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

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Abstract

In hilly regions, engineered construction is constrained by local topography resulting in the adoption of either a step back or step back & set back configuration as a structural form for buildings. The adopted form invariably results in a structure which is irregular by virtue of varying column heights leading to torsion and increased shear during seismic ground motion. The Response spectrum analysis (RSA) is carried out on two types of building frames namely ***step back frames*** *and* ***step back & set back building frames*** *on sloping ground with varying number of bays and hill slope ratio. The dynamic response i.e. fundamental time period, top storey displacement and, the base shear action induced in columns have been studied with different building configurations on sloping ground. It is observed that Step back & Set back building frames are found to be more suitable on sloping ground in comparison with step back frames.*

Keywords **–** *Hill slope angle, number of bays, response spectrum analysis, step back frames, step back & set back frames.*

1. Introduction

In some parts of world, hilly region is more prone to seismic activity; e.g. northeast region of India. 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. 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. Since, the behaviour of buildings during earthquake depends upon the distribution of mass and stiffness in both horizontal and vertical planes of the buildings, both of which vary in case of hilly buildings with irregularity and asymmetry due to step back frame and step back & set back frame configuration. Such constructions in seismically prone areas makes them exposed to greater shears and torsion as compared to conventional construction.

Hill buildings constructed in masonry with mud mortar or cement mortar without conforming to seismic codal provisions have proved unsafe and resulted in loss of life and property when subjected to earthquake ground motions. The economic growth and rapid urbanization in hilly region has accelerated the real estate development. Due to this, population density in the hilly region has increased enormously. Therefore, there is popular and pressing demand for the construction of multistorey buildings on hill slope in and around the cities.

It is observed during the past earthquakes, 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. Hence, while adopting practice of multistorey buildings in these hilly and seismically active areas, utmost care should be taken for making these buildings earthquake resistant.

Mr. Satish Kumar and Mr. D.K. Paul[2] have presented the methodology of analysis for irregular buildings with rigid floor system where center of mass and center of stiffness of each floor lie on different vertical axes. Also, short columns are worst affected in both the cases. Mr. Satish Annigeri and A.K. Jain[4] evaluated the eccentricity distribution for floor eccentricity and storey eccentricity for different types of lateral load distributions along the height of the building. There is need to upgrade the torsional provisions in IS-1893 to explicitly define how to compute design eccentricity. Mr. B.G. Birajdar and Mr. S.S. Nalawade[5] presented the results obtained from seismic analysis performed on three different configurations viz., Step back building, Step back Set back building and Set back building. 3 -D analysis including torsional effect has been carried out by using response spectrum method. It has been found that combination of step back and set back building was less affected by torsion as compared to step back buildings. Hence, they observed that Step back & set back buildings are found to be more suitable on sloping ground.

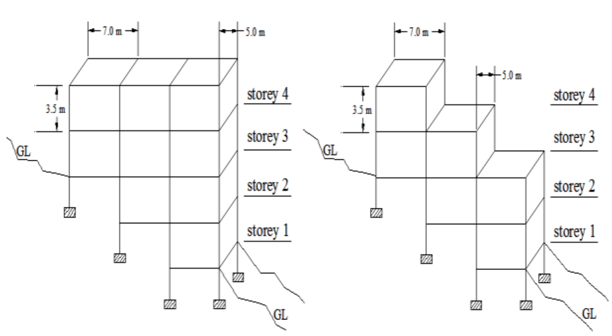
2. Building frame configurations

The buildings shown in **Table 1**, having step back configuration is labelled as STEP 4 to STEP11 for 4 to 11 storey. Step back & Set back configuration of building frames, are designated as STPSET 4 to STPSET 11, according to height of building.

Table 1. Building frame configurations & member properties.

