Seismic Performance of Buildings with Various Configurations in Hilly Regions

Saurav Kumar Verma, Hrishikesh Dubey*

Department of Civil Engineering, Delhi Technological University, Delhi, 110042, India

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Abstract Structures on incline ground are vulnerable to earthquakes because of irregularities in plan and elevation. The structural configurations on slopes have been observed, with stepback and stepback-setback configurations being the most common. In mid to high rise buildings, shear wall and C-shaped shear wall cores are commonly used lateral load resisting components. The current research focuses on comparing the seismic performance of L-shear walls (LSW) at the corners, C shear-walls at core (CSW) and Reinforced concrete-filled steel tube column (RCFST) at corners and cores in stepback, and stepback-setback configurations buildings considering the base of the structures fixed designed for Indian codes using response spectrum analysis. The structural analysis tool ETABS 2017 was used to perform seismic analysis. Buildings on a hill slope with various configurations are studied: bare frame, concrete blockwork infill, LSW full bay at corners, LSW half bay at corners, CSW and RCFST column at corners and core. The characteristic parameters such as base shear, forces in the columns at the ground floor, storey drift, maximum storey displacement, time period, the bending moment in columns at every floor level and storey shear in structures will be determined and analysed for the different structures at the sloping ground. Structures with corner LSW perform better than buildings with centrally located shear walls at the core, whereas LSW at half bay in the corner and RCFST columns at corners and core serve the dual objective of space constraint and improved performance.

Keywords Stepback, Stepback-Setback Building, Shear Walls, Shear Wall Cores, Reinforced

Concrete-Filled Steel Tube Column, Response Spectrum Analysis (RSA)

1. Introduction

Strong earthquakes arise at any time, and constructions with irregularity have been shown to be the most susceptible. Construction activity on steep slopes is compelled by a scarcity of plain ground in the hilly terrain. Structures on inclines differ from those on flat land so that they are very uncertain and asymmetrical in both along and across incline directions. The mass and stiffness of such constructions vary vertically and laterally resulting in the centre of mass and rigidity on various floors do not coincide, leading to dominant torsional mode of vibration. Given the circumstances, it is necessary to explore the responses of such structures in order to make them earthquake-resistant and avoid their failure, hence minimising casualties. Due to the unpredictability of mountainous slopes, the influence of slope on structures subjected to seismic loads must be investigated.

A "Shear-wall" is a part of a structure that is subjected to lateral loads in its plane. The stiffness and strength characteristics of the wall determine the extent to which this wall shares the lateral load applied to the structure. The frame's strength and stiffness are enhanced by the shear wall and RCFST column. The shear-walls are capable of withstanding lateral stresses even those caused by seismic tremors and wind. The height of columns is not the same

for buildings on sloping land, which impacts the building's performance during an earthquake. The purpose of the present work is to reduce the damage in structures built on sloping grounds by using shear wall, RCFST column etc.

For the Design Basis Earthquake, the performance of shear-wall and CSW buildings is Immediate Occupancy (IO), whereas the performance of shear-wall buildings is Life Safety (LS) and CSW buildings are Collapse Prevention for the Maximum Considered Earthquake (CP). As a result, it may be inferred that shear-wall construction has fared marginally better than CSW construction [1].

Plan irregularities are indicated by the existence of short columns on the uphill side, while vertical irregularities result from differences in strength and stiffness of succeeding stories all along the height, resulting in a complex dynamic response during seismic excitation [2].

Seismic analysis was conducted using RSA on an eight-story structure that included a bare frame and structure with shear-wall in seismic zone III, with the conclusion that when the contribution of the shear wall is considered, storey drifts and displacements are significantly reduced [3].

The floor at road level, simply if there should be an occurrence of downhill structures, is most vulnerable to damage, according to a dynamic analysis of a building at 450 slope and vertical cuts with varying heights for a bunch of five ground movements from Pacific Earthquake Engineering Research Centre database. Under cross incline excitation, stepback buildings are prone to significant torsional impacts, and storey drift there in upper three storeys of a sloping ground building is equivalent to that of a three-storey regular building; as a result, the pattern of inter-storey drifts varies between structures. The results of the analytical investigation are backed up by observations of the damage pattern during the Sikkim earthquake [4].

