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Seismic Analysis of RCC Buildings Resting on Sloping Ground with Varying Number of Bays and Hill Slopes

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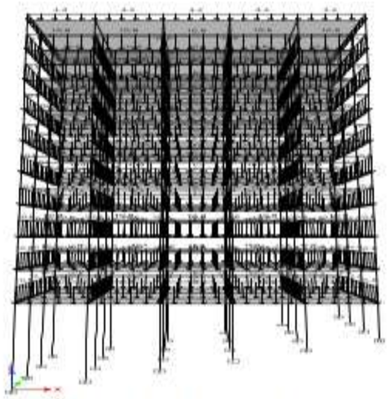
ABSTRACT: Structures resting on sloping ground are highly vulnerable to earthquakes due to irregularities in plan and elevation. Struc- tures are often analysed under earthquake loadings, without considering the effect of soil–structure interaction (SSI). This practice is not advisable from practical point of view. In this present study, an attempt has been made to study the effect of slope angle variation for the structures resting on sloping ground, considering the base of the structures fixed as well as flexible (SSI). The analysis is performed in equivalent static force method (ESFM), response spectrum method (RSM), time history method (THM), nonlinear static method (NLSM) and nonlinear time history method (NLTHM). Results expose the criticality associated with increment of slope angle, with and without SSI consideration. Importance of considering SSI in seismic analysis is also revealed.

KEYWORDS: Structures · Sloping ground · Irregularity · soil–structure interaction · Nonlinear time history method.

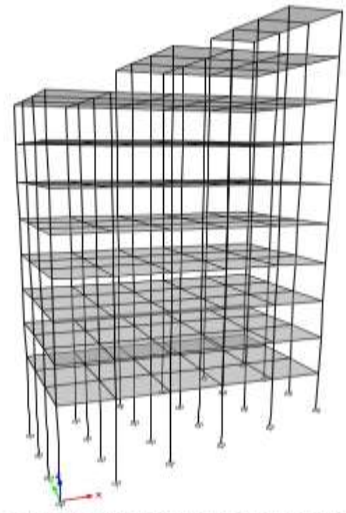
I. INTRODUCTION

Seismic forces acts more sever in hilly regions due to the structural irregularity also it has been studied that the earthquake actions are prone in hilly areas. In India, for example, the north-east states. The scarcity of plain ground in hilly areas compels construction activity on sloping ground resulting in various important buildings such as reinforced concrete framed hospitals, colleges, hotels and offices resting on hilly slopes. The behavior of buildings during earthquake depends upon the distribution of mass and stiffness in both horizontal and vertical planes of the buildings In hilly region both these properties varies with irregularity and asymmetry. Such constructions in seismically prone areas make them exposed to greater shears and torsion. The economic growth and rapid urbanization in hilly region has accelerated the real estate development. Because of which, population density in the hilly region has increased. Therefore, there is popular and pressing demand for the construction of multi-storey buildings on hill slope. While considering the fast and economic constructions, precast construction technique is most suitable in every angle as far as the project size is not small. Buildings in hilly regions have experienced high degree of damage leading to collapse though they have been designed for safety of the occupants against natural hazards. In hilly regions, locally available traditional material like, the adobe, brunt brick, stone masonry and dressed stone masonry, timber reinforced concrete, bamboo, etc., is used for the construction of houses. Earthquake is the most disastrous and unpredictable phenomenon of nature. When a structure is subjected to seismic forces it does not cause loss to human lives directly but due to the damage cause to the structures that leads to the collapse of the building and hence to the occupants and the property. Mass destruction of the low and high rise buildings in the recent earthquakes leads to the need of investigation especially in a developing country like India. 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. Analysis of buildings in hill region is somewhat different than the buildings on levelled ground, since the column of the hill building rests at different levels on the slope. The unsymmetrical buildings require great attention in the analysis and design under the action of seismic excitation. Past earthquakes in which, buildings located near the edge of a stretch of hills or on sloping ground suffered serious damages. The shorter column attracts more forces and undergoes damage, when subjected to earthquakes. **ETABS** is an engineering software product that caters to multi-story building analysis and design. Modeling tools and templates, code-based load prescriptions, analysis methods and solution techniques, all coordinate with the grid-like geometry unique to this class of structure. The biggest hurdles boil down to two main factors: the gradient of the slope and whether the lot is upslope or down slope. The other problems associated with hill buildings are, additional lateral earth pressure at various levels, slope instability, different soil profile yielding unequal settlement of foundation. The main objective of this work is to improve the structure which is on a sloping ground. The structure is analyzed using the Response Spectrum method using the E-TAB software. The structure should withstand moderate level of earthquake ground motion without structural damage, but possibly with some structural as well as non-structural damage. The annual losses due to earthquakes are very large in many parts of the world. They not only cause great destruction in terms of human casualties, but also have a tremendous economic impact on the affected area. India had witnessed several major disasters due to earthquakes over the past century. The north - east region of the country as well as the entire Himalayan belt is susceptible to great earthquakes of magnitude more than 8.0. The main cause of earthquakes in these regions is due to the movement of the Indian plate towards the Eurasian plate at the rate of about 50 mm per year. The Buildings on hill slopes are highly unsymmetrical in Plan and elevation.