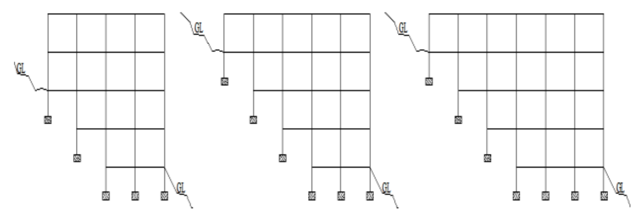
Sr. No.	Types of Frames	No. of Storey	Column Size (mm)	Beam Size (mm)
1	Step back frames	STEP 4 &5	230 x 500	230 x 450
		STEP 6 &7	230 x 650	
		STEP 8 &9	300 x 650	
		STEP 10 &11	300 x 850	
2	Step back & set back frames	STEP SET 4 & 5	230 x 500	230 x 450
		STEP SET 6 & 7	230 x 650	
		STEP SET 8 & 9	300 x 650	
		STEP SET 10 & 11	300 x 850	

The geometrical properties of frame members of buildings that are considered for analysis are given in **Table 1.** Buildings resting on sloping ground are constructed with minimum possible cutting and filling of the hill slope. The earth on one side of the building may be in contact with the building at various levels which will be supported by retaining walls, or by separating the earth from the building by providing retaining walls at different levels.



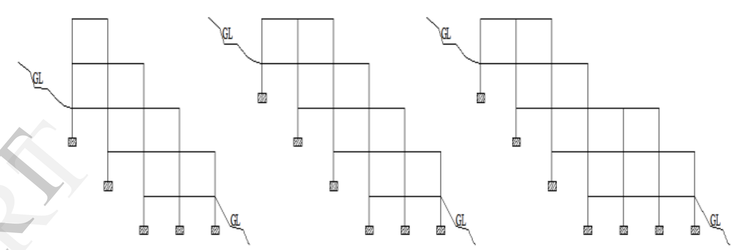
(a) **(b)**

Figure 1. Typical (a) 3 bay step back frame and (b) 3 bay step back & set back frame.



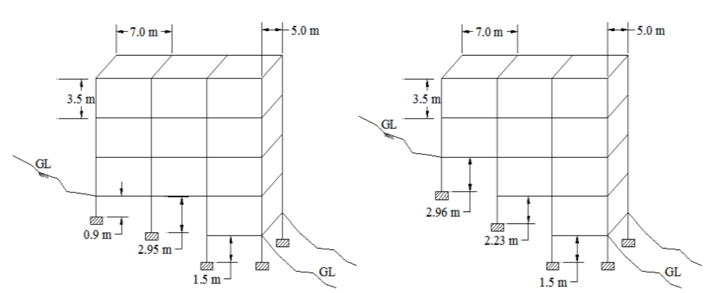
(a) **(b)** **(c)**

Figure 2. Typical (a) 4 bay, (b) 5 bay & (c) 6 bay step back frame.



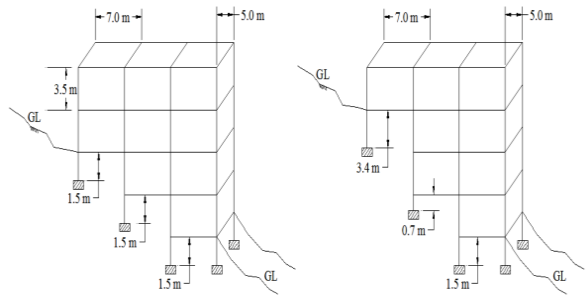
(a) **(b)** **(c)**

Figure 3. Typical (a) 4 bay, (b) 5 bay & (c) 6 bay step back & set back frame.



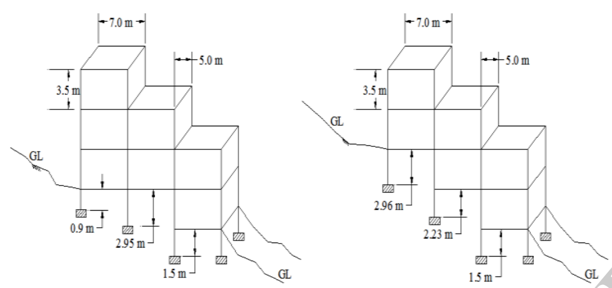
(a) **(b)**

Figure 4. Typical (a) 16.32^0 & (b) 21.58^0 hill slope step back frame.



