A Study on Dynamic Characteristics of RC Buildings on Hill slopes

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Abstract: *The buildings situated in hilly areas are much more prone to seismic environment in comparison to the buildings that are located in flat regions. Structures on slopes differ from other buildings since they are irregular both vertically and horizontally hence torsionally coupled and are susceptible to severe damage when subjected to seismic action. The columns of ground storey have varying height of columns due to sloping ground. In this study, behaviour of G+3 storied sloped frame building having step back set back configuration is analyzed for sinusoidal ground motion with different slope angles i.e., 16.7°, 21.8°, 26.57° and 30.96° using structural analysis tool STAAD Pro. by performing Response Spectrum analysis have been carried out as per IS:1893 (part 1): 2002. The results were obtained in the form of top storey displacement and base shear. It is observed that short column is affected more during the earthquake. The analyses showed that for construction of the building on slopy ground the stepback setback building configuration is suitable.*

Keywords: Step back set back, Sloping ground, Response spectrum analysis

1. Introduction

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 north-eastern parts of India have large scale of hilly terrain which fall in the category of seismic zone IV and V. Recently Sikkim (2011), Doda (2013) and Nepal earthquake (2015) caused huge destruction. In this region there is a demand of construction of multistory RC framed buildings due to the rapid urbanization and increase in economic growth and therefore increase in population density. Due to the scarcity of the plain terrain in this region there is an obligation of the construction of the buildings on the sloping ground..

Based on the observations, it can be stated that Step back buildings are subjected to higher amount of torsional moments as compared to Step back Set back buildings and may prove more vulnerable during the seismic excitation. The configuration of Step back Set back building has an advantage in neutralizing the torsional effect, resulting into better performance and relatively less displacements than the Step back building during the earthquake ground motion, provided the short columns are taken care of in design and detailing

2. Objectives

In the present study, the dynamic characteristics of a G+3 storied RC framed step back set back building on a hill slope is investigated by varying the slope angles. Modelling an analysis is performed using STAAD.Pro.The main objectives of the study is as follows:

a) To study the variation of base shear, displacement with respect to variation in various hill slopes.
b) To determine the angle that is subjected to less displacement and which is safe in increasing the height of building.

3. Modelling of Building

The general software STAAD Pro. has been used for the modelling. It is more user friendly and versatile program that offers a wide scope of features like static and dynamic analysis, non linear dynamic analysis and non linear static pushover analysis ,response spectrum analysis, time history analysis etc. STAAD Pro. Software is used in modelling of building frames and it is general purpose software for performing the analysis and design of a wide variety of structures.

### 3.1 Building Plan and Dimension Details

The building used in this study are G+3 storied with 3 m bays along longitudinal direction and 3 m bays along transverse direction and it is located in seismic zone III. Table 1 shows the specification of G+3 storied RC building and the complete details of the structure including modelling concepts. The three dimensional RC frame of G+3 storied building having 4 columns of different height with respect to the slope angle variation were considered in this study. Figure 1 shows the plan of the building representing the X and Y direction used for analysis. Figure 2 shows the three dimensional line sketch of the building frame on ground slope in the X, Y and Z direction

Figure 1: Plan of Building

Table 1: Details and dimension of the building models

Title	Specifications
Floor height	3.5 m
Spacing in X direction	3m
Spacing in Y direction	3m
Beam sizes	230 x 450 mm
Column sizes	550 x 550 mm
Slab thickness	125 mm
Live load	3 kN/m²
Floor finish	1 kN/m²
Concrete Grade	M20
Modulus of Elasticity	22360000 kN/m²
Poison's ratio	0.17
Compressive strength	20000 kN/m²
Steel	Fe 415
Strength of steel	415000 kNm²
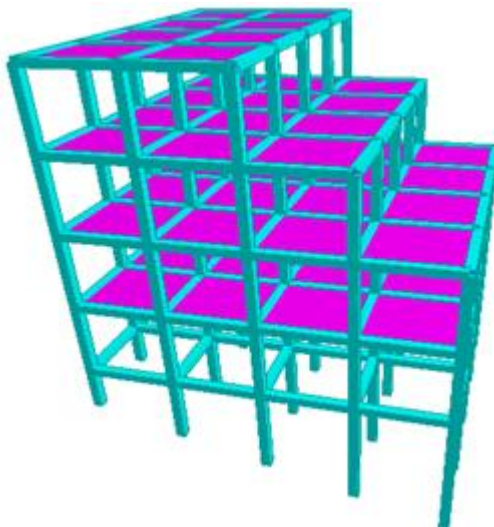
Figure 2: Three Dimensional View of Model

3.2 Load Formulation

3.2.1 Gravity Loads
Gravity loads on the structure include the self weight of beams, columns and slabs other permanent members. The self weight of beams, columns (Frame members) and slabs (Area section) were automatically considered by the program itself.