II. PROBLEM FORMULATION



STEP BACK TYPE FRAME



STEP BACK-SET BACK TYPE FRAME

A study of seismic behavior of an unsymmetrical multistory buildings resting on sloping ground is done considering different structural configuration. Building configuration will be specified by following factors.

Type of Frame
Step Back type of Building frame structure (STP-FRAME)
Step Back-Set Back type of building frame structure (STP-SET-FRAME)

Number of storey's
The model used to scrutinize in the dissertation have 3 distinct storey numbers.

Most of the buildings in the region are considered to have 6, 8 and 10 stories and hence are used to configure the models. Three story configuration are considered such as6-story, 8-story and 10-story.

Number of the Bays

To compare more generalized building figure two types of bay configuration are considered both are unsymmetrical and give excruciating results in both planar axis. Two bay configurations are, 1. 3X5 Bay-system and 3X7 Bay-system.

Slope of the hills

Most noted hill slop angles as per the records registered with national terrain data are alanysed and four most feasible hill slopes are considered in vicinity of optimized earthwork process. Such as, 16.32°, 21.58°, 26.56° and 31.56°.

Model No	**CONIFGURATION**			
	Frame Type	**Hill Slope Angle in ^{0}**	**Bay System**	**No of Storey**
1	STP BACK	16.32	3X5	10
2	STP BACK	16.32	3X5	8
3	STP BACK	16.32	3X5	6
4	STP BACK	16.32	3X7	10
5	STP BACK	16.32	3X7	8
6	STP BACK	16.32	3X7	6
7	STP BACK	21.58	3X5	10
8	STP BACK	21.58	3X5	8
9	STP BACK	21.58	3X5	6
10	STP BACK	21.58	3X7	10
11	STP BACK	21.58	3X7	8
12	STP BACK	21.58	3X7	6
13	STP BACK	26.56	3X5	10
14	STP BACK	26.56	3X5	8
15	STP BACK	26.56	3X5	6
16	STP BACK	26.56	3X7	10
17	STP BACK	26.56	3X7	8
18	STP BACK	26.56	3X7	6
19	STP BACK	31.56	3X5	10
20	STP BACK	31.56	3X5	8
21	STP BACK	31.56	3X5	6
22	STP BACK	31.56	3X7	10
23	STP BACK	31.56	3X7	8
24	STP BACK	31.56	3X7	6
25	STP-SET BACK	16.32	3X5	10
26	STP-SET BACK	16.32	3X5	8
27	STP-SET BACK	16.32	3X5	6
28	STP-SET BACK	16.32	3X7	10
29	STP-SET BACK	16.32	3X7	8
30	STP-SET BACK	16.32	3X7	6
31	STP-SET BACK	21.58	3X5	10

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32	STP-SET BACK	21.58	3X5	8
33	STP-SET BACK	21.58	3X5	6
34	STP-SET BACK	21.58	3X7	10
35	STP-SET BACK	21.58	3X7	8
36	STP-SET BACK	21.58	3X7	6
37	STP-SET BACK	26.56	3X5	10
38	STP-SET BACK	26.56	3X5	8
39	STP-SET BACK	26.56	3X5	6
40	STP-SET BACK	26.56	3X7	10
41	STP-SET BACK	26.56	3X7	8
42	STP-SET BACK	26.56	3X7	6
43	STP-SET BACK	31.56	3X5	10
44	STP-SET BACK	31.56	3X5	8
45	STP-SET BACK	31.56	3X5	6
46	STP-SET BACK	31.56	3X7	10
47	STP-SET BACK	31.56	3X7	8
48	STP-SET BACK	31.56	3X7	6

III. RESULTS

In this chapter the results of flat ground floor building and sloping ground floor building (0˚ , 5˚ ,10˚ ,15˚ & 20˚) will obtained in two seismic zones (zone II & zone IV), then these results will be compared between them in the following categories as shown in Figs.9 to 37:

- Time Periods, frequency
- Base reaction, base shear
- Building displacement (Ux)
- Inter story drift.
- Bending Moment, shear force, axial force.

