Analysis of Torsional Irregularity and Mode Shape of RC Buildings in Sloping Ground with Shear wall and Steel Bracing

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ABSTRACT:

The investigation of RC buildings' seismic behaviour in sloping, steep terrain. It has been studied how a structure responds dynamically in steep terrain. Almost thirteen different structural configurations have been taken into consideration. Six of them take into account the slope of the ground and are step-back. Six have a set-back arrangement, much like in a plain. The last one is called plan buildings. The remaining three models are a combination of shear walls and steel bracings, and the three models are conventional step back, setback, and plan buildings. This study examines and presents a number of reviews of the literature on the seismic behaviour of RC buildings in sloping, hilly terrain. The study conclude that shorter column attracts more forces and cause damage when earthquake occurs. Step back configuration could prove more vulnerable to seismic activities. We also concluded that building with shear wall improves seismic behavior of building by increasing strength and stiffness and also reduce in deflection. The study suggested that when designing the stepback and setback buildings it is important to consider the torsional irregularity in the structure.

Keywords: Hilly areaSs, torsional irregularity, set- back configuration, seismic behavior, shear wall, mode shape

INTRODUCTION

The Federal Democratic Republic of Nepal lies in one of the active continental collision zone of the world, the Himalaya, where the probability of Earthquake occurrence is very high. Many destructive Earthquakes have been reported in the historical records within the Himalayan arc. Out of which the 1934 Bihar-Nepal Earthquake and 2015 Gorkha Earthquake Ml 7.6 (Mw 7.8) occurred in the Nepal Himalaya. [1]. Due to steep nature of ground building are irregular and unsymmetrical in horizontal and vertical planes. Mostly locally available traditional materials were used for construction of building in hilly areas. Anil Dangol, Gokarna Bahadur Motra (2021), This study conclude that the performance of building is decrease with increasing number of stories in sloppy area and The displacement is increases steeply with increase in number of stories in both plain area and step back building while in step back-set back building rate of increment is found to be low.[2] A. S. Swathi et al. (2015), It is concluded that the seismic performance of open ground storey buildings is very less and Addition of shear wall is an ideal solution to improve the seismic performance of open ground storey building constructed on a sloping ground [3]. Prasad Ramesh Vaidya et al (2015), this study concluded that Good control over the displacement and storey drift can be achieved if the shear walls are located symmetrically in plan and to have a good control over the forces such as shear force and bending moment it is preferable to locate the shear wall towards the shorter column side [4]. SUJIT KUMAR et al (2014), It was concluded that the critical horizontal force and bending moment in footing increases significantly with increase in ground slope and the critical bending moment in the column increases significantly for sloping ground compared to plane ground. [5]

METHODOLOGY

Building behaviour is determined by the size, form, layout, and placement of structural components. Depending on the type of soil and the geography, the building will respond differently to earthquakes. Various building styles are developed on the hillside based on their economic viability. In practise, step-back building constructions are popular on India's and Nepal's hillside. When it comes to earthquake-related issues, we have to use moment-resisting structures, shear walls, and bracing to solve a variety of issues with hillside buildings. When compared to a shear wall, the steel bracing and concrete bracing are more cost-effective ways to withstand lateral loading and earthquakes. Because bracing increases the rigidity and capacity of the building's loading, it is utilised in the retrofitting process. Additionally, the use of steel and concrete bracing in the structure improves the building's seismic performance. In reality, a fault and geological plate border are beneath the Indian hillside. which implies that there might be an earthquake in these regions. As a result, the building should be earthquake-resistant.

The modulus of elasticity of concrete is 25000 N/mm^2 and Poisson's ratio to be 0.2. The yield stress of reinforced steel is taken as 415 N/mm$^{2.}$ Floor system for all floors to be considered as the rigid diaphragm. The modulus of elasticity of the steel section to be 210000 MPa. Having Poisson's ratio is 0.3. The foundation level of all support is considered as a rigid support. IS 1893 (Part-1) 2016. Criteria for Earthquake Resistant Design of Structures, Part 1 used to design the structure. The researcher uses the steel of different types of bracing like X, inverted V, diagonal (D), and also using the shear wall (S). The live load on the floor is taken as 3KN/m^2 and 25% of the imposed load to be considered in the calculation of seismic weight as per IS 1893 (Part-1) 2016, table 10. The seismic parameter is considered a response spectrum method. The zone factor is assumed to be zone V with a peak ground acceleration value of 0.36g.

