Research Paper

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Siesmic Effect on Rc Building Resting on Sloping Ground

Engineering

KEYWORDS : Hilly areas, Seismic Effect, Shear wall location, ETABS, Equivalent Static Method, Response Spectrum Method, and Building Performance

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ABSTRACT

The buildings which are located in hilly areas in earthquake prone regions are generally irregular, unsymmetrical and torsionally coupled & hence, susceptible to serve destruction when affected by earthquake. Due to the varied configurations of buildings in sloping areas, these buildings become highly irregular and unsymmetrical, due to variation in mass and stiffness distributions on different vertical axis at each floor. In the present study G+19 storey RCC building frame on varying slope angles i.e., 8° and 16° is studied and compared with the same on the flat ground and the importance of shear wall location in a RC building have been studied. The structural analysis software ETABS V9.7.4 is used to study the effect of sloping ground on building performance during earthquake. Seismic Analysis is done by Equivalent static method and Response spectrum method. Shear force, bending moment, axial forces are critically analyzed to study the effect on various sloping ground.

INTRODUCTION

On the earth surface, everyone is aware that many natural disasters such as earthquakes, floods, tornadoes, hurricanes, droughts, and volcanic eruptions occur of all natural disasters the least understood and most destructive are earthquakes. The annual losses due to earthquakes are very large in many parts of the world. They not only cause great destruction in terms of human casualties, but also have a tremendous economic impact on the affected area. Although the incidents of earthquakes of destructive intensity have been confined to a relatively few areas of the world, the catastrophic consequences of the few that have struck near centers of population have stressed on the need to provide adequate safety against this most terrible nature's quirks.

Hill buildings are different from those in plains; they are very irregular and unsymmetrical in horizontal and vertical planes, and torsionally coupled. Hence, they are susceptible to severe damage when affected by earthquake ground motion. Past earthquakes [e.g. Kangra (1905), Bihar- Nepal (1934 & 1980), Assam (1950), Tokachi-Oki-Japan (1968), Uttarkashi-India (1991), have proved that buildings located near the edge of stretch of hills or sloping ground suffered severe damages. Such buildings have stiffness and mass varying along the vertical and horizontal planes, resulting the center of rigidity and center of mass do not coincide on various floors. Such buildings requires torsional analysis; in addition to lateral forces under the action of earthquakes. With the immense loss of property and life witnessed in the last couple of decades alone in India, due to failure of building structures caused by earthquakes, such investigation is need of the hour. The investigation presented in this paper aimed at predicting the seismic response of RC buildings on sloping and plain grounds.

LITERATURE REVIEW

(2014): A Performance study and seismic evaluation of RC frame buildings on sloping ground

Authors: Mohammed Umar Farooque Patel, A.V.Kulkarni and Nayeemulla Inamdar

They focused on performance study and seismic evaluation of RC building on sloping ground. They studied the behavior of RC frame on sloping ground with the presence of shear wall with different positions at centre and at corner and given the performance of structures with shear wall on sloping ground. From the above studies it has been observed that the performance of the buildings on sloping ground suggests an increased vulnerability of the structure with formation of column hinges at base level and beam hinges at each story level at performance point. For the buildings studied, it is found that the plastic hinges are more in case of buildings resting on sloping ground as compared to buildings resting on plain ground.

(2014): Seismic performance of buildings resting on sloping ground–A review

Authors: Dr. R. B. Khadiranaikar and Arif Masali

They studied the seismic response on hill slopes. The dynamic response of the structure on hill slope has been discussed in their study. A review of studies on the seismic behavior of buildings resting on sloping ground has been presented. It is observed that the seismic behavior of buildings on sloping ground differ from other buildings. The various floors of such buildings step backs towards hill slope and at the same time buildings may have setbacks also. Most of the studies agree that the buildings resting on sloping ground has higher displacement and base shear compared to buildings resting on plain ground and the shorter column attracts more forces and undergo damage when subjected to earthquake. They concluded that Step back building could prove more vulnerable to seismic excitation.

