Seismic Response of Hill Side Step-back RC Framed Buildings with Shear Wall and Bracing System

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***Abstract*—**The hillside building shows different behavior as a flat ground building in lateral loading. Especially the step back building in the sloping ground has different seismic behavior. The hillside building 3D model having different types of structural elements is introduced and analyzed with a seismic effect. The structural elements such as the shear wall, steel, and concrete bracing are used to resist the earthquake load and compared with without using any shear wall and bracing system. The X, inverted V, and diagonal bracing are used. The total nine models are prepared in ETABs finite element coding software. The linear dynamic analysis is the response spectrum analysis (RSA) carried out to study dynamic behaviors in means of top story displacement, story drift, fundamental time period, story stiffness, and story shear. The results are analyzed and made some decisions based on seismic performance. It is also observed that it is better to use the X bracing system for lateral load resisting elements.

***Keywords*—**Step-back buildings, bracing system, hill side buildings, response spectrum method.

I. Introduction

THE seismic performance of buildings depends upon the shape, size, plan, and arrangement of structural elements. The seismic response of the buildings is different in different terrains and soil types. On the hillside, different types of buildings are constructed from their economical point of view. The step back building constructions in a hillside in Nepal and India are common in practice. Because of the sloppy surface in hillsides, the foundations of the structures lie in a different level of surface. Hillside buildings may possess seismic vulnerability and failure of the story. The vertical irregularities, stiffness, and mass irregularities are a common problem in hillside building. Irregularities along with the distribution of mass, geometry, and stiffness of buildings are known as vertical irregularities. In the hillside for aesthetics and utility, irregularities intrude. It is important to develop the relationship between the earthquake ground motion and structural failure of structures, which helps to make a seismic risk assessment of the buildings. Some examples of earthquakes in the hill region, Nepal (2015), Sikkim (2011), Kashmir (2005) and Uttarkashi (1990), had shown that damage of nonstructural and structural members, even fully collapse of buildings were recorded. To overcome the various problems related to hillside buildings, researchers [12], [21] have used shear wall, bracing and moment-resisting structure when the problem is related to the earthquake effect. The steel bracing and concrete bracings are more economically sound to resist the earthquake or lateral loading as a comparison to the shear wall. Bracing is used in the retrofitting process because it increases the stiffness and capacity of the loading on the building. Also, it increases the seismic behaviors of the structures when the steel and concrete bracing are introduced in the structure. The Indian hillside actually lies under a geological plate boundary and fault which suggests that earthquakes may come in these areas. Hence the structure should be earthquake resisting.

So many researchers have suggested the vertical and horizontal irregularity in structure and their seismic response. Mohammad et al. studied the step back setback and step back configurations commonly located in hill side area. They have modeled in the ETABs software (finite element code) applied to the response spectrum method. They concluded that step back setback building shows better performance than step back configuration. Also, they suggested that static linear method was not sufficient to design the hillside step-back building [1]. Surana et al. presented an analytical observation of seismic behaviors and vulnerability of hillside in the Indian Himalayan region. In this paper, they observed different parameters such as fundamental time period, PGA (peak ground acceleration), ground motion intensity, and spectral acceleration were observed. They compared the irregular structural configuration to the regular structures and analyzed the damaged ratio [2]. Siva et al. studied single and multiple irregularities concerning the regular configuration and they found that not every irregularity in the structures amplifies the response of the structures and certain combinations cause a serious seismic effect. One of the conclusions of that study is vertical irregularity showed maximum response [3]. Azadeh et al. found a new technique to know the soft story just using the geometric configuration of architectural drawings, the implication of the infill walls in adjacent stories [4]. Kumar [5] and Kumar and Paul [6], [7] demonstrated the 3D approach for elastic seismic analysis of irregular hillside (steps back and set back step) and asymmetry in plan structure. It is found that on the hillside even low magnitude earthquakes in Sikkim showed serious structural and nonstructural damage in building [8]. Neelavathi et al. compared the dynamic and static analysis of building and concluded that RSA has given lower values for displacement and drift, compared with ESA [9]. Kumar and Paul studied the hillside building and compared the result with the IS Code method 1893 [10], [11]. Some papers also suggested the bracing and shear wall in several hillside structures. Sanjay and Parekar observed step-back, 8 stories with single-bay across the hillside building having different types of steel bracing. They concluded that the