The important factor is taken as 1.5 and response reduction factor 5 for the SMRF system assumed. These values were taken in the IS 1893 (Part-1) 2016. The damping ratio for RC building is taken as 5%.

Building frames

- Step back (SB) frames
- Set back (SEB) frames
- Building on plain land
- Step back and setback buildings with combo

The properties of frame members of buildings that are considered for analysis are given in table 1.

Table 1. Step back, set back and plan buildings with sectional properties.

Building Configuration	**Parametric variation**		**Designation of models**	**Shear wall mm**	**Steel bracing**	**Column size (mm)**	**Beam size (mm)**
Step-back (SB)	along x axis	5 bays	SB			520*520	250*500
			SBSC	200			
	Along Y axis	4 bays	SBSM	200			
			SBX		ISLC300		
			SBIV		ISLC300		
			SBD		ISLC300		
Set back (SEB) frames			SEB				
			SEBSC	200			
			SEBSM	200			
			SEBX		ISLC300		
			SEBIV		ISLC300		
			SEBD		ISLC300		
Plain land			P				

RESULTS AND DISCUSSIONS

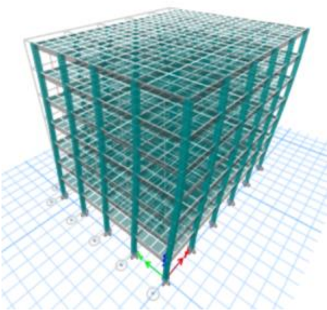
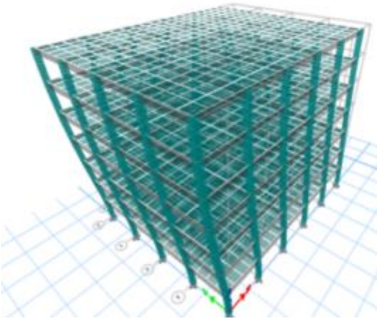
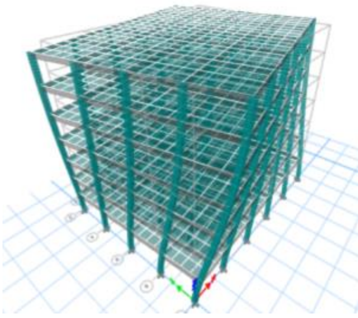
For analysis of all considered building seismic load is considered along with accidental eccentricity. For this seismic force was applied in both directions i.e. X- direction and Y- direction. Some important result after analysis of considered buildings are presented below and interpretation of result is done simultaneously. Here data are presented in two section in first section data are presented of three configurations (step back, set back configuration)

Step back Buildings

Study of step-back building having fixed building height having a different type of structural elements like shear wall and bracing system along and across the hill slope [6]. All six models have been analyzed for earthquake loads as per code provisions. The seismic loads applied along and across the slope in hill side building. The result is obtained and analyzed & discussed in the term of seismic parameters such as Vibration mode shapes and torsional irregularity ratio.

Vibration mode shapes

Mode shape of oscillation associated with a natural period of a building is the deformed shape of the building when shaken at the natural period. Hence, a building has as many mode shapes as the number of natural periods. For a building, there are infinite numbers of natural period. For this study the deformed shape of the building associated with oscillation at fundamental natural period is termed its first mode shape as shown in Figure 1. Similarly, the deformed shapes associated with oscillations at second, third, and other higher natural periods are called second mode shape, third mode shape, and so on, respectively (see Figure 1). There are three basic modes of oscillation, namely, pure translational along X-direction, pure translational along Y-direction and pure rotation about Z-axis. Regular buildings have these pure mode shapes. Irregular buildings (i.e., buildings that have irregular geometry, no uniform distribution of mass and stiffness in plan and along the height such as SB and SEB) have mode shapes that are a mixture of these pure mode shapes. Each of these mode shapes is independent, implying, it cannot be obtained by combining any or all of the other mode shapes. In regular buildings too, care should be taken to locate and size the structural elements such that torsional and mixed modes of oscillation do not participate much in the overall oscillatory motion of the building. One way of avoiding torsional modes to be the early modes of oscillation in buildings is increasing the torsional stiffness of building. This is achieved by adding in-plane stiffness in the vertical plane in select bays along the perimeter of the building; this addition of stiffness should be done along both plan directions of the building, such that the building has no stiffness eccentricity. Adding braces or introducing structural walls in select bays are some common ways in which this is done. Figure 1 shows that different models with their mode shape with fundamental time period. It is observed that when improper shear wall is provided in the buildings the modes shapes also affected and no longer as a pure mode shape. The torsional behaviors are observed in the models.

