SEISMIC RESPONSE OF REINFORCED CONCRETE FRAME RESTING ON HILL SLOPES

A DISSERTATION

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IN

STRUCTURAL ENGINEERING

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I, Saurav Kumar Verma, Roll No. 2K19/STE/05 student of M. Tech (Structural Engineering), hereby declare that the project dissertation titled "**SEISMIC RESPONSE OF REINFORCED CONCRETE FRAME RESTING ON HILL SLOPES**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled "**SEISMIC RESPONSE OF REINFORCED CONCRETE FRAME RESTING ON HILL SLOPES**" which is submitted by Salil Jha, Roll No. 2K19/STE/05, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any degree or diploma to this university or elsewhere.

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Saurav Kumar Verma

ABSTRACT

The Constructions done in the hilly regions are more vulnerable seismically in contrast with the structures built in flat terrains. The structures constructed in hilly regions are usually irregular, these structures are irregular both in mass and stiffness. Constructions done on the sloping ground is different from usual structures since they're asymmetrical in both horizontal and vertical directions. Columns of the bottommost storey have a varying height because of inclining ground and are torsionally coupled, henceforth draw in a lot of shear forces, and without proper detailing building constructed on sloping ground is susceptible to moderate to heavy damage. In this analysis, the seismic response of three different building configurations i.e., Regular, Stepback, Stepback-Setback is evaluated. The structural analysis tool ETABS 2017 was used to perform seismic analysis utilising the linear static and dynamic methods. Buildings on a hill slope with various configurations are studied in two parts; first being: bare frame, soft storey, totally concrete blockwork infill, a soft storey with shear wall at corners, frame with composite columns at the bottommost storey and second part being: L-shear walls(LSW) at the corners, C shear-walls at core(CSW) and Reinforced concrete-filled steel tube column (RCFST) at corners and core in stepback, and stepback-setback configurations. The characteristic parameters such as base shear, forces in the columns at the ground floor, storey drift, maximum top 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. Finally, the reasonableness of various designs of slope structures would be proposed.

Keywords— Stepback, Stepback-Setback building, ETABS 2017, Shear walls, Shear wall cores, Reinforced concrete-filled steel tube column, seismic analysis

TABLE OF CONTENTS

ABSTRACT..5

Chapter 1

Introduction..11

Chapter 2

Literature Review..13

Chapter 3

Scope of the study...18

Chapter 4

Modelling and analysis..20

4.1 Models investigated

4.2 Analysis method

4.3 Detailed data of buildings

Chapter 5

Results and Discussions

PART I...28

5.1 Time period

5.2 Axial force distribution

5.3 Base shear

5.4 Time period (T) and Modal mass participation (Pk)

5.5 Lateral Displacement

5.6 Storey Drift

5.7 Storey Stiffness

5.8 Bending Moment in Column

5.9 Shear force in Column at ground level

PART II 44

5.10 Time period

5.11 Axial force distribution

5.12 Base shear

5.13 Time period (T) and Modal mass participation (Pk)

5.14 Lateral Displacement

5.15 Storey Drift

5.16 Storey Stiffness

5.17 Bending Moment in Column

5.18 Shear force in Column at ground level

Chapter 6

Conclusions.. 60

References 62

LIST OF FIGURES

Figure 1	(i) Plan of the building (ii) Elevation of Hill slope	21
Figure 2	(i)RCC ISMB250 Composite I column (ii) RCFST composite column	22
Figure 3	Different configuration of building (a) Regular building on levelled ground (b)Stepback building (c)Stepback-setback building	23
Figure 4	Extruded view of stepback building with shear wall at corner panels	23
Figure 5	Models Investigated	25
	PART I	
Figure 6	Time Period along the slope direction	30
Figure 7	Time Period across the slope direction	30
Figure 8	Axial force along the storey in kN	31
Figure 9	Base Shear	32
Figure 10	Lateral Displacement in mm by Equivalent Static Method (a) along slope (b) across slope	35
Figure 11	Lateral Displacement in mm by Response Spectrum Method (a) along slope (b) across slope	36
Figure 12	Storey drift profile (a) along the slope direction by EQX (b) across the slope direction by EQY	37
Figure 13	Storey drift profile (a) along the slope direction by RSX (b) across the slope direction by RSY	38
Figure 14	Variation of storey stiffness of models in (a) ESM (b) RSM	40
Figure 15	Column bending moment of (a) P0 (b) S0 (c) S1 (d) S2 (e) S3 (f) S4 (g) SS0 (h) SS1 (i) SS2 (j) SS3 (k) SS4	42
Figure 16	Time Period along the slope direction	45
Figure 17	Time period across the slope direction	45
Figure 18	Axial force along the storey in kN	46
Figure 19	Base Shear	47

Figure 20	Lateral Displacement in mm by Equivalent Static Method (a) along slope (b) across slope	49
Figure 21	Lateral Displacement in mm by Response Spectrum Method (a) along slope (b) across slope	50
Figure 22	Storey drift profile (a) along the slope direction by EQX (b) across the slope direction by EQY	52
Figure 23	Storey drift profile (a) along the slope direction by RSX (b) across the slope direction by RSY	53
Figure 24	Variation of storey stiffness of models in (a) ESM (b) RSM	55
Figure 25	Column bending moment of (a) P (b) 1S (c) 2S (d) 3S (e) 4S (f) 5S (g) 6S (h) 1SS (i) 2SS (j) 3SS (k) 4SS (l) 5SS (m) 6SS	58

LIST OF TABLES

Table 1	Building data	20
	PART I	
Table 2	Analytical and Codal Fundamental Time Period in sec	22
Table 3	Axial force along the storey in kN	24
Table 4	Base Shear in kN	25
Table 5	Fundamental periods (T) in sec and Modal Participation Mass Ratios (Pk) in % in along-slope direction	26
Table 6	Fundamental periods (T) in sec and Modal Participation Mass Ratios (Pk) in % in across-slope direction	27
Table 7	Shear force in columns at ground level in kN in (a) along the slope direction	36
	(b) across the slope direction	
	PART II	
Table 8	Analytical and Codal Fundamental Time Period in sec	22
Table 9	Axial force along the storey in kN	24
Table 10	Base Shear in kN	25
Table 11	Fundamental periods (T) in sec and Modal Participation Mass Ratios (Pk) in % in along-slope direction	26
Table 12	Fundamental periods (T) in sec and Modal Participation Mass Ratios (Pk) in % in across-slope direction	27
Table 13	Shear force in columns at ground level in kN in (a) along the slope direction	36
	(b) across the slope direction	

Chapter 1

INTRODUCTION

INTRODUCTION

North regions of India have enormous number of sloping landscape, which are divided into seismic zone IV and V. The scarcity of flat land in uneven areas forces to build the structures on sloping ground. As the performance of structures during an earthquake is dependent on mass along with stiffness conveyance in both the flat and upright planes of the structures.

The stepback structures typically have various stories diminishing progressively at the base in each bay, toward the incline keeping up a similar rooftop level, while stepback-setback structures do not have a similar rooftop level. When compared to standard, the existence of such developments in seismically inclined terrain exposes them to more prominent shears and torsion. The short stiff columns on the uphill side draw in; due to failure of short column, a lot higher lateral forces during an earthquake bringing about the failure of the structure.

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 ground by using Shear wall, RCFST columns etc.

Chapter 2

LITERATURE REVIEW

LITERATURE REVIEW

- **B.G. Birajdar and S.S. Nalawade (2004):** The seismic response of various setup of building arranged on hill slopes and found that as the tallness of the stepback building increases, increment in the time period in addition to storey displacement is higher than stepback-setback building and when compared to the rest of the columns, shear force in the column towards the limit left is significantly larger; in the instance of a stepback-setback construction, it is discovered to be 55-250 per cent higher.

- **S.M.Nagargoje and K.S.Sable (2012):** The dynamic response of 3D space frame of different configurations with varying heights and suggested stepback-setback buildings may be encouraged on the slanted ground.

- **Y. Singh & Phani Gade (2011):** Dynamic analysis of building at 45degree slope and vertical cuts with varying heights for a bunch of five ground movements from the database of pacific Earthquake engineering research centre was done and tracked down that the floor at road level, simply if there should be an occurrence of downhill structures, is most vulnerable to damage. Under cross incline excitation, stepback buildings are subjected to massive torsional impacts, and storey drift in the upper 3 storeys of a building on the sloping ground are similar to those in a three-storey regular building; as a result, the pattern of inter-storey drifts differs among various structures. Perceptions of the damage pattern during a ten-story RC frame structure that collapsed during the Sikkim earthquake support the conclusions of the analytical investigation.

- **Mohammed Umar Farooque Patel, A.V.Kulkarni,Nayeemulla Inamdar (2018):** Buildings on sloping terrain with shear walls at various places at the centre and corners analysed by static and dynamic analyses and assessed utilizing pushover analysis inferred that among all the models of the simple frame and shear wall positioned at the centre; shear wall at exterior corners encounters the least displacement. Spectral displacement and roof displacement and plastic hinge formation are decreasing for structures on flat ground when contrasted with structures model on the hilly ground.

- **Y. Singh, V.R. Yeluguri, and D.H. Lang (2014):** Time history analysis of a sloped building utilizing bidirectional components of time histories of seven recorded ground motion showed the performance of sloped structures is especially poor in the cross-slope direction, being brought about by torsional irregularities, bringing about disappointment at even lower intensities of shaking. The primary justification for the disappointment of these structures, in both along and cross slope excitation, is because short columns showed brittle shear failure at ground level.

- **Nilesh B.Mevawala, Dr.Atul K.Desai (2016):** A non-linear time history investigation considering the acceleration time history of the Bhuj, Chamoli, Uttarkashi and Nepal earthquake of 2015 at the base of the building carried out on five and ten storey structures at 15degree, 23degree and 35degree slope concluded that the displacement and bending moment increments as the slant of the ground increases. The bending moment, displacement, and shear force increments as we move from ground to upper storeys. In Nepal response of building in respect to displacement; for an earthquake is more when stood out from others, as, Uttarkashi, Bhuj and Chamoli.

- **Surana M, Singh Y, Lang DH (2015):** 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.

- **Huggins SJW, Rodgers.J, Holmes.W, Liel.A.B. (2017):** 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.

- **Patel FUM, Kulkarni A V, Inamdar N (2018):** 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.

- **Singh Y, Phani Gade (2012):** 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 45-degree 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.

- **Dilmac H, Ulutas H, Tekeli H, Demir F (2018):** The stiffness, roof displacements, and seismic performance of RC buildings are all improved by infill walls.

- **Jadhav PG, Jawalkar PGC (2017):** When a shear wall is installed at two corners of a structure for 7.5, 15, and 30 degrees, it was discovered that the mode contributes to modal mass participation up to higher modes due to the building's asymmetry.

- **Prashant D, G JK (2013):** 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 27degree 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.

- **Halkude SA, Kalyanshetti MG, Ingle VD (2013):** On slanting terrain, stepback-setback building frames were found to be more acceptable than stepback frames.

Chapter 3

SCOPE OF THE STUDY

SCOPE OF THE STUDY

The scope of present work is as under:-

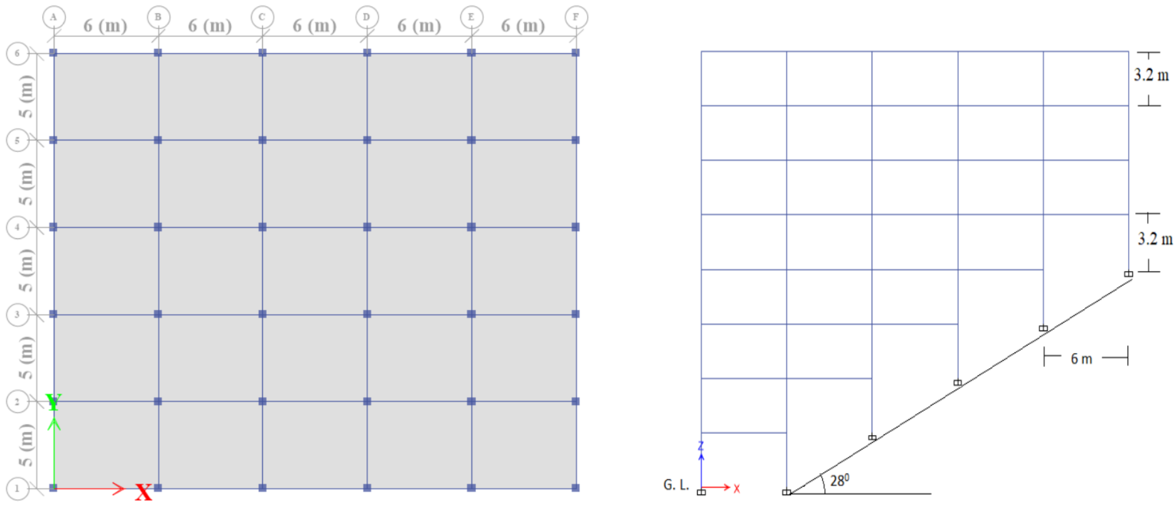
1. 3-D space frame analysis using Etabs2017 is done for four distinct designs of structures i.e., 8 storeys laying on the plain and slanted ground under the activity of seismic load.
2. The structures' dynamic response is discussed in terms of base shear, fundamental time period, storey displacement, storey drift, storey stiffness and analysed inside the considered course of action just as with different arrangements.
3. 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.
4. In the long run, a suitable plan of attempting to be used in a hilly region is proposed.

Chapter 4

MODELLING AND ANALYSIS

MODELLING AND ANALYSIS

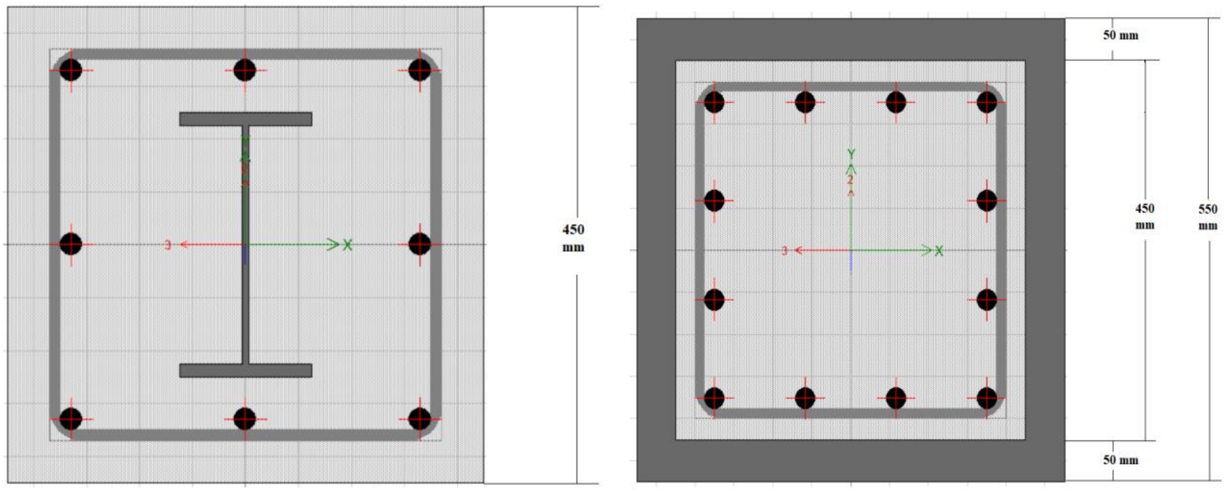
Shear walls are regarded shell elements while beams are considered 2-noded beam elements with 6dof at each node. The floor slabs are represented as 4-noded shell components with 6dof at each node and are expected to behave as diaphragms, ensuring integrated action of all vertical load resisting parts. 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 26.565 degrees and that for the half-panel infill wall as 44.74 degrees as per clause 7.9 of IS 1893 (Part I). The analysis considers torsional effects and accidental eccentricity by Indian code IS 1893 (Part I): 2016. Storeys with one way slanted at 28 degrees, with a dimension in the plan as 30m x 25m and storey height of 3.2m, as illustrated in Fig. 1.