The stiffness, roof displacements, and seismic performance of RC buildings are all improved by infill walls. [5].

The seismic response of three different structures placed on sloping terrain is considered, and it is discovered that stepback-setback constructions are better appropriate on inclining terrain [6].

The performance of sloped structures is especially poor in the cross-slope direction, caused by torsional irregularities, resulting in disappointment at even lower intensities of shaking, according to a time history analysis of a sloped building using bidirectional components of time histories of seven recorded ground motions. Short columns displayed brittle shear failure at ground level, which is the fundamental reason for these structures' failure in both along and cross slope excitation [7].

When a shear wall is installed at two corners of a structure for 7.50, 150, and 300, it was discovered that the mode contributes to modal mass participation up to higher modes due to the building's asymmetry [8].

The base shear of the infill structure grows with the addition in stiffness of the structure, according to a pushover analysis on G+9 storey structures situated on sloping land at a 270 slope with and without infill walls. The storey drift of the soft storey structure is properly controlled by masonry infills within the bottommost storey, showing that the soft-story building's performance during earthquakes is more sensitive than the full-infill type [9].

On slanting terrain, stepback-setback building frames were found to be more acceptable than stepback frames [10].

SAP2000 is used to analyse the response system for four mathematical models. The maximum forces, displacements, and storey drift were also investigated. Short columns are the most important component for steep slope building. It is preferable to install the shear wall on the shorter column side to reduce shear force and bending moment. [11].

The collapse of hill structures is mostly caused by shear failure of short columns, according to stepback buildings planned and evaluated for gravity loads and specific moment resisting frame. Furthermore, when bidirectional ground movements are applied to a step-back structure, the highest inter storey drift is not always in the major direction [12].

2. State of the Art

In this paper, the state of art on seismic analysis, behaviour, and analytical modelling of elements of building on hill slopes with various configuration i.e., stepback-setback and stepback building has been brought out. The buildings in hilly region have different dynamic properties when compared with the buildings built on level ground [19].

In buildings resting on sloping ground, within a particular storey there is huge variation of column forces and the columns with higher bending moment at the upper side of the slope are affected severely during earthquake[20].

Stepback and setback building frames are observed to be more reasonable on slanting ground, contrasted with stepback frames[21].

The purpose of present work is to improve the performance of the structures built on sloping grounds. The same is compared by placing shear wall in various orientations and by using RCFST column instead of shear wall.

3. Scope of the Study

Seismic analysis is carried out on a building on plain ground and two types of buildings resting on slopes,

namely stepback and stepback-setback, by response spectrum approach using finite element software ETABS Version 2017. An attempt has been made to strengthen these buildings which are formed commonly due to architectural purpose with the help of shear walls at different locations, RCFST column at corners and blockwork infill in the open ground storey by reducing the response of such building in terms of drift, displacements, time period and storey shear etc. In the long run, a suitable plan of attempting to be used in a hilly region is proposed.

4. Modelling and Analysis

Shear walls are regarded shell elements while beams are considered 2-noded beam elements with 6dof at each node. The floor slabs are represented as 4-noded shell components with 6dof at each node and are expected to behave as diaphragms, ensuring integrated action of all vertical load resisting parts. Columns are considered to be

square. To support the notion of a strong-column weak-beam, the beams' cross-sectional area is kept less than that of the columns. In the modelling, the material is assumed to be isotropic. The concrete block infill wall's deadweight is assigned to the beam as a uniformly distributed load. The concrete block infill wall is modelled as an equivalent diagonal-strut member pinned with eccentric back bracing. The angle of the diagonal-strut for the full panel infill wall is taken as 26.5650 and that for the half-panel infill wall as 44.740 as per clause 7.9 of IS 1893 (Part I) [13]. Storeys with one way slanted at 280, with a dimension in the plan as 30 m x 25 m and storey height of 3.2 m, as illustrated in Figure 1.

For the built-up RCFST composite column 550 mm × 550 mm, Reinforced cement concrete (RCC) column of 450 mm × 450 mm is embedded in the 50 mm thick Fe345 steel tube as demonstrated in Figure 2. The RCFST composite column is designed using section designer in Etabs 2017 [14].