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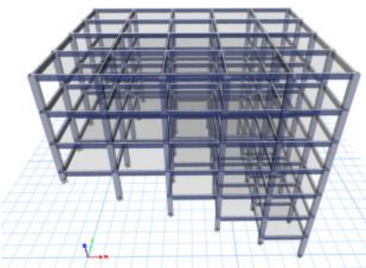
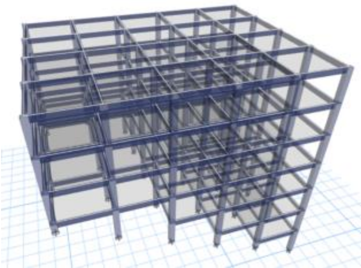
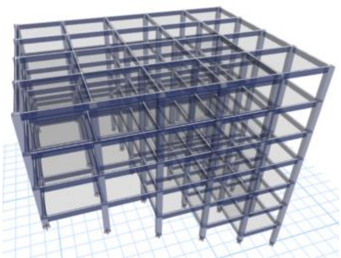
P

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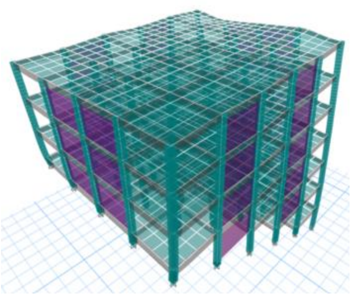
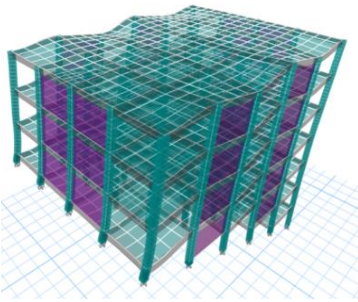
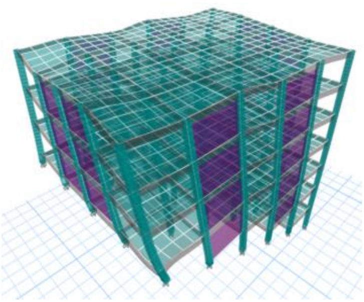
SB

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SBSM

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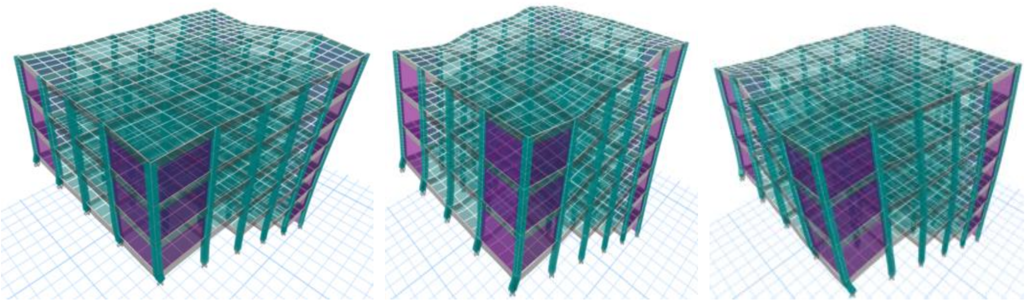

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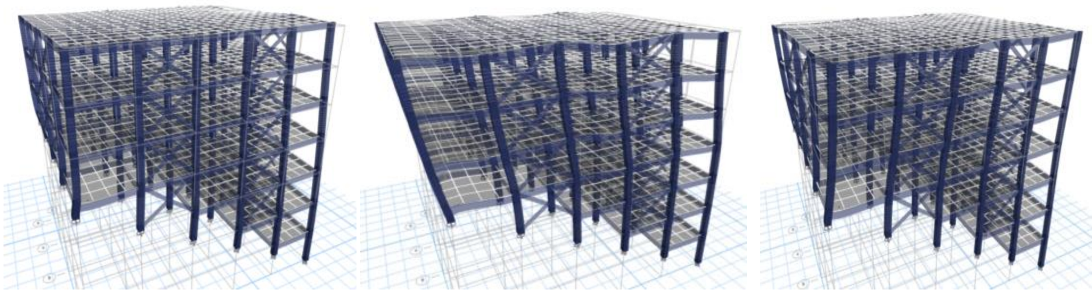
SBSC



