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Seismic Behaviour of Reinforced Concrete Framed Buildings with Columns of Different Heights within One Storey

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ABSTRACT

The aim of this work is to make a study on seismic behaviour of reinforced concrete framed buildings with columns of different heights within on storey. For this study an MS Excel sheet was developed in which 20 cases of varying slope by small increments which can formulate the mode shapes, frequency, time period, storey drift, base shear, etc. The results were compared. Using STAAD Pro v8i, 4 reinforced concrete frames on plane ground were modelled. Then the analysis was carried out for gravity as well as seismic loading. Models were created for the above cases when placed on sloped terrain. Comparison for various results like time period, base shear, spectral acceleration, response spectrum, stress in columns were done. The reinforcement detailing of all the above 8 models were done using STAAD Pro v8i, which were used as input data while doing the modelling in ANSYS 12. All the above mentioned 8 models were modelled in ANSYS 12 with element material as SOLID65. The volume ratio and orientation angles were entered as obtained from STAAD Pro v8i concrete design results. Monotonic loading was applied to the models and results like load displacement hysteresis curve, stress on members, deflected shapes, etc. were extracted. The results show that when a reinforced concrete framed structure is built on a sloping terrain, the short columns tend to fail easily. Shear cracking pattern appeared at the beam column joint of short columns. Long column being more ductile takes up lesser lateral force when compared to the short columns.

***Keywords*—** Base Shear, Displacement, Drift, Monotonic loading, Seismic behaviour, Short column effect, Time Period.

I. INTRODUCTION

During past earthquakes, reinforced concrete (RC) frame buildings that have columns of different heights within one storey, suffered more damage in the shorter columns as compared to taller columns. When earthquake affects buildings constructed on slope grounds, all columns move horizontally by the same amount along with the floor slab at a particular level. If short and tall columns exist within the same storey level, then the short columns attract several times larger earthquake force and suffer more damage as compared to taller ones. Poor behaviour of short columns is due to the fact that in an earthquake, a tall column and a short column of same cross-section move horizontally by same amount However, the short column is stiffer as compared to the tall column, and it attracts larger earthquake force. Stiffness of a column means resistance to deformation – the larger is the stiffness, larger is the force required to deform it. If a short column is not adequately designed for such a large force, it can suffer significant damage during an earthquake. This behaviour is called Short Column Effect. The damage in these short columns is often in the form of X-shaped cracking – this type of damage of columns is due to shear failure. Many situations with short column effect arise in buildings. When a building is rested on sloped ground during earthquake shaking all columns move horizontally by the same amount along with the floor slab at a particular level (this is called rigid floor diaphragm action). If short and tall columns exist within the same storey level, then the short columns attract several times larger earthquake force and suffer more damage as compared to taller ones as shown in Figure1&2