Software analysis of all the 48 models is done and result obtained is tabulated in parametric values of Base Shear, Top Story Displacement and Fundamental Time Period. ETABS results for base shear or story shears reported in the global coordinate system as P, VX, VY, T, MX and MY. The forces are reported at the top of the story, just below the story level itself, and at the bottom of the story, just above the story level below. The sign convention for story level forces is exactly the same as that for frame elements with the bottom of the story corresponding to the i-end of the frame element and the top of the story corresponds to the j-end of the frame element. The story shears and overturning moments are always reported at the following locations; Global X=0, Global Y=0 and Global Z.ETABS results for Top story Displacement or any generalized displacement is a named displacement measure that is user defined. It is simply a linear combination of displacement degrees of freedom from one or more joints. For example, a defined generalized displacement named "DRIFTX" could be the difference of the UX displacements at two joints on different stories of a building. Another defined generalized displacement named AVGRZ could be the sum of three rotations about the Z axis, each scaled by 1/3.Generalized displacements are primarily used for output purposes, except that a generalized displacement also can be used to monitor a displacement-controlled nonlinear static analysis. ETABS results for Fundamental Time Period are obtained from the codal provision, as described below.

Model No	**CONIFGURATION**				**BASE SHEAR in kN**	
	Frame Type	**Hill Slope Angle in ^{0}**	**Bay System**	**No of Storey**	**Fx**	**Fy**

1	STP BACK	16.32	3X5	10	516.167	284.65
2	STP BACK	16.32	3X5	8	492.977	278.016
3	STP BACK	16.32	3X5	6	372.84	266.41
4	STP BACK	16.32	3X7	10	580.136	286.33
5	STP BACK	16.32	3X7	8	529.91	260.2
6	STP BACK	16.32	3X7	6	365.03	221.46
7	STP BACK	21.58	3X5	10	511.67	273.366
8	STP BACK	21.58	3X5	8	497.33	265.077
9	STP BACK	21.58	3X5	6	377.1984	251.6622
10	STP BACK	21.58	3X7	10	575.0837	267.1452
11	STP BACK	21.58	3X7	8	538.1762	240.897
12	STP BACK	21.58	3X7	6	373.297	203.636
13	STP BACK	26.56	3X5	10	508.683	264.073
14	STP BACK	26.56	3X5	8	381.63	254.6945
15	STP BACK	26.56	3X5	6	572.326	240.2412
16	STP BACK	26.56	3X7	10	543.712	252.35
17	STP BACK	26.56	3X7	8	381.7	226.545
18	STP BACK	26.56	3X7	6	506.77	190.96
19	STP BACK	31.56	3X5	10	506.77	256.98
20	STP BACK	31.56	3X5	8	506.62	245.98
21	STP BACK	31.56	3X5	6	386.48	230.411
22	STP BACK	31.56	3X7	10	543.404	240.411
23	STP BACK	31.56	3X7	8	390.99	215.305
24	STP BACK	31.56	3X7	6	518.2	181.43
25	STP-SET BACK	16.32	3X5	10	425.86	284.161
26	STP-SET BACK	16.32	3X5	8	305.73	276.21
27	STP-SET BACK	16.32	3X5	6	659.3	262.23
28	STP-SET BACK	16.32	3X7	10	501.685	327.03
29	STP-SET BACK	16.32	3X7	8	336.805	305.485
30	STP-SET BACK	16.32	3X7	6	513.39	272
31	STP-SET BACK	21.58	3X5	10	430.225	272.987
32	STP-SET BACK	21.58	3X5	8	310.087	263.505
33	STP-SET BACK	21.58	3X5	6	652.014	248.084
34	STP-SET BACK	21.58	3X7	10	509.953	304.48
35	STP-SET BACK	21.58	3X7	8	345.073	282.11
36	STP-SET	21.58	3X7	6	510.2713	249.7