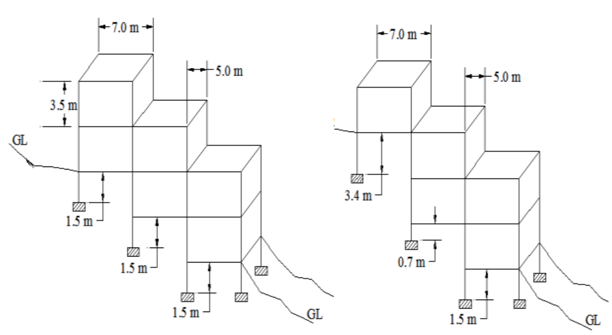
(a) **(b)**

Figure 5. Typical (a) 26.56^0 & (b) 31.56^0 hill slope step back frame.



(a) **(b)**

Figure 6. Typical 16.32^0 & 21.58^0 hill slope step back & set back frame.



(a) **(b)**

Figure 7. Typical (a) 26.56^0 & (b) 31.56^0 hill slope step back & set back frame.

3. Dynamic analysis

IS-1893 (2002) has given definitions of regular and irregular buildings. Irregular buildings can be identified due to plan irregularity and vertical irregularity. Plan irregularity may be due to plan re-entrant corners, diaphragm discontinuity, out of plane offsets, non-parallel systems, etc. Vertical irregularity can be because of soft story, extreme soft story, mass irregularity, vertical geometric irregularity, weak storey, etc.

As per IS-1893 (2002), the dynamic analysis is recommended for both types of building depending upon seismic zone and height of building. It is summarized in **Table 2**.

Table 2. Dynamic analysis.

Type of Building	Zone	Height of Building	Dynamic Analysis
Regular Building	IV, V	H > 40 m	Mandatory
	II, III	H > 90 m	Mandatory
Irregular Building	IV, V	H > 12 m	Mandatory
	II, III	H > 40 m	Mandatory
	II, III	H < 40 m	Recommended

Seismic analysis of different configurations of buildings is carried out by Response Spectrum as per IS 1893 (Part I): 2002, including the effect of eccentricity (static + accidental) for the buildings located in Zone III (Moderate) with Importance Factor as 1.0. Damping is 5% and Response Reduction Factor considered is 3.0 for ordinary moment resisting RCC frame.

4. Objective of the Study

Response of building frame on sloping ground depends on many parameters such as number of bays, hill slope angle and number of stories etc. In the study, two building configurations are considered namely *step back* frames and *step back & set back* frames. The objective of study is as follows:

1. To study the effectiveness of configuration of building frames such as *step back* and *step back & set back* frames.

2. To study the variation of base shear with respect to variation in number of bays, hill slope angle, storey height for different configurations of building frames.

3. To study the variation of time period with respect to variation in number of bays, hill slope

angle, storey height for different configurations of building frames.

4. To study the variation of top storey displacement with respect to variation in number of bays, hill slope angle, storey height for different configurations of building frames.

5. Parametric study

A study of seismic behaviour of a hill buildings resting on level ground and on sloping ground is done considering different configurations. These buildings are in the range of 4 to 11 storey with maximum height of buildings restricted to 40 m. The location of these building is in Seismic zone III. Bay width of frame is 7.0 m x 5.0 m and in general story height considered as 3.5 m. The depth of footing below ground level is considered about 1.50 m below ground surface.

Table 3 Parametric study programme.

