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A Performance study and seismic evaluation of RC frame buildings on sloping ground

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ABSTRACT : *The Buildings on hill differ from other buildings. The various floors of such building steps back towards the hill slope and at the same time buildings may have setbacks also. Buildings situated in hilly areas are much more vulnerable to seismic environment. In this study, 3D analytical model of eight storied buildings have been generated for symmetric and asymmetric building Models and analyzed using structural analysis tool 'Etabs" to study the effect of varying height of columns in ground storey due to sloping ground and the effect of shear wall at different positions during earthquake. Seismic analysis has been done using Linear Static, Linear Dynamic method and evaluated using pushover analysis. 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.*

I. INTRODUCTION

Earthquake is the most disastrous due to its unpredictability and huge power of devastation. Earthquakes themselves do not kill people, rather the colossal loss of human lives and properties occur due to the destruction of structures. Building structures collapse during severe earthquakes, and cause direct loss of human lives. Numerous research works have been directed worldwide in last few decades to investigate the cause of failure of different types of buildings under severe seismic excitations. Massive destruction of high-rise as well as low-rise buildings in recent devastating earthquake proves that in developing counties like India, such investigation is the need of the hour. Hence, seismic behaviour of asymmetric building structures has become a topic of worldwide active research. Many Investigations have been conducted on elastic and inelastic seismic behaviour of asymmetric systems to find out the cause of seismic vulnerability of such structures. The purpose of the paper is to perform non-linear static pushover analysis of medium height RC buildings and investigate the changes in structural behaviour due to consideration of shear wall. In this paper, Multi-storied buildings i.e. Eight Storied building located in zone III of medium soil sites has been analysed by Linear Static and Linear Dynamic method given in Indian code and evaluated using pushover analysis as per the procedure prescribed in ATC-40 and FEMA-356.

II. MODELLING AND ANALYSIS

In the present study lateral load analysis as per the seismic code for the bare Frame and concrete Shear wall structure is carried out and an effort is made to study the effect of seismic loads on them and thus assess their seismic vulnerability by performing pushover analysis. The analysis is carried out using Etabs analysis package. Concrete frame elements are classified as beam and column frames. Columns and beams are modelled using three dimensional frame elements. Slabs are modelled as rigid diaphragms. The beam column joints are assumed to be rigid. Default hinge properties available in ETABS Nonlinear as per ATC- 40 are assigned to the frame elements. Location of hinges in various stages can be obtained from pushover curve. Different building components are modelled as described below Using Software**,** three distinct analyses are carried on eight storied building models on plain ground and on sloping ground, which are as follows:

Equivalent Static Analysis
Response Spectrum Analysis

Pushover analysis

In this study six models are studied as described below

Model 1: Building on Sloping ground (Bare Frame) - Building has no walls at all stories and is modelled as bare frame. However masses of the walls are included. In addition to wall masses the other load like floor finish and imposed live load is added at each Storey.

Model 2: Building on Sloping ground (Shear Wall at Centre) - Structural concrete shear wall (150mm) thick is provided in centre along longitudinal and transverse direction.

Model 3: Building on Sloping ground (Shear Wall at Corner) - Structural concrete shear wall (150mm) thick is provided in corner. However masses of the walls are included.

Model 4: Building on Plain Ground (Bare Frame) - Building has no walls at all stories and is modelled as bare frame. However masses of the walls are included.

Model 5: Building on Plain Ground (Shear Wall at Centre) - Structural concrete shear wall (150mm) thick is provided in centre along longitudinal and transverse direction.

Model 6: Building on Plain Ground (Shear Wall at Centre) - Structural concrete shear wall (150mm) thick is provided in corner.

The plan layout of the reinforced concrete moment resisting frame of Eight Storey building is shown in Figures 1 to 3.In this study, the plan layout is deliberately kept same to study the effect of step backs. The Storey height is kept 3.5 m for all buildings. The building is considered to be located in the seismic zone-III and intended for office use. In the seismic weight calculations only 50% of the floor live load is considered. The input data given for the buildings is detailed below.

