www.ijiarec.com

ISSN:2348-2079

Volume-7 Issue-2

International Journal of Intellectual Advancements and Research in Engineering Computations

Seismic analysis of R.C framed buildings resting on hilly slopes

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ABSTRACT

Most of the hilly regions in India are highly seismic. A building resting on hilly slope region differs in quite different way from the buildings located at plane surfaces. The buildings are situated in hilly areas are much more vulnerable to seismic environment. The various floor levels of such building steps back towards the hill slope and at the same time buildings may have setbacks also. Analysis of hilly slope buildings is somewhat different than the ground level buildings, since the column of such building rests at different levels on the slope. In present study, the analysis of G+3 buildings on varying slope angles includes 0°, 7.5°, 15°, 22.5° and 30° respectively. The seismic forces are considered as per IS: 1893-2002. The buildings are considered to be located at seismic zone III with the damping ratio of 5%. Seismic analysis has been performed using Equivalent static analysis. The 3D analytical model of buildings has been generated and analyzed using STAAD.Pro to study the effect of varying height of columns in ground storey due to sloping ground.

Keywords: Hilly region, Linear static, Seismic analysis, STAAD.pro.

INTRODUCTION

Seismic analysis is a type of structural analysis and is the analysis of the response of a building structure to earthquakes. It is part of the process of design of structure, earthquake engineering or structural assessment and in regions where earthquakes are frequent or earthquake zones. This kind of approach involves a set of forces acting on a building to demonstrate the effect of earthquake motion. The building must be low-rise and should not twist when the ground moves. The response is obtained from a design response spectrum through natural frequency of building. India having a great arc of mountains consisting of the Himalayas defines the northern Indian and the Western and Eastern Ghats which defines the Southern India. These were formed by the on-going tectonic collision of the Indian and Eurasian plates where housing densities of approximately 62159. 2 per Sq. Km are around as per 2011 Indian census. Hence there is a requirement to research to be done on the seismic safety factor and designing of these structures on terrain plane. Calculation of ground terrain is fundamental to many traditional Geographical Information Systems (GIS) applications. Slope is an important component in scientific, military and civilian analyses. Analysis of buildings in hill region is somewhat different than the buildings on leveled ground, since the column of the hill building rests at different levels on the slope. Such buildings have mass and stiffness varying along the vertical and horizontal planes resulting the center of mass and center of rigidity do not coincide on various floors, hence they demand torsional analysis, in addition to lateral forces under the action of earthquakes.

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Seismic Analysis

The seismic demands on the structure are estimated by two different methods which includes Elastic and inelastic method. In elastic method, the structure remains elastic and the seismic demands on the structure is reduced using response reduction factor which assumes that the structure has the capacity to go beyond elastic limit but the performance is never checked. While in inelastic method, unreduced seismic demands are tested against the force resisting capacity and inelastic deformation capacity of the structure. In this scenario a true performance of the structure is tested and made sure it meets all the criteria of collapse prevention under maximum considered earthquake.

Hilly Slopes

Buildings resting on hill slopes can be categorized as Up-slope buildings and Down-slope buildings.

Up-slope buildings

These buildings are constructed on ground that rises above the road level. The main level of such buildings is generally built directly on or relatively close to its foundations.

Down-slope buildings

Down-slopes buildings are constructed on ground that drops. Hence the main level of the building is at or near street level with supports that rise from foundations that are embedded in the ground that slopes down and away from the main level.

LITERATURE STUDY

Birajdar and Nalawade (2004) studied unstable behaviour of buildings resting on hill slopes. They analysed twenty four RC building frames with 3 completely different configurations as Step back building, Step back building located at a slope of twenty seven degree with the Horizontal. They studied the unstable response of buildings with variable storeys starting from four to eleven (15.75m to 40.25m), carries with it 3 bays on slope direction and one bay across slope, settled in unstable zone III.

Rayyan-Ul Hassan and H.S.Vidyadhara (2013) [2] studied the impact of earthquake on six totally different models resting on plain and sloping ground that are clean frame model, building with initial soft floor and different floors with brick infill wall and building with initial soft storey and different storeys with brick infill and additionally supplied with shear wall at corners. The numbers of bays in horizontal direction were unbroken four with twelve numbers of stories and every one buildings were set in seismal zone V.

Ravikumar C. M et al. (2012) [3] studied seismal performance of RC buildings within which they contemplate vertically irregular buildings resting on plain ground and buildings resting on slopes for which 2 kinds of configurations were thought of particularly buildings resting on diagonal ground in X-direction and buildings resting on diagonal ground in Y-direction. The amount of bays in X-direction and Y-direction were unbroken five and four severally, with three levels and set in severe zone V. The performance of those buildings was studied by linear analysis mistreatment code IS 1893 (part-1) 2002 on sloping ground area unit additional susceptible to earthquake than the buildings resting on plain ground.