(i) (ii)

Fig. 1. (i) Plan of the building (ii) Elevation of Hill slope

For the built-up RCC ISMB250 Composite I Column, the ISMB250 section is embedded in the RCC column of 450mm × 450mm as demonstrated in Fig. 2 (i). The RCC ISMB250 Composite I Column is loaded up with a similar RC section of 450mm× 450mm, which has a similar grade of cement (M30) and a similar pattern of reinforcement of other 450mm × 450mm columns. For the built-up RCFST composite column 550mm × 550mm, RCC column of 450mm × 450mm is embedded in the 50mm thick Fe345 steel tube as demonstrated in Fig. 2 (ii). The composite column is designed using section designer in Etabs 2017.



(i) (ii)

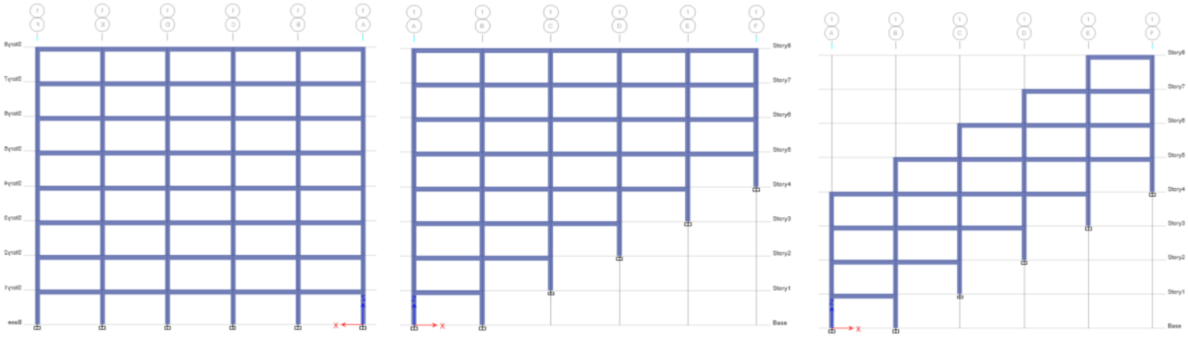
Fig. 2. (i) RCC ISMB250 Composite I column (ii) RCFST composite column

4.1 Models Investigated

Three distinct building configurations, Regular Fig. 3(a), Stepback Fig. 3(b), and Stepback-Setback Fig. 3(c), are analysed in this study and models are investigated as follows: -

Part I:-

P0: Bare Frame on plain ground.
S0: Stepback bare frame at a slope.
S1: Stepback frame at a slope with fully Concrete block infill walls (200mm).
S2: Stepback frame at a slope with no walls in the bottommost storey and 200mm thick fully Concrete block infill walls in all the upper storeys.
S3: As with model S2, only the bottommost storey's corner panels are infilled with the shear wall (200mm), as shown in Fig. 4.
S4: As with model S2, only bottommost storey columns are substituted by RCC ISMB250 Composite I column.
SS0: Stepback-Setback bare frame at a slope.
SS1: Stepback-Setback frame at a slope with fully Concrete block infill walls (200mm).
SS2: Stepback-Setback frame at a slope with no walls in the bottommost storey and complete Concrete block infill walls (200mm) in upper storeys.
SS3: As with model SS2, only corner panels of the bottom storey are filled in with the shear wall (200mm).
SS4: As with model SS2, only bottommost storey columns are replaced by RCC ISMB250 Composite I column.



(a) (b) (c)

Fig. 3. Different configuration of building (a) Regular building on levelled ground (b)Stepback building (c)Stepback-setback building

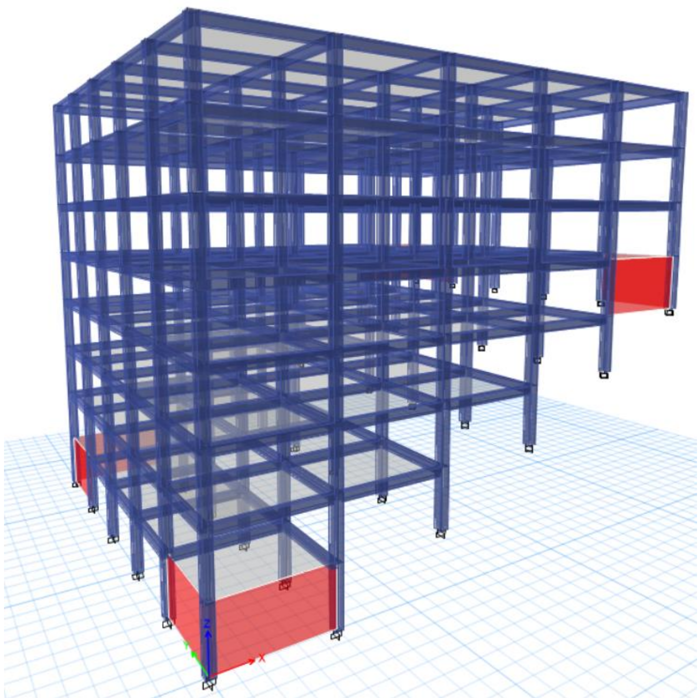


Fig. 4. Extruded view of stepback building with shear wall at corner panels

Part II:- Fig. 5 shows models investigated in this part

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.

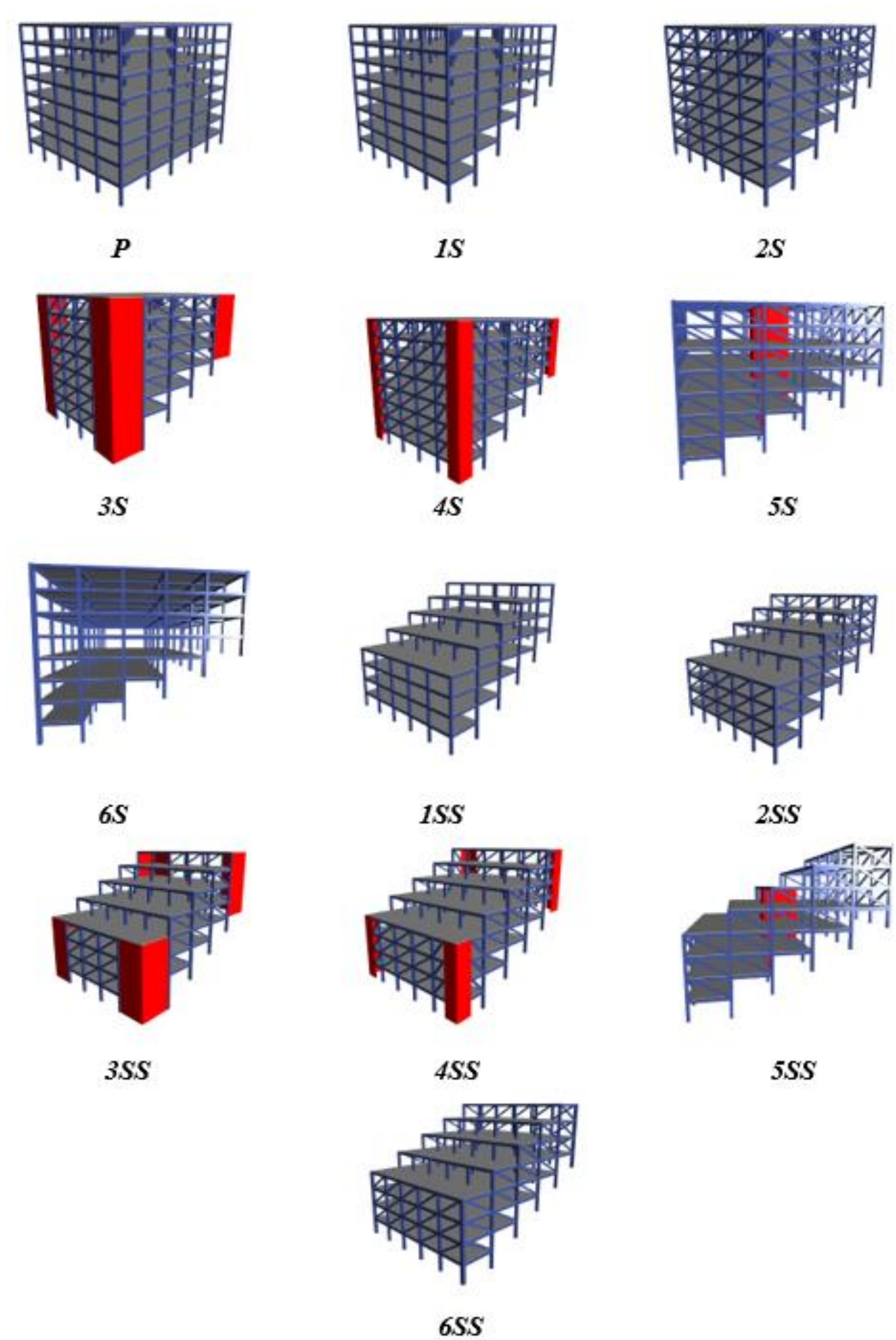


Fig. 5. Models investigated

4.2 Analysis method

All of the models in this study are analysed using the linear static method (ESFM) and the linear dynamic method (RSM). 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 ESFM 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

The properties adopted for the buildings are as shown in Table 1.

Table 1. Building data

Building details	
Total storeys	8
Storey height	3.2m
Building frame system	SMRF
Building use	Office building without separate storage
Foundation	Isolated Footing
Seismic zone	Zone V
Soil type	Medium soil
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
Structural Members	
Thickness of slab	150mm
RCC Beam size	300 x 450 mm
RCC Column size	450 x 450 mm
RCC ISMB250 Composite I Column	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	3.3 kN/m3
Floor finishes	1.2 kN/m3
Live Load	
Terrace	1.5 kN/m3
Floor	4 kN/m3
Earthquake Live load on the slab	

Roof	0 kN/m3
Floor	0.50 x 4.0 = 2 kN/m3

Chapter 5

RESULTS AND DISCUSSION

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.

PART I:-

5.1 Time period

The natural time periods from IS: 1893-2016 codal provision and Etabs analysis results for Model P0 to SS4 are presented in Table 2. The natural time periods obtained from the code do not match the analysis results, as seen in Fig. 6 and Fig. 7. Their variation in along and across slope direction is illustrated in Fig. 6 and Fig. 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 the slope direction i.e., along and across, whereas Response spectrum analysis using free vibration analysis produced better results. If there should arise an occurrence of stepback-setback buildings, the fundamental time period is discovered to be less when contrasted to stepback buildings. In the across slope direction, the response of stepback shows a minimal increase in fundamental time period whereas stepback-setback buildings show a decrease in the time period. Because of the presence of a shear wall, the fundamental natural period of the structure reduces as storey stiffness increases.

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***
P0	2.314	2.151	0.854	0.854
S0	1.346	1.559	0.508	0.508
S1	1.449	1.705	0.21	0.23
S2	1.446	1.702	0.21	0.23
S3	0.931	0.928	0.35	0.43
S4	1.427	1.686	0.21	0.23
SS0	0.974	0.941	0.508	0.508
SS1	1.038	1.008	0.21	0.23
SS2	1.034	1.004	0.21	0.23
SS3	0.694	0.672	0.35	0.43
SS4	1.021	1	0.21	0.23

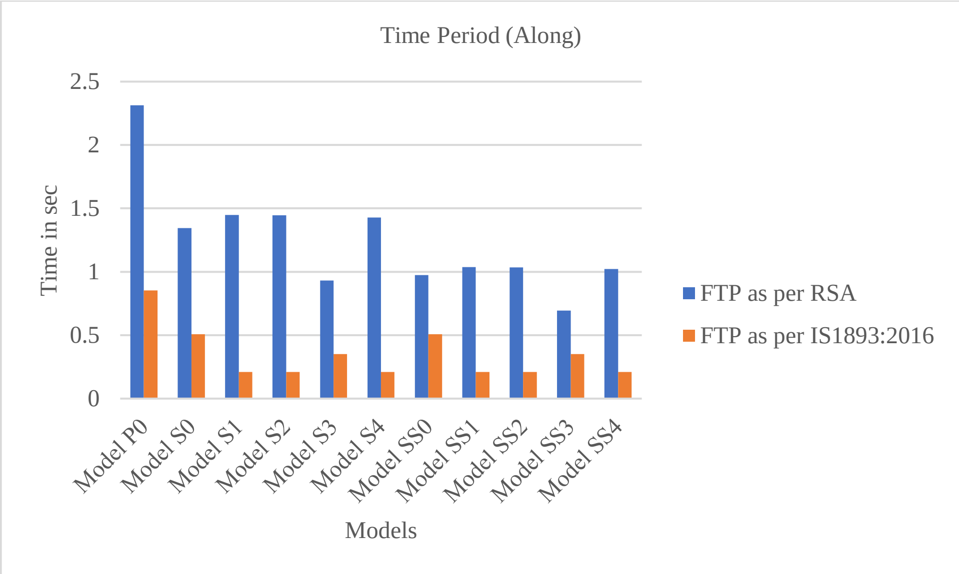


Fig. 6. Time Period along the slope direction

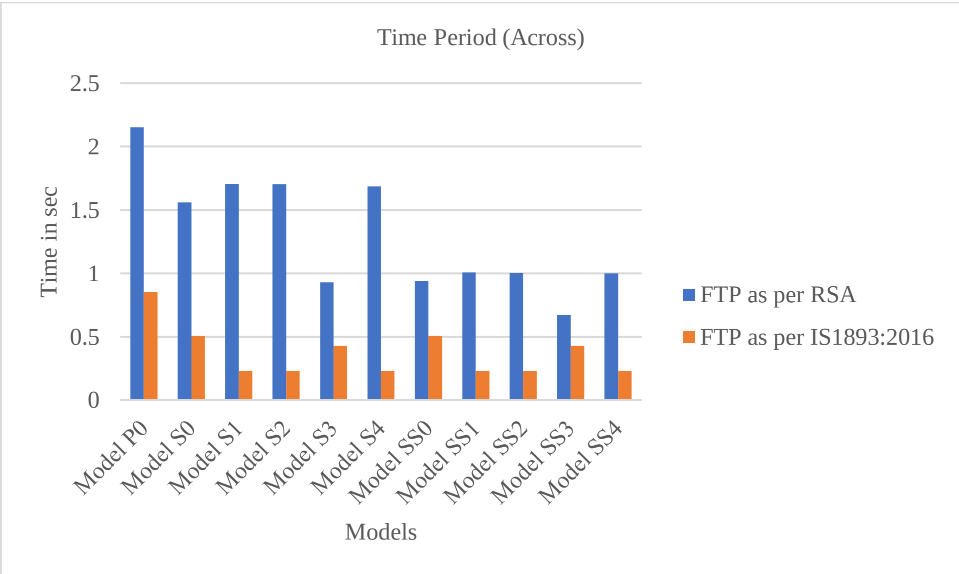


Fig. 7. Time Period across the slope direction

5.2 Axial force distribution

Axial force down the storey height of various structures setup has appeared in Table 3. From Fig. 8, the contrast between axial force distribution down the storey height of different models is noticed. Storey shear depends on the mass and stiffness of the building, so we can see that it is maximum in models having a shear wall(S3 and SS3) due to the higher stiffness provided by shear walls. Models with no infill wall in the ground storey (S2 and SS2) has less storey shear than the model with a fully infilled wall (S2 and SS2) from ground to top. The axial force is higher in the model with stepback and stepback-setback configuration than the model on plain ground at most severe stories.