(2014): Study of Short Column Behavior Originated from the Level Difference on Sloping Lots during Earthquake (Special Case: Reinforced Concrete Buildings)

Authors: Keyvan Ramin, Foroud Mehrabpour

They studied the experimental modeling and numerical modeling for a four-story reinforced concrete building that the analysis of simple 3-D frames of varying floor heights and varying number of bays with different slope angles using a very popular software tool STAAD Pro. on both a sloping and a flat lot. Also Sap2000 software had been used to show that the displacement of floors is greater for a flat lot building than a sloping lot building. It is observed those short columns are required to have more resistant sections and are suggested to be reinforced with more bars. In addition, more steel should be used as stirrups than as longitudinal bars. Also for existing structures, shear capacity of short columns should be retrofitted by FRP, Steel Jacket or other materials.

(2014): Design of 3D RC Frame on Sloping Ground

Authors: Shivanand and.B H.S.Vidyadhara

They studied experimental 3D analytical model of 12 storied building, which has been generated for symmetric and asymmetric case. Building models like step back buildings on slope ground, set back-step back buildings on slope ground and buildings on plain ground are analyzed and designed by ETABS software to study the effect of influence of bracings, shear wall at different positions. Seismic analysis is done by linear static (ESA), linear dynamic (RSA) and non-linear static Analysis (Pushover Analysis).The results obtained from three buildings shows that Setback-Step back buildings resting on sloping ground produce relatively less displacements when compared to Step back Buildings and plain building. The Presence of Bracings and Shear Wall reduces the lateral displacement considerably both by ESA & RSA

(2014): Effect of Sloping Ground on Structural Performance of RCC Building Under seismic Load

Authors: Sujit Kumar, Dr. Vivek Garg and Dr. Abhay Sharma

They studied seismic analysis of a G+4 storey RCC building on varying slope angles i.e., 7.5° and 15° and compared with the same on the flat ground. The seismic forces are considered as per IS: 1893-2002. The structural analysis software STAAD Pro v8i is used to study the effect of sloping ground on building performance during earthquake. Seismic analysis has been done using Linear Static method. Their study emphasizes the need for proper designing of structure resting on sloping Ground

MODELLING AND ANALYSIS

In the present study, three groups of building (i.e. configurations) are considered, out of which first one is on the plain ground and the two are resting on ground of (8°and 16°slope) with shear wall at different locations. The modeling and the analysis of the building frames were carried out using commercial software **ETABS v 9.7.4.** Two analyses are performed on G+ 19 storeys building on plain and sloping ground.

Equivalent static lateral force method

As per IS 1893-2002 code requirements Equivalent static lateral force method is performed.

Response spectrum method

According to IS-1893(Part-l):2002, high rise and irregular buildings must be analyzed by response spectrum method using design spectra shown . There are significant computational advantages using response spectra method of seismic analysis for prediction of displacements and member forces in structural systems.

In this present study 12 models are studied as described below

- Buildings on Plain Ground
- Buildings on Sloping ground of 8° slope
- Buildings on Sloping ground of 16° slope

Buildings resting on Plain ground labeled as **MODEL 1**, **MODEL 2**, **MODEL 3** and **MODEL 4**.

MODEL 1 – Building modeled as Bare Frame on Plain ground

MODEL 2 – Building modeled as Bare Frame with Shear wall at Periphery on Plain ground

MODEL 3 – Building modeled as Bare Frame with shear wall at corner on Plain ground

MODEL 4 – Building modeled as Bare Frame with Shear wall at center on Plain ground

The building resting on sloping ground of 8° slope is labeled as **MODEL 5**, **MODEL 6**, **MODEL 7** and **MODEL 8**.

MODEL 5 – Building modeled as Bare Frame on Sloping ground of 8° slope

MODEL 6 – Building modeled as Bare Frame with Shear wall at Periphery on Sloping ground of 8° slope

MODEL 7– Building modeled as Bare Frame with shear wall at corner on Sloping ground of 8° slope

MODEL 8– Building modeled as Bare Frame with Shear wall at center on Sloping ground of 8° slope

The Building resting on sloping ground of 16° slope is labeled as **MODEL 9, MODEL 10, MODEL 11** and **MODEL 12**. Here except MODEL 9 other MODELS have Shear wall at different locations.