Sunilsinghrawat (2015) In his study, the analysis of G+3 and G+4 buildings on varying slope angles i.e.0°,7.5°,15°,22.5° and 30° has been conducted. Both type of building configurations (step back and step back setback) has been considered. The seismic forces are considered as per IS: 1893-2002. The buildings are considered in seismic zone IV and damping ratio 5%. Seismic analysis has been done using Linear Static, Linear Dynamic method. 3D analytical model of buildings have been generated and analyzed using structural analysis tool "STAAD. Pro 2007" to study the effect of varying height of columns in ground storey due to sloping ground. The response parameters base shear, top storey displacement, shear in bottom storey column, time period are critically analyzed to quantify the effects of various sloping ground. It is found that column on the higher side of slope i.e. short columns are subjected to large shear force than longer columns on lower side. The step back setback buildings performed better than step back buildings under earthquake forces. The base shear and top storey displacement in step back setback buildings is much lower than the setback buildings on the sloping ground.

Babu et al. (2012): The present investigation performed seismic analysis of different symmetric and assymmetric structures built on plain as well as on inclining ground. They directed investigation utilizing structures with various setups which are plan symmetry and asymmetry having different seismic zones. They considered a G+4 structure in which one storey is over the ground level and it is developed at an inclination of 30 degree. They observed that the short column subjected to worst level of severity and lie beyond prevention from failure.

Achin Jain, Rakesh Patel (2017): [4] This paper investigates the seismic behaviour of multi storey buildings on sloping ground considering soil-structure interaction. The analysis of a G+4 storey RCC building on varying slope angles. This paperalso has analysis of structure resting on sloping ground for different soil conditions like Soft Clay, Hard Clay, Dense Sand and Rock. Maximum top storey displacement for the structure has been obtained from equivalent static analysis for soft clay, dense sand, hard clay and rock.

Narayan Kalsulkar, Satish Rathod (2015): [3] In this study, the response spectrum method is carried out on the type of structure that rests on the sloping ground. Building frames which occurs in hilly regions are narrowed down to two basic formats such as step back frames and step back-set back frames and dynamic responses have been studied for various building configuration. They have also given that the performance of step back frames during seismic excitation could prove more vulnerable than other configurations of building frames, hence step back-set back frames are more desirable than step back frames. As number of bays increases time period & top storey displacement decreases. Therefore, they concluded that greater numbers of bays are observed to be better under seismic conditions.

ANALYTICAL STUDY

Angle of ground slope = 0°,7.5°,15°,22.5° and 30°
Number of bays in X direction=4
Number of bays in Z direction=1
Bay width in X direction=4 m
Bay width in Z direction=4 m
Top three storey height=3.5 m
Bottom storey short column height=1.5m
Bottom storey long column height=3.7 m
Size of beams =0.4m× 0.4m
Size of columns =0.4m× 0.4m
Slab thickness=120 mm
Exterior masonry wall thickness=200 mm
Interior masonry wall thickness=100 mm
Type of supports=Fixed
Grade of concrete= M25
Grade of steel reinforcement= Fe250
Density of brick masonry= 20 kN/m^3
Elasticity of concrete = 2.5×10^4 N/mm^2
Poisson ratio for concrete= 0.17
Live load on floor = 4 kN/m^2
Live load on roof = 2 kN/m^2
Type of structure= Ordinary RC moment-resisting frame without considering brick infill panels
Seismic zone= III
Response reduction factor= 3
Importance factor= 1
Damping= 5%
Soil type= medium soil