Table 3. Axial force along the storey in kN

Storey No	***P0***	***S0***	***S1***	***S2***	***S3***	***S4***	***SS0***	***SS1***	***SS2***	***SS3***	***SS4***
8	376.75	517.15	499.97	489.05	779.48	495.65	210.09	204.41	199.08	297.92	201.79
7	274.52	376.82	459.81	449.76	716.86	455.84	291.99	329.58	320.98	480.34	325.35
6	201.68	276.85	337.82	330.43	526.67	334.90	316.95	366.97	357.39	534.83	362.26
5	140.06	192.25	234.60	221.25	366.35	224.31	291.32	341.60	317.07	482.66	321.50
4	89.63	99.94	122.43	114.03	195.67	115.65	188.11	221.16	204.50	314.58	207.43
3	50.42	42.73	52.54	48.17	81.91	48.86	81.14	100.40	91.65	137.15	92.98
2	22.40	12.99	16.09	14.31	25.08	14.52	24.68	30.75	27.22	40.74	27.63
1	5.60	1.75	2.20	1.65	3.42	1.68	3.32	4.22	3.15	5.04	3.20

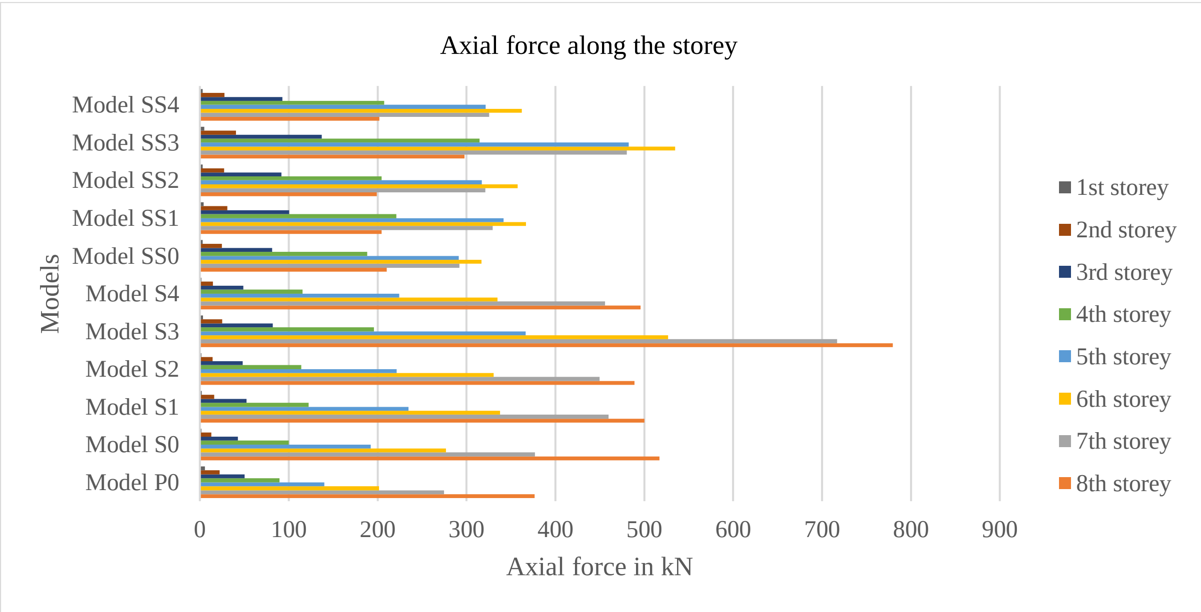


Fig. 8. Axial force along the storey in kN

5.3 Base Shear

The base shears for all of the models are shown in Table 4. Base shear is an element of mass and stiffness of the structure; in this manner, aside from the bare frame model, in the wide range of various models, because of the stiffness and mass given by the infilled walls, shear wall, and composite columns, the base shear has been enhanced. The base shear of infilled models rises with the rise in mass of the building models. Maximum base shear is seen in models having a shear wall (S3 and SS3) due to increased stiffness. The least base shear is seen in Regular building on levelled ground and highest in the stepback-setback building. The variation of base shear for various models is shown in Fig. 9.

Table 4. Base Shear in kN

Model	*Base Shear (kN)*
P0	1249.25
S0	1520.5226
S1	1725.4975
S2	1668.6865
S3	2704.7765
S4	1691.4439
SS0	1456.3319
SS1	1646.7339
SS2	1567.1872
SS3	2926.6431
SS4	1574.4812

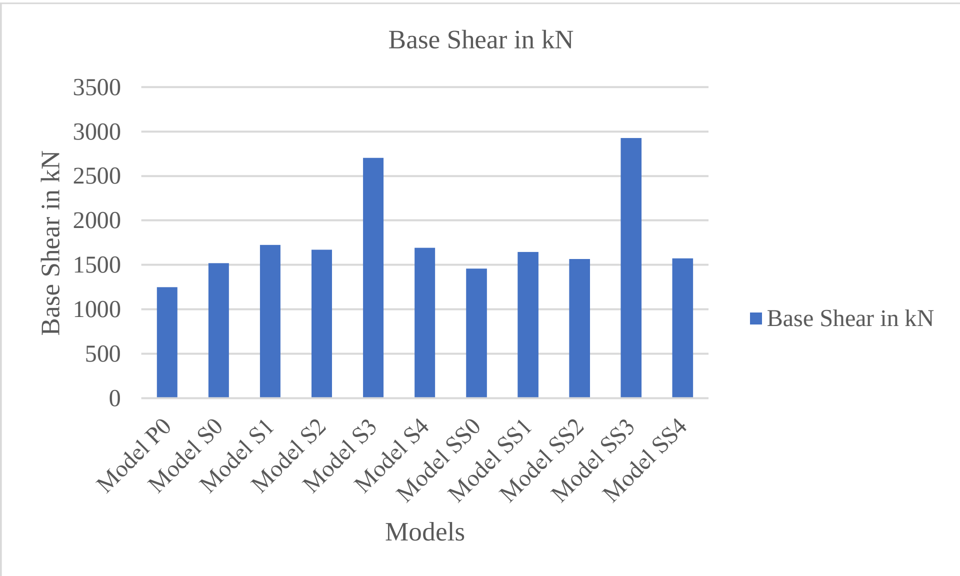


Fig 9. Base Shear

5.4 Fundamental periods(T) and Modal participating Mass Ratios(Pk)

Dynamic mass participation ratios and fundamental periods in the first three modes are illustrated in Table 5 and Table 6 for all building configurations along and across the slope direction. According to IS 1893:2016 building located 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 lateral storey irregularity in a principal plan direction [9]. This is well satisfied in all the models. Because of the inconsistency of designs, the mass participation in the fundamental mode in the event of working in slope is a lot lower than the regular building. The stepback-setback, when subjected to an earthquake along the slope direction, endures stiffness irregularity. But, when subjected to earthquake across the slope direction; besides stiffness irregularity, the buildings undergo torsion response, due to non-coincidence in the centre of mass and centre of stiffness. This underlines the significance of the uniform distribution of stiffness and mass in a structure to ensure uniform distribution of lateral forces over the elevation of a building. Further, the fundamental period of regular building on plain ground is close to setback building on plain ground.

Table 5. Fundamental periods (T) in sec and Modal Participation Mass Ratios (Pk) in % in along-slope direction

Mode	***P0***	
	T	***P_k***
1	2.314	80.62
2	0.723	9.83
3	0.396	4.08

Mode	***S0***		***S1***		***S2***		***S3***		***S4***	
	T	***P_k***	***T***	***P_k***	***T***	***P_k***	***T***	***P_k***	***T***	***P_k***
1	1.346	69.95	1.449	69.56	1.446	70.87	0.931	44.41	1.427	70.08
2	0.447	19.81	0.491	20.77	0.483	19.69	0.276	22.36	0.475	19.8
3	0.305	8.01	0.339	7.46	0.33	6.69	0.255	11.87	0.326	7.93

Mode	***SS0***		***SS1***		***SS2***		***SS3***		***SS4***	
	T	***P_k***	***T***	***P_k***	***T***	***P_k***	***T***	***P_k***	***T***	***P_k***
1	0.974	56.93	1.038	56.87	1.034	57.91	0.694	26.48	1.021	56.7
2	0.426	29.34	0.46	30.96	0.451	29.86	0.262	26.05	0.444	30.1
3	0.301	10.3	0.33	8.92	0.322	9.12	0.246	18.11	0.317	9.91

Table 6. Fundamental periods (T) in sec and Modal Participation Mass Ratios (Pk) in % in across-slope direction

Mode	***P0***	
	T	***P_k***
1	2.151	80.98
2	0.678	9.80
3	0.375	3.99

Mode	***S0***		***S1***		***S2***		***S3***		***S4***	
	T	***P_k***	***T***	***P_k***	***T***	***P_k***	***T***	***P_k***	***T***	***P_k***
1	1.559	62.99	1.705	62.06	1.702	63.38	0.928	43.02	1.686	63.64
2	1.035	13.48	1.114	14.13	1.111	14.30	0.772	02.17	1.108	13.86
3	0.532	10.61	0.588	10.46	0.583	10.05	0.366	37.37	0.579	10.30

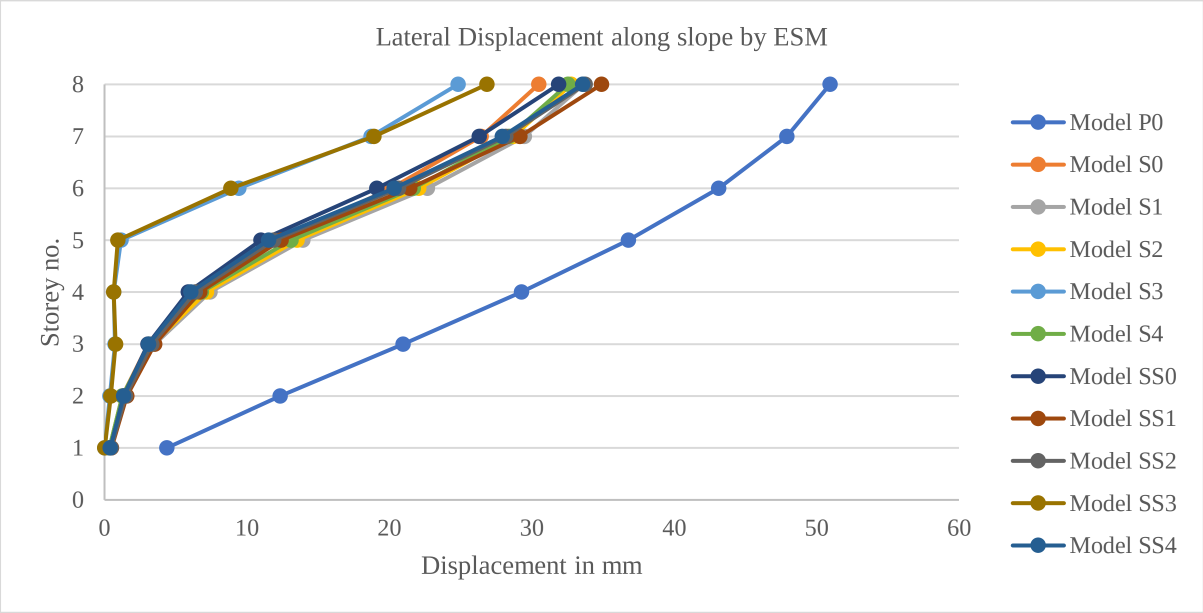
Mode	***SS0***		***SS1***		***SS2***		***SS3***		***SS4***	
	T	***P_k***	***T***	***P_k***	***T***	***P_k***	***T***	***P_k***	***T***	***P_k***
1	0.941	70.98	1.008	71.38	1.004	72.47	0.672	18.71	1.000	71.09
2	0.831	03.27	0.894	02.85	0.889	03.19	0.507	06.51	0.880	04.34
3	0.471	07.68	0.506	07.35	0.501	07.25	0.351	49.01	0.499	07.66

5.5 Lateral Displacement

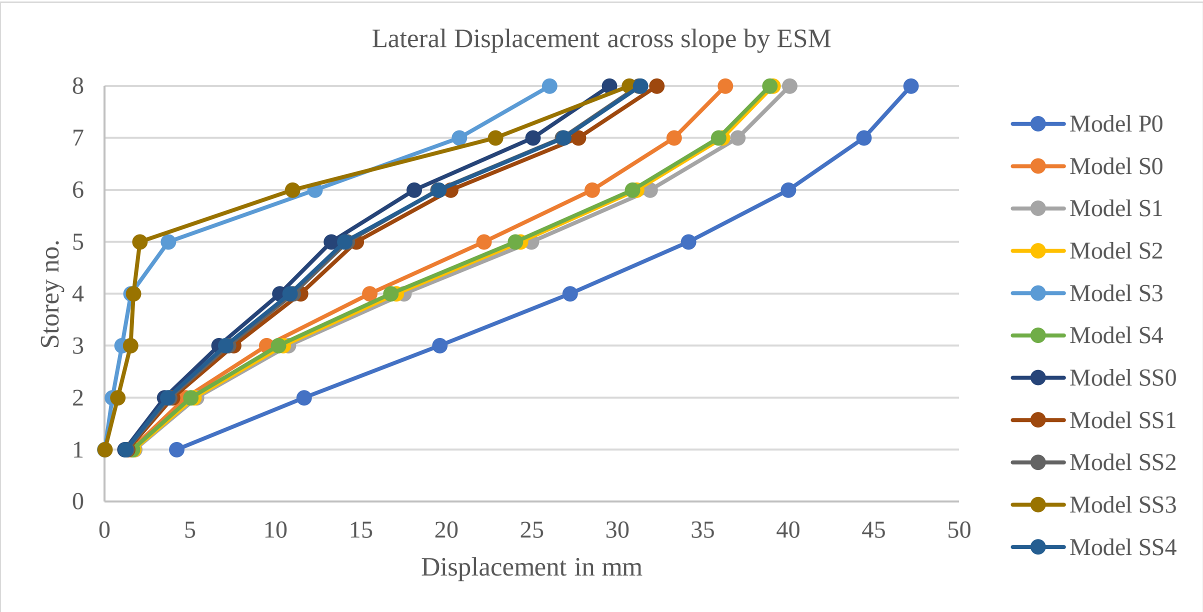
The maximum displacements at each storey level concerning the ground determined using the equivalent static and the response spectrum method for various configurations are displayed in both directions, i.e., along, and across in Fig. 10 and Fig. 11. To represent the impact of torsion the displacements are seen both along and across direction when force is acting in a specific direction. The storey displacement is largest at the top storey, gradually decreasing down the structure's height until it is nearly insignificant at the bottom storey.

As the centre of mass and rigidity of different configurations buildings do not coincide because of irregularity, displacements have occurred in both along and across direction; thus, the structure is clearly twisted in terms of displacement within the minor direction of the force. 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 whose open ground story has been incorporated with shear wall and composite columns show generally excellent displacement control. When earthquake forces are applied in an across the direction, the top storey displacement is much higher than when they are applied in an along the direction.