Sr. No.	Building Response	Parameters		
		No. of bays	Hill slope	No. of storey
1	Base shear	3 to 6	16.32^0 to 31.56^0	4 to 11
2	Time period	3 to 6	16.32^0 to 31.56^0	4 to 11
3	Top Storey Disp.	3 to 6	16.32^0 to 31.56^0	4 to 11

6. Results and discussion

Results are divided in to two parts, variation for number of bays and variation for hill slope. Both types of building frames such as step back and step back set back frames are analysed under seismic loading using response spectrum method. The results obtained are expressed in terms of base shear, time period & top storey displacement.

5.1. Comparison of Step back and Step back & Set back building frames with respect to variation of number of bays.

Analysis is carried out on these above mentioned configurations of building frames by considering different number of bays varying from 3 bays to 6 bays & number of stories varying from 4 storeys to 11 storeys and results obtained are discussed in further sections.

5.1.1 Base shear variation of *step back* and *step back & set back* frames for different number of bay.

The variation of base shear for different number of bays and configurations of building frames is shown in **Figure 8** & **Figure 9.**

a) Base shear variation for step back frames.

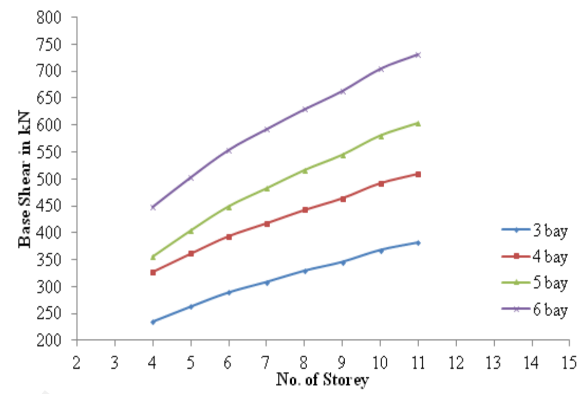


Figure 8. Variation of base shear for step back frame

For a given number of bay, the base shear increases with increase in number of storey. For a given number of storey, the base shear increases with increase in number of bay. The base shear increases rapidly with increase in number of bay. The nature of variation observed is non linear for all number of bays.

b) Base shear variation for step back & set back frames.

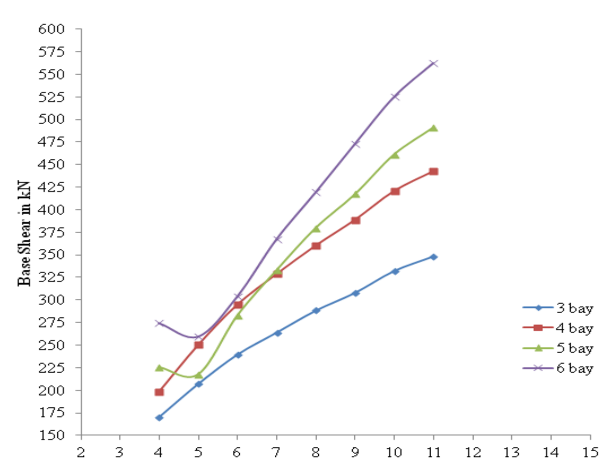


Figure 9. Variation of base shear for step back & set back frame

For a given number of bay, the base shear increases with increase in number of storey. For a given number of storey, the base shear increases with increase in number of bay. The rate of change of base shear increases with increase in number of bays. The nature of variation observed is non linear for all number of bays. The rate of increases of base shear increases with increases in number of storey.

5.1.2 Time period of step back and step back & set back frames for different number of bay.

The variation of time period for different number of bays and configurations of building frames is shown in **Figure 10** & **Figure 11**.

a) Time period variation for step back frames.