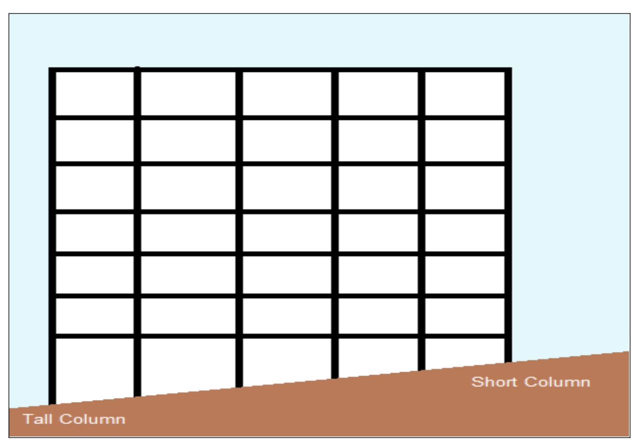


Figure 1: Columns of Different Heights within One Storey

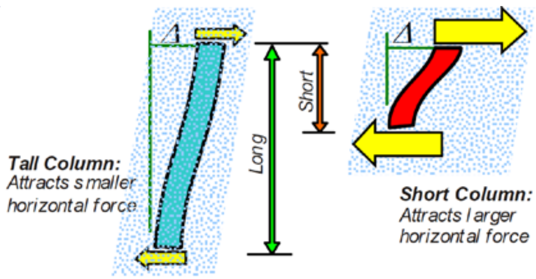


Figure 2: Behaviour of Tall and Short column

II. ANALYSIS

Analysis using MS Excel

An MS Excel spreadsheet was prepared for analysis of G+2 reinforce concrete building frame with 2 bays along the X axis and 3 bays along the Y axis as shown in Figure 3. The input for the dimensions of parameters like height of floor, span of beams in X & Y direction, beam & column dimensions, thickness of slab & walls, characteristic strength of materials to used, loads and seismic factors (viz, Zone factor, importance factor, response reduction factor) could be entered.

The spread sheet is so prepared that it automatically calculates the loads (viz., DL, LL) and then the lumped weight at each level. Keeping the height of column at node C constant, those at A and B were increased by small increments. The increment value can be given as input. 20 trials were considered by changing the heights of columns at A & B. This will resemble the frame be place on a sloped terrain. Hence by increasing the height at A & B, the terrain slope is increased. The stiffness of columns was computed for 20 trials. The mode values were calculated using the characteristic equation; making use of the Newton Raphson method for solving it:

$$| \{k\} - \omega^2 \{m\} | = 0$$

Natural frequency & time period were calculated using:

$$T = (2\pi/\omega)$$

Considering rocky / hard soil and 5% damping, the Response Spectrum Ordinates (Sa/g) and Horizontal Seismic Coefficient (Ah) Modal Mass (M_k), Modal Participation Factor (P_k) and Nodal forces were calculated Were calculated as per IS 1893 (Part 1): 2002

$$Sa/g = \begin{cases} 1+15T & (0.00 \le T \le 0.10) \\ 2.50 & (0.10 \le T \le 0.40) \\ 1.00/T & (0.40 \le T \le 4.00) \end{cases}$$

$$A_h = \frac{Z\,I\,Sa}{2\,R\,g}$$

Modal mass

$$M_k = \underline{\textstyle\sum_{i=1} [W_i \Phi_{ik}]}$$

Modal participation factor

$$P_k = \frac{\sum_{i=1}^{n} [W_i \Phi_{ik}]}{\sum_{i=1}^{n} [W_i (\Phi_{ik})^2]}$$

Nodal Force (*Q*)

$$Q_{11} = Ah_1 * \Phi_{11} * P_1 * W_1$$

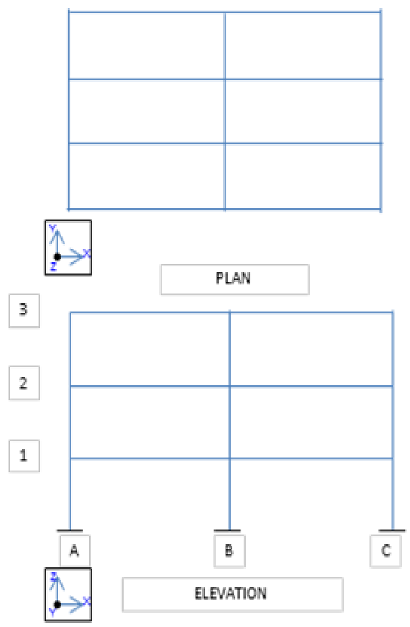


Figure 3: Plan &Elevation of G+2 reinforced concrete building frame

From the Nodal Forces, the maximum Base shear can be calculated. The Storey drift and displacement were also calculated.

Analysis using STAAD Pro

Models Considered:

Four models in plane ground and four in slope terrain were considered for analysis as shown in Figure 4.