(i)

Figure 1. (i) Building plan (ii) Elevation of Hill slope

Figure 2. RCFST Composite column

4.1. Models Investigated

Three distinct building configurations, Regular, Stepback, and Stepback-Setback, are used in this study, as indicated in Figure 3, with plan view of shear wall positions and RCFST column configuration in Figure 4, and thirteen models as indicated in Figure 5 are investigated as follows:

P: Bare Frame on plain ground.

1S: Stepback bare frame at a slope.

2S: Stepback frame at a slope with Concrete block infill walls and open ground storey.

3S: As with model 2S, only the corner panels have L type shear wall till top.

4S: As with model 2S, only the corner half panels are infilled with L type shear wall till top.

5S: As with model 2S, only the centre core of building is infilled with C type shear wall core till top.

6S: As with model 2S, the columns at corner and core

are replaced RCFST Composite column.

1SS: Stepback-Setback bare frame at a slope.

2SS: Stepback-Setback frame at a slope with Concrete block infill walls and open ground storey.

3SS: As with model 2SS, only the corner panels have L type shear wall till top.

4SS: As with model 2SS, only the corner half panels are infilled with L type shear wall till top.

5SS: As with model 2SS, only the centre core of building is infilled with C type shear wall core till top.

6SS: As with model 2SS, the columns at corner and core are replaced RCFST Composite column.

(i)

(ii)

(iii)

Figure 3. Different configuration of building (i) Regular building on levelled ground (ii) Stepback building (iii) Stepback-setback building

(i)

(ii)

(iii)

(iv)

Figure 4. Plan view of (i) L-Shear wall of full panel at corner (ii) L-shear wall of half panel at corner (iii) C-Shear wall core (iv) RCSFT column at corner and core

4.2. Analysis Method

All of the models in this study are analysed using the linear static method i.e., Equivalent static method (ESM) and the linear dynamic method i.e., Response spectrum method (RSM). The software ETABS 2017 is used to do linear analysis. Buildings have been assigned dead and live loads according to IS 875 Part I and II. All of the structures are designed as per IS 1893 and IS 13920. To analyse the seismic response of the structures, ESM and RSM analyses

are carried out and the findings compared. Mode shapes are usually acquired in a normalised form in modal analyses; hence the results of the RSM must be suitably scaled. The scaling in this study was done by equal the base shears acquired from ESM and RSM according to IS1893 (2016). A minimum number of modes was considered for each structure instance, with the entire sum of modal masses equating at least 99 per cent of the overall seismic mass. Accidental eccentricity and torsional effect are considered. Damping is estimated to be 5%.

4.3. Detailed Data of Buildings

Table 1 shows the properties that were used for the buildings.

Table 1. Building data

Building details	
Total storeys	8
Storey height	3.2m
Frame system	SMRF
Building use	Office building without separate storage
Seismic zone	V
Soil type	Medium
Material Properties	
Concrete grade	M30
Steel grade	Fe415
Young's modulus of M30 concrete, E	27386 MPa
Poisson's ratio of concrete	0.2
Infill concrete blockwork wall thickness	200mm
The density of the Infill wall including finishing	10 kN/m ³
Modulus of Elasticity of infill wall	2040 MPa
Structural Members	
Thickness of slab	150mm
RCC beam size	300 x 450 mm
RCC column size	450 x 450 mm
RCFST Composite I Column	550 x 550 mm
The thickness of the Shear wall	200 mm
Super Imposed Dead Load	
Terrace finishes with water proofing	3.3 kN/m ²
Floor finishes	1.2 kN/m ²
Infill wall load on beams	5.5 kN/m
Live Load	
Terrace	1.5 kN/m ²
Floor	4 kN/m ²

Figure 5. Models investigated

5. Results and Discussion

The various models were analysed using Etabs 2017. The outcomes are presented in a way that is acceptable for each of the study's models.

5.1. Time Period

The natural time periods from IS: 1893-2016 codal provision and Etabs analysis results for Model P to 6SS are presented in Table 2. The natural time periods obtained from the code do not match the analysis results, as seen in

Figure 5 and Figure 6. Their variation in along and across slope direction is illustrated in Figure 6 and Figure 7. As per the equivalent static method, in IS 1893(Part 1):2016, the empirical relation is given cannot portray the right values of the time period in both along and across the slope direction, whereas Response spectrum analysis using free vibration analysis produced better results. It is seen that time period decreases as the seismic weight of the structure decreases as seen in P, 1S and 1SS. It is noticed that as the structural stiffness increments, time period decreases. Buildings with LSW at corners have the shortest period of vibration.