Example Description

Number of Storey	: 08
Floor height	: 3.5 m
No of bay in X direction	: 5
No of bay in Y direction	: 5
Spacing in X direction	: 4 m
Spacing in Y direction	: 4 m
Beam sizes	: 300X450 mm
Column sizes	: 450X450 mm
Slab thickness	: 120 mm
Thickness of concrete Shear wall	: 150 mm
Live Load	: 4 kN/m^2
Floor Finish Load	: 1 kN/m^2
Concrete grade	: M30
Steel	: Fe415

Earthquake parameters

Type of frame	: SMRF
Seismic zone	: III
Response Reduction Factor	: 5
Importance Factor	: 1

Type of soil	: Medium
Damping of structure.	:5%

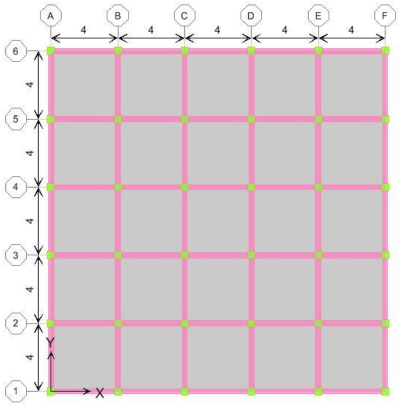

Fig-1 Plan view of Model-1

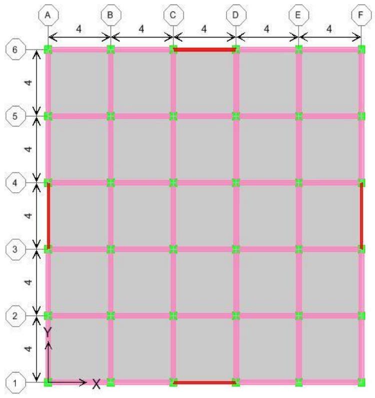

Fig-2 Plan view of Model-2

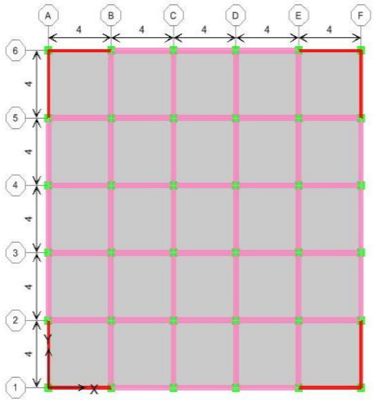

Fig-3 Plan view of Model-3

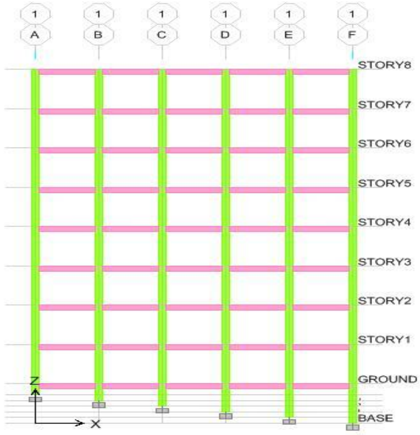

Fig-4 Elevation along X Direction

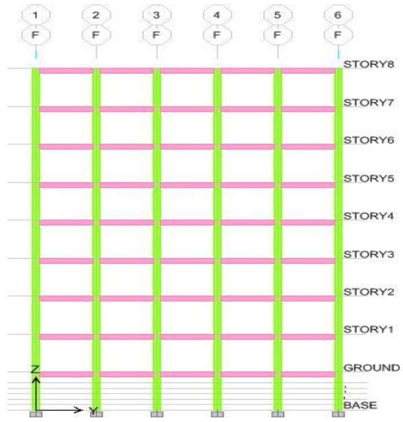

Fig-5 Elevation along X Direction

III. RESULTS AND DISCUSSIONS

3.1 Lateral Displacements

The maximum displacements at each floor level with respect to ground are presented in Table 1 to 4 for Equivalent static and Response spectrum method. For better comparability the displacement for each model along the two directions of ground motion are plotted in graphs as shown in Figure-6 to 8.Moreover, the floor displacement is maximum at the top floor, gradually reducing down the height of the building to an almost negligible displacement at the lowest basement floor.