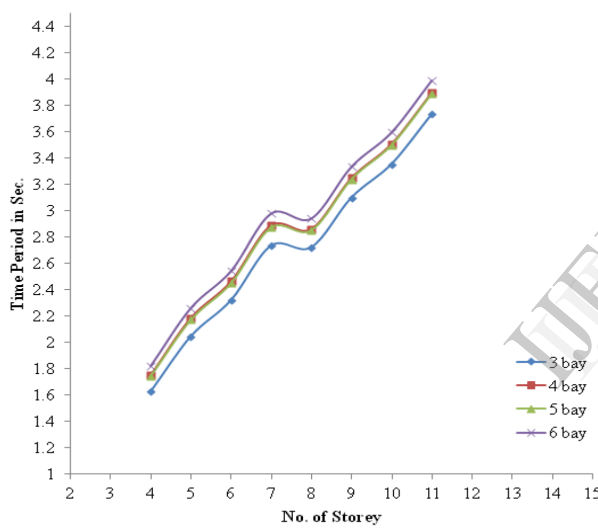


Figure 10. Variation of time period for step back frame

For a given number of bay, the time period increases with increase in number of storey. However, it is observed that, the time period slightly decreases from 7th to 8th storey and again it increases with further increase in number of storey. For a given number of storey, the time period increases with increase in number of bay. However, it is also observed that, the time period remains nearly constant for 4 & 5 bays and again it shows higher values of time period for 6 bay frames. The time period increases mildly with increase in number of bay. The nature of variation observed is non linear for all number of bays.

b) Time period variation for step back & set back frames.

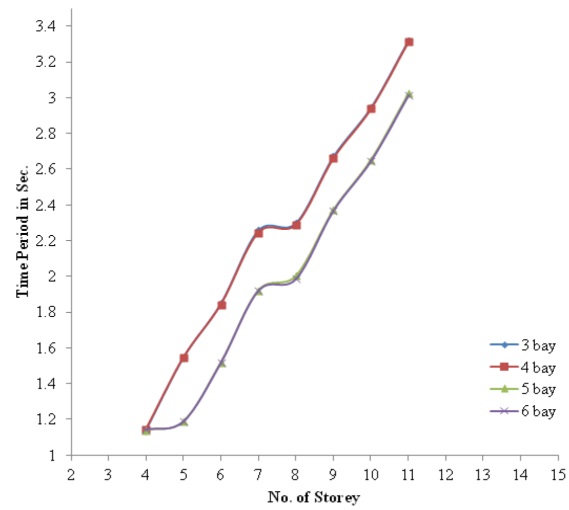


Figure 11. Variation of time period for step back & set back frame

For a given number of bay, the time period increases with increase in number of storey. However, it is observed that, the time period remains nearly constant from 7th to 8th storey and again it increases with further increase in number of storey. For a given number of storey, the time period decreases with increase in number of bay. However, it is also observed that, the time period shows minor change for 3 & 4 bays and also for 5 & 6 bays. The time period decreases with increase in number of bay. The nature of variation observed is non linear for all number of bays.

5.1.3 Top storey displacement of step back and step back & set back frames with respect to different number of bay.

The variation of top storey displacement for different number of bays and configurations of building frames is shown in **Figure 12** & **Figure 13**.

a) Top storey displacement variation for step back frames.

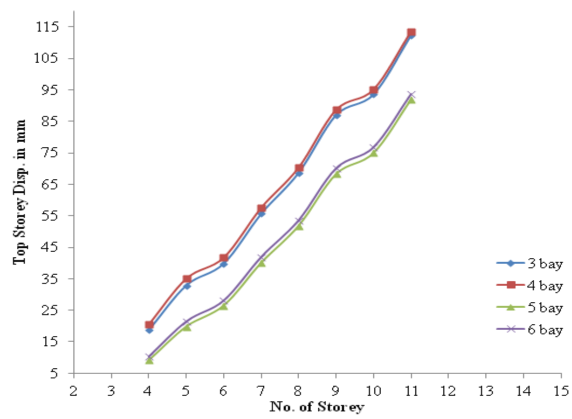


Figure 12. Variation of top storey displacement for step back frame

For a given number of bay, the top storey displacement increases with increase in number of storey. The rate of increase of top storey displacement becomes steeper for higher number of stories. For a given number of storey, the top storey displacement is nearly alike for 3 bay & 4 bay. But, it is decreases considerably from 4 bay to 5 bay and further increases mildly for 6 bay. However, it is also observed that, the top storey displacement shows higher values for 3 & 4 bays and lower values for 5 & 6 bays. The nature of variation observed is non linear for all number of bay.

b) Top storey displacement variation for step back & set back frames.