MODEL 9 – Building modeled as Bare Frame on Sloping ground of 16° slope

MODEL 10 – Building modeled as Bare Frame with Shear wall at Periphery on Sloping ground of 16° slope

MODEL 11 – Building modeled as Bare Frame with shear wall at corner on Sloping ground of 16° slope

MODEL 12 – Building modeled as Bare Frame with Shear wall at center on Sloping ground of 16° slope

The plan of the building is shown in below figures. In this study the plan is kept same to study the effect of step backs on sloping ground. Height of the building is 3m and building is located in Zone IV. The basic data of the building is shown below.

Basic Data

Basic Data	
Structure	Symmetric Regular Building
Plan Dimension	25 x 25 m
Height of Typical Floor	3m
Ground Floor Height	3m
Floors	20
Dimension of Column	600x600mm
Dimension of Beam	230 x 500 mm
Slab Thickness	150mm
Walls	230 mm thick brick masonry walls
Shear wall	250 mm thick concrete wall
Support	fixed
Type of Soil	Type II, Medium Soil As Per IS: 1893
Zone	IV
Live Load on Typical Floor	2.0 KN/M^2
Dead Load on Typical Floor	5.5 KN/M^2

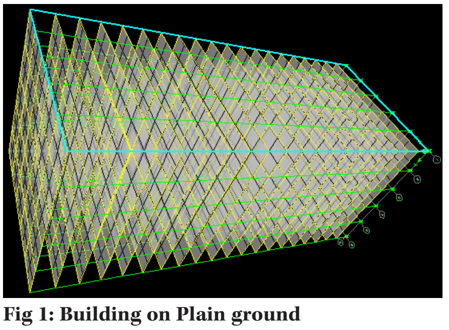

Fig 1: Building on Plain ground

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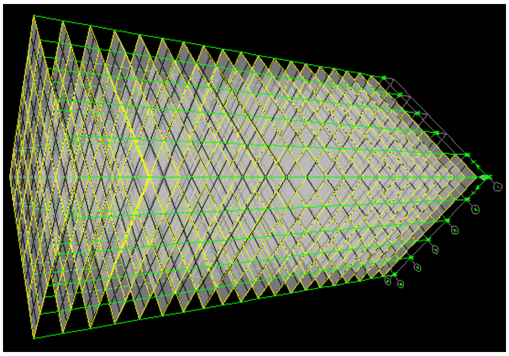

Fig 2: Building on sloping ground (8° slope)

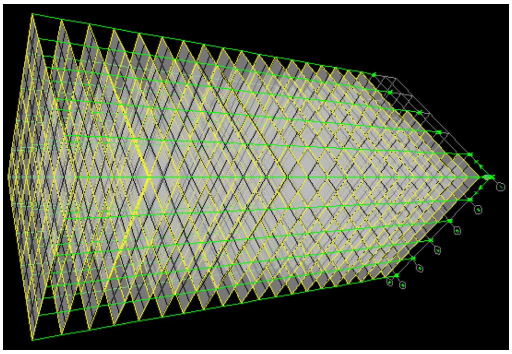

Fig 3: Building on sloping ground (16° slope)