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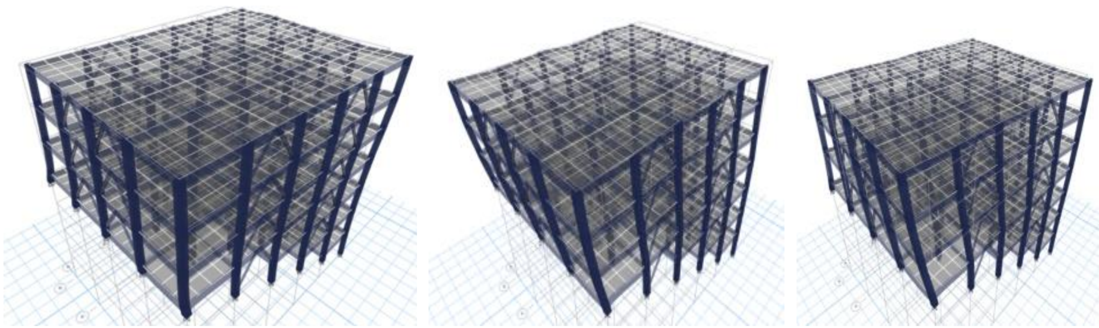
SBX



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SBIV

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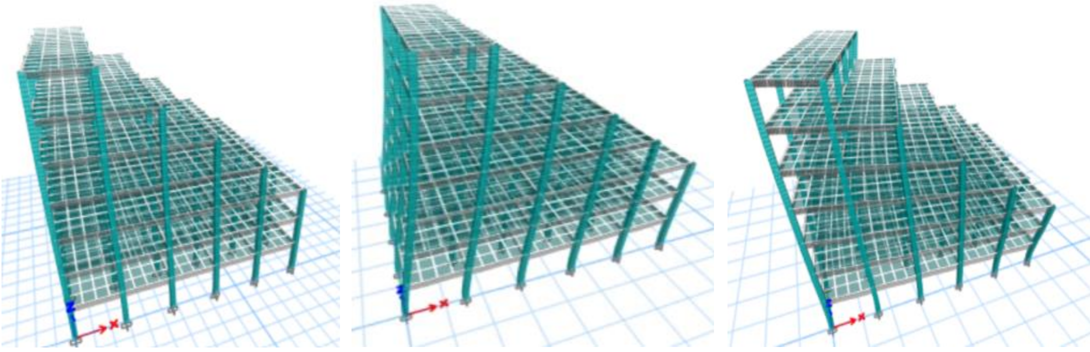
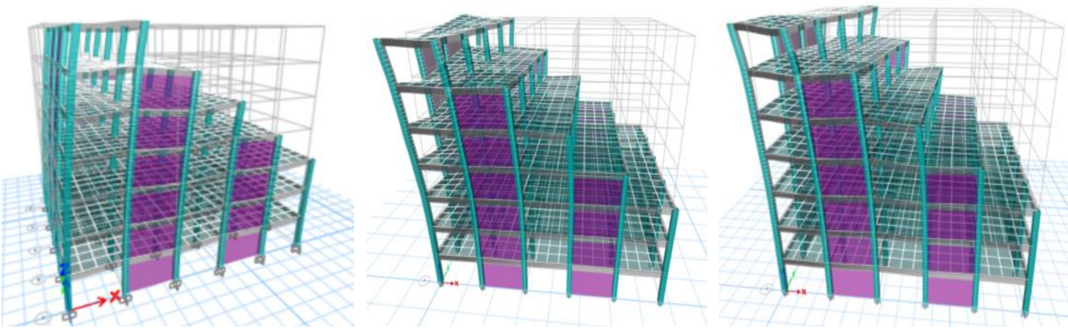