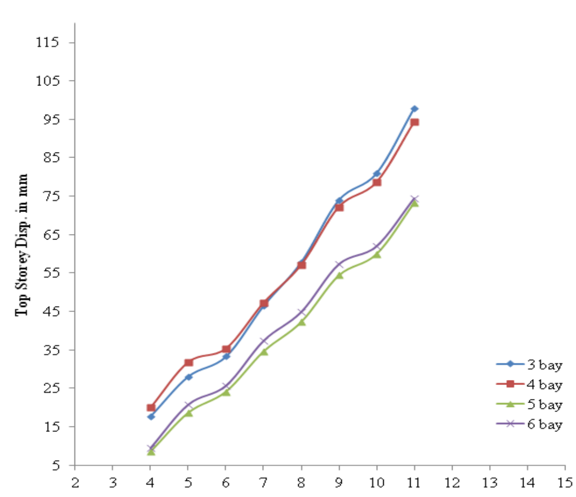


Figure 13. Variation of top storey displacement for step back & set back frame.

For a given number of bay, the top storey displacement increases with increase in number of storey. The rate of increase of top storey displacement becomes steeper for higher number of stories. For a given number of storey, the top storey displacement increases mildly from 3 bay to 4 bay. But, it is decreases considerably from 4 bay to 5 bay and further increases mildly for 6 bay. However, it is also observed that, the top storey displacement shows higher values for 3 & 4 bays and lower values for 5 & 6 bays. The nature of variation observed is non linear for all number of bay.

5.2. Comparison of Step back and Step back & Set back building frames with respect to variation of hill slope angles.

Analysis is carried out on these above mentioned configurations of building frames by considering different hill slopes varying from 16.32^0 to 31.56^0 & number of stories varying from 4 storey to 11 storey and results obtained are discussed in following section.

5.2.1. Variation of base shear for *step back* and *step back & set back* frames with respect to different hill slopes.

The base shear variation for different hill slopes and configurations of building frames is shown in **Figure 14** & **Figure 15**.

a) Base shear variation for step back frames.

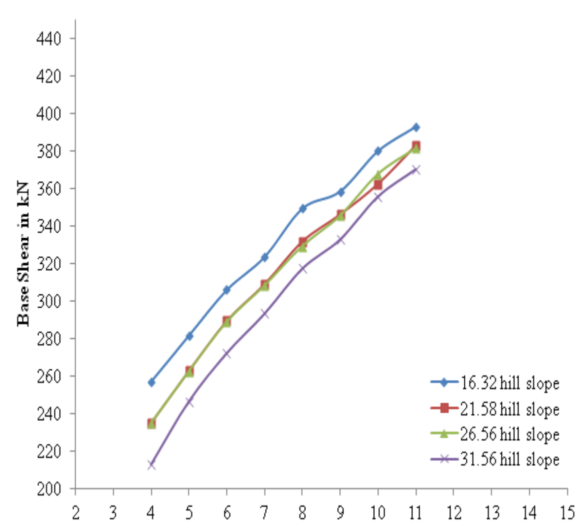


Figure 14. Variation of base shear for step back frame

For a given hill slope, the base shear increases with increase in number of storey. For a given number of storey, the base shear decreases mildly from 16.32^0 to 21.58^0 with increase in hill slope. Further it shows minor change for 21.58^0 & 26.56^0 frames and again it deceases for remaining 31.56^0 hill slope. The nature of variation observed is non linear for all hill slopes.

b) Base shear variation for step back & set back frames.