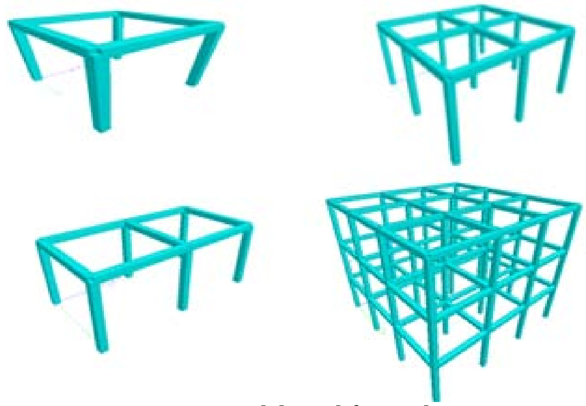


Figure 4: Model used for analysis

For the four models on plane ground the dimensions are considered as 3.5m for height and 4m for each bay length and for the columns on sloped ground the bay length is 4m, the slope is increased gradually as 2m, 2.5m, 3m, 3.5m.

Input Parameters:

Zone factor: The building considered is assumed to be located in zone three in accordance with the seismic zone map of IS 1893:2002. From table 2 of the code, its value is 0.16

Response reduction factor: It is a factor by which the base shear generated due to design basic earthquake is to be reduced to get the design lateral force. Its value from table 7 of code for special moment resisting frame is 5.

Importance factor: It is a factor used to obtain the design seismic force depending upon the functional use of the building. From table 6 of the code, its value is obtained as 1.

Soil factor: Soil factor is 1 for hard soil, 2 for medium soil, and 3 for soft soil. Depending on it program calculates the average response acceleration coefficient Sa/g as per clause 6.4.5 of IS 1893:2002. Here hard soil is considered.

Response factor : The response spectrum employed in this analysis is given in IS 1893:2002 for natural damping of 5% and table 3 of the code gives the multiplying factors for obtaining spectral values of various other damping.

Grade of concrete: The grade of concrete considered is M30 with a compressive strength of 30 MPa.
Grade of reinforcing steel: The grade of reinforcing steel used is Fe415 (HYSD bars).

Loads Applied:

Dead Loads
Live Loads - Floor Load of 4 KN/m^2
Seismic Loads as per IS 1893: 2002
Load Combinations

DL + LL
1.5(DL + LL)
1.5(DL + SL)
1.5(DL – SL)
1.2 DL + 0.3 LL + 1.2 SL
1.2 DL + 0.3 LL – 1.2 SL

Analysis using ANSYS

The first 6 models used for STAAD Pro analysis were again modelled in ANSYS as shown in Figure 6. The volumetric ratio and orientation angles obtained from STAAD Pro were given as input while defining SOLID65 model in Ansys as shown in Figure 5&6. Monotonic loading were given to the structure. A total of 150kN divided among numerous nodes were applied. Loading was further sub-divided to a minimum of 5 sub steps