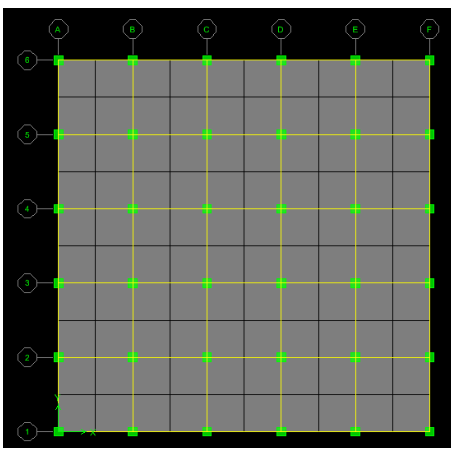

Fig 5: Bare frame

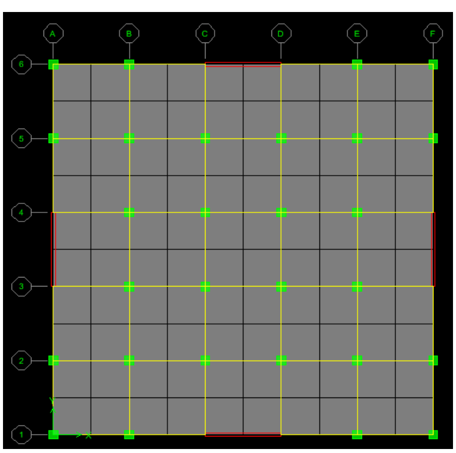

Fig 6: Shear wall at periphery

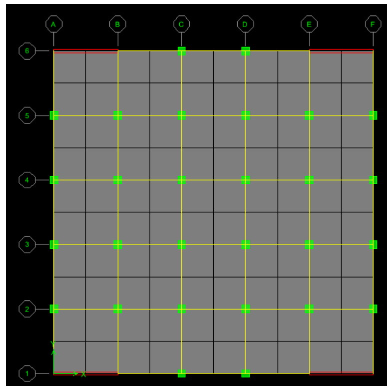

Fig 7: Shear wall at corner

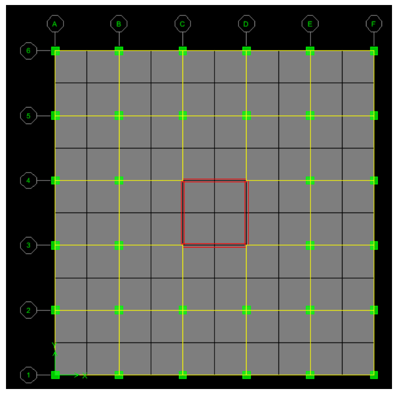

Fig 8: Shear wall at center

RESULTS AND DISCUSSIONS

Lateral Displacements

The lateral displacements for each model are plotted in graphs for Equivalent static method and Response Spectrum method. Here buildings on plain ground and sloping ground for 8° slope are presented.

Table 1 Displacement values for Building Models on Plain ground along X-direction Equivalent static method (ESM)

S.NO	STOREY LEVEL	UX			
		MODEL 1	MODEL 2	MODEL 3	MODEL 4
1	20	201.34	111.64	92.44	75.18
2	19	198.55	106.82	87.47	71.00
3	18	194.88	101.77	82.40	66.70
4	17	190.09	96.47	77.21	62.32
5	16	184.13	90.87	71.87	57.84
6	15	177.01	84.94	66.40	53.29
7	14	168.77	78.70	60.80	48.66
8	13	159.48	72.18	55.10	43.99
9	12	149.19	65.40	49.34	39.32
10	11	137.98	58.43	43.56	34.66
11	10	125.93	51.33	37.81	30.08
12	9	113.09	44.20	32.16	25.60
13	8	99.56	37.13	26.68	21.29
14	7	85.42	30.23	21.44	17.19
15	6	70.82	23.64	16.54	13.37
16	5	55.94	17.49	12.07	9.88
17	4	41.10	11.96	8.12	6.79
18	3	26.82	7.22	4.82	4.17
19	2	14.00	3.49	2.28	2.10
20	1	4.17	0.99	0.62	0.65

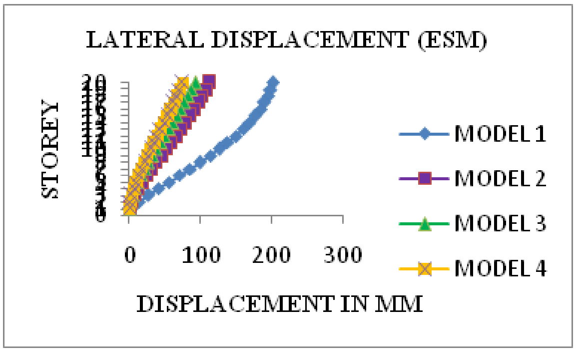

Figure 9

Table 2 Displacement values for Building Models on Plain ground along Y-direction Equivalent static method (ESM)