MODELLING

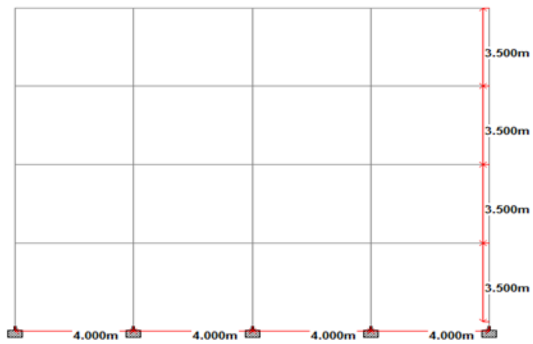

Fig. 1G+3 building with 0° slope

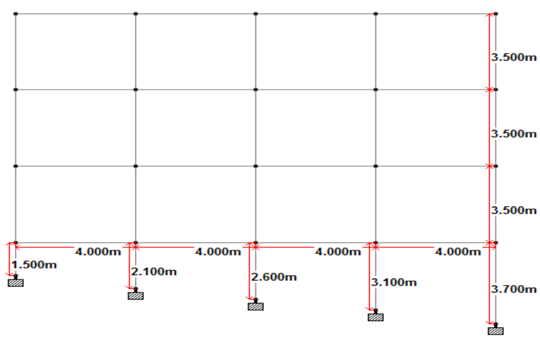

Fig 2 G+3 building with 7.5° slope

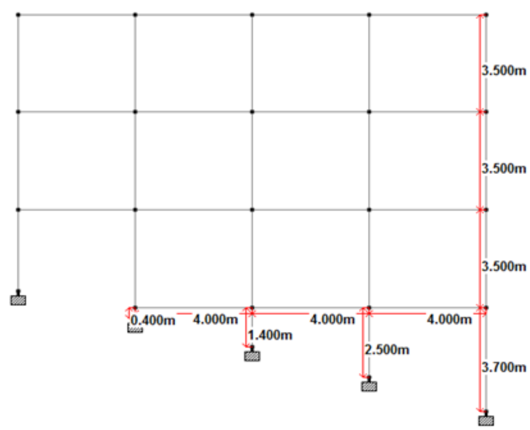

Fig 3 G+3 building with 15° slope

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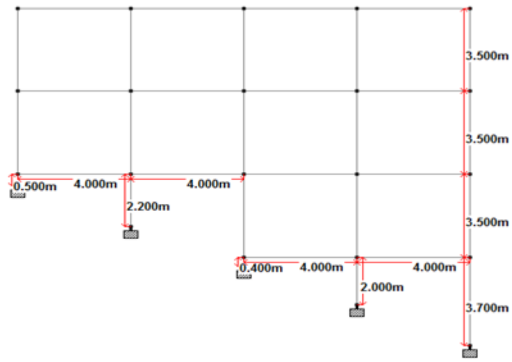

Fig 4 G+3 building with 22.5° slope

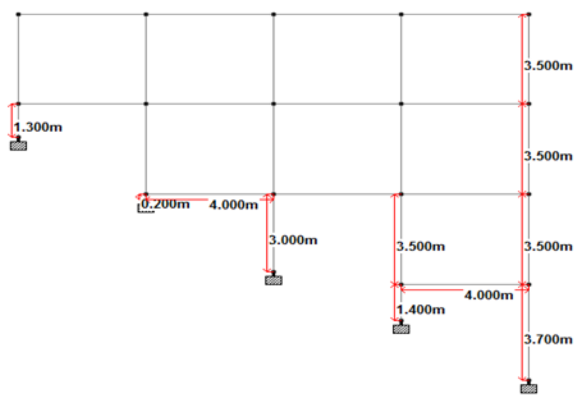

Fig 5 G+3 building with 30° slope

RESULTS AND DISCUSSIONS

Manual Time period and Base shear calculations

Fundamental time period of building, **T= 0.075h**$^{0.75}$

Height of building, h= 14.2 m

∴ Time Period T= $0.075 \times 14.2^{0.75}$

= 0.55 sec

∴ Response acceleration coefficient,

sa/g = 2.5

Seismic weight of roof= Dead load on roof

∴ Seismic weight of roof = 792 kN

Seismic weight of 3rd floor = Dead load on 3rd floor + 50% of live load on floor.

∴Seismic weight of 3rd floor= 1184 + 0.5 x (4 x64) =1312kN

Seismic weight of 2nd floor= Dead load on 2nd floor + 50% of live load on floor

∴ Seismic weight of 2nd floor = 1184 + 0.5 × (4 × 64)
= 1312 kN

Seismic weight of 1st floor = Dead load on 1st floor + 50% of live load on floor

∴ Seismic weight of 1st floor = 1065.6 + 0.5 × (4 × 64) = 1193.6 kN

Total seismic weight of building,

W = 792 + 1312 + 1312 + 792 = 4609.6 kN

Base shear VB= Ah* w

A_h= $(Z*I*S_a)/(2R*g)$ = 0.0667

∴V_b= 0.0667*4610 = 310 kN

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Base shear values given by STAAD Pro for different sloping conditions:

Table 1 Base shear and time period values given by STADD for different degrees of slope

Slope of the building (degree)	Base shear V_b (kN)	Time period (S)
0	327.81	0.547
7.5	325.32	0.549
15	305.5	0.552
22.5	285.6	0.552
30	248.03	0.560

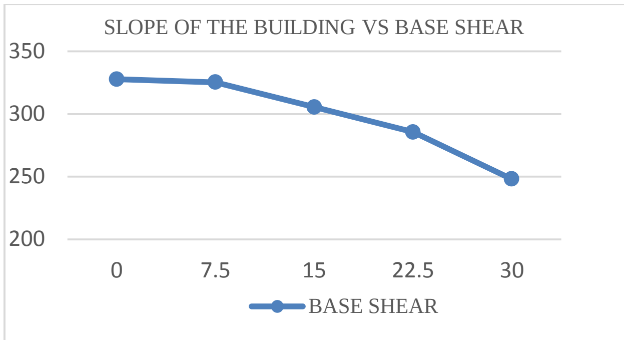

Fig 6 Variation of Base shear for different hilly slopes

Table 2 Maximum Displacement is given for different slope of the structures

Slope of the structure (degree)	Maximum Displacement
0	15.372
7.5	31.322
15	31.322
22.5	26.459
30	20.758