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inverted V and X bracings have shown better results in hillside step-back buildings [12]. Likhitharadhya analyzed that seismic effect on hillside step-back buildings have been more than the flat ground buildings. The study concluded that, story displacement of the buildings decreases with an increase in slope angle in hillside building [13]. Krishna studied the step back and set back step building by using the response spectrum method [14]. Maheri and Sahebi experimentally studied the RC frame and steel bracing system and overall concluded that the steel bracing is an alternative use of the shear wall in the seismic area [15]. Ankit and Umesh studied the step back hillside building with different positions of shear wall building. However, they use the static linear analysis using the sap 2000 software [16]. Hirde and Shelar studied the comparative study on the hillside and flat ground building with the different shape of the shear wall and applied the RSM in the building [17]. The shear wall used in buildings affects the seismic behaviors of RC buildings. The performance improves with the shear wall [18]. Harish et al. studied the step back and setback step back building with steel X, V, Inverted-V bracing in a different position and concluded that X bracing showed better seismic performance than others [19]. Suresh and Arunakanthi studied step back and set-step back building with steel X bracing and with dynamic analysis and concluded that step-set back building showed better performance than step building in lateral loading [20]. Bhosle and Shaikh studied that the X-concrete bracing significantly contributes to the structural stiffness and reduces the maximum story drift [21].

In this study we observed different research papers which mainly focused on the study of a step back and setback building to know the need of this research. Some researchers try to relate the shear wall and steel bracing in step back building. In this paper, we have studied the seismic effect on hillside buildings with and without shear wall and bracing. We have analyzed comparative study on steel bracing and RC bracing. We use different types of bracing both steel and RC which are X, diagonal, and inverted V shape bracing. By using the ETABs software with the help of the response spectrum method (RSM), the 7 story buildings are analyzed in this study.

II. Materials and Methods

The step-back buildings in hillside structures are considered and analyzed. The step-back building having columns, beams and slabs is constant but only the shear wall steel and RC bracing are introduced on the model. The analysis is done in ETABs finite element software and applied linear dynamic analysis in the models. With the help of RSA (Response Spectrum Analysis), the seismic behaviors are determined such as the natural building time period, maximum displacement, story drift, story shear, story stiffness and comparative study have been done on each model. The study was carried out on both sides that are along the hillside and across the hillside. The concrete is assumed as homogeneous, isotropic, and elastic in nature. The modulus of elasticity of concrete is 25 kN/mm^2 and Poisson’s ratio is 0.2. For reinforcement, the yield stress of steel is taken as 415 N/mm^2. It is assumed as rigid diaphragm for each floor. The modulus of elasticity is 210 GPa for steel materials. The foundation level of all support is considered as rigid support. IS 1893 (Part-1) 2016 “Criteria for Earthquake Resistant Design of Structures, Part 1” is used to design the structures. We use the steel and concrete bracing of different types of bracing like X, inverted V, diagonal (D), and also using the shear wall (S).

The structure rests in the inclination of the earth's surface. The inclination of the ground is 26° (Fig. 2). The structural properties, size of columns, beams, bracing, are given in Table I. The inter-story height is taken as 3.3 meters and foundation depth is varying as sloping. The thickness of all floor slabs is 200 mm. Researchers consider the along hill slope as 5 bays (x-axis) and across the hill slope by 4 bays (y-axis). Each bay's width is 5 m.

The live load on the floor is taken as 3 kN/m^2 and 25% of the live 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 (Fig. 3). The zone factor is assumed to be zone V with a PGA value of 0.36g. The important factor is taken as 1.5 and response reduction factor 5 for the SMRF (special moment resisting frame) system assumed. These values were taken from the IS 1893 (Part-1) 2016. The damping ratio for RC building is taken as 5%.