S.NO	STOREY LEVEL	UY			
		MODEL 1	MODEL 2	MODEL 3	MODEL 4
1	20	201.30	111.64	191.02	75.18
2	19	198.55	106.82	188.27	71.00
3	18	194.88	101.77	184.66	66.70
4	17	190.09	96.47	179.99	62.32
5	16	184.13	90.87	174.22	57.84
6	15	177.01	84.94	167.38	53.29
7	14	168.77	78.70	159.50	48.66
8	13	159.48	72.18	150.65	43.99
9	12	149.19	65.40	140.90	39.32
10	11	137.98	58.43	130.29	34.66
11	10	125.93	51.33	118.91	30.08
12	9	113.09	44.20	106.83	25.60
13	8	99.56	37.13	94.10	21.29
14	7	85.42	30.23	80.83	17.19
15	6	70.82	23.64	67.11	13.37
16	5	55.94	17.49	53.14	9.88
17	4	41.10	11.96	39.17	6.79
18	3	26.82	7.22	25.67	4.17
19	2	14.00	3.49	13.48	2.10
20	1	4.17	0.99	4.05	0.65

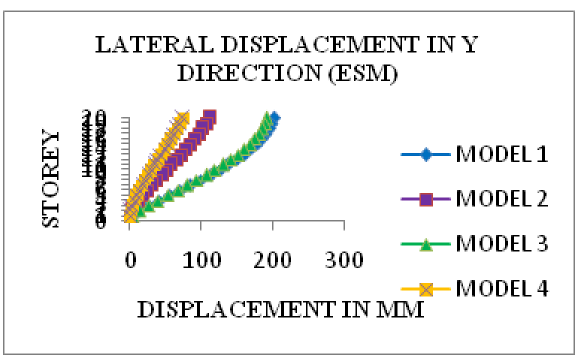

Figure 10

Table 3 Displacement Values for Building Models on Sloping ground for 8° slope along X-direction Equivalent Static Method (ESM)

S.NO	STOREY LEVEL	UX			
		MODEL 5	MODEL 6	MODEL 7	MODEL 8
1	20	178.45	96.82	81.72	69.22
2	19	175.82	92.30	77.10	65.15
3	18	172.31	87.58	72.39	60.96
4	17	167.72	82.63	67.56	56.69
5	16	162.00	77.39	62.60	52.32
6	15	155.16	71.86	57.52	47.88
7	14	147.25	66.06	52.34	43.39
8	13	138.32	60.00	47.08	38.86
9	12	128.44	53.74	41.77	34.34
10	11	117.67	47.33	36.46	29.87
11	10	106.10	40.85	31.22	25.49
12	9	93.80	34.40	26.10	21.25
13	8	80.86	28.08	21.18	17.21
14	7	67.41	22.01	16.54	13.42
15	6	53.62	16.33	12.26	9.95
16	5	39.78	11.20	8.45	6.87
17	4	26.38	6.78	5.21	4.25
18	3	14.21	3.29	2.64	2.16
19	2	4.69	0.95	0.87	0.69
20	1	0.68	0.09	0.12	0.09

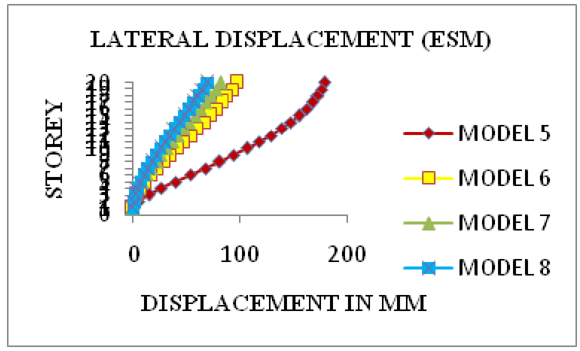

Figure 10

Table 4 Displacement values for building models on sloping ground for 8° slope along Y-direction Equivalent Static Method (ESM)

S.NO	STOREY LEVEL	UY			
		MODEL 5	MODEL 6	MODEL 7	MODEL 8
1	20	177.88	98.67	169.02	69.18
2	19	175.25	94.10	166.41	65.11
3	18	171.74	89.34	162.96	60.92
4	17	167.14	84.33	158.49	56.65
5	16	161.41	79.04	152.97	52.28
6	15	154.55	73.45	146.41	47.84
7	14	146.61	67.58	138.86	43.35
8	13	137.66	61.45	130.37	38.82
9	12	127.74	55.12	121.02	34.30
10	11	116.94	48.63	110.85	29.83
11	10	105.33	42.07	99.95	25.45
12	9	92.99	35.52	88.38	21.20
13	8	80.00	29.10	76.23	17.16
14	7	66.51	22.92	63.61	13.37
15	6	52.68	17.12	50.67	9.90
16	5	38.82	11.86	37.66	6.82
17	4	25.42	7.63	25.01	4.20
18	3	13.33	4.16	13.48	2.10
19	2	4.82	1.62	4.39	0.64
20	1	0.93	0.33	0.65	0.06