Table 2. Analytical and Codal Fundamental Time Period in sec

Model	FTP as per RSA		FTP as per IS1893:2016	
	(sec)		(sec)	
	Along	Across	Along	Across
P	2.314	2.151	0.854	0.854
1S	1.346	1.559	0.508	0.508
2S	1.159	1.314	0.210	0.230
3S	0.353	0.416	0.490	0.510
4S	0.493	0.629	0.510	0.510
5S	0.615	0.885	0.510	0.510
6S	0.918	1.059	0.210	0.230
1SS	0.987	0.955	0.508	0.508
2SS	0.864	0.882	0.210	0.230
3SS	0.256	0.300	0.490	0.510
4SS	0.373	0.482	0.510	0.510
5SS	0.644	0.450	0.510	0.510
6SS	0.693	0.706	0.210	0.230

Figure 6. Time Period along the slope direction

Figure 7. Time Period across the slope direction

5.2. Axial Force Distribution

Axial force down the storey height of various structures setup has appeared in Table 3. From Figure 8, contrast between axial force distribution down the storey of different models is noticed. Axial force is maximum in models having an L-shear wall at full panel then half-panel and then at shear wall core, due to the higher stiffness provided by shear walls. Bare frame models have the least storey shear. Axial force in stepback-setback models decreases after 6th storey because of setbacks which results in less seismic weight of storeys as compared to stepback building. As the model is laying on an inclined base, the measure of axial forces in the stepback-setback models is lower than the stepback models.

Figure 8. Axial force along the storey in kN

Table 3. Axial force along the storey in kN

Storey No	Axial force(in kN) in Models												
	P	1S	2S	3S	4S	5S	6S	1SS	2SS	3SS	4SS	5SS	6SS
8	376.755	517.156	629.147	1374.09	1355.12	1197.72	788.257	206.064	246.646	401.384	400.397	393.7556	312.5794
7	274.52	376.827	581.088	1276.61	1256.33	1108.02	734.573	299.513	413.623	665.388	670.313	658.0572	527.1947
6	201.688	276.852	426.922	937.916	923.017	814.056	539.686	320.516	453.856	720.598	730.272	726.308	582.9226
5	140.061	192.259	295.935	650.857	639.898	564.3	361.135	292.428	418.436	640.247	670.946	673.5727	535.5602
4	89.6393	99.9463	154.307	342.14	334.538	293.744	186.341	188.787	270.828	412.747	436.293	435.9228	345.1728
3	50.4221	42.7334	66.2586	144.411	142.508	126.404	79.0474	79.5843	120.949	179.152	193.459	195.0367	154.9914
2	22.4098	12.9986	20.3197	44.6901	43.8735	39.567	23.6859	24.208	37.0916	53.8743	59.56	61.0505	47.7998
1	5.6025	1.7512	2.783	6.295	6.0736	5.3483	2.7677	3.2613	5.0801	6.962	8.2451	8.2523	6.482

Figure 9. Base Shear

Table 4. Base Shear in kN

Model	Base Shear in kN
P	1249.25
1S	1520.5226
2S	2176.7607
3S	4777.0057
4S	4701.358
5S	4149.1571
6S	2715.4937
1SS	1414.3594
2SS	1966.5098
3SS	3080.3518
4SS	3169.4855
5SS	3151.9558
6SS	2512.7029

5.3. Base Shear

Table 4 lists the base shears for all of the models. Base shear is an element of mass as well as stiffness of the structure. However, due to increase in seismic weight of structure due to shear wall and composite columns, there is an increase in the base shear. The infill structure's base shear increases as the structure's mass increases. Maximum base shear is seen in models having a shear wall due to

increased stiffness. Least base shear is seen in Regular building on levelled ground and highest in the stepback building. Base shear in Half panel L- shear wall and full panel L-shear wall is approximately near. Figure 9 depicts the base shear variations of various models.