In Equivalent static analysis it has been found that Model-2, Model-3, Model-4, Model-5 and Model-6 has 41.4%, 61.5%, 16.4%, 54.6% and 70.7% respectively less displacement as compared to the model-1 in longitudinal direction and in transverse direction Model-2, Model-3, Model-4, Model-5 and Model-6 has 43%, 62.2%, 14.4%, 53.5% and 70% respectively less displacement compared to model-1

In Response spectrum analysis it can be seen that Model-2, Model-3, Model-4, Model-5 and Model-6 has 23.6%, 38.1%, 12.2%, 34.3% and 47.3% respectively less displacements compared to model-1in longitudinal direction, and in transverse direction Model-2, Model-3, Model-4, Model-5 and Model-6 has 23.9%, 37.1% 4.9%, 28.9% and 42.9% respectively less displacements compared to model-1.

From above conclusion it is clear that the buildings resting on sloping ground has more displacement compared to buildings on Plain ground and the presence of Shear wall reduces the lateral displacement considerable by both Equivalent static and Response spectrum analysis

Storey No	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6
8	30.40	17.80	11.70	25.40	13.80	8.90
7	28.70	15.70	10.20	23.90	12.10	7.60
6	25.90	13.50	8.60	21.50	10.20	6.30
5	22.60	11.10	6.70	18.40	8.10	4.90
4	18.50	8.60	5.10	14.70	6.00	3.50
3	14.10	6.10	3.50	10.70	3.90	2.30
2	9.40	3.70	2.20	6.60	2.10	1.20
1	4.60	1.70	0.90	2.60	0.70	0.40

Table 1 Lateral Displacements (mm) along Longitudinal direction (Equivalent Static Method)

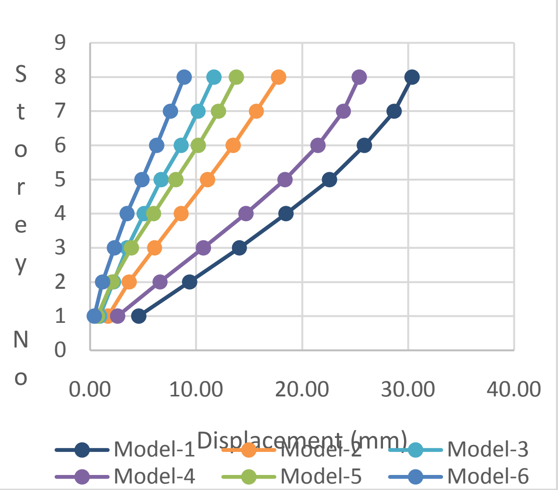

Fig-6 Storey-wise Lateral displacement along X-direction (Equivalent Static Method)

Storey No	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6
8	29.70	16.90	11.20	25.40	13.80	8.90
7	28.20	15.00	9.70	23.90	12.10	7.60
6	25.60	12.90	8.20	21.50	10.20	6.30
5	22.30	10.60	6.50	18.40	8.10	4.90
4	18.40	8.10	4.90	14.70	6.00	3.50
3	14.00	5.70	3.40	10.70	3.90	2.30
2	9.40	3.50	2.00	6.60	2.10	1.20
1	4.80	1.60	0.90	2.60	0.70	0.40

Table 2 Lateral Displacements (mm) along Transverse direction (Equivalent Static Method)

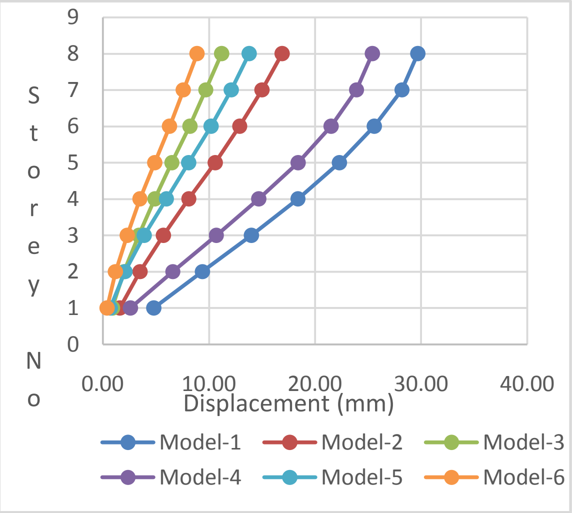

Fig-7 Storey-wise Lateral displacement along Y-direction (Equivalent Static Method)