3.2.2 Lateral loads:
Response Spectrum Method as per IS1893 (Part1):2002
Z = 0.16 considering zone factor for zone 3 (Table 2 of code)
I = 1.0 considering residential building (Table 6 of code)
R=5.0 considering special RC moment resistant frame (SMRF) (Table 7 of code)

The response spectrum analysis is carried out using the spectra for medium soil as per IS 1893 (Part 1) 2002 for seismic zone V, medium soil and 5% damping. The spectral acceleration coefficient (Sa/g) values are calculated as follows.

For medium soil sites,
$Sa/g = 1 + 15T$, $(0.00 \leq T \leq 0.10)$, (T= time period in seconds)
$= 2.50$, $(0.10 \leq T \leq 0.55)$
$= 1.36/T$, $(0.55 \leq T \leq 4.00)$

4. Analysis

After assigning the loads to the structure, seismic analysis is done to evaluate the dynamic results in the form of base shear and lateral top storey displacements. After analysis design can be executed in STAAD Pro.as it includes various international codes and the structure can be designed using this codes. Design codes (IS; 1893, Part 1) specify response spectra which determine the base acceleration applied to each mode according to its period.

5. Results and Discussion

After analysing the models various results are obtained. And these results are evaluated by preparing various graphs. The graphs are compared to understand the behaviour of building and find the angle that subjected to less displacement for increase the height of the building and is more effective against lateral loads.

5.1 Lateral displacement
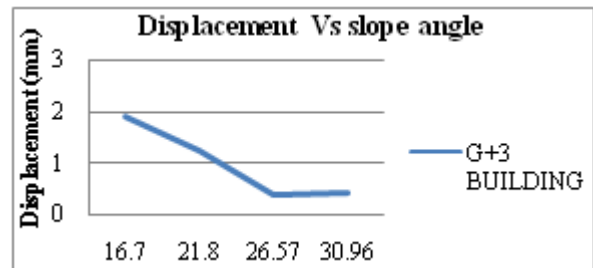
Figure 3: Maximum Lateral Displacement (mm) in X Direction

Table 2: Lateral Displacements Values in mm

Model	Ground slope in degrees	Top storey displacement (mm)
1	16.7	1.934
2	21.8	1.265
3	26.57	0.405
4	30.96	0.439

The resulting lateral displacement curve for the 4 models with G+3 storey on different slope angles is shown in the Fig 6.1. From the above graph, it is observed that the lateral displacement on 16.7 degree sloped frame experiences maximum storey displacement due to low value of stiffness of short column while the 26.57 degree frame experiences minimum storey displacement. The slope angle influences the displacement values. It can be seen that the 26.57 degrees and 30.96 degrees does not make significant difference but as the story height increases the values are clearly distinct

5.2 Base shear
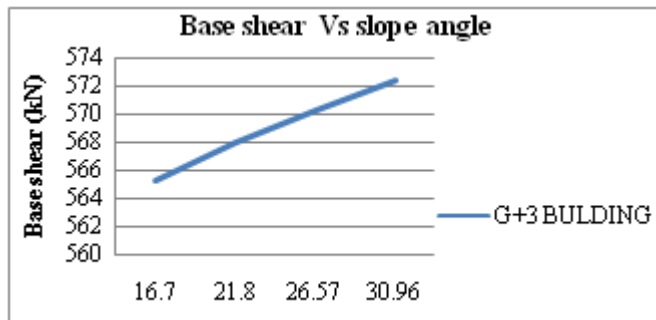
Figure 4: Maximum base shear (kN) in X Direction

The resulting base shear graph for the 4 models with G+3 storey is shown in the Fig. From the above graph, it is observed that the base shear of the sloped frame increases with the increase in the slope angle

Table 3: Base shear Values in kN

Model	Ground slope in degrees	Base shear (kN)
1	16.7	565.28
2	21.8	567.97
3	26.57	570.27
4	30.96	572.40

The base shear of all the buildings are nearly the same with little variations but their distribution on columns of ground storey is such that the short column attracts the majority (75% approx.) of the shear force which leads to plastic hinge formation on the short column and are vulnerable to damage.

6. Conclusions

The main conclusions obtained from the analysis of models are summarized below:
- It is found that the 16.7 degree sloped frame experiences maximum storey displacement due to low value of stiffness of column

- It can be seen that the top storey displacement decreases with the increase in slope angles.
- The base shear value increases with the increase in slope angles.
- The base shear of all the buildings are nearly the same with little variations but their distribution on columns of ground storey is such that the short column attracts the majority (75% approx.) of the shear force which leads to plastic hinge formation on the short column and are vulnerable to damage.
- The base shear acts more in longitudinal direction than in transverse direction.
- From this study we observed that for 21.8 and 26.57 degrees are safe to increase the height of the building due to the less displacement values.

7. Future Scope

This present study considered to only seismic analysis. The same may be extended to wind analysis as per BIS code 875(Part-III):1987.

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