	BACK					
37	STP-SET BACK	26.56	3X5	10	434.65	263.67
38	STP-SET BACK	26.56	3X5	8	341.515	253.67
39	STP-SET BACK	26.56	3X5	6	647.785	263.93
40	STP-SET BACK	26.56	3X7	10	518.352	286.702
41	STP-SET BACK	26.56	3X7	8	353.473	264.27
42	STP-SET BACK	26.56	3X7	6	508.373	233.194
43	STP-SET BACK	31.56	3X5	10	439.505	255.64
44	STP-SET BACK	31.56	3X5	8	319.367	244.442
45	STP-SET BACK	31.56	3X5	6	645.83	227.792
46	STP-SET BACK	31.56	3X7	10	527.55	272.25
47	STP-SET BACK	31.56	3X7	8	439.505	250.173
48	STP-SET BACK	31.56	3X7	6	362.67	220.504

Model No	**CONIFGURATION**				**Fundamental Time Period in sec**
	Frame Type	**Hill Slope Angle in ^{0}**	**Bay System**	**No of Storey**	
1	STP BACK	16.32	3X5	10	1.439
2	STP BACK	16.32	3X5	8	1.184
3	STP BACK	16.32	3X5	6	0.935
4	STP BACK	16.32	3X7	10	1.621
5	STP BACK	16.32	3X7	8	1.36
6	STP BACK	16.32	3X7	6	1.161
7	STP BACK	21.58	3X5	10	1.509
8	STP BACK	21.58	3X5	8	1.253
9	STP BACK	21.58	3X5	6	1.001
10	STP BACK	21.58	3X7	10	1.758
11	STP BACK	21.58	3X7	8	1.492
12	STP BACK	21.58	3X7	6	1.225
13	STP BACK	26.56	3X5	10	1.573
14	STP BACK	26.56	3X5	8	1.316
15	STP BACK	26.56	3X5	6	1.061
16	STP BACK	26.56	3X7	10	1.883
17	STP BACK	26.56	3X7	8	1.612
18	STP BACK	26.56	3X7	6	1.335

19	STP BACK	31.56	3X5	10	1.635
20	STP BACK	31.56	3X5	8	1.376
21	STP BACK	31.56	3X5	6	1.118
22	STP BACK	31.56	3X7	10	2.002
23	STP BACK	31.56	3X7	8	1.724
24	STP BACK	31.56	3X7	6	1.439
25	STP-SET BACK	16.32	3X5	10	1.284
26	STP-SET BACK	16.32	3X5	8	1.03
27	STP-SET BACK	16.32	3X5	6	0.779
28	STP-SET BACK	16.32	3X7	10	0.881
29	STP-SET BACK	16.32	3X7	8	1.097
30	STP-SET BACK	16.32	3X7	6	0.827
31	STP-SET BACK	21.58	3X5	10	1.347
32	STP-SET BACK	21.58	3X5	8	1.091
33	STP-SET BACK	21.58	3X5	6	0.835
34	STP-SET BACK	21.58	3X7	10	1.481
35	STP-SET BACK	21.58	3X7	8	1.208
36	STP-SET BACK	21.58	3X7	6	0.923
37	STP-SET BACK	26.56	3X5	10	1.406
38	STP-SET BACK	26.56	3X5	8	1.147
39	STP-SET BACK	26.56	3X5	6	0.887
40	STP-SET BACK	26.56	3X7	10	1.592
41	STP-SET BACK	26.56	3X7	8	1.31
42	STP-SET BACK	26.56	3X7	6	1.013
43	STP-SET BACK	31.56	3X5	10	1.462
44	STP-SET BACK	31.56	3X5	8	1.201
45	STP-SET BACK	31.56	3X5	6	0.937
46	STP-SET BACK	31.56	3X7	10	1.699
47	STP-SET BACK	31.56	3X7	8	1.409
48	STP-SET BACK	31.56	3X7	6	1.099

IV.CONCLUSIONS

- Step back frames produce higher base shear as compared with step back-set back frames.
- The step back building frames gives higher values of time period as compared with step back-set back frames.
- The step back building frames give higher values of top storey displacement as compared with step back-set back frames.
- In step back and step back-set back frames; it is observed that extreme left columns, which are on the higher side of the sloping ground and are short, are the most affected. Special attention is required while designing these short columns.
- The performance of step back frames during seismic excitation could prove more detrimental than other configurations of building frames. Hence, step back building frames on sloping ground are not desirable. However, it may be adopted, provided system to control the large displacement is adopted.
- Step back-set back frames produces less torsion effects as compared to step back frames. In case step back building frames are proposed, then step back frame shall be designed for higher moments induced in columns due to earthquake.

- As number of bays increases time period & top storey displacement decreases. Therefore, it is concluded that greater number of bays are observed to be better under seismic conditions.
- As hill slopes increases time period & top storey displacement decreases

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