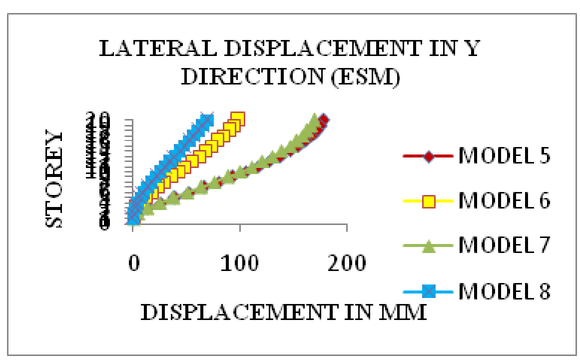

Figure 11

Table 5 Displacement values for building models on plain ground along X-direction Response Spectrum method (RSM)

S.NO	STOREY LEVEL	UX			
		MODEL 1	MODEL 2	MODEL 3	MODEL 4
1	20	153.34	68.81	50.32	39.48
2	19	151.70	65.93	47.60	37.18
3	18	149.53	62.94	44.84	34.86
4	17	146.66	59.83	42.04	32.51
5	16	143.02	56.56	39.20	30.15
6	15	138.56	53.11	36.31	27.78
7	14	133.26	49.48	33.38	25.40
8	13	127.11	45.66	30.40	23.03
9	12	120.10	41.66	27.40	20.66
10	11	112.22	37.52	24.37	18.31
11	10	103.50	33.26	21.35	16.00
12	9	93.93	28.93	18.35	13.73
13	8	83.56	24.57	15.41	11.52
14	7	72.43	20.26	12.55	9.40
15	6	60.65	16.06	9.82	7.39
16	5	48.37	12.06	7.28	5.52
17	4	35.86	8.38	4.98	3.83
18	3	23.59	5.15	3.01	2.37
19	2	12.39	2.54	1.45	1.20
20	1	3.71	0.74	0.41	0.38

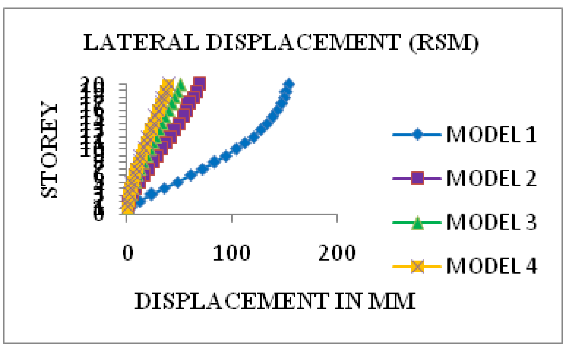

Figure 12

Table 6 Displacement values for building models on plain ground along Y-direction Response Spectrum Method (RSM)

S.NO	STOREY LEVEL	UY			
		MODEL 1	MODEL 2	MODEL 3	MODEL 4
1	20	153.34	68.81	150.26	39.48
2	19	151.70	65.93	148.80	37.18
3	18	149.53	62.94	146.80	34.86
4	17	146.66	59.83	144.11	32.51
5	16	143.02	56.56	140.65	30.15
6	15	138.56	53.11	136.39	27.78
7	14	133.26	49.48	131.30	25.40
8	13	127.11	45.66	125.37	23.03
9	12	120.10	41.66	118.60	20.66
10	11	112.22	37.52	110.99	18.31
11	10	103.50	33.26	102.53	16.00
12	9	93.93	28.93	93.24	13.73
13	8	83.56	24.57	83.14	11.52
14	7	72.43	20.26	72.28	9.40
15	6	60.65	16.06	60.73	7.39
16	5	48.37	12.06	48.65	5.52
17	4	35.86	8.38	36.27	3.83
18	3	23.59	5.15	24.04	2.37
19	2	12.39	2.54	12.75	1.20
20	1	3.71	0.74	3.87	0.38