Fundamental natural time period is calculated as [22]:

a) Bare MRF buildings (without any masonry infills):

$$T_a = \begin{cases} 0.075h^{0.75} \text{ (for RC MRF building)} \\ 0.080h^{0.75} \text{ (for RC Steel comp. MRF building)} \\ 0.085h^{0.75} \text{ (for steel MRF Building)} \end{cases}$$

b) Buildings with RC structural walls:

$$T_a = \frac{0.075h^{0.75}}{\sqrt{A_w}} \geq \frac{0.09h}{\sqrt{d}}$$

The given height (h) and width (b) are assumed as shown in Fig. 1.

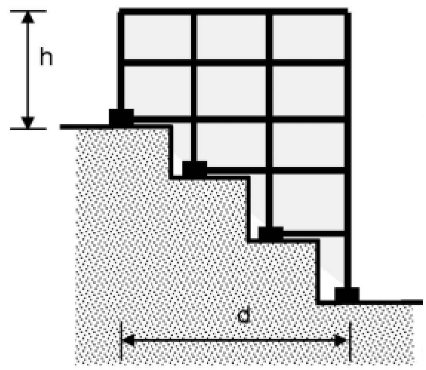


Fig. 1 Height and base width of hill side building [22]

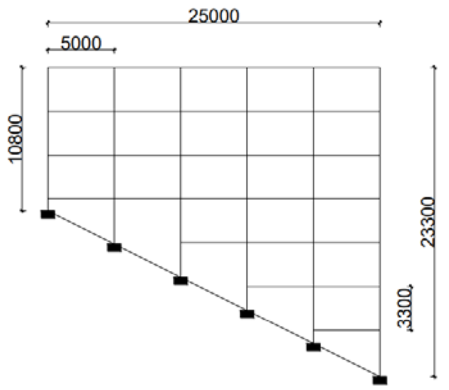


Fig. 2 Hillside properties of hill slope

Fig. 3 Response function [22]

III. Results and Discussion

Study of step-back buildings having fixed building height having different types of structural elements like shear wall and bracing system along and across the hill slope are investigated by using the software. All nine models have been analyzed for earthquake loads as per code provisions. The seismic loads are applied along and across the slope in the hillside building. The results are obtained and analyzed & discussed in the term of seismic parameters such as fundamental time period (FTP), top story displacement, story drift, story shear, and story stiffness.

The step-back building, the FTP obtained by the code provision (empirical relation), and the obtained from ETABs software are having some marginal differences. In Table II it observed that simple RC1 has a maximum FTP value of 0.514 sec by RSA and minimum FTP by RSA is 0.217 sec for RC2SC building. Along the slope direction the top story displacement of each 9 models, it is observed a maximum of 12.016 mm and a minimum of 2.07 mm. In all models it is observed that the top story displacement along the y-axis or across the slope has a maximum of 21.71 mm and a minimum of 4.026 mm. The shear is also investigated and it is observed that the maximum story shear of the models has a range of 2519.4 kN to 2047.71 kN along the slope direction whereas 2308.61 kN to 2042.59 kN across the hill slope as shown in Table II. However, the value of the story shear obtained along with and across the hill slope, is found maximum near the middle portion of the building height, it is because of the step-back configuration. The maximum story shear along and across the hill slope is shown in Table II and Fig. 5.

As shown in Figs. 6 and 7 the maximum top story displacement is shown in the RC1 configuration. In Figs. 6 and 7 the maximum displacement is 21.713 mm across the hill slope. The study also noticed the reduction of top story displacement of 82.77% in the RC2SC and RC3SM models along the slope direction. Top story displacements are reduced by 49.7%, 46.2%, 37.4%, 57.2%, 55.7% and 47.01% for RC4XSB, RC6IVSB, RC8DSB, RC5XCB, RC7IVCB and RC9DCB respectively along the slope direction. Across the hillside, the top story displacements are reduced by 81.48%, 80.6%, 52.12%, 48.04%, 39.4%, 60.1%,57.49% and 49.1%, for RC2SC, RC3SM, RC4XSB, RC6IVSB, RC8DSB, RC5XCB, RC7IVCB and RC9DCB respectively. The shear wall provided in a corner and middle configuration shows minimum top story displacement; it is because the shear wall increases the stiffness of the building. If we consider the X bracing only, the stop story displacement of X steel bracing shows more values as compared to the x concrete bracing. In overall observation, Fig. 8, concrete bracing shows less displacement value as compared to the steel bracing.