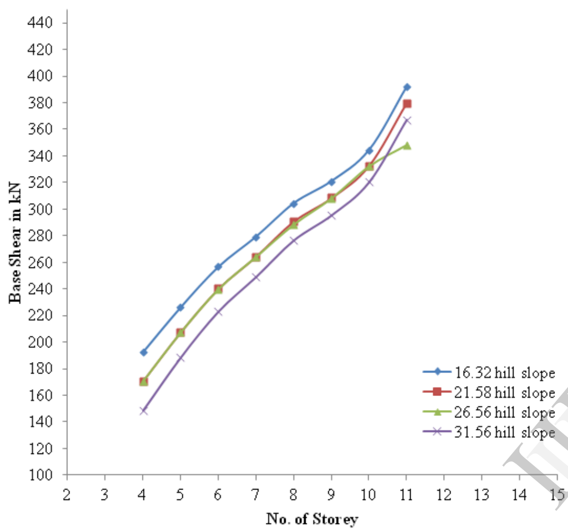


Figure 15. Variation of base shear for step back & set back frame

For a given hill slope, the base shear increases with increase in number of storey. For a given number of storey, the base shear decreases with increase in hill slope. The base shear decreases mildly with increase in hill slope. But, it shows minor change for 21.58^0 & 26.56^0 hill slopes and again it decreases for remaining 31.56^0 hill slope. The nature of variation observed is non linear for all hill slopes.

5.2.2. Variation of time period for step back and step back set back frames with respect to different hill slopes.

In this time period variation for different hill slopes and configurations of building frames is shown in **Figure 16** & **Figure 17**.

a) Time period variation for step back frames.

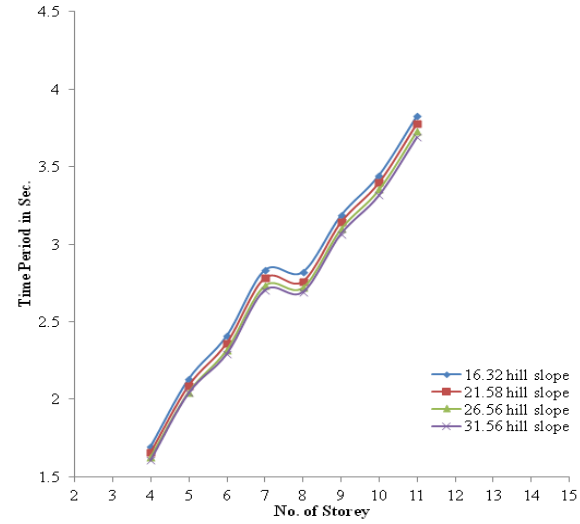


Figure 16. Variation of time period for step back frame

For a given hill slope, the time period increases with increase in number of storey. However, it is observed that, the time period slightly decreases from 7th to 8 th floor and again it increases with further increase in number of storey. For a given number of storey, the time period decreases with increase in hill slope. The time period decreases mildly with increase in hill slope showing minor change in time period. The nature of variation observed is non linear for all hill slopes.

b) Time period variation for step back & set back frames.

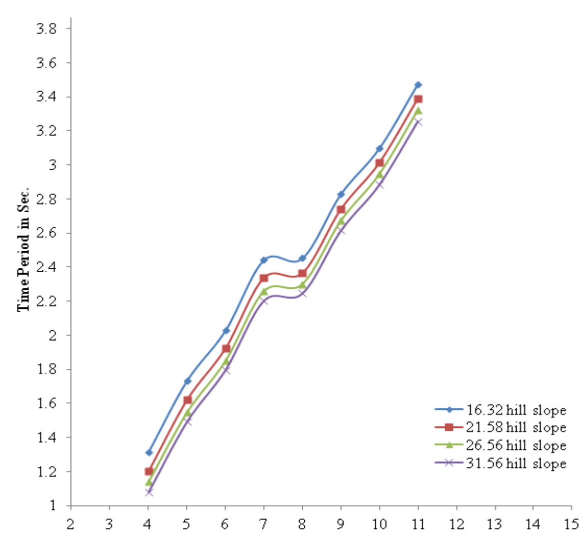


Figure 17. Variation of time period for step back & set back frame

For a given hill slope, the time period increases with increase in number of storey. However, it is observed that, the time period slightly decreases from 7th & 8th storey and again it increases with further increase in number of storey. For a given number of storey, the time period decreases with increase in hill slope. The time period decreases mildly with increase in hill slope showing minor change in time period. The nature of variation observed is non linear for all hill slopes.