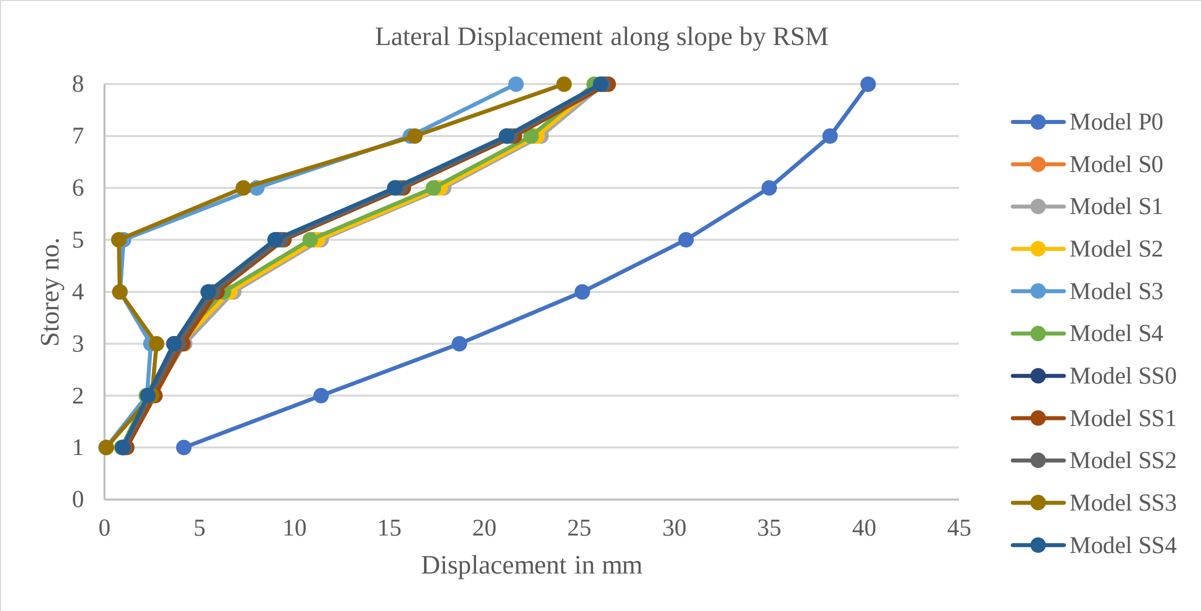


(a)

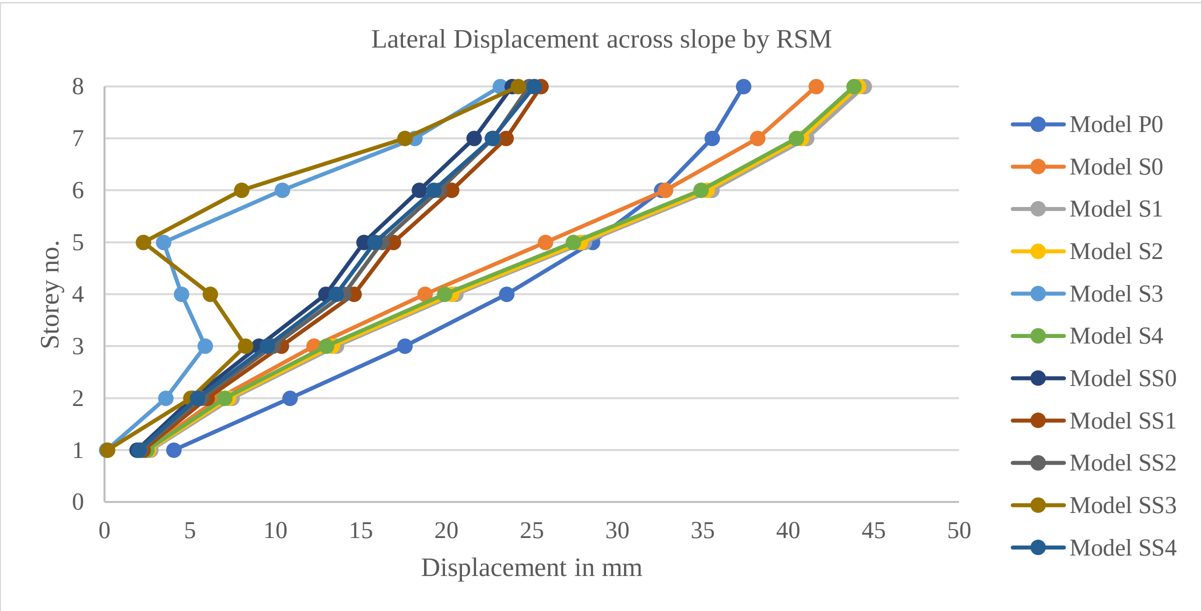


(b)

Fig. 10. Lateral Displacement in mm by Equivalent Static Method (a) along slope (b) across slope



(a)



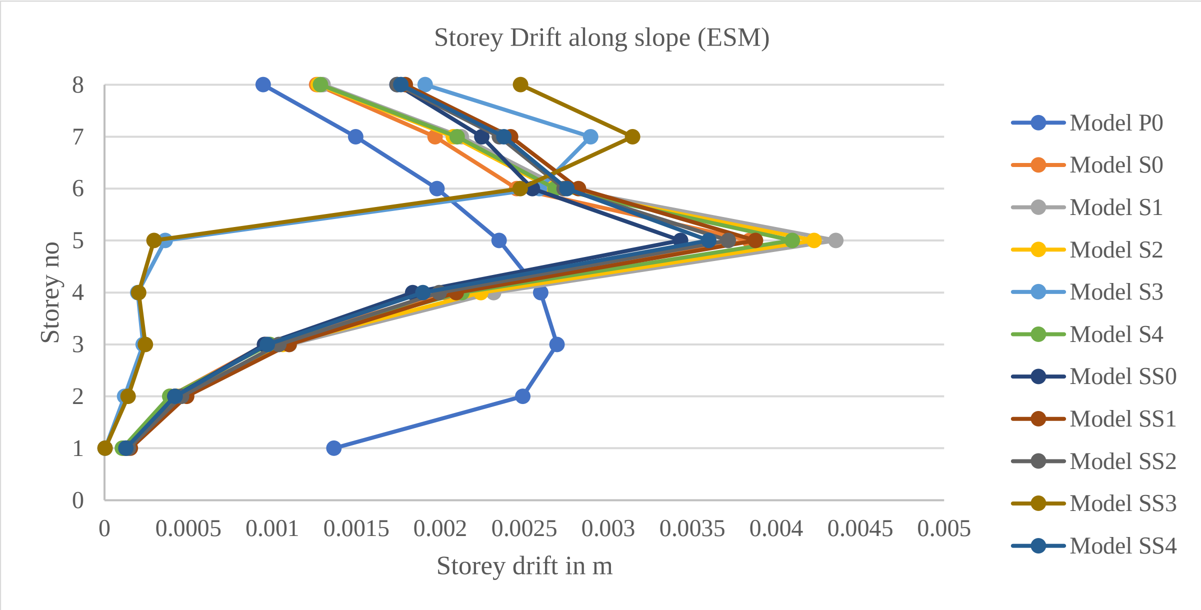
(b)

Fig. 11. Lateral Displacement in mm by Response Spectrum Method (a) along slope (b) across slope

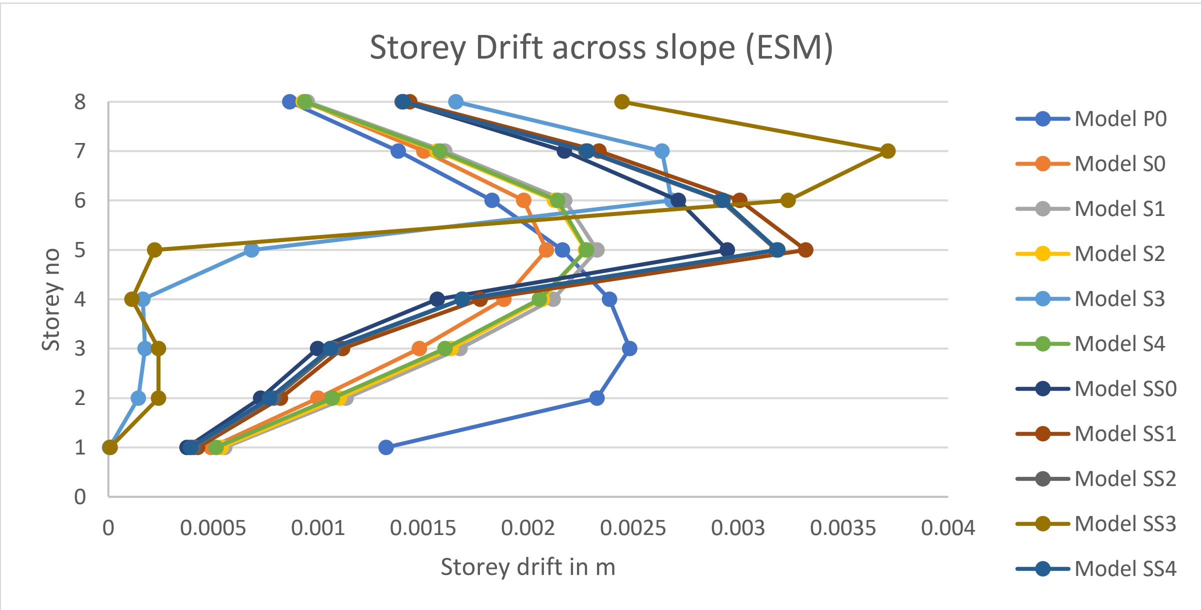
5.6 Storey Drift

According to IS 1893(Part 1): 2016 clause 7.11.1 Storey drifts in any storey should not exceed 0.004 times the storey height [9]. Storey height of 3.2m has got 12.8mm. Fig. 12 and Fig. 13

show the maximum storey drift at each storey level derived using the equivalent static and the response spectrum method for the different configurations, as well as both orientations, i.e., along and across the slope. 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 where the open ground storey is modified by the shear wall and composite columns show extremely less inter-storey drifts.

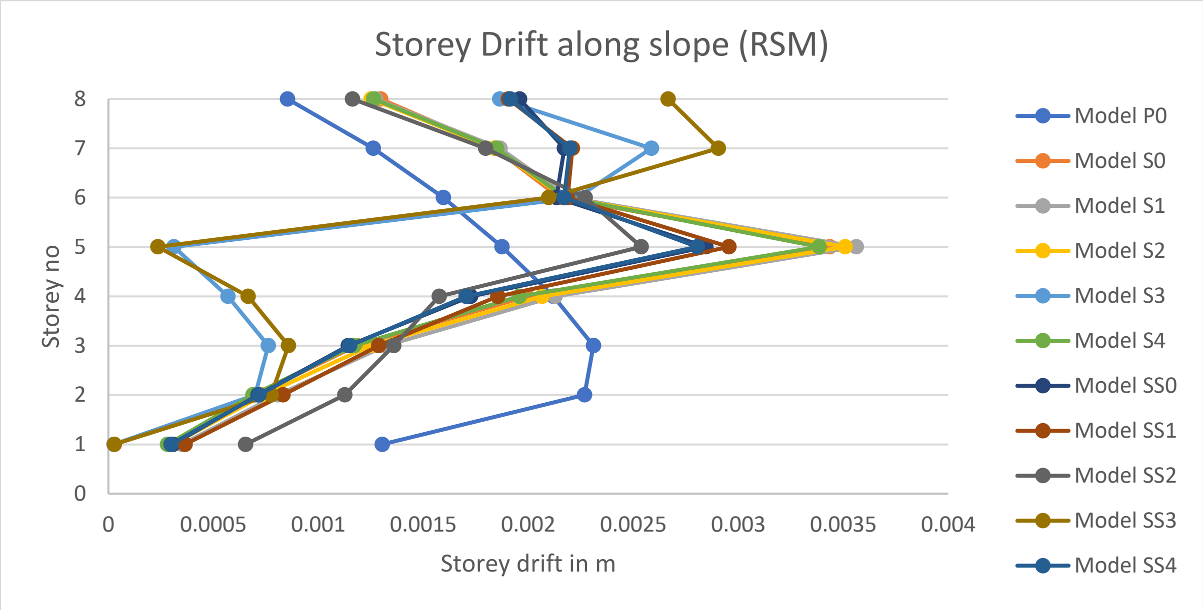


(a)

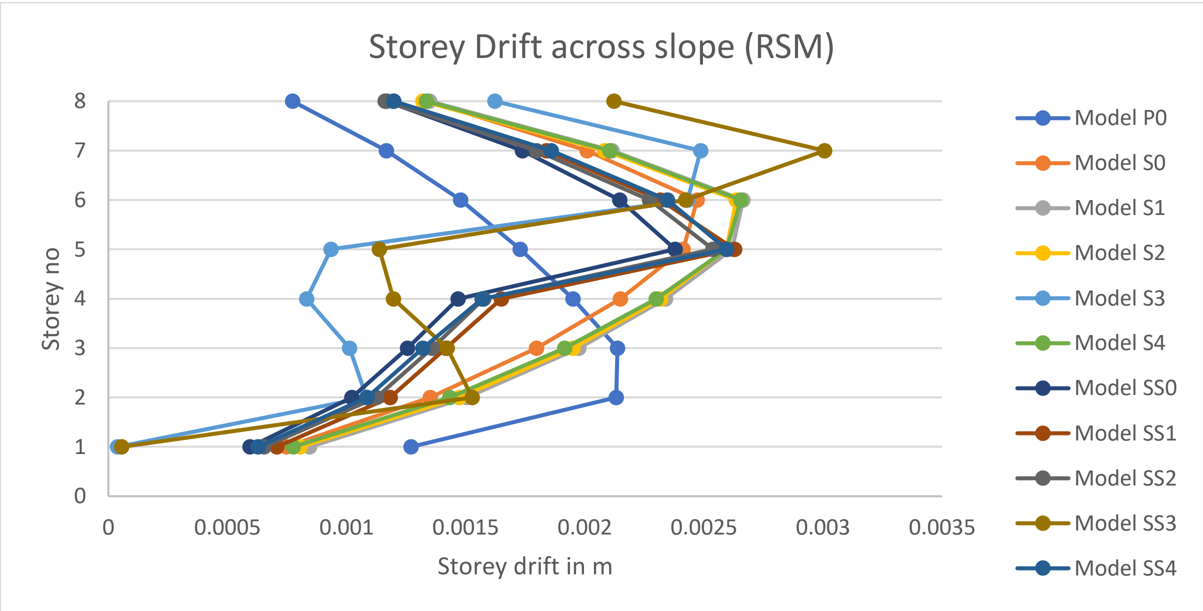


(b)

Fig. 12. Storey drift profile (a) along the slope direction by EQX (b) across the slope direction by EQY



(a)

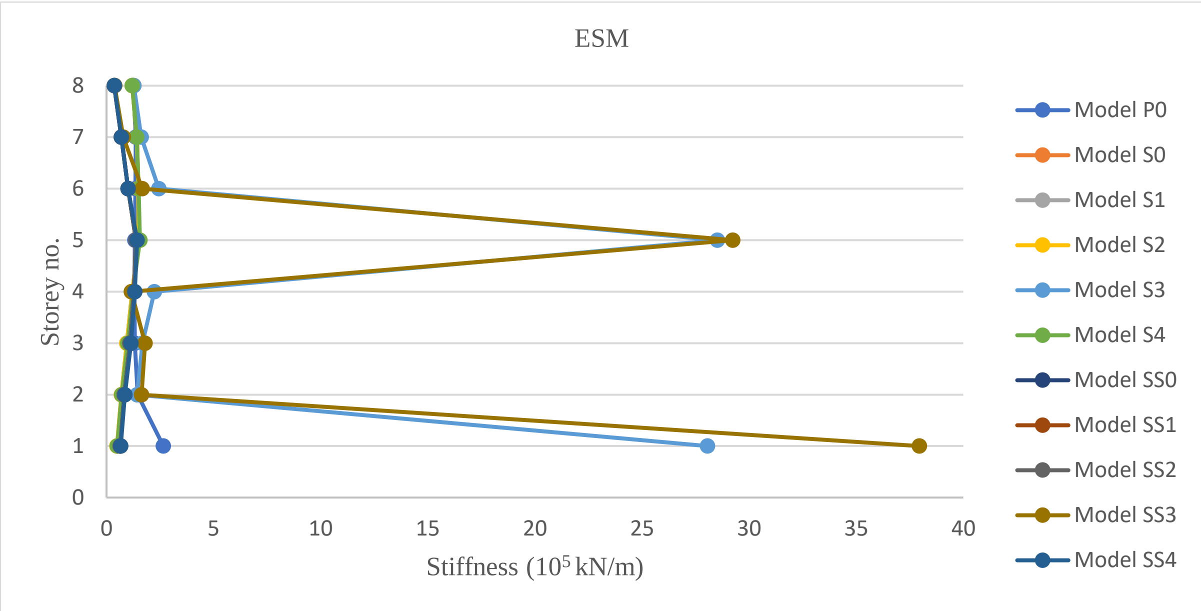


(b)

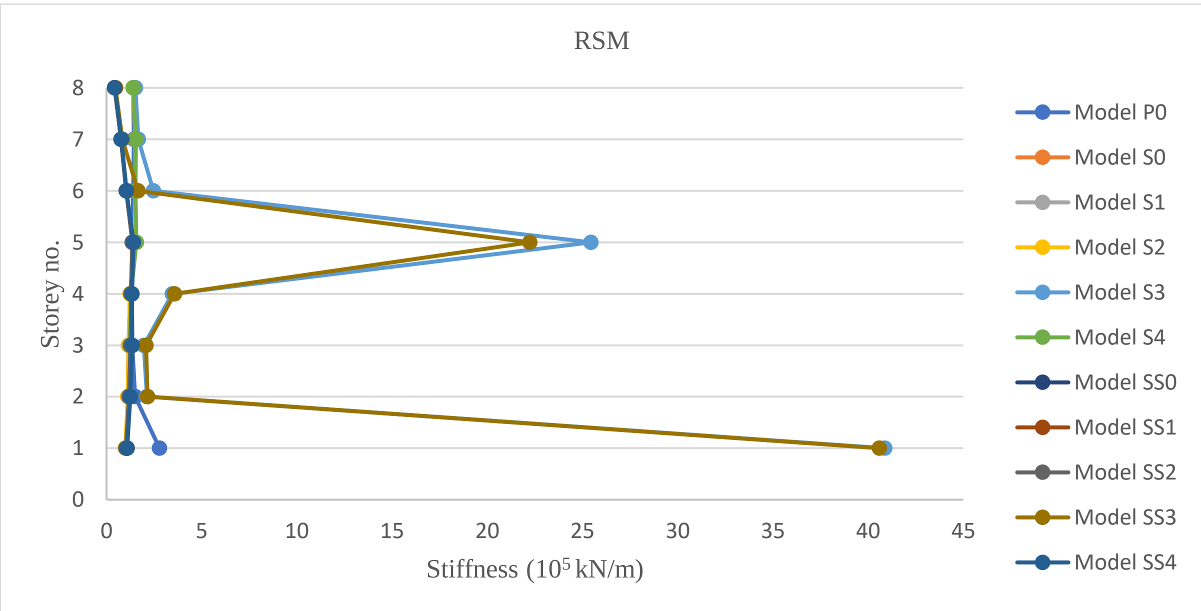
Fig. 13. Storey drift profile (a) along the slope direction by RSX (b) across the slope direction by RSY

5.7 Storey Stiffness

The total 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 Fig. 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 vulnerable during an earthquake. To prevent this, shear walls are provided to overcome the issue of stiffness deficiency. There is a drastic increase in stiffness of Model S3, Model S4 due to shear wall at ground storey and in Model S4, Model SS4 due to composite I column in ground storey.