5.4. Time Period (T) and Modal Mass Participation (P_k)

Dynamic mass participation ratios and fundamental periods in the first three modes are illustrated in Tables 5 and Table 6 for all building configurations along and across the slope direction. According to IS 1893:2016 building in seismic zone IV and V, the initial 3 modes together, in each principal plan direction, ought to contribute at least 65per cent mass participation factor to avoid irregularity in lateral storey in a principal plan axis. This is well satisfied in all the models. Because of design inconsistency, mass participation in the fundamental mode in the case of working on a slope is significantly lower than in ordinary construction. The participation of higher mode is more in building resting on sloping ground. In stepback-setback, when an earthquake strikes in the direction of the slope, it endures stiffness irregularity. But, when subjected to earthquake across the slope; besides stiffness irregularity, buildings undergo torsion response, due to non-coincidence in the centre of stiffness and mass. This emphasises how important it is for a structure's stiffness and mass to be distributed uniformly along its elevation to maintain uniform lateral force distribution.

Table 5. Time period (T) in sec and Modal Mass Participation (P_k) in % in along slope direction

Mode	P	
	T(sec)	P_k (%)
1	2.314	80.62
2	0.723	9.83
3	0.396	4.08

Mode	1SS		2SS		3SS		4SS		5SS		6SS	
	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)
1	0.987	57.34	0.864	69.55	0.256	57.92	0.373	48.1	0.644	15.07	0.693	52.47
2	0.43	28.99	0.405	23.73	0.141	2.27	0.255	35.91	0.518	27.51	0.306	33.00
3	0.303	10.22	0.285	4.26	0.13	31.98	0.113	4.68	0.284	23.31	0.214	7.97

Mode	1S		2S		3S		4S		5S		6S	
	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)
1	1.346	69.95	1.159	78.53	0.353	68.88	0.493	56.25	0.615	41.31	0.918	68.61
2	0.447	19.81	0.415	16.64	0.146	0.49	0.198	39.06	0.212	4.85	0.311	21.02
3	0.305	8.01	0.287	3.34	0.131	3.3	0.155	0.32	0.172	10.69	0.208	6.57

Table 6. Time period (T) in sec and Modal Mass Participation (P_k) in % in across slope direction

Mode	P	
	T(sec)	P_k (%)
1	2.151	80.98
2	0.678	9.8
3	0.375	3.99

Mode	1S		2S		3S		4S		5S		6S	
	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)
1	1.559	62.99	1.314	73.86	0.416	63.53	0.629	66.04	0.885	19.27	1.059	71.91
2	1.035	13.48	0.83	7.15	0.199	0.33	0.313	0.19	0.675	51.2	0.648	3.77
3	0.532	10.61	0.435	11.32	0.16	0.71	0.242	28.61	0.286	3.08	0.369	12.9

Mode	1SS		2SS		3SS		4SS		5SS		6SS	
	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)
1	0.955	72.43	0.882	76.62	0.3	44.32	0.482	48.33	0.45	23.23	0.706	66.59
2	0.842	1.94	0.413	12.08	0.21	34.28	0.295	34.04	0.434	8.29	0.356	14.54
3	0.477	7.68	0.244	8.08	0.153	0.53	0.216	4.68	0.294	8.75	0.24	1.56

(i)

(ii)

Figure 10. Lateral Displacement in mm by Equivalent Static Method (i) along slope (ii) across slope

(i)

Figure 11. Lateral Displacement in mm by Response Spectrum Method (i) along slope (ii) across slope

5.5. Lateral Displacement

The maximum displacements at every storey level concerning the ground determined using ESM and RSM for various configurations are displayed both along and across the slope in Figure 10 and Figure 11. To represent the impact of torsion, the displacements are seen both along and across directions when force is acting in a specific direction. The storey displacement is largest for top storey, steadily decreasing down the structure until it is nearly insignificant at the bottom storey.

With models resting on slope; as the centre of mass and rigidity of different configurations buildings do not overlap because of irregularity, bi-directional displacement (along and across) for unidirectional force is seen. In stepback and stepback-setback models, it is seen that the taller side of the model displaces more than the shortened side as the taller side has columns longer than that of the shorter side. Because of this explanation, the taller side acts more flexible in comparison to the shorter side when subjected to a similar measure of force.

