
Story4	D1	SPEC X Max	24.432	25.919
Story3	D1	SPEC X Max	12.373	14.045
Story2	D1	SPEC X Max	4.385	6.35
Story1	D1	SPEC X Max	0.757	1.457

Table -9: Building on 25 degree slope

Story	Diaphragm	Load Case/Combo	UX	UY
Additional Story 2	D1	SPEC X Max	81.147	87.284
Additional Story 1	D1	SPEC X Max	78.282	80.908
Terrace	D1	SPEC X Max	74.243	73.351
Story9	D1	SPEC X Max	69.149	65.231
Story8	D1	SPEC X Max	63.039	56.975
Story7	D1	SPEC X Max	55.637	49.886
Story6	D1	SPEC X Max	46.451	41.299
Story5	D1	SPEC X Max	35.416	31.215
Story4	D1	SPEC X Max	24.219	21.253
Story3	D1	SPEC X Max	13.823	12.523
Story2	D1	SPEC X Max	5.63	5.547
Story1	D1	SPEC X Max	1.12	1.239

Table -10: Building on 35 degree slope

Story	Diaphragm	Load Case/Combo	UX	UY
Additional Story 5	D1	SPEC X Max	68.674	64.149
Additional story 4	D1	SPEC X Max	65.858	63.472
Additional story 3	D1	SPEC X Max	61.616	61.351
Additional story 2	D1	SPEC X Max	56.273	58.001
Additional Story 1	D1	SPEC X Max	49.743	51.948
Terrace	D1	SPEC X Max	41.803	45.973
Story7	D1	SPEC X Max	33.292	37.696
Story6	D1	SPEC X Max	23.233	27.977
Story5	D1	SPEC X Max	16.592	22.553
Story4	D1	SPEC X Max	12.225	18.019
Story3	D1	SPEC X Max	8.772	13.558
Story2	D1	SPEC X Max	5.112	8.288
Story1	D1	SPEC X Max	1.057	1.804

4. CONCLUSIONS

Based on dynamic analysis of various building model following conclusions can be drawn.

1) The performance of 25degree and 35 degree slope building is more vulnerable than plain and 15 degree slope buildings when compare modal analysis results.
2) Sudden change of stiffness is observed from the results of storey drift and displacement due to variation in column heights especially for 25 and 35 degree slope building.
3) 35 degree slope building models performance is worst due to highest diaphragm displacement and successive storey diaphragm displacement is varying reaches to terrace.
4) Building model on plain ground shows uniformly increasing base shear towards the base.
5) 15 degree slope building is attracted more storey shear due to reduced column height (short column effect).

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