(a)

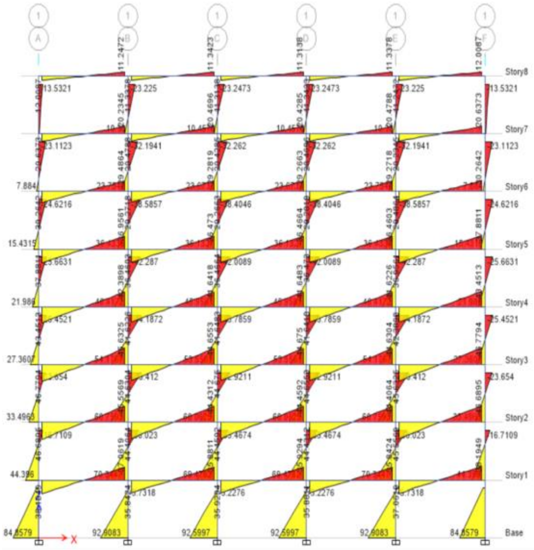


(b)

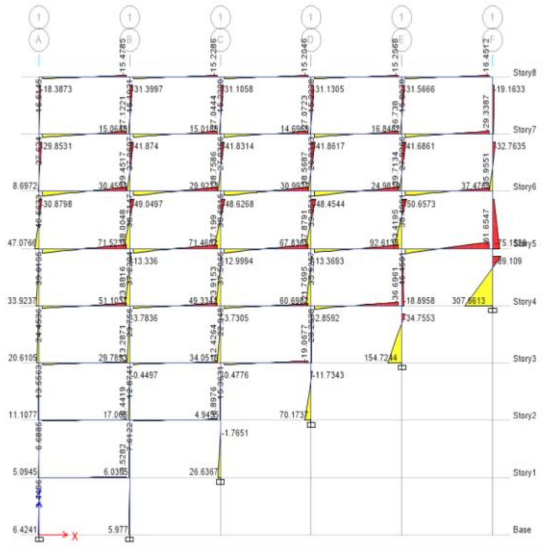
Fig. 14. Variation of storey stiffness of models in (a) ESM (b) RSM

5.8 Bending Moment in Column

Bending Moment in the column at every storey level and in each model is shown in Fig 14. It is seen in both the methods ESM and RSM, the measure of bending moment in each column of every storey in model P0 is practically comparative. The greatest bending moment is at the columns of ground storey and as the storey height increments, the value of bending moment lessens in the model on the plain ground i.e., P0. 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. In comparison to the columns at the lower level of the slant, the columns at the higher level of the slant are subjected to larger bending moment; hence, the columns at the higher level of the slant require special attention.



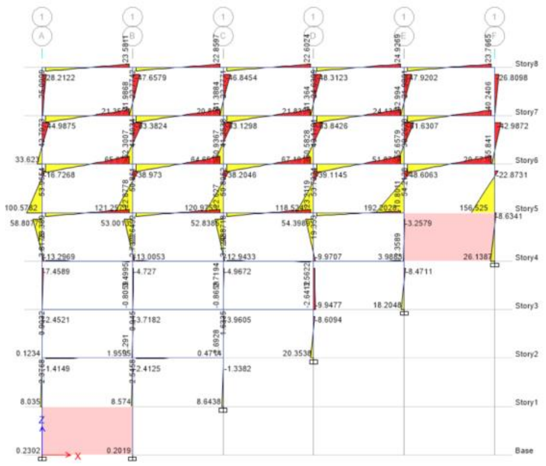
(a)



(b)

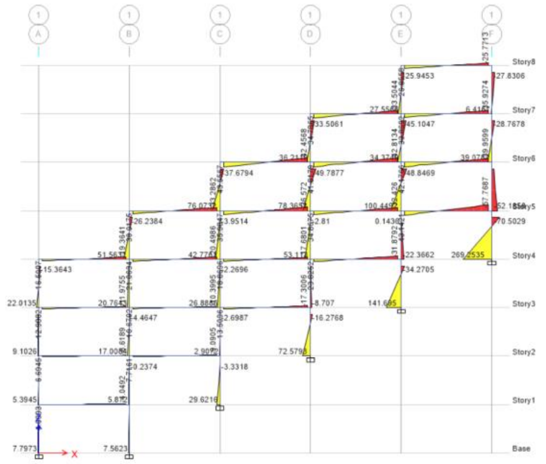
(c)

(d)

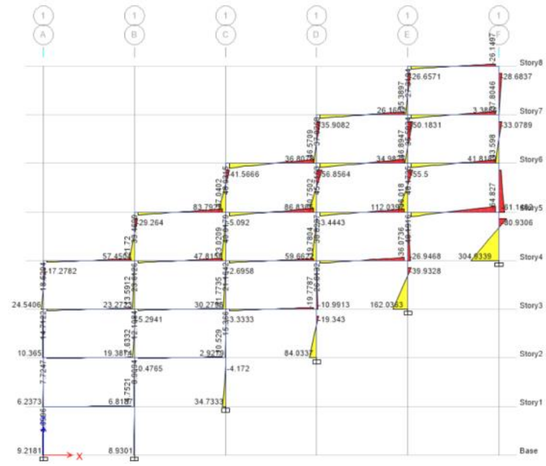


(e)

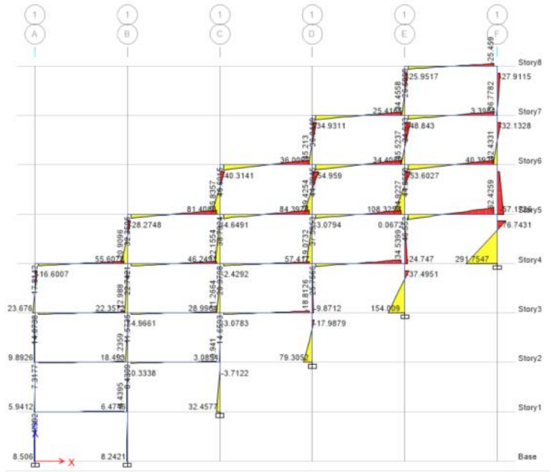
(f)



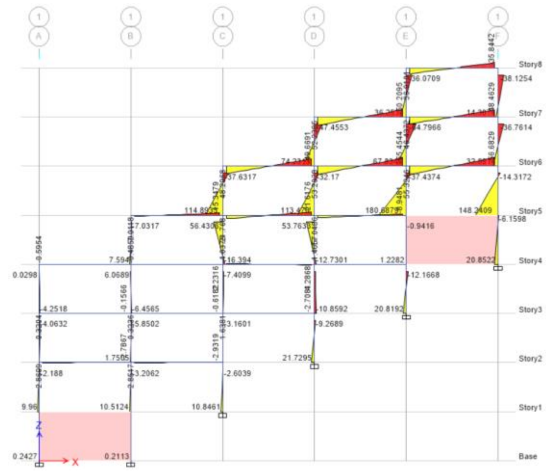
(g)



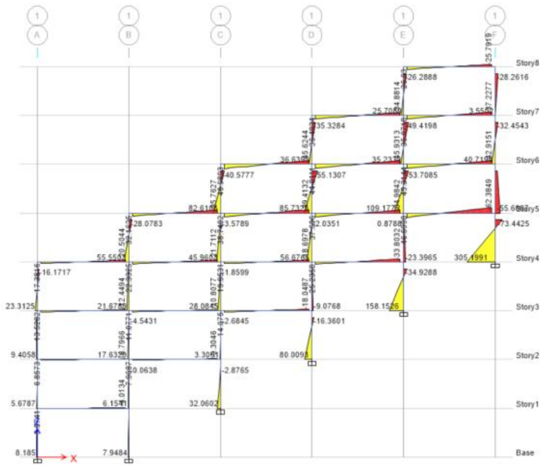
(h)



(i)



(j)



(k)

Fig. 15. Column bending moment of (a) P0 (b) S0 (c) S1 (d) S2 (e) S3 (f) S4 (g) SS0 (h) SS1 (i) SS2 (j) SS3 (k) SS4

5.9 Shear force in Column at ground level

Shear force in Column at ground level in each model is shown in Table 7. In the building on plain ground, shear force in the columns at ground level is almost the same in all columns and both along and across the slope direction. Along the slope in the stepback building, the shear force in the column towards the extreme right is significantly higher when compared with the rest of the columns on the ground floor as short columns on uphill side attracts more horizontal excitation. 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, the 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 the design point of view, it is noticed that specific consideration ought to be given to the size and stiffness demand of the extreme right column at ground level such that it is safe under the worst possible load combinations along and across the direction of the slope.

In contrast with stepback building, stepback-setback building experience 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 S3 and SS3 shear force value is reduced to only 5-10% of the value of the bare frame model.

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

Table 7. Shear force in columns at ground level in kN in

(a) along the slope direction (b) across the slope direction.

Model	Frame A	Frame B	Frame C	Frame D	Frame E	Frame F
P0	27.1	34.33	34.04	34.04	34.33	27.1
S0	1.73	1.28	9.96	29.03	67.57	143.04
S1	1.97	1.43	11.42	33.25	77.09	162.45
S2	1.84	1.32	10.86	31.9	74.45	157.55
S3	0.06	0.034	3.48	10.29	9.52	10.85
S4	1.66	1.17	10.31	31.28	74.89	162.17
SS0	2.32	2.08	11.74	31.75	62.89	122.45
SS1	2.76	2.46	13.79	36.78	71.88	138.74
SS2	2.52	2.24	12.84	34.66	68.24	132.59
SS3	0.07	0.04	4.79	11.09	11.83	8.43
SS4	2.33	2.09	12.42	34.38	68.89	136.33

(a)

Model	Frame A	Frame B	Frame C	Frame D	Frame E	Frame F
P0	28.92	29.63	29.65	29.65	29.63	28.92
S0	9.7	6.64	22.92	37.07	51.28	71.94
S1	10.82	7.35	25.72	41.72	57.53	80.05
S2	10.48	7.11	24.9	40.35	55.56	77.24
S3	0.08	1.15	2.62	3.29	6.95	7.26
S4	9.98	6.92	24.67	40.54	56.45	79.3
SS0	7.92	5.72	18.9	32.42	53.42	102.6
SS1	9	6.49	21.49	36.84	60.52	115.91
SS2	8.56	6.15	20.39	34.88	57.37	110.6
SS3	0.16	2.24	5.97	11.3	10.49	8.67
SS4	8.22	6.02	20.27	35.01	57.83	111.71

(b)

PART II:-

5.10 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 8. The natural time periods obtained from the code do not match the analysis results, as seen in Fig. 16 and Fig. 17. Their variation in along and across slope direction is illustrated in Fig. 16 and Fig. 17. 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 8. Analytical and Codal Fundamental Time Period in sec

Model	FTP as per RSA (sec)		FTP as per IS1893:2016 (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

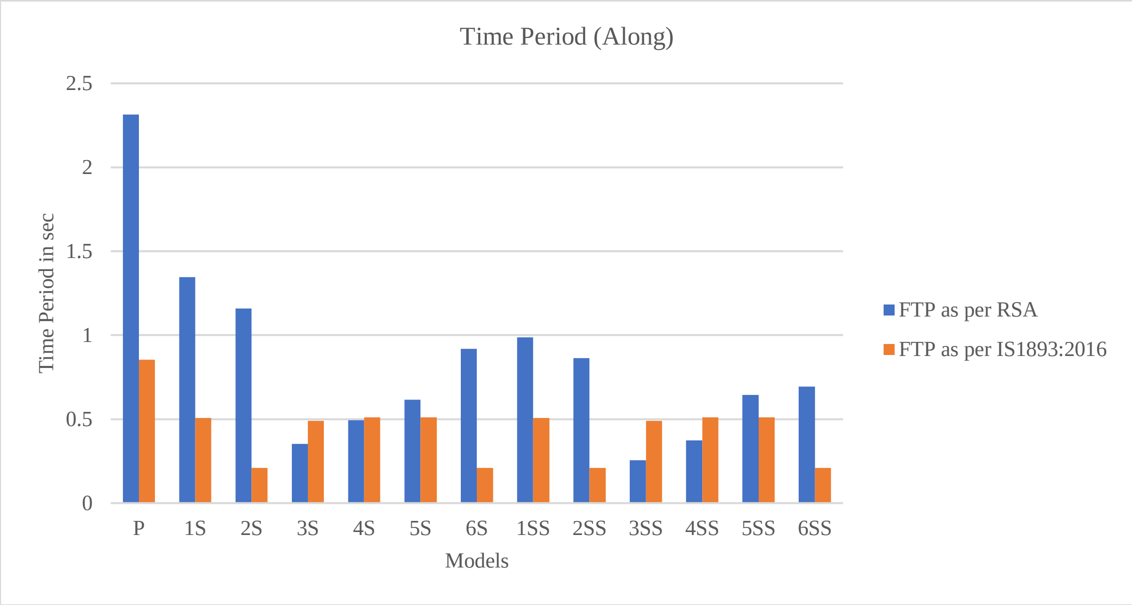


Fig. 16. Time Period along the slope direction

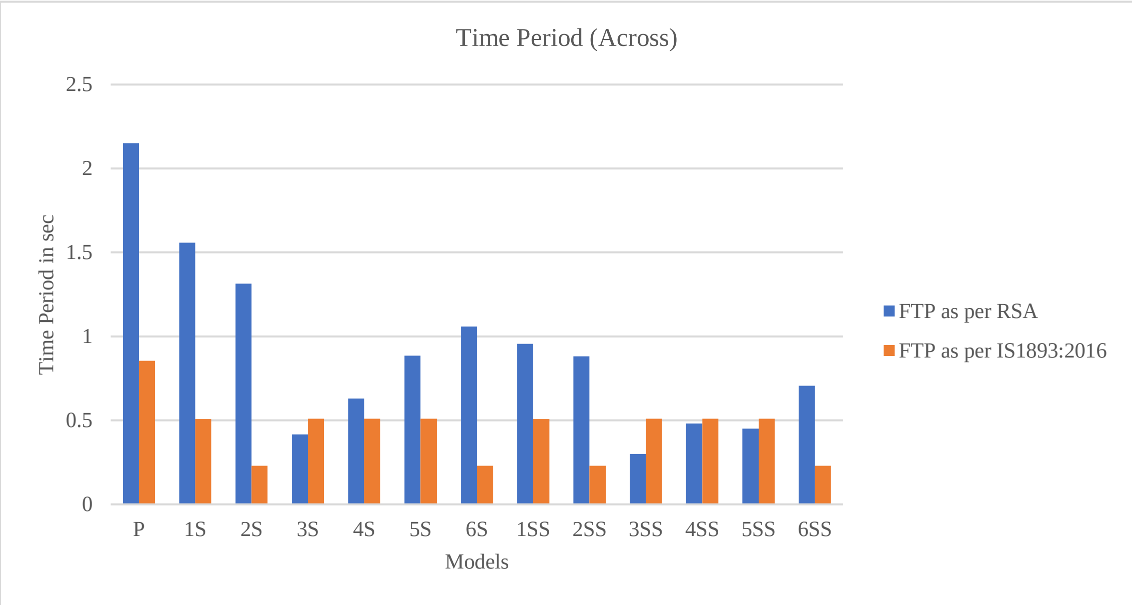


Fig. 17. Time Period across the slope direction

5.11 Axial force distribution

Axial force down the storey height of various structures setup has appeared in Table 9. From Fig. 18, 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 axial force. Because the model is laying on an inclined base, the measure of axial forces in the stepback and stepback-setback models is higher than the model on the plain ground.