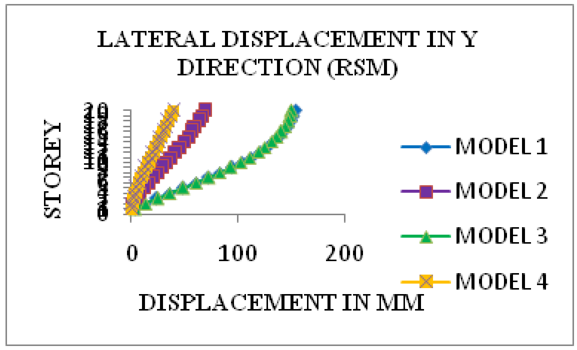

Figure 13

Table 7 Displacement values for building models on sloping ground for 8° slope along X-direction Response Spectrum method (RSM)

S.NO	STOREY LEVEL	UX			
		MODEL 5	MODEL 6	MODEL 7	MODEL 8
1	20	136.99	59.26	43.74	36.57
2	19	135.36	56.54	41.23	34.30
3	18	133.20	53.72	38.69	32.00
4	17	130.34	50.79	36.13	29.69
5	16	126.72	47.72	33.52	27.37
6	15	122.29	44.50	30.88	25.04
7	14	117.03	41.12	28.21	22.71
8	13	110.93	37.58	25.51	20.40
9	12	104.00	33.91	22.79	18.10
10	11	96.23	30.12	20.07	15.83
11	10	87.64	26.26	17.37	13.61
12	9	78.25	22.36	14.70	11.44
13	8	68.12	18.48	12.09	9.36
14	7	57.34	14.68	9.59	7.37
15	6	46.04	11.06	7.23	5.52
16	5	34.47	7.70	5.07	3.85
17	4	23.03	4.75	3.18	2.40
18	3	12.48	2.34	1.65	1.22
19	2	4.11	0.69	0.56	0.40
20	1	0.59	0.07	0.08	0.06

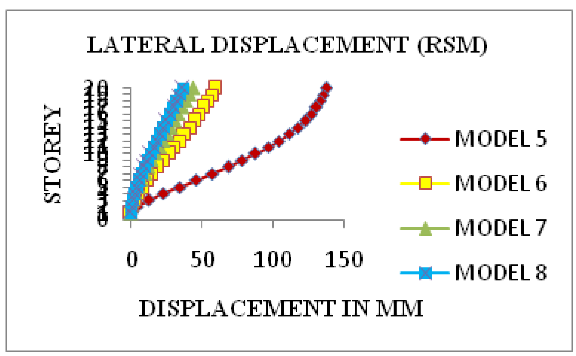

Figure 14

Table 8 Displacement values for building models on sloping ground for 8° slope along Y-direction response spectrum method (RSM)

S.NO	STOREY LEVEL	UY			
		MODEL 5	MODEL 6	MODEL 7	MODEL 8
1	20	142.47	63.97	134.38	36.61
2	19	140.81	61.13	132.93	34.35
3	18	138.60	58.20	130.92	32.05
4	17	135.68	55.14	128.23	29.74
5	16	131.97	51.94	124.78	27.41
6	15	127.44	48.58	120.54	25.09
7	14	122.05	45.04	115.47	22.76
8	13	115.81	41.34	109.59	20.44
9	12	108.70	37.49	102.88	18.15
10	11	100.74	33.51	95.35	15.88
11	10	91.94	29.44	87.00	13.65

12	9	82.31	25.31	77.87	11.49
13	8	71.92	21.19	67.98	9.40
14	7	60.84	17.13	57.42	7.41
15	6	49.22	13.22	46.30	5.57
16	5	37.29	9.56	34.85	3.89
17	4	25.45	6.26	23.46	2.44
18	3	14.40	3.48	12.84	1.27
19	2	5.43	1.38	4.31	0.44
20	1	1.06	0.30	0.66	0.08

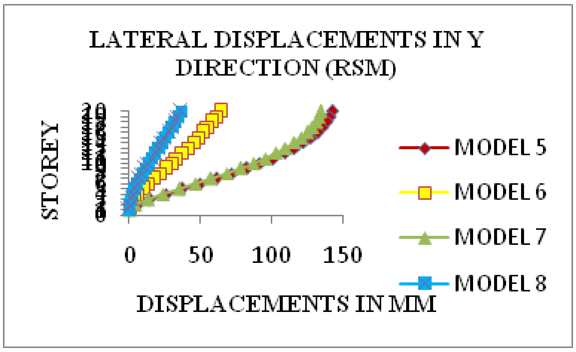

Figure 15

Bending moment

The bending moments for the ground floor columns for ground slopes 0° and 8° **are tabulated below**. The results of only ground floor columns are shown as they are critical. Here for C15 column results are shown.