Storey No	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6
8	13.10	10.00	8.10	11.50	8.60	6.90
7	12.40	8.80	7.10	10.90	7.50	5.90
6	11.20	7.70	6.00	10.00	6.40	4.90
5	10.00	6.40	4.60	8.80	5.20	3.80
4	8.50	5.00	3.60	7.30	3.90	2.80
3	6.70	3.60	2.50	5.50	2.60	1.80
2	4.60	2.30	1.60	3.50	1.40	1.00
1	2.30	1.10	0.60	1.40	0.50	0.30

Table 3 Lateral Displacements along Longitudinal direction (Response Spectrum Method)

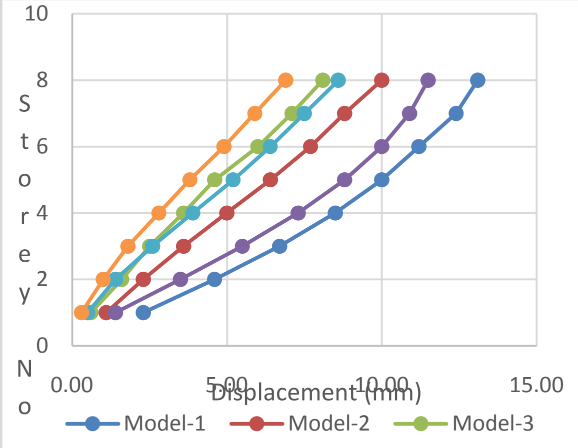

Fig-8 Storey-wise Lateral displacement along X-direction (Response Spectrum Method)

Storey No	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6
8	12.10	9.20	7.60	11.50	8.60	6.90
7	11.60	8.20	6.60	10.90	7.50	5.90
6	10.70	7.10	5.50	10.00	6.40	4.90
5	9.50	5.90	4.50	8.80	5.20	3.80
4	8.00	4.60	3.40	7.30	3.90	2.80
3	6.30	3.30	2.40	5.50	2.60	1.80
2	4.40	2.10	1.40	3.50	1.40	1.00
1	2.30	1.00	0.70	1.40	0.50	0.30

Table 4 Lateral Displacements (mm) along Transverse direction (Response Spectrum Method)

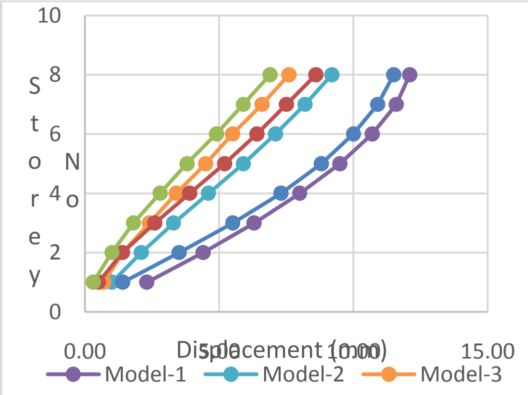

Fig-9 Storey-wise Lateral displacement along Y-direction (Response Spectrum Method

3.2 STRUCTURAL RESPONSE

In order to examine the hinge status and deformations of building models, pushover analysis is done along the longitudinal and transverse directions for all models and the Results are presented in Table-5 to 6. In Pushover analysis it can be seen that Model-2, Model-3, Model-4, Model-5 and Model-6 has 6.1%, 14.1%, 3.1%, 9.4% and 20.1% respectively less displacements compared to model-1in longitudinal direction, and in transverse direction Model-2, Model-3, Model-4, Model-5 and Model-6 has 26%, 39.1% 1.4%, 8% and 18.7% respectively less displacements compared to model-1.

From above conclusion it is clear that the buildings resting on sloping ground has more displacement compared to buildings on Plain ground and the presence of Shear wall reduces the lateral displacement considerable.

3.2.1 Performance point

Performance point determined from pushover analysis is the point at which the capacity of the structure is exactly equal to the demand made on the structure by the seismic load. The performance of the structure is assessed by the state of the structure at performance point. This can be done by

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studying the status of the plastic hinges formed at different locations in the structure when the structure reaches its performance point. It is therefore important to study the state of hinges in the structure at performance point.

The performance point of the building models in longitudinal and transverse directions are shown in figure-10 to 14 as obtained from Etabs. The values of performance point parameters such as structural acceleration (Sa), structural displacement (Sd), base shear (V) and roof displacement (D) are shown in table-5 to 6 for all the building models.