Table 9. Axial force along the storey in kN

Storey No	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

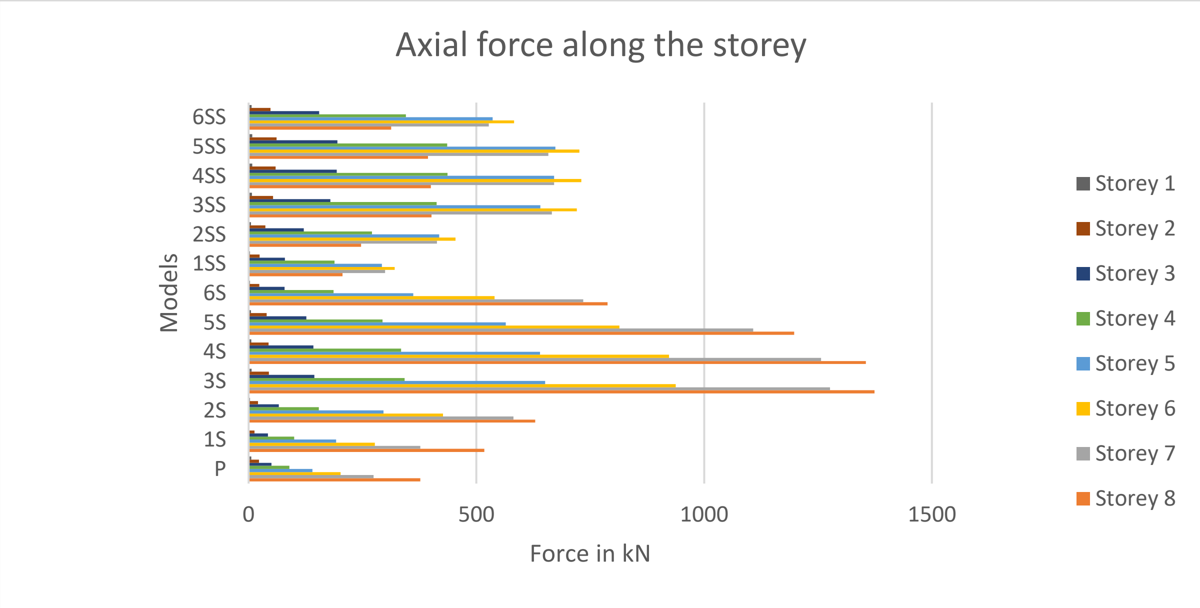


Fig. 18. Axial force along the storey in kN

5.12 Base shear

Table 10 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. Fig. 19 depicts the base shear variations of various models.

Table 10. 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

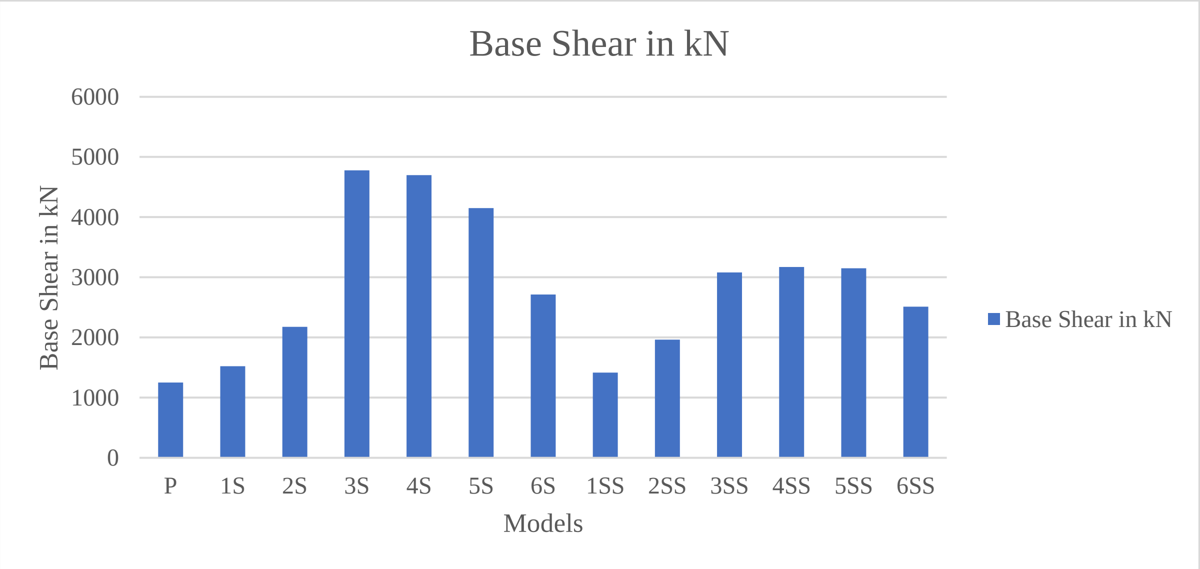


Fig 19. Base Shear

5.13 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 11 and Table 12 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 11. 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	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

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

Table 12. 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

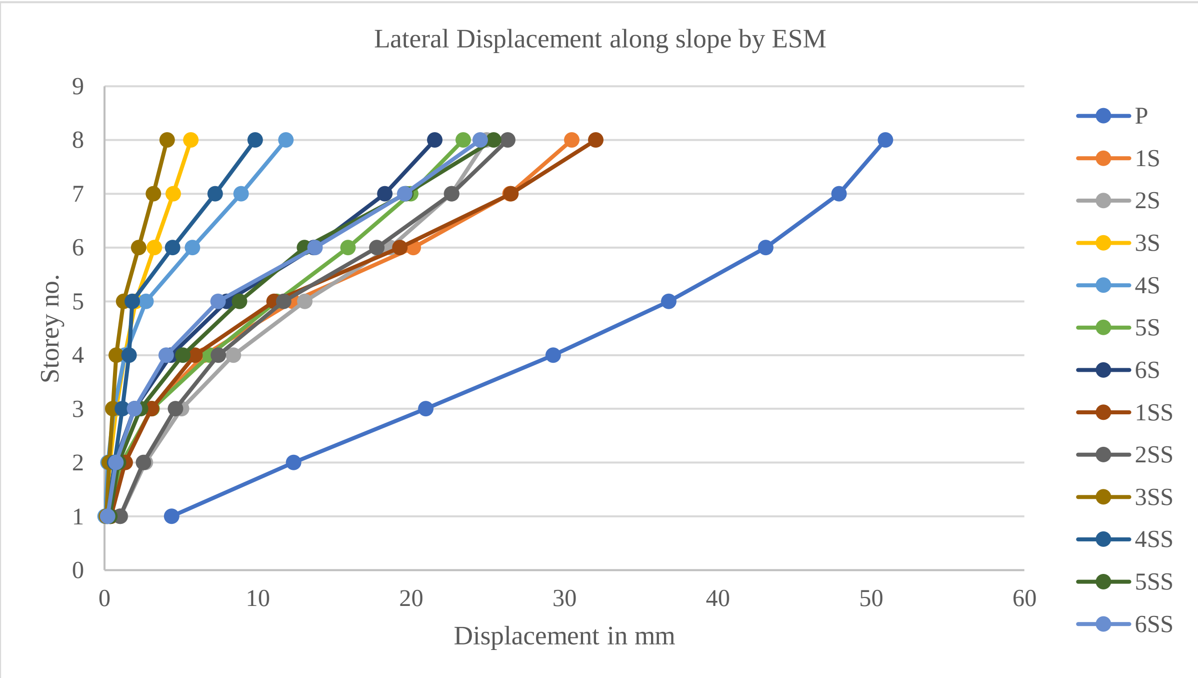
Mode	1SS		2SS		3SS		4SS		5SS		6SS	
	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)	T(sec)	P_k (%)
1	0.955	72.43	0.882	76.62	0.3	44.32	0.482	48.33	0.45	23.23	0.706	66.59
2	0.842	1.94	0.413	12.08	0.21	34.28	0.295	34.04	0.434	8.29	0.356	14.54
3	0.477	7.68	0.244	8.08	0.153	0.53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

5.14 Lateral displacement

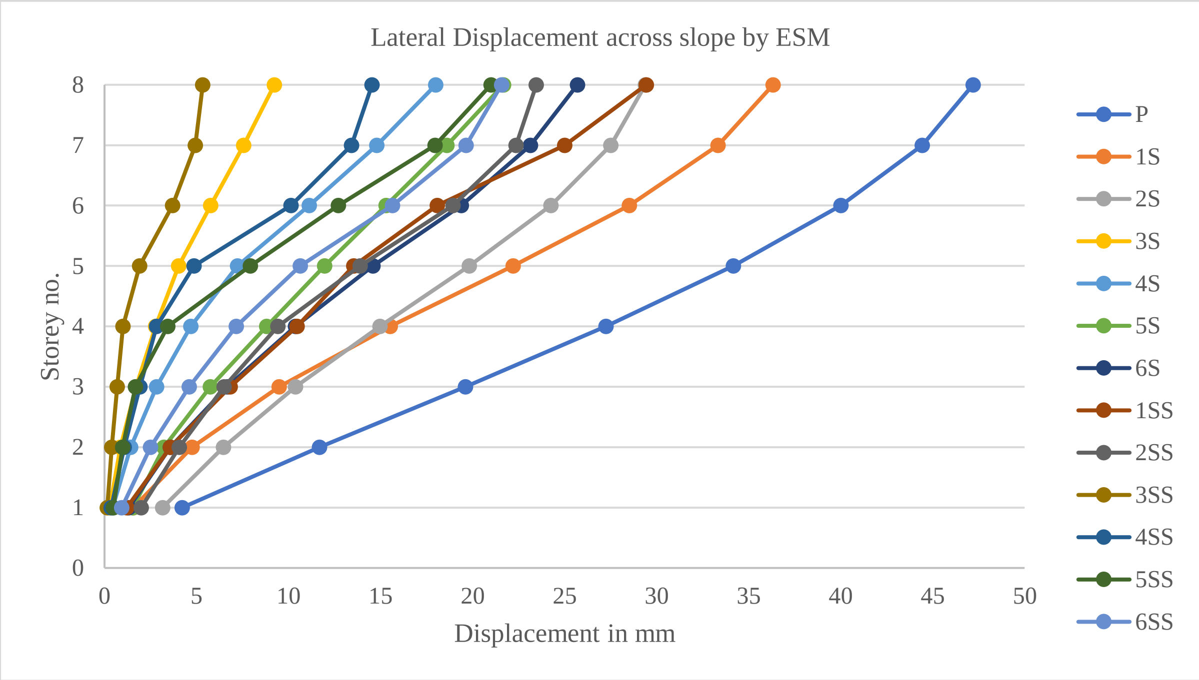
The maximum displacements at every storey level concerning the ground determined using ESM and RSM for various configurations are displayed both along and across the slope in Fig. 20 and Fig. 21. To represent the impact of torsion the displacements are seen both along and across directions when force 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 is stepback-setback models RCFST columns 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.

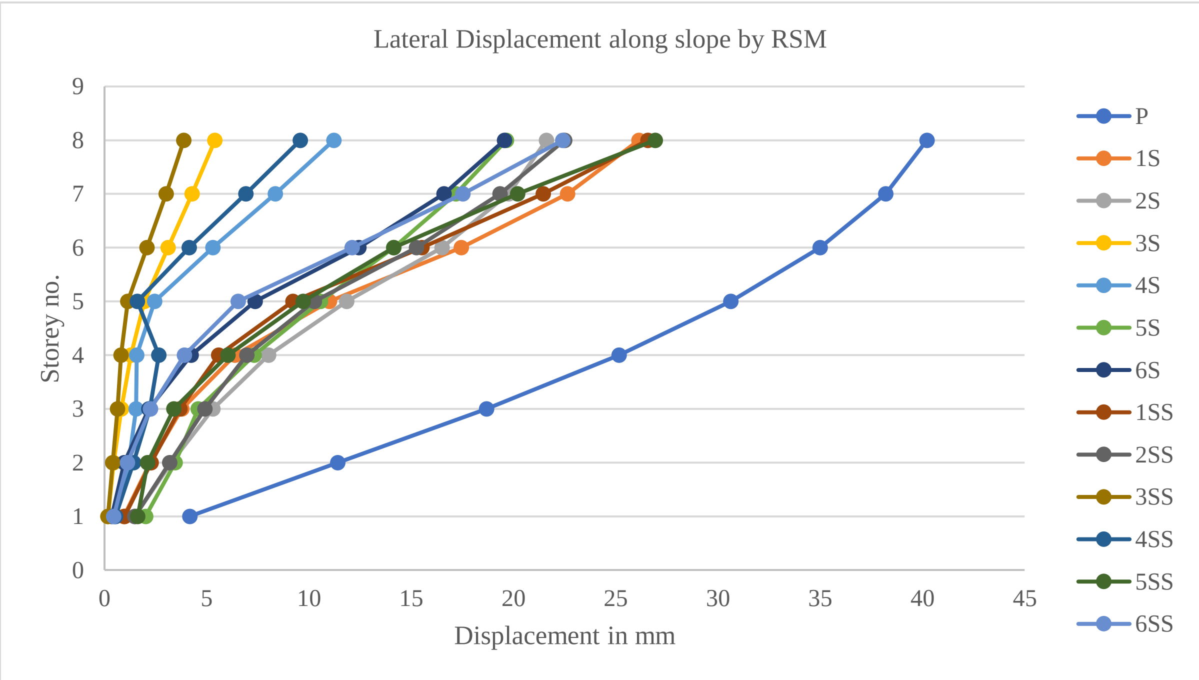


(i)



(ii)

Fig. 20. Lateral Displacement in mm by Equivalent Static Method (i) along slope (ii) across slope