Models with L-shear wall at corner showed excellent

displacement control than shear wall core and composite column models. But stepback-setback models RCFST columns are proved more beneficial in displacement control than only infill model and shear wall core. When earthquake forces are applied across the direction, the top storey displacement is much higher than when they are applied along the direction.

5.6. Storey Drift

According to IS 1893(Part 1): 2016 storey drifts in any storey should not outperform 0.004 times the storey height [9]. Storey height of 3.2m has got 12.8mm. Figure 12 and Figure 13 show the highest storey drift at each storey level derived using ESM and RSM for the various configurations, as well as both orientations of the slope, i.e., along, and across. In all methodologies, stepback-setback models indicate maximum storey drift in top storeys. Ground storey drift is maximum in the model on the plain ground due to stiffness. Models with L-shear walls at corners in full panel show extremely less inter-storey drifts.

Figure 12. Storey drift profile (i) along the slope direction by EQX (ii) across the slope direction by EQY

(i)

(ii)

Figure 13. Storey drift profile (i) along the slope direction by RSX (ii) across the slope direction by RSY

(i)

Figure 14. Variation of storey stiffness of models in (i) ESM (ii) RSM

5.7. Storey Stiffness

The overall stiffness provided inside a storey by its walls, lateral load resisting elements, and columns is referred to as the storey's stiffness. The stiffness of every storey for each model is shown in Figure 14 as per ESM and RSM. It is observed that in both RSM and ESM, stiffness variation along the storey heights is comparative. Models on the slope show exceptionally less stiffness in both the methods, which is most susceptible in the event of an earthquake. To prevent this, shear walls are provided to overcome the issue of stiffness deficiency. L-shear wall at corners proved more beneficial than shear wall core in respect of performance.

5.8. Bending Moment in Column

Bending moment in the column at each storey level and

in each model is shown in Figure 15. It is seen in both ESM and RSM, the measure of moment in each column of every storey in model P is practically comparative. The greatest bending moment is at the columns of bottommost storey and as the storey height increments, the value of bending moment lessens in the model on the plain ground i.e., P. Models with shear wall have the least bending moment in columns of ground storey. Strangely, in the stepback-setback models i.e., SS category models despite having similar tallness of columns on one or the other side of the structure, enormous variation in column bending moment have been seen inside a specific storey. The columns at the upper level of the slant are confined to a greater bending moment than the columns at the bottom level of the slant which is overcome by providing an L-shear wall at the corners and RCSFT columns at corners.

(i)

(ii)

(iii)

(iv)

(v)

(vi)

(viii)

(ix)

(x)

(xi)

(xii)

(xiii)

Figure 15. Column bending moment of (i) P (ii) 1S (iii) 2S (iv) 3S (v) 4S (vi) 5S (vii) 6S (viii) 1SS (ix) 2SS (x) 3SS (xi) 4SS (xii) 5SS (xiii) 6SS

Table 7. Shear force in columns at ground level in kN in (i) along the slope direction (ii) across the slope direction

(i)

Model	Frame A	Frame B	Frame C	Frame D	Frame E	Frame F
P	27.1	34.33	34.04	34.04	34.33	27.1
1S	1.73	1.28	9.96	29.03	67.57	143.04
2S	7.9157	7.048	27.1915	56.3939	99.4996	164.486
3S	0	0.229	3.4866	8.8543	21.8408	0
4S	0	0.5034	1.6404	5.5674	12.9782	0
5S	3.1672	2.7782	8.2435	26.4103	78.1943	143.2084
6S	26.42	2.95	9.258	22.36	48.89	753.48
1SS	2.3148	2.0699	11.7165	31.8018	63.2119	123.3032
2SS	8.2978	7.673	27.0569	54.412	88.1751	142
3SS	0	1.2627	3.5043	6.8275	11.643	0
4SS	0	1.9946	7.325	13.9258	23.9443	0
5SS	2.9907	2.8142	6.9896	21.0614	55.9879	112.5691
6SS	5.148	0.7128	5.3303	18.691	44.493	689.791

(ii)