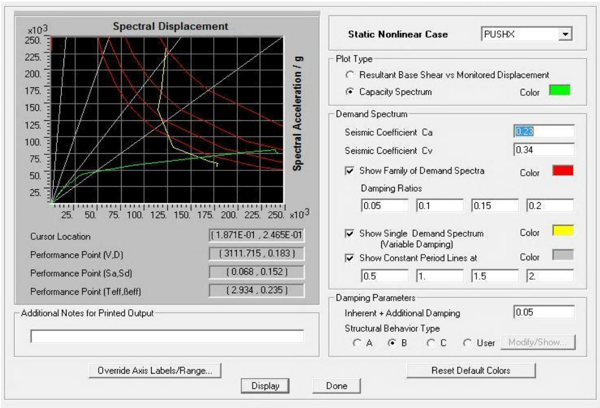

Fig 10 -Performance point of Model-1 along longitudinal direction

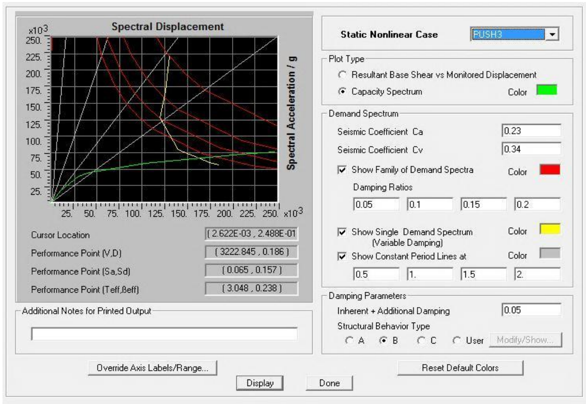

Fig-11: Performance point of Model-1 along Transverse direction

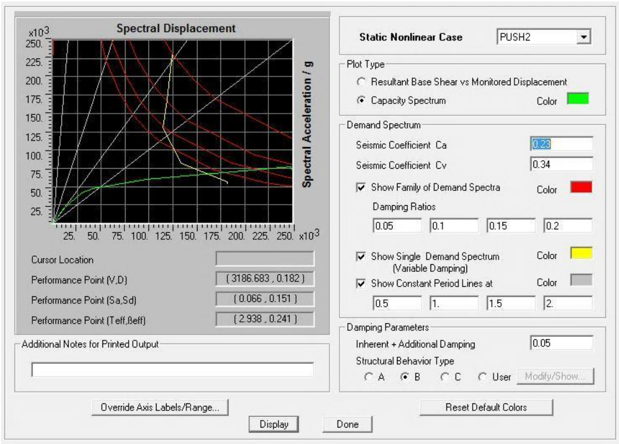

Fig12 - Performance point of Model-4 along longitudinal direction

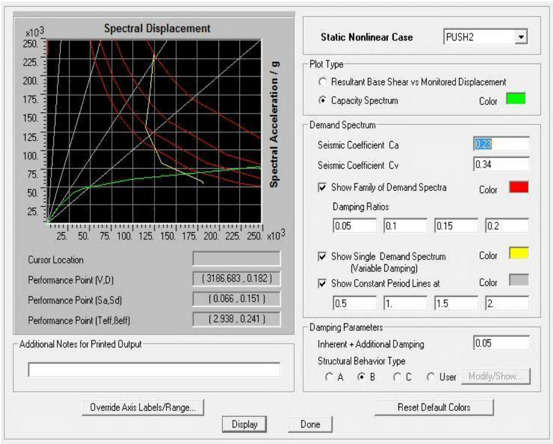

Fig 13 - Performance point of Model-4 along Transverse Direction

Model No	Structural acceleration (Sa)	Structural Displacement Sd(mm)	Base shear V(kn)	Roof displacement D(mm)
Model 1	0.07	152.00	3111.72	183.00
Model 2	0.17	87.00	7536.82	125.00
Model 3	0.32	73.00	13920.42	106.00
Model 4	0.07	151.00	3186.68	182.00
Model 5	0.19	82.00	7761.38	116.00
Model 6	0.36	71.00	15059.62	102.00

Table 5: Performance point parameters for Models along Longitudinal direction

Model No	Structural acceleration (Sa)	Structural Displacement Sd(mm)	Base shear V(kn)	Roof displacement D(mm)
Model 1	0.07	157.00	3222.85	186.00
Model 2	0.21	135.00	9286.96	187.00
Model 3	0.31	74.00	14024.09	102.00
Model 4	0.07	152.00	3111.72	183.00
Model 5	0.19	82.00	7761.38	116.00
Model 6	0.36	71.00	15059.62	102.00