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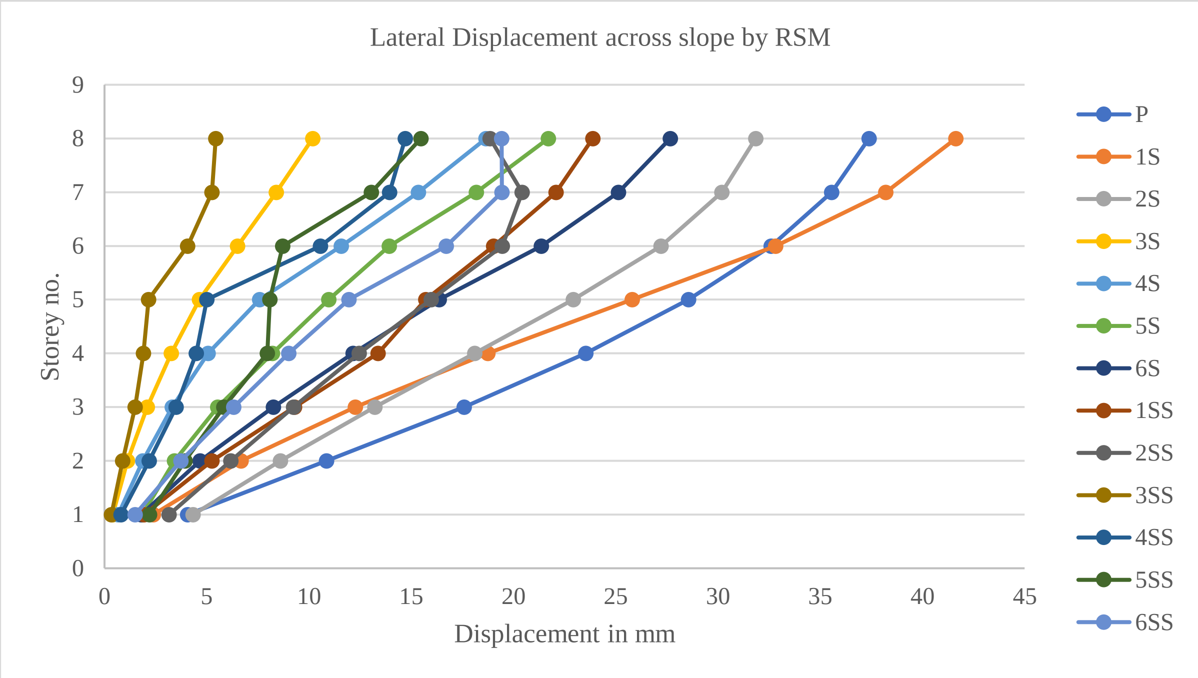
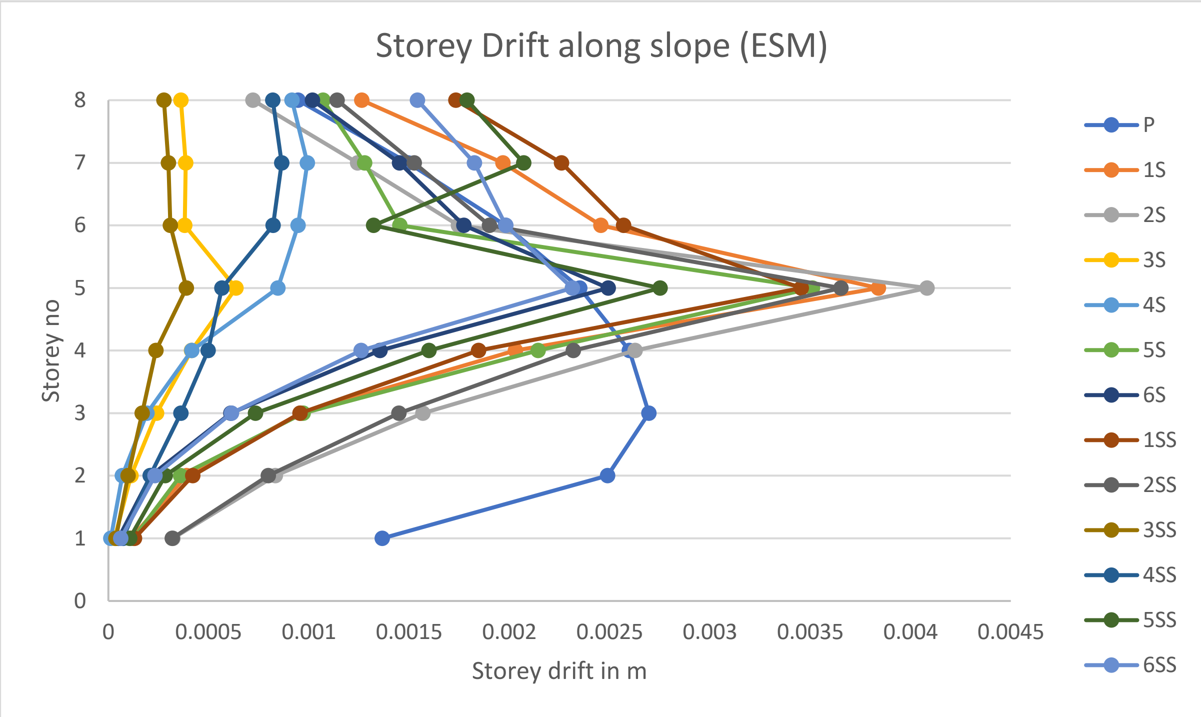


(ii)

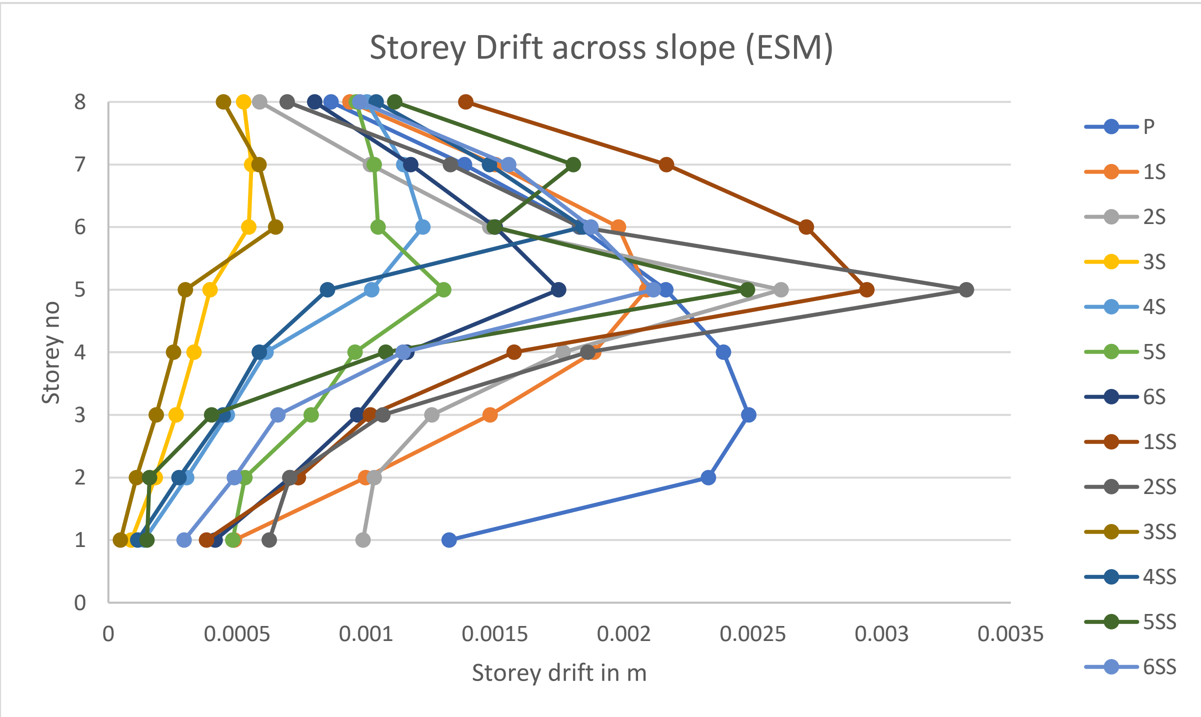
Fig. 21. Lateral Displacement in mm by Response Spectrum Method (i) along slope (ii) across slope

5.15 Storey drift

According to IS 1893(Part 1): 2016 storey drifts in any storey should not outperform 0.004 times the storey height. Storey height of 3.2m has got 12.8mm. Fig. 22 and Fig. 23 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.

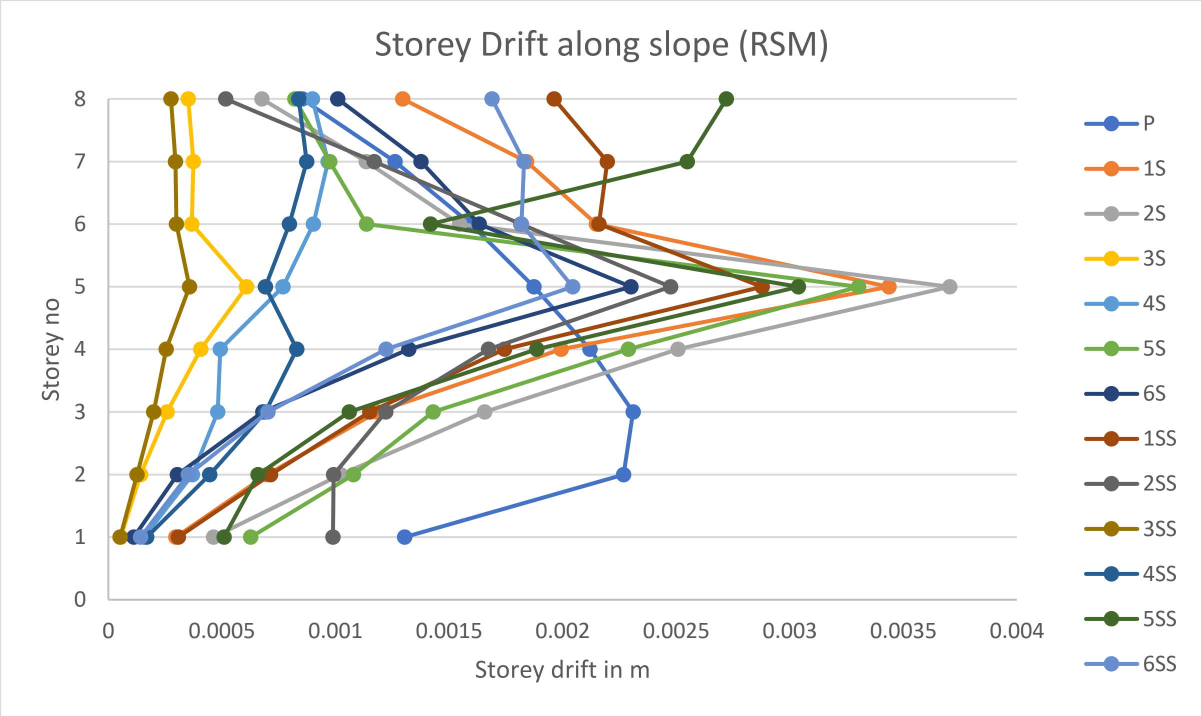


(i)

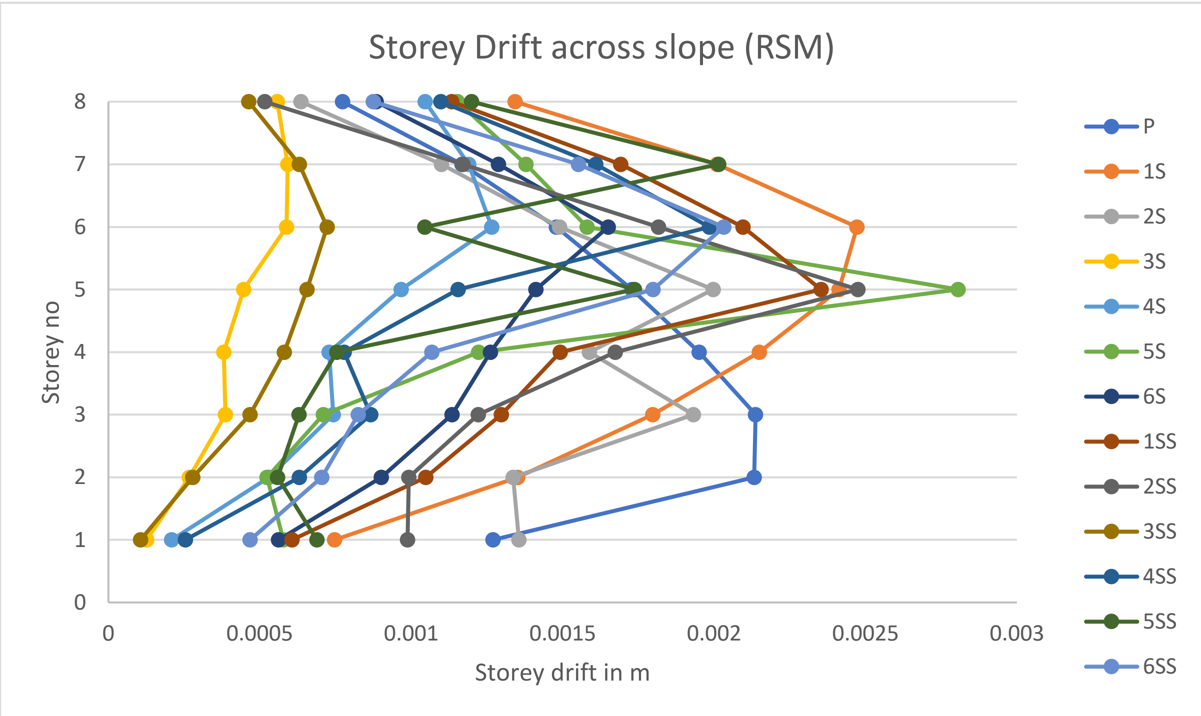


(ii)

Fig. 22. Storey drift profile (i) along the slope direction by EQX (ii) across the slope direction by EQY



(i)

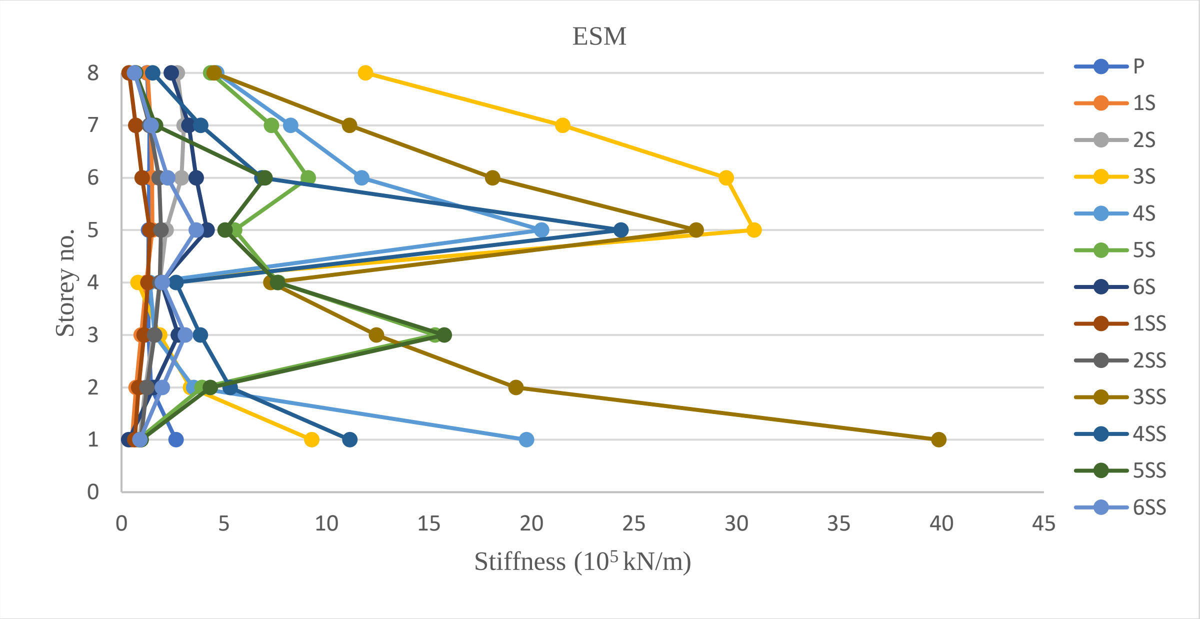


(ii)

Fig. 23. Storey drift profile (i) along the slope direction by RSX (ii) across the slope direction by RSY

5.16 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 Fig 24 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.