5.2.3. Variation of top storey displacement for step back and step back set back frames with respect to different hill slopes.

The top storey displacement variation for different hill slopes and configurations of building frames is shown in **Figure 18** & **Figure 19**.

a) Top storey displacement variation for step back frames.

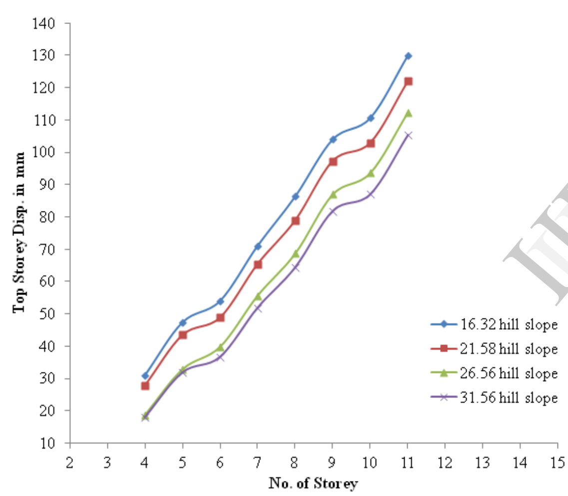


Figure 18. Variation of top storey displacement for step back frame

For a given hill slope, the top storey displacement increases with increase in number of storey. The rate of increase of top storey displacement becomes steeper for higher number of stories. For a given number of storey, the top storey displacement decreases with increase in hill slope. The top storey displacement decreases mildly with increase in hill slope showing lower values for higher hill slopes. The nature of variation observed is non linear for all hill slopes.

b) Top storey displacement variation for step back & set back frames.

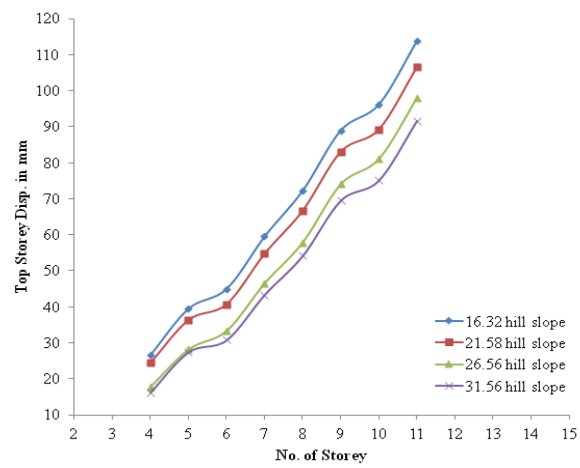


Figure 19. Variation of top storey displacement for step back & set back frame

For a given hill slope, the top storey displacement increases with increase in number of storey. The rate of increase of top storey displacement becomes steeper for higher number of stories. For a given number of storey, the top storey displacement decreases with increase in hill slope. The top storey displacement decreases mildly with increase in hill slope showing lower values for higher hill slopes. The nature of variation observed is non linear for all hill slopes.

6. Conclusion

From the data revealed by the seismic analysis for the structures with various loading combinations the following conclusions are drawn:

1. *Step back frames* produce higher base shear as compared with *step back & set back frames*.
2. The *step back building frames* give higher values of time period as compared with *step back & set back frames*.
3. The *step back building frames* give higher values of top storey displacement as compared with *step back & set back frames.*
4. 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.
5. 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 a system to control the large displacement is adopted.

6. *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.
7. 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.
8. As hill slopes increases time period & top storey displacement decreases.

7. References

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