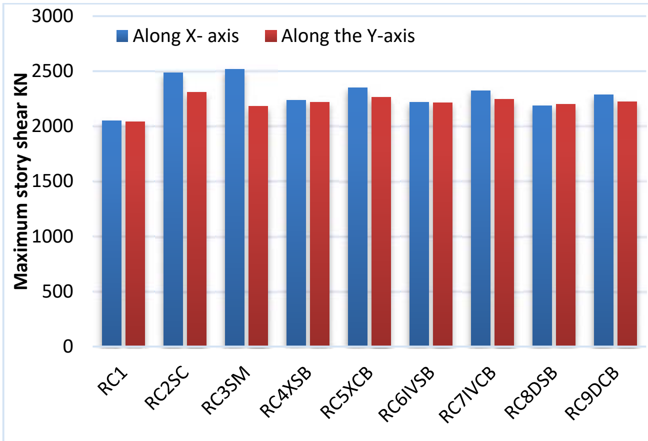


Fig. 4 Maximum story shear along X and Y axis

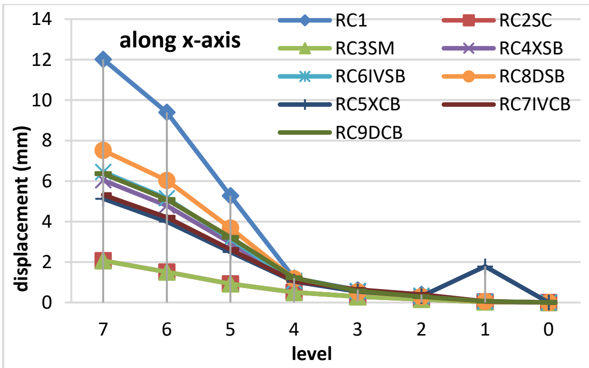


Fig. 5 Displacement along the sloping

A significant amount of variation in story drift is found both along the slope and across the slope direction. It is found that the maximum story drift is observed in the RC1 configuration as in Fig. 9. The reduction in story drift ranges from 85.355% to 35.69% along the slope direction whereas reduction in story drift ranges from 87.0 to 47.18% across the slope direction.

The maximum reduction is in RC2SC and minimum in the RC8DSB model.