Model	Frame A	Frame B	Frame C	Frame D	Frame E	Frame F
P	28.92	29.63	29.65	29.65	29.63	28.92
1 S	9.7	6.64	22.92	37.07	51.28	71.94
2 S	32.252	21.442	32.7597	42.927	61.9565	104.8275
3 S	0	0.7547	5.3639	9.6558	12.7364	0
4 S	0	1.641	9.6598	17.3187	23.3287	0
5 S	15.8228	9.1604	6.6051	13.0526	25.2768	48.5408
6 S	108.72	9.34	14.84	20.25	35.12	442.72
1 SS	8.0251	6.7878	19.1078	32.7006	53.6735	102.4565
2 SS	20.8104	14.7088	24.492	37.553	65.0975	134.4079
3 SS	0	0.7757	3.9622	7.8647	13.1056	0
4 SS	0	1.9673	9.9229	18.5903	26.7486	0
5 SS	5.1386	3.3276	3.1626	10.6171	36.9732	100.1263
6 SS	97.166	8.807	13.438	18.0973	36.281	540.174

5.9. Shear Force in Columns at Ground Level

Shear force at ground level columns in each model is shown in Table 7. In the building on levelled ground, shear force in the ground level columns is almost the same in all columns and both along and across the slope direction. When compared to the remainder of the columns on the bottommost floor, the shear force in the extreme right column is much larger along the slope of the stepback building. Comparatively, in the extreme left column and adjoining column (frame A and B) at ground level, the value of shear force is only 1 to 2% of that of the extreme right column. Across the slope, value of shear force in the extreme right column (frame F) at ground level is less than the corresponding values obtained for earthquake forces along the slope direction. From a design perspective, it is clear that the size and stiffness need of the extreme right column at ground level must be carefully considered such that it is safe even in the worst probable load combinations both along and across the slope's direction.

In contrast with stepback building, stepback-setback building experiences less shear force in the extreme right column (frame F) in both the direction.

It is seen that due to the presence of the shear wall in Model 3S, 4S, 3SS and 4SS, shear force value is reduced to approximate nil.

According to Table 7, it is seen that the actions needed for design purposes are predominant when earthquake forces are in along the slope direction.

6. Conclusions

The seismic response of the two typical configurations

of building on slopes and building on flat terrain was studied by performing Response spectrum analysis.

The ends drawn from the above investigation were summed up underneath:

1. In comparison to the CSW building, it can be determined that the LSW at corners in full and half-panel has performed better. Nonetheless, both of the structures designed per the Indian code perform admirably.
2. Structures on slanted terrain are shown to be more vulnerable than those on flat ground.
3. The models on sloping terrain have been observed to move orthogonally under unidirectional force.
4. Due to the reduction in column height, columns on the higher side of the slope are likewise susceptible to increased bending moments.
5. When the L-shear wall at corners and RCFST columns are employed, there is a large reduction in lateral displacement and lateral drift requirement, and therefore the building's performance improves. In setback buildings, shear walls and RCFST composite columns have been proven to be phenomenally successful in decreasing lateral displacements.
6. The addition of shear walls increases base shear for all models, which is related to the increased seismic weight of the building.
7. When structures are subjected to lateral stresses, the presence of a shear wall affects the overall behaviour of the structures. Displacement and storey drift are much minimised due to shear walls contribution.
8. In regular type building without any setback on sloping ground, with incorporation of shear walls at various locations reduction is found in lateral displacement up to 3-5times, in fundamental time

- period up to 70-80% and increment found in base shear up to 2-3times in all the suggested models.
9. In stepback-setback models on incline ground, with incorporation of shear walls at various locations reduction is found in lateral displacement up to 5-7times, in fundamental time period up to 50-80% and increment found in base shear up to 2-2.5times in all the suggested models.
 10. A dual-type structural system with properly placed shear walls is more effective than a moment-resisting frame system in resisting earthquake stresses and can be employed efficiently for structures on slopes.
 11. Shear walls with a spreader construction exhibit superior torsional control, however the difficulty with shear walls is that they limit access to the open ground level, reducing the structure's functional efficiency and concentrating stiffness at a certain point but the stiffness of RCFST composite columns is equally dispersed on entire base of the building, and the RC column cross section does not change at the junction, therefore they can be selected where more space access is required.

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