Table 6: Performance point parameters for models along Transverse direction

LONGITUDINAL DIRECTION

From the Table-5 it can be seen that for different building models in longitudinal direction Spectral acceleration (Sa) and Base Shear (V) is minimum for model 1 and maximum for model 6 whereas Spectral displacement (Sd) and Roof displacement (D) is minimum for model 6 and maximum for model 1. From the Table-5 it is evident that Spectral displacement (Sd) and Roof displacement (D) is decreasing considerably for building models on plain ground as compared to building models on sloping ground.

TRANSVERSE DIRECTION

From the Table-6 it can be seen that for the different building models in transverse direction, Spectral acceleration (Sa) and base shear (V) is maximum for model-6 and it can be also noted that Spectral displacement (Sd) and roof displacement (D) is larger for model 1 as compared to other models.

3.2.2 HINGE STATUS AT PERFORMANCE POINT

The performance of the structure is assessed by the state of the structure at performance point. This can be done by studying the status of the plastic hinges formed at different locations in the structure when the structure reaches its performance point. It is therefore important to study the state of hinges in the structure at performance point. The status of hinges at performance point for different models considered for the analysis i.e. Buildings on sloping ground and buildings on plain ground are shown in Tables 7 to 8.

Models are subjected to pushover analysis in X-direction and Y-Direction and it can be observed from the Table 7 to 8 the effect of asymmetry on the status of hinges at performance point. In Model-1, the numbers of hinges in elastic range are decreasing and numbers of plastic hinges are increasing. The numbers of Plastic hinge formation along longitudinal direction are more as compared to transverse direction because of the effect of asymmetry along longitudinal direction.

The performance of the structures 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. Most of the elements are in the range of LS-CP and some of the elements lie in the range of C-D which indicates failure of those elements, so these structural elements requires retrofitting.

In general, if the Model-1, Model-2, Model-3 are compared with Model-4, Model-5 and Model-6 respectively then the numbers of Plastic hinge formation along longitudinal and transverse direction are more in Model-1, Model-2, Model-3 as compared to Model-4, Model-5 and Model-6. So we can say that more the number of hinges at performance point in elastic range and fewer the number of plastic hinges is a better performance.

Model No	Hinge Status at Performance Point								
	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	Total Applied
1	**1452**	94	122	236	0	4	0	0	1908
2	**1296**	162	384	64	0	2	0	0	1908
3	**1292**	286	272	56	0	2	0	0	1908
4	**1148**	88	88	212	0	0	0	0	1536
5	**1022**	260	238	14	0	2	0	0	1536
6	**1024**	376	124	10	0	2	0	0	1536

Table 7 Hinge Status at Performance Point along X- direction

Model No	Hinge Status at Performance Point								
	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	Total Applied
1	**1443**	136	108	221	0	0	0	0	1908
2	**1286**	184	378	59	0	0	1	0	1908
3	**1289**	385	196	37	0	1	0	0	1908
4	**1148**	88	88	212	0	0	0	0	1536
5	**1022**	260	238	14	0	2	0	0	1536
6	**1024**	376	124	10	0	2	0	0	1536

Table 8 Hinge Status at Performance Point along Y- direction

IV. CONCLUSION

Buildings resting on sloping ground have more lateral displacement compared to buildings on Plain ground and the presence of Shear wall reduces the lateral displacement.

The presence of shear wall influences the overall behavior of structures when subjected to lateral forces. Lateral displacements and storey drifts are considerably reduced while contribution of shear wall is taken into account.

In case of shear wall at exterior corners the structure is subjected to less displacement in all cases against the structure with bare frame and shear wall at Centre.

Spectral displacement (Sd) and Roof displacement (D) is decreasing considerably for building models on plain ground as compared to building models on sloping ground.

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. Most of the elements are in the range of LS-CP and some of the elements lie in the range of C-D which indicates failure of those elements. Hence the structural elements which lies in the range of collapse point increases the seismic vulnerability of the structure and such elements requires retrofitting.

The numbers of Plastic hinge formation in buildings on sloping ground are more in longitudinal direction as compared to transverse direction because of the effect of asymmetry along longitudinal direction.

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.

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