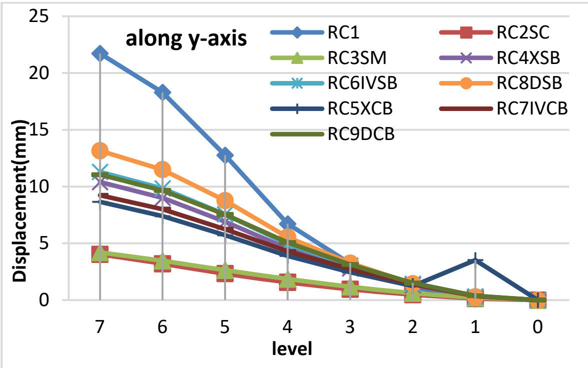


Fig. 6 Displacement across the slope

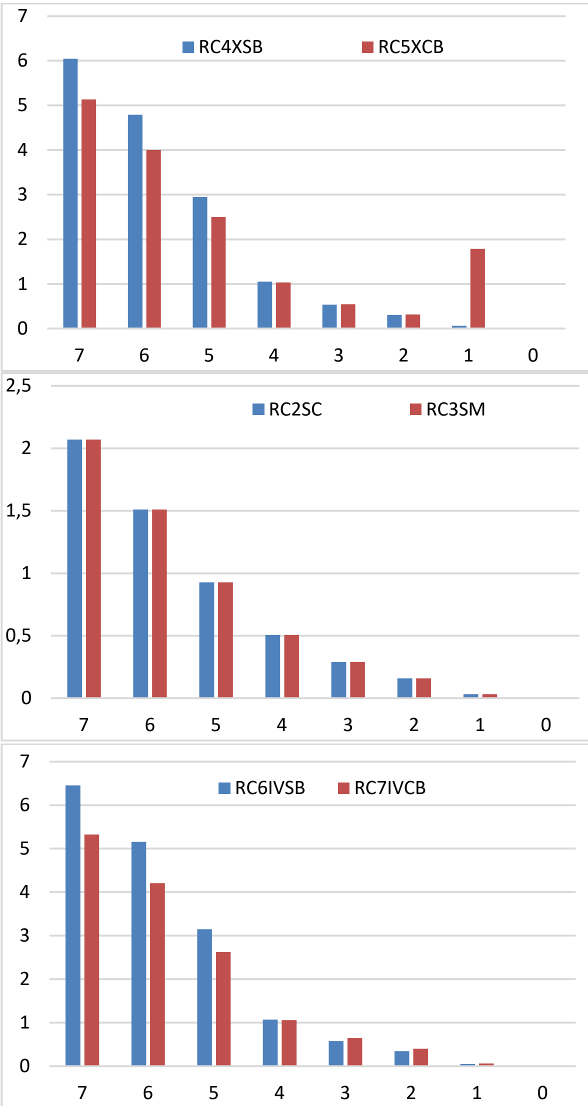
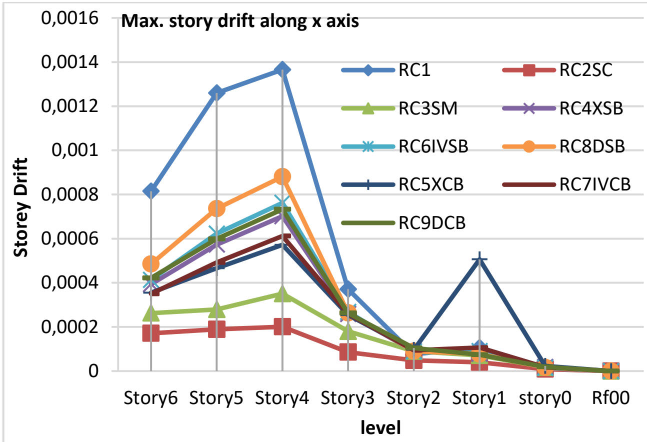
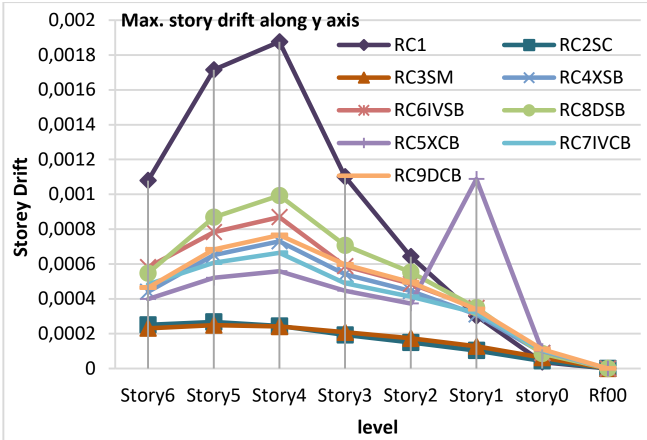


Fig. 7 Comparative study of displacement along the slope



(a)



(b)

Fig. 8 Story drift (a) along and (b) across the hill slope

If the comparative study is done, the X concrete bracing shows lower values as compared to the steel X bracing, Fig. 10. The reduced story drift of RC2SC has more drift as compared to the RC3SM configuration. The story stiffness, along and across the slope significant differences, is observed between shear wall buildings to other bracing or non-bracing building configuration. It is found that along the X-axis RC2SC shows more stiffness values and across the slope direction the RC3SM configuration building shows more story stiffness values. It is also observed that the RC1 building shows minimum story stiffness (Fig. 11). However as shown in Fig. 11 the shear wall building configuration (RC2SC, RC3SM) shows a more irregular stiffness value along with the height, it is because of the irregular vertical configuration of the building. Also, the concrete bracing system shows more stiffness value as compared to the steel bracing system (Fig. 11).