Mode1:T1=0.759s mode 2:T2=0.674s mode 3:T3=0.499s

SEB



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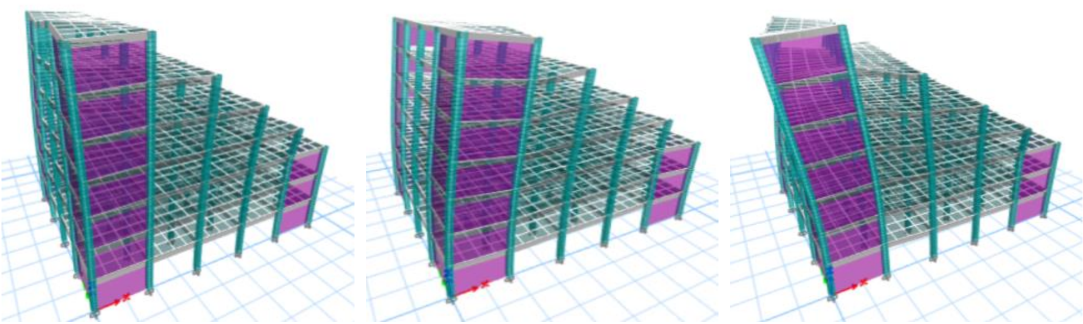
SEBSM



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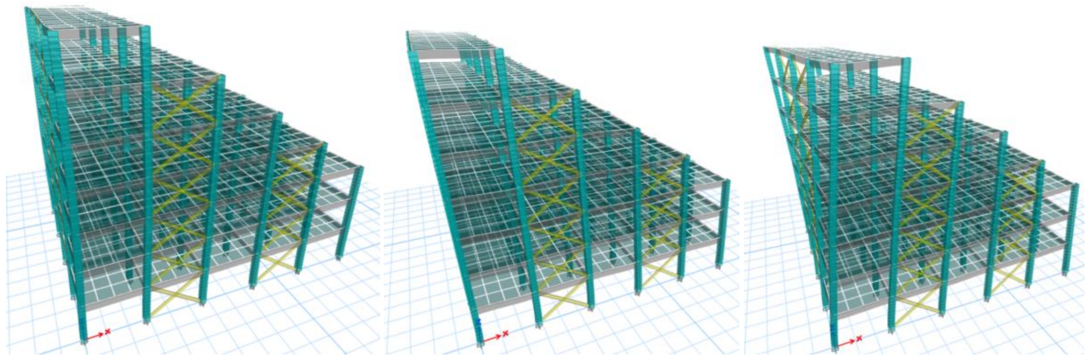
Mode1:T1=0.313s mode 2:T2=0.284s mode 3:T3=0.170s

SEBSC



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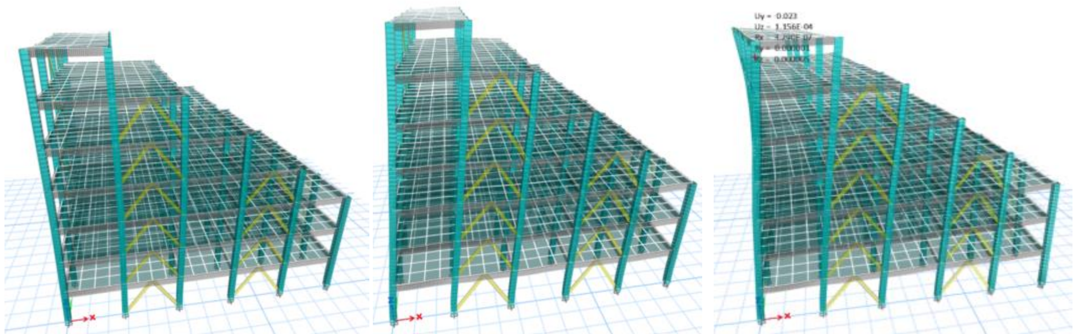
SEBX