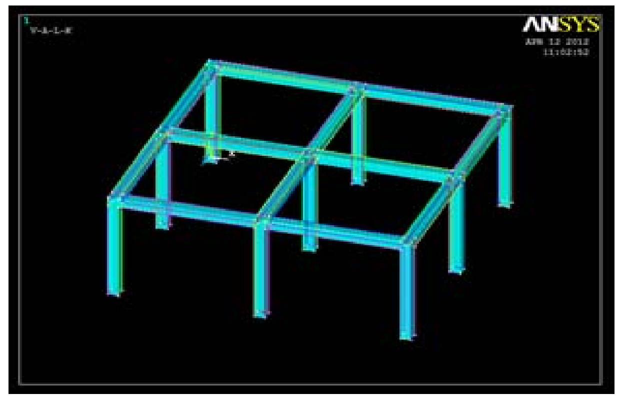


Figure 5: Model with same height columns

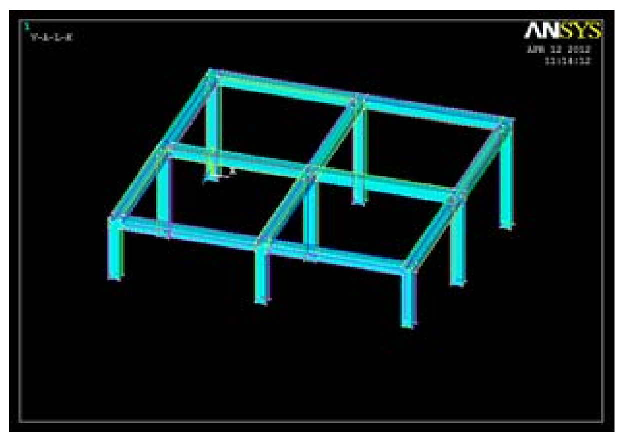


Figure 6: Model with Different height columns

III. RESULTS AND DISCUSSION

The results are discussed under three categories
Results from MS Excel
Results from STAAD Pro
Results from ANSYS

Results from MS Excel:

The slope of ground was changed from 0˚ to 6˚ 45’ with the horizontal. The following observations were found. The storey displacement value was decreasing at a rate of 0.1 % as the slope gradient changes by 0˚ 21’ with the horizontal.

Time period of structures decreased by 5.5% as the slope is increased. It is clear from the above plot that chance of failure is increased as the gradient of ground increases.

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. After analysis it was found that the base shear values were increasing as the slope increases. The base shear values increased in each trial by 3.24 % as the slope changed.

Results from STAAD Pro:

Comparing the results for models, it shows that the base shear almost doubled for the building on sloped ground when compared with the building in plane ground both in the x and z directions (Model 1 & 2). In other models also, base shear was found more in case of sloped ground than in normal ground buildings. The value was 55% more in average for frames in sloped ground as shown in Figure 7.

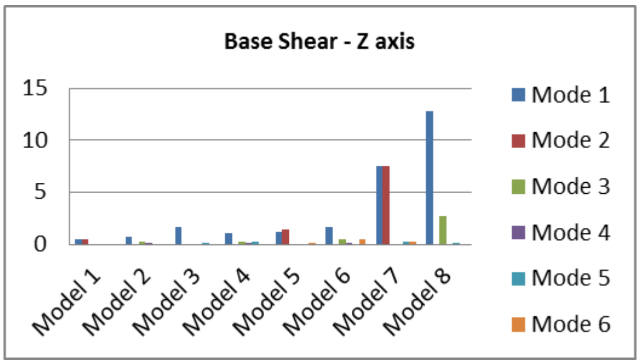
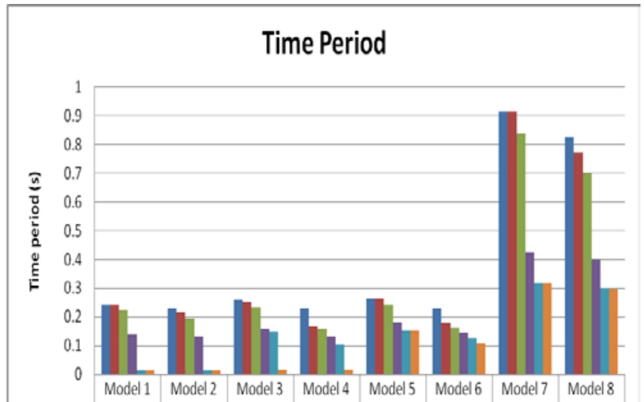


Figure 7: Base shear for building on plane and slope ground

The time period value was 10 % less for frame in sloped ground. As the time period is less, the chance of failure is more for building constructed on sloped ground as shown in Figure 8.