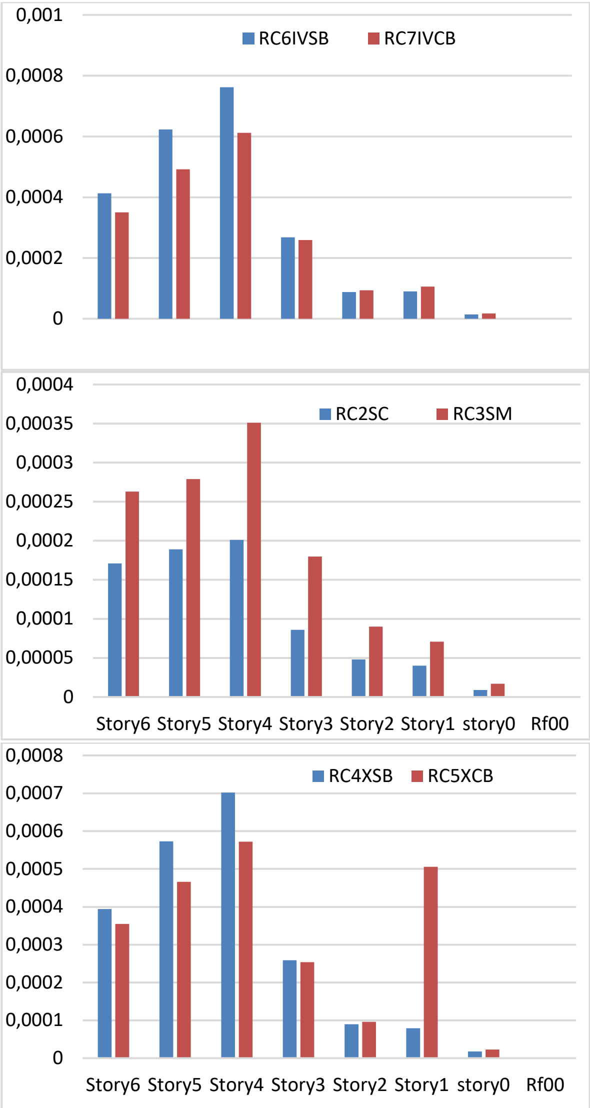
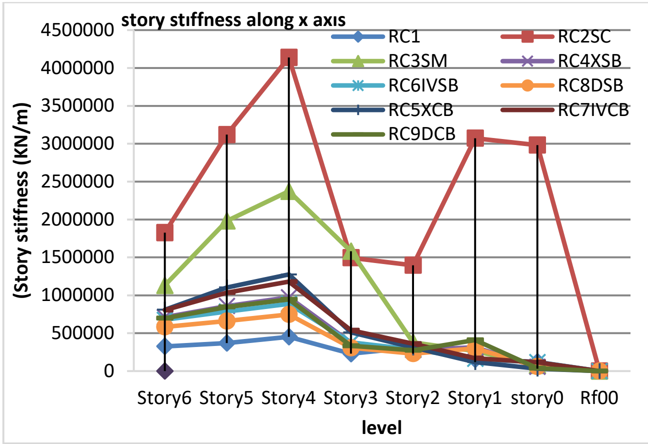
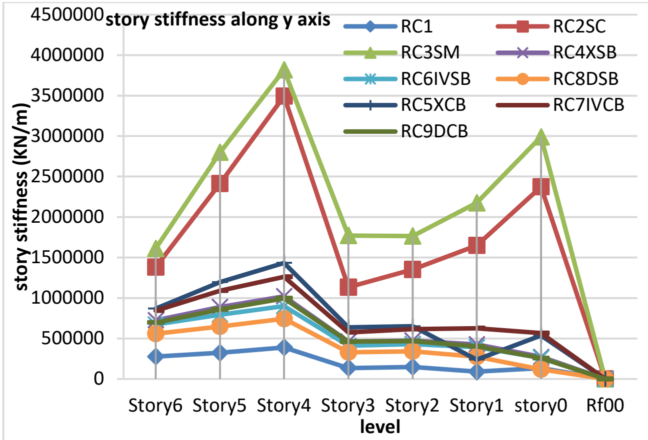