Mode1:T1=0.473s mode 2:T2=0.456s mode 3:T3=0.289s

SEBIV

Figure 1. Different mode shape for selected buildings

Torsional irregularity

4.6.1Code provisions for torsional irregularity

Torsional irregularity is calculated with the help of drift at each corner of the 3D model. Almost every seismic code (IS 1893:2016, UBC 97, ASCE 7–10 [7]) has a similar provision for calculation of the torsional irregularity of the L shape building. For understanding, the accidental torsional effect torsional amplification factor (A_x) [7] shall be observed. The Δ_{max}, Δ_{min} and Δ_{avg} are the maximum, minimum and average drift as shown in respectively. Torsional irregularity coefficient is defined as the ratio of the drift maximum and average drift ($\eta_t = \Delta_{max} / \Delta_{avg}$). Three conditions are described:

i) when η_t is less than or equal to the 1.2 then no torsional irregularity exists and A_x is equal to the 1,

ii) when η_t is between 1.2 to 2.083 the torsional irregularity exists and A_x is calculated as given formula,

iii) When the η_t is greater than 2.083 then η_t=2.083 and A_x equal to 3.

$$A_x = \left(\frac{\Delta_{max}}{1.2\Delta_{avg}}\right)^2$$

4.6.2 Torsional irregularity ratio

The torsional irregularity ratio of the structures gives the most important information about buildings' damages levels during earthquake loading. It is an analytical index, created based on the structural response, multidirectional response of the asymmetry structure. The different studies studied the limit of torsional irregularity ratio which is 1.2 [8]. It means when the torsional irregularity ratio limits exceed such structures is affected by differential displacements in the plan. It affects the seismic behaviors of the structure. When the torsional irregularity ratio is less than 1.2, there is no torsional irregularity exist in the buildings.

Fig 2 and 5 show the torsional irregularity ratio for SB, SEB and P types and other braced and shear walled structure along with the story of the buildings. The torsional irregularity ratio changed over the building story height. In some models lower story shows a more torsional irregularity ratio than the upper story. It may be due to the stiffness irregularity of the buildings and the lower story is created as a soft story. The maximum torsional irregularity ratio when unidirectional spectrum used along the x-axis for all cases except plan frame seems greater than 1.2. It is observed that model which is shear walled shows the maximum torsional irregularity ratio in all models. however for models P show the safe torsional irregularity ratio (less than 1.2). In all case except P models have torsional irregularity ratios are greater than 1.2 along the y-axis (see Fig 2 and 5).

It is observed if carefully shear wall are applied in the L shape RC buildings shows good seismic behaviors. It is important to design such types of buildings careful selection of buildings types, implementation of shear wall or steel bracing and locations should be good [9] and [10] buildings are more affected by torsionally in such SB and SEB buildings even when improper shear wall are used it increase the torsional irregularity of the structure.