	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Mode 1	0.24377	0.2286	0.25959	0.22844	0.26334	0.23122	0.91552	0.82383
Mode 2	0.24377	0.21784	0.25251	0.16968	0.26334	0.17748	0.91552	0.77223
Mode 3	0.22338	0.19406	0.2339	0.15875	0.24353	0.16068	0.83592	0.69985
Mode 4	0.13959	0.1334	0.1579	0.13306	0.18294	0.1472	0.42222	0.39779
Mode 5	0.01284	0.01284	0.14858	0.10472	0.15082	0.12585	0.31843	0.3023
Mode 6	0.01283	0.01283	0.01813	0.01806	0.15082	0.10811	0.31843	0.29831

Figure 8: Time period for the building on plane and slope ground

Results from ANSYS:

Von Mises stresses are taken from post processing mode in the numerical study using element solution. Appropriate colour scales are show below the stress diagram to identify the stress intensity as shown in Figure 9. It shows very clearly that short columns has more stress as yellow colour stand for high intensity is observed more in support of the short column while compare to others.

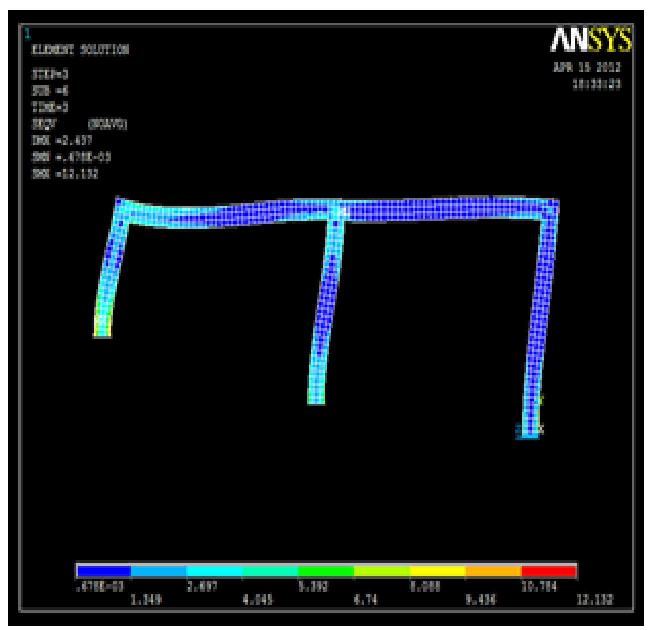


Figure 9: Von Mises stresses for building on sloped ground

Load vs. Displacement:

The displacement observed because of the loads is taken from model 5 and model 6, it shows the short column shows very less displacement while compare to the normal columns as shown in table 1

TABLE 1
LOAD VS DISPLACEMENT

Time	Load KN	Displacement in mm	
		Model 5	Model 6
0.1	15	0.34794	0.170358
0.2	30	0.695881	0.340716
0.35	52.5	1.21779	0.596253
0.55	82.5	1.91367	0.936969
0.75	112.5	2.60955	1.27769
0.875	131.25	3.04448	1.49063
1	150	3.4794	1.70358

IV. CONCLUSION

In this study an analytical investigation of Reinforced Concrete framed buildings with columns of different heights within one storey is carried out. First, the modal analysis and calculation of displacement, drift, base shear, and nodal force is done using MS Excel. 20 trials were taken by varying the slope by small increments. The results were compared and discussed. Secondly, 8 models were considered. Analysis and concrete design were carried out using STAAD Pro v8i. Finally, these models were modeled and analyzed using ANSYS 12. The design details obtained from STAAD Pro were given as input for the volumetric ratio of reinforcement in SOLID65 element With limited observations the following conclusions are presented:

Time period of short column buildings are less compared to regular building. There is nearly 10% decrease in time period of short column buildings when compared to that of regular buildings considered.

Base shear values were more in case of sloped ground buildings when compared to that of buildings on normal ground. There was an average increase of 55 % for sloped frame structures when compared to buildings on normal ground.

The short column is stiffer as compared to the tall column, and it attracts larger earthquake force and it has been observed in displacement as the column on sloped ground shows very less displacement while compare to compare to the column on plane ground.

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