Fig. 9 Comparative story drift along the slope



(a)



(b)

Fig. 10 Story stiffness (a) along the X-axis and (b) along Y-axis

TABLE I
CONFIGURATIONS OF HILL BUILDINGS WITH GEOMETRICAL PROPERTY

Building type	Hill side		Models	Shear wall mm	Steel bracing	RC bracing mm	Column (mm)	Beam (mm)
	along x axis	5 bays	RC1				520*520	250*500
			RC2SC	200				
	along Y axis	4 bays	RC3SM	200				
			RC4XSB		ISLC300			
Step-back			RC5XCB			250*300		
			RC6IVSB		ISLC300			
			RC7IVCB			250*300		
			RC8DSB		ISLC300			
			RC9DCB			250*300		

RC: reinforced concrete, SC: shear wall in corner side, SM: shear wall in the middle side, SB: steel bracing, CB: concrete bracing.

TABLE II
LINEAR DYNAMIC PARAMETER OF THE HILL SIDE STRUCTURES

Designation	Height (m) from upper hill side	Height (m) from lower hill side	FTP by RSA (sec)	FTP as per IS 1893 (sec)	Max. Top story displacement (mm) Along	Max. Top story displacement (mm) Across	Maximum Storey shear KN Along	Maximum Storey shear KN Across
RC1	10.8	23.3	0.514	0.447	12.016	21.713	2047.71	2042.59
RC2SC	10.8	23.3	0.217	0.194	2.07	4.026	2484.54	2308.61
RC3SM	10.8	23.3	0.223	0.194	3.172	4.207	2519.4	2181.4
RC4XSB	10.8	23.3	0.356	0.477	6.043	10.396	2237.12	2217.15
RC5XCB	10.8	23.3	0.323	0.194	5.133	8.66	2350.3	2261.1
RC6IVSB	10.8	23.3	0.373	0.477	6.454	11.283	2218.9	2215.4
RC7IVCB	10.8	23.3	0.335	0.194	5.324	9.23	2321.8	2243.6
RC8DSB	10.8	23.3	0.403	0.477	7.517	13.153	2184.7	2197.2
RC9DCB	10.8	23.3	0.367	0.194	6.367	11.044	2285.7	2223.08

IV. CONCLUSION

In this study, the behaviors of hillside buildings with seismic effect by using the linear dynamic analysis (RSM) are investigated. The step-back building having seven-story buildings having different configurations is observed in this study. The structural elements like shear wall and steel bracing are observed seismic behaviors in terms of the fundamental time period, story drift, maximum top story displacement, and maximum story base shear parameter. The study shows that the shear wall placed in the corner side shows better performance. X concrete and X steel bracing also have good performance value in comparison to the other bracing system. It is also found that the fundamental period from software analysis and code provided time period shows the marginal difference. It also suggested that in step-back hillside with a high seismic zone side, the design provision of the linear dynamic analysis should be carried out to get an accurate design of the building. As increasing the stiffness of the building, the time period decreases. The research concludes that the shear wall building shows a small time period as compared to the other. In the hillside, the building shows different behavior of the shear wall structures and the story stiffness shows irregularities along with the height. It is also studied that the rectangular plan of building the maximum top story displacement across the slope direction was found more compared to the along the slope direction. It is noticed that it is better to use the X bracing system. The bracing has less base shear value as compared to concrete bracings and so the steel bracings may be economical to use as lateral load resisting systems. However, to know about the failure mechanism, plastic hinge formation and more accurate design nonlinear static analysis must be considered. Further research on the behavior of hillside building is required to take more knowledge in such type of building against the lateral loading. It is also needed to consider the over strength factor, failure mechanism, the connection of frame to bracing, ductility of the structure by using appropriate methodology. These topics have some potential for future studies.

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