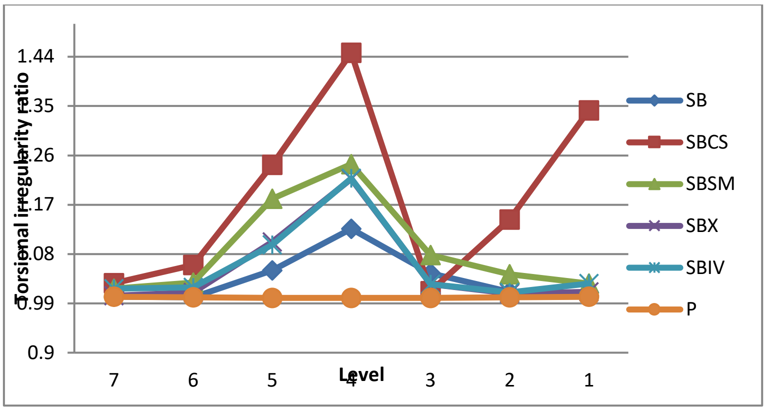


Figure 2. Torsional irregularity ratio for SB model along x axis

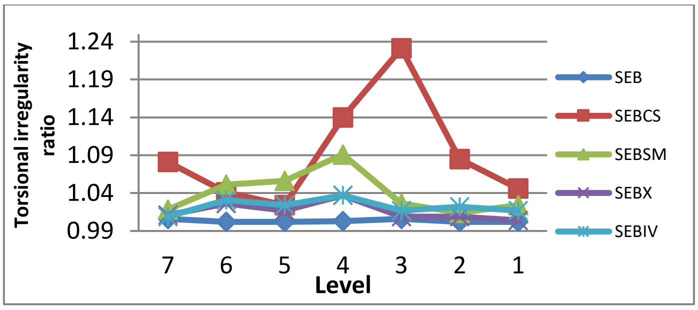


Figure 3. Torsional irregularity ratio for SEB models along x axis

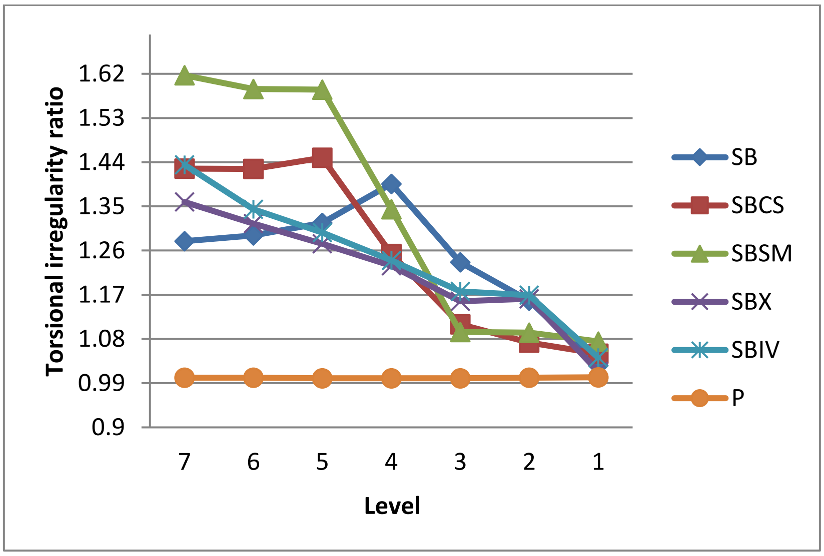


Figure 4. Torsional irregularity ratio for SB models along y axis

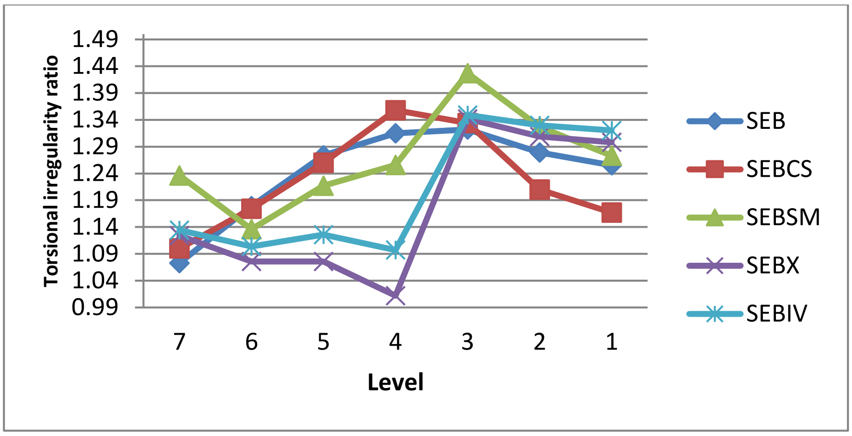


Figure 5.1 Torsional irregularity ratio for SEB models along y axis

CONCLUSION

The study has improved our knowledge of the seismic behaviour of RC buildings in sloping terrain by examining every configuration. In summary, step back buildings (SBs) on sloping terrain will experience more torsional moments during an earthquake, resulting in greater damage than set back buildings (SEBs) on level terrain. Compared to step back buildings, the combination of set back and step back in SSB structures offers torsional forces vulnerability and lateral stability. This study uses linear dynamic analysis (RSM) to examine the seismic behaviours of hillside buildings. The step-back building is a seven-story structure with a unique layout. Thus, in comparison to the other, the shear wall constructing displays a shorter time period. Buildings on hillsides behave differently, and shear walls exhibit inconsistencies in both story stiffness and height. Additionally, compared to the slope direction, the maximum top story displacement across the rectangular plan of the building was found to be greater. The additional parameter likewise shows a greater seismic impact in the direction of the slope. It was also observed that it is better to use the X bracing system. The bracing have less base shear value and also economical. However, to know about the failure mechanism, plastic hinge formation and more accurate design nonlinear static analysis must be considered. The torsional irregularity ratios are studied in both SB and SEB and show an unexpected torsional effect. While using the shear wall in the irregular building, the torsional irregularity ratio should be check carefully.

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