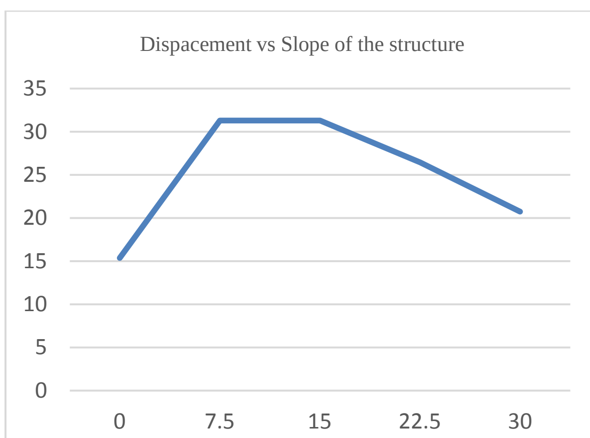

Fig 7 Variation of maximum displacement for different hilly slopes

Table 3 Storey drift in X direction

	0^0	**7.5^0**	**15^0**	**22.5^0**	**30^0**
Ground floor	0.258	0.0358	0.0358	0	0.0073
First floor	0.0358	0.0358	0.0358	0	0.0073
Second floor	0.5215	0.6215	0.6215	0.0627	0.1550
Third floor	0.6821	0.7081	0.7081	0.5452	0.3246

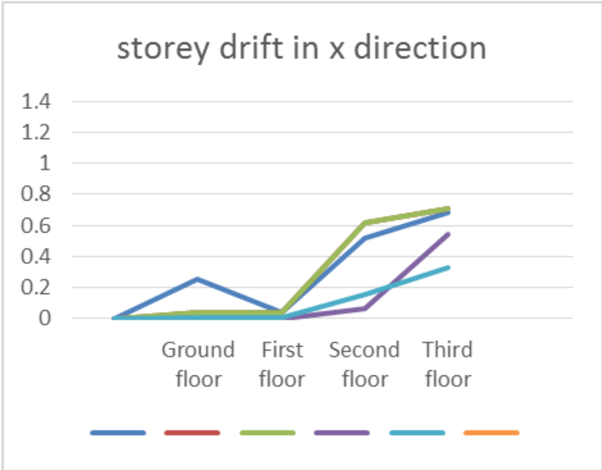

Fig 8 Graph showing Storey drift in X direction

Table 4 Storey drift in Z direction

	0^0	**$7.5\ ^0$**	**$15\ ^0$**	**22.5^0**	**30^0**
Ground floor	0.2638	0.2738	0.2738	0	0.4938
First floor	0.2588	0.2738	0.2738	0.6469	0.4938
Second floor	0.9212	1.0558	1.0558	0.7973	0.7083
Third floor	0.8264	0.9374	0.9374	0.5848	0.4775

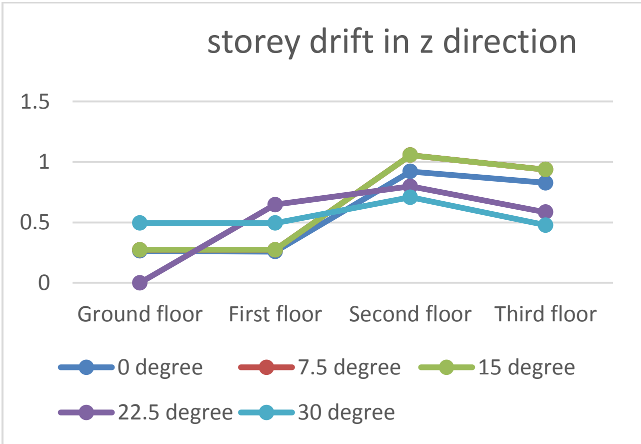

Fig 9 Graph showing Storey drift in Z direction

CONCLUSION

Due to scarcity of plain land area majority of the buildings are constructed on the hill slopes with irregular structural configuration having foundations at different levels. when they subjected to lateral loads, these buildings are generally subjected to significant torsional response. The seismic analysis is performed for buildings resting on variable slopes. it is mainly due to the differential loading in columns and the combination of short columns and long columns. Base shear is the most important factor in designing of earthquake resistant structures. The value of base shear gradually decreases as the slope of the hill increases. However displacement is maximum at 7.5 degree and 15 degree slope beyond that the value of displacement decreases due to the reduction in number of bays as well as the length of the column. Hence the seismic forces can be minimized by providing shear walls and retaining walls in hilly slopes.

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