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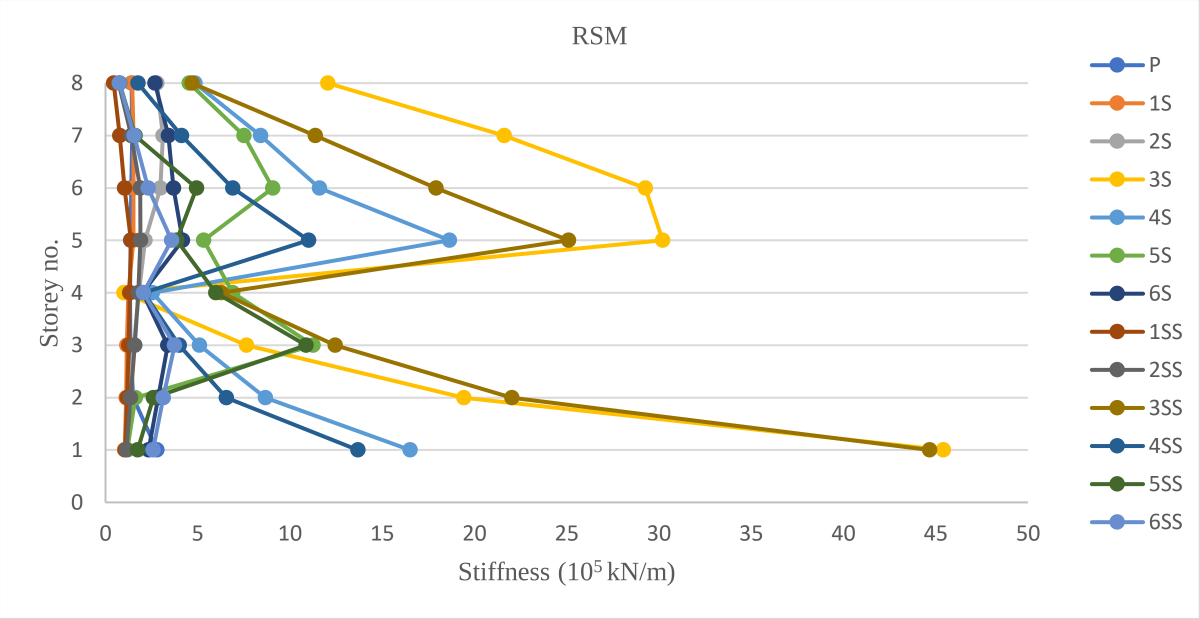
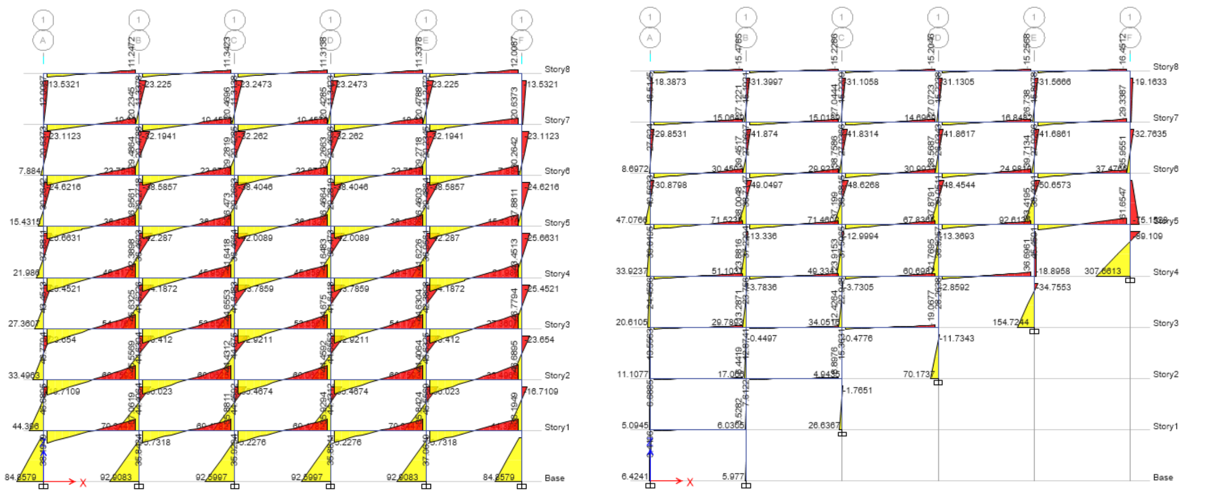


(ii)

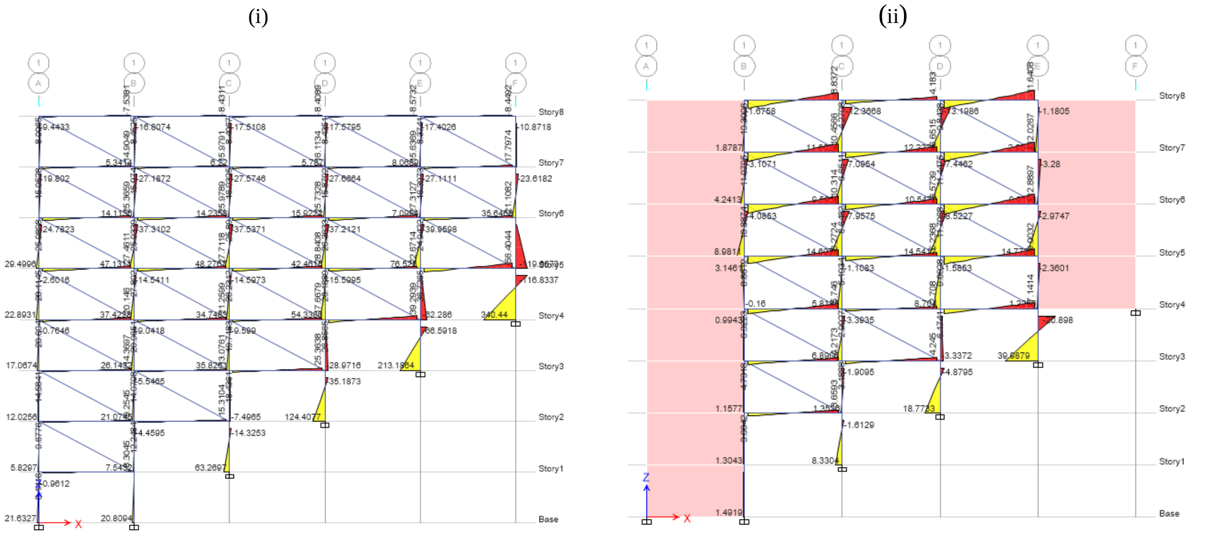
Fig. 24. Variation of storey stiffness of models in (i) ESM (ii) RSM

5.17 Bending Moment in Column

Fig. 25 depicts the bending moment in the column at each storey level and in each model. 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)



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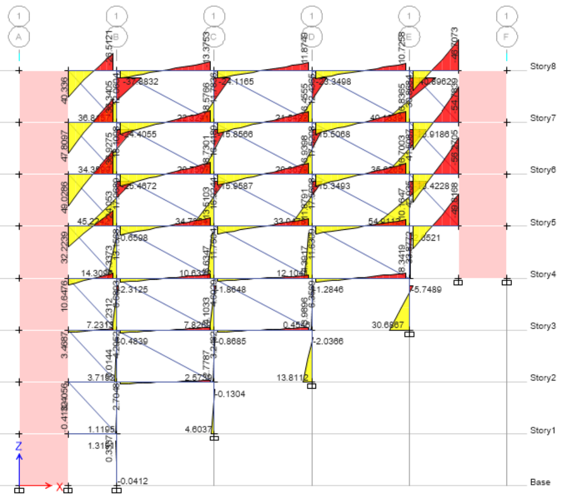

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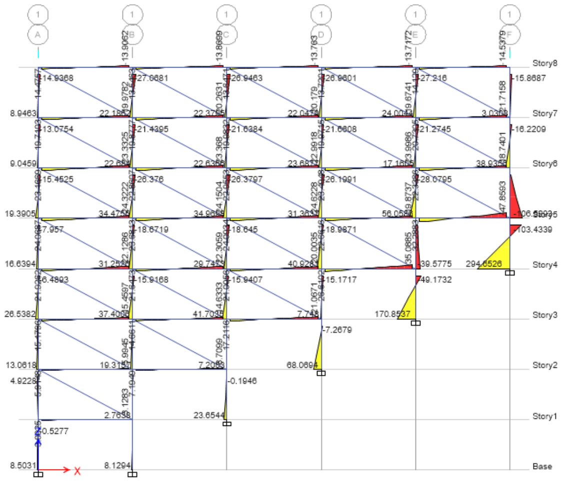

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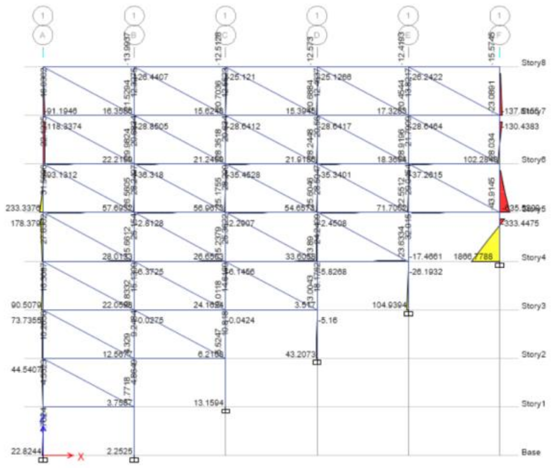

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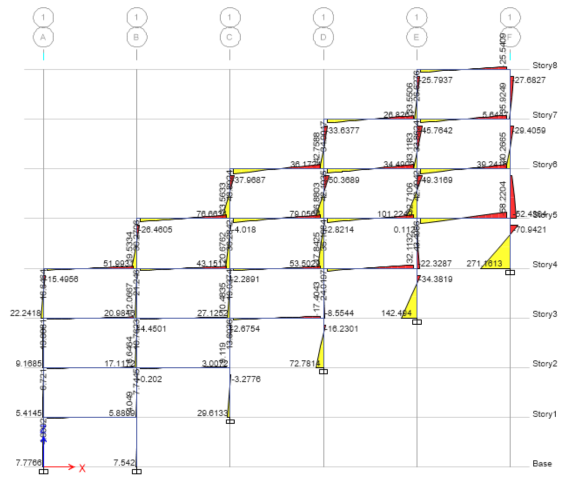

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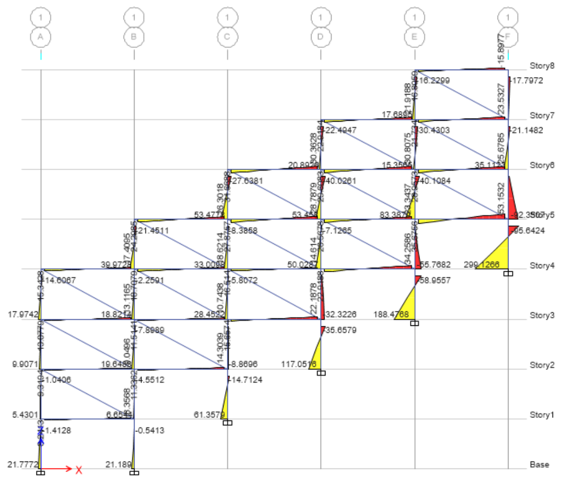

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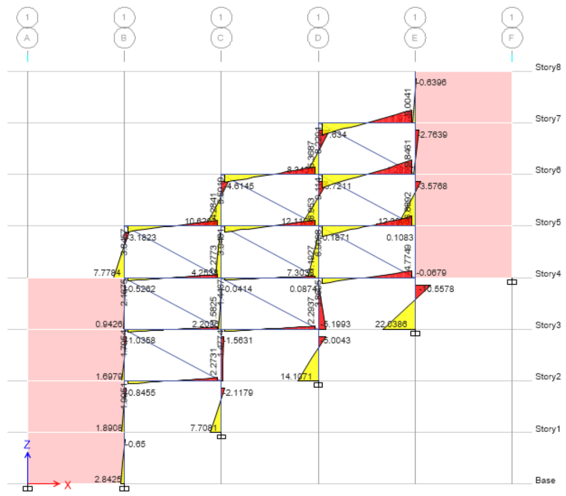

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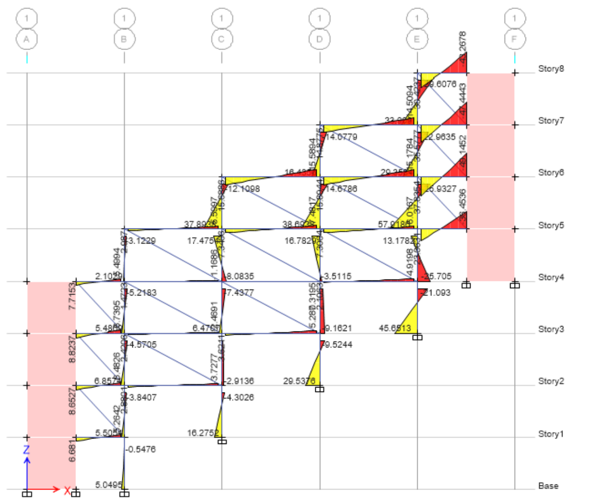
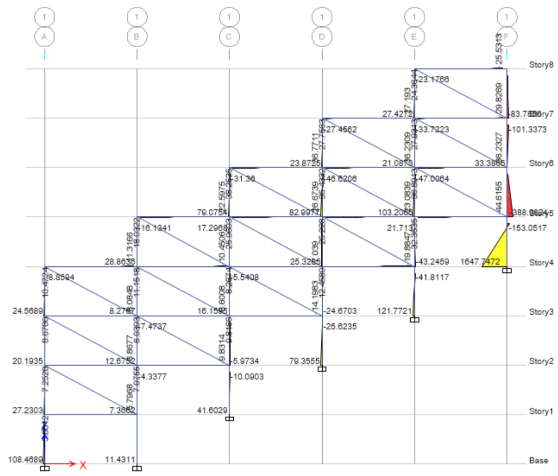
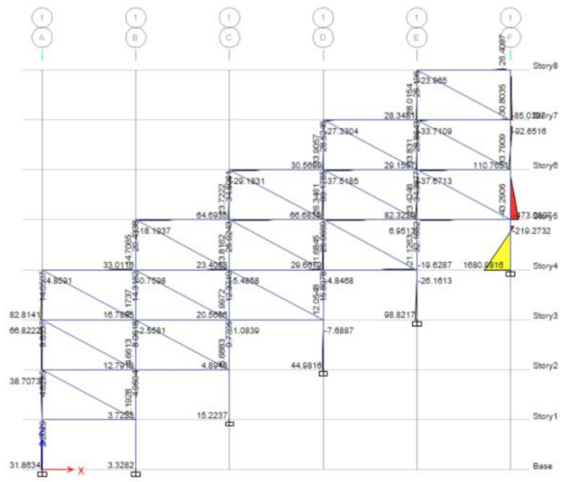
(x)





(xi)

(xii)



(xiii)

Fig. 25. 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

5.18 Shear force in Columns at ground level

Shear force at ground level columns in each model is shown in Table 12. 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 experience 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 12, it is seen that the actions needed for design purposes are predominant when earthquake forces are in along the slope direction.

Table 12. Shear force in columns at ground level in kN in (i) along the slope direction

(ii)across the slope direction.

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

(i)

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

(ii)

Chapter 6

CONCLUSIONS

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. The performance of, stepback and the stepback-setback building is essentially not normal when compared with one another and unique concerning a structure laying on flat ground. IS 1893 (Part 1) has the empirical relationships: 2016 is unable to depict the proper upsides of the time period in both the along and across incline directions. Since the boundaries associated with comparable equivalent static method rely upon the time period value, consequently this strategy ought not to be utilized to plan a slope structure. To determine true behaviour, a response spectrum analysis of a three-dimensional model of complex structures such as hill buildings should be performed. Due to the existence of the shear wall and composite sections, the fundamental natural period of the structures reduces as storey stiffness increases. The energy dissipation capacity of buildings on flat ground is larger than that of hill buildings, as evidenced by the cumulative modal mass participation ratio.

2. If the structure is exposed to earthquake forces; the column in the uphill side of slope building, being rigid draws in the more bending moment while the column on the declining of slope building, being flexible pulls in lesser. So special attention needed during the designing of columns on the uphill side.

3. The maximum base shear was induced in stepback building on the inclined plane followed by stepback-setback and least on regular building on levelled ground. Base shear increases as the stiffness and mass of the structure rises; consequently, base shear is greater for structures with shear walls than for conventional structures.

4. The top storey displacement in across and along direction of regular building on levelled ground is highest followed by stepback and least in stepback-setback. The addition of shear wall in the building will results in the drastic reduction of lateral displacement of the building thereby, in turn, assures the safety of the structures.

5. Shear wall construction demonstrates superior control, but the difficulty with shear walls is that they obstruct open ground storeys., consequently decreasing the practical productivity of the design and stiffness in assembling at some specific area of the construction. Both these issues are adequately settled utilizing composite columns in an open ground storey, as the model with composite columns is not obstructing any entrance in an open ground storey, stiffness is uniformly conveyed over the entire base of the design and the RC column area is not changing at the intersection.

6. This paper suggests the use of shear wall at corners and composite columns; in place of ordinary RC column in the sloping ground to resist tremors.

7. 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.

8. Structures on slanted terrain are shown to be more vulnerable than those on flat ground.

9. The models on sloping terrain have been observed to move orthogonally under unidirectional force.

10. Due to the reduction in column height, columns on the higher side of the slope are likewise susceptible to increased bending moments.

11. 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.

12. The addition of shear walls increases base shears for all models, which is related to the increased seismic weight of the building.

13. 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.

14. 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.

15. 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.

16. 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.

17. 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 points but the stiffness of RCFST composite columns is equally dispersed on entire base of the building, and the RC column crossection does not change at the junction, therefore they can be selected where more space access is required.

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