Table 9 Bending moment for building models on Plain ground

STOREY LEVEL	COLUMN NO	MODEL 1	MODEL 2	MODEL 3	MODEL 4
1	C15	231.372	55.021	32.825	36.071

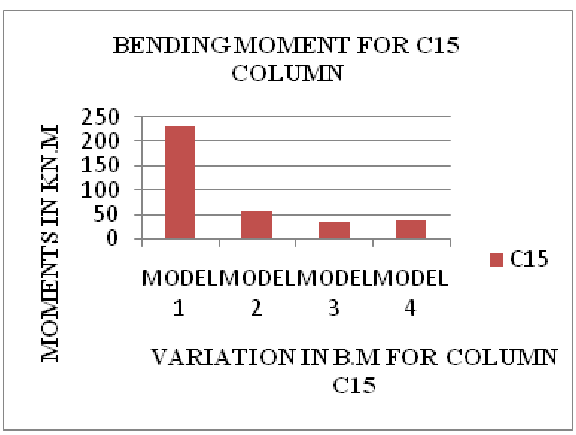

Figure 17

Table 10 Bending moments for building models on sloping ground for 8° slope

STOREY LEVEL	COLUMN NO	MODEL 5	MODEL 6	MODEL 7	MODEL 8
1	C15	275.716	51.196	53.157	38.490

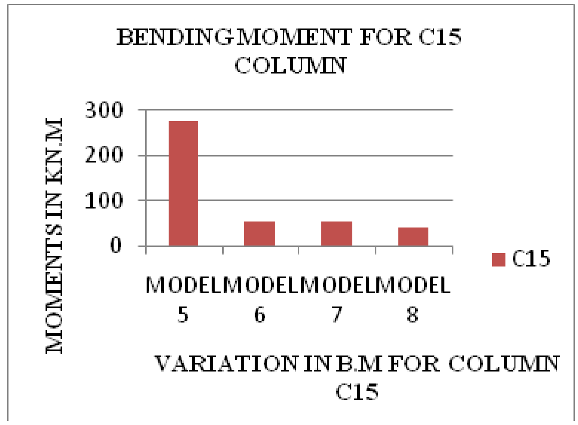

Figure 18

CONCLUSIONS AND FUTURE SCOPE

- Lateral displacements in both Equivalent lateral force method and response spectrum method on plain and sloping ground in both X and Y directions is reduced by the presence of shear wall.
- Among all three cases studied Base shear is more in building with shear wall provided at the center.
- Storey drifts in both Equivalent lateral force method and response spectrum method on plain and sloping ground in both X and Y directions is reduced by the presence of wall.
- The presence of shear wall in the building influence the overall behavior of the structure and it increases the strength and stiffness of the structure.
- Lateral displacements are lesser in shear wall provided at the center in all the cases.
- Storey drifts are lesser in shear wall provided at the center in all the cases.
- Bending moment in critical ground floor columns increases with increase in slope and the presence of shear wall reduces the bending moment in all the cases.
- Shear force in critical ground floor columns increases with increase in slope and the presence of shear wall reduces the Shear force in all the cases.
- Axial force on the columns remains same on all ground slopes.

FUTURE SCOPE

- A rectangular Building has to be studied to check the effect of sloping ground with rectangular columns.
- The present study is based on linear static analysis using Equivalent static method. The results need to be verified with the non-linear static analysis.
- The present study is based on linear dynamic analysis using Response spectrum method. The results need to be verified with the non-linear dynamic analysis.
- The present study is based up on high building configuration the results need to be studied if the masses of the building are reduced.
- Further study may be carried on other zones

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