

Seismic Analysis of Asymmetric Structure on Flat & Sloping Terrain with variable Shear Wall Placement

Abhishek K. Muley

Department of Civil Engineering

Deogiri Institute of Engineering & Management Studies, Chhatrapati Sambhajanagar-431005, Maharashtra, India

Dipak B. Gaidhane

Department of Civil Engineering

Deogiri Institute of Engineering & Management Studies, Chhatrapati Sambhajanagar-431005, Maharashtra, India

Abstract : The rapid growth in population has intensified the demand for land, leading to the construction of high-rise buildings in both urban and hilly regions. These structures are subjected to gravity loads as well as lateral forces caused by wind and earthquakes. With an increase in building height, structural flexibility also increases, making the building more susceptible to lateral displacement and vibration. Buildings constructed on sloping ground generally possess irregular geometry and varying column heights, resulting in an uneven distribution of stiffness and mass. Consequently, such structures are more vulnerable to seismic and wind-induced damage than buildings located on level ground. To enhance their resistance against lateral loads, different structural systems are adopted, among which shear walls are considered one of the most efficient solutions. This study investigates the seismic performance of unsymmetrical buildings incorporating shear walls at different locations. The research aims to determine the optimum shear wall position and compare the structural response of buildings constructed on flat ground and sloping ground based on important performance parameters.

Keywords : Unsymmetrical building, Shear wall, Story displacement, Story shear, Story drift ratio, ETABS, Flat ground, Sloping ground, Seismic analysis.

I. INTRODUCTION

The rapid growth of population and industrialization has considerably increased the demand for land, resulting in a shortage of available space for development. Consequently, the construction of high-rise buildings has become a practical solution to accommodate the increasing population. These buildings are mainly subjected to two categories of loads: vertical loads due to gravity and lateral loads caused by wind and earthquake forces. As the height of a building increases, its slenderness also increases, making it more vulnerable to lateral displacement. Excessive lateral movement can reduce the structural stability and safety of the building.

Structures located on hilly terrain differ significantly from those constructed on flat ground because of uneven topography and irregular site conditions. Such terrain often leads to asymmetrical building configurations, which influence structural performance during seismic events. Symmetrical buildings generally exhibit better stability, uniform load distribution, and improved architectural appearance. On the other hand, asymmetrical buildings are more prone to larger lateral displacements and torsional effects during earthquakes due to the irregular distribution of mass and stiffness. Since complete symmetry is not always achievable in hilly regions, it becomes necessary to evaluate the seismic behaviour of asymmetrical structures.

Various lateral load resisting systems, including shear walls, bracing systems, space trusses, and tubular structures, are used to improve the seismic performance of buildings. Among these, shear walls are considered one of the most effective and practical structural systems. A shear wall is a reinforced cement concrete (RCC) element designed to resist lateral forces generated by wind and earthquakes. It extends continuously from the foundation to the top of the structure, providing adequate stiffness and strength. Shear walls effectively reduce lateral displacement, enhance structural stability, and improve the overall earthquake resistance of high-rise buildings.

II. LITERATURE REVIEW

1. Dhimant Parmar, Nikhilesh Ponnappan, Advaita Thampi & Prasanth S. (2025)

The authors investigated the seismic behavior of RC buildings constructed on sloping ground by considering Soil-Foundation-Structure Interaction (SFSI). Different lateral load-resisting systems such as shear walls, steel bracing, grade beams, and hybrid systems were compared under earthquake loading. The study concluded that hybrid systems significantly improve structural stiffness and reduce displacement and inter-storey drift. This research is helpful for the present study because it demonstrates effective methods to improve seismic performance of buildings on sloping terrain and provides guidance for selecting suitable lateral load-resisting systems.

2. Vijay Kumar Pandit, Akshit Lamba & Indra Narayan Yadav (2025) The authors compared the seismic design and reinforcement requirements of a G+6 RC residential building using ETABS and STAAD Pro. They evaluated story displacement, story drift, base shear, and reinforcement detailing according to IS 1893:2016. The study found that ETABS provides more accurate seismic response and economical reinforcement design than STAAD Pro. This work is useful for the present project because ETABS is also adopted for modelling and evaluating seismic parameters of a G+10 building.

3. Antony Vimal Paul Pandian et al. (2024) The authors studied the seismic performance of square, L-, T-, and U-shaped multi-storey buildings using Response Spectrum Analysis and Pushover Analysis. The influence of natural time period, base shear, base torsion, roof displacement, and inter-storey drift was investigated under different earthquake records. They concluded that L-shaped buildings perform better than T- and U-shaped configurations despite being unsymmetrical. This study is useful because it explains the influence of plan irregularity on seismic response, which is important when comparing different structural configurations.

4. Aashish Nimbe & Raghvendra Singh (2024) The authors reviewed the dynamic behavior of symmetrical and unsymmetrical high-rise buildings with curtailed shear walls. They discussed the influence of shear wall discontinuity on axial force, node displacement, and base shear. The review concluded that improper curtailment of shear walls increases displacement and torsional effects, particularly in irregular buildings. This paper provides valuable information regarding the effectiveness and placement of shear walls for improving earthquake resistance.

5. Manoj Kumar Sharma & Hemant Kumar Sain (2024) The authors presented a comprehensive review on seismic analysis of connected and high-rise buildings. They discussed the historical development of high-rise structures, seismic analysis methods, and the interaction between adjacent buildings during earthquakes. The review emphasized that accurate seismic analysis is essential for improving structural safety and resilience. This work provides useful background knowledge for understanding modern seismic analysis techniques used in ETABS.

6. Ankit Yogi & Vinod Kumar Modi (2024) The authors analyzed G+5 RC buildings of different shapes on flat and sloping terrain using ETABS. Response Spectrum Analysis was performed according to IS 1893:2016 to evaluate base shear, story drift, displacement, and vertical irregularity. The study showed that sloping ground significantly increases seismic demand because of varying column heights and structural irregularities. The findings are directly applicable to the present research on buildings located on sloping ground.

7. K. Veera Babu, S. Siva Rama Krishna & Venu Malagavelli (2023) The authors compared multi-storey RC buildings constructed on flat ground and sloping ground with different slope angles using ETABS. Response Spectrum Analysis was used to evaluate story shear, story drift, displacement, and bending moments. The results showed that buildings on sloping terrain experience greater lateral displacement and short-column effects than buildings on flat terrain. This paper provides an excellent reference for evaluating seismic parameters in sloping ground buildings.

8. Hanmant Jadhav & Samadhan Lengare (2023) The authors investigated an unsymmetrical RC building resting on flat and sloping ground with shear walls placed at different locations. They compared story displacement, story drift, and story shear to determine the optimum shear wall position. The study concluded that proper placement of shear walls significantly improves seismic performance and reduces lateral deformation. This work is highly relevant because the objective of the present project is also to study the influence of shear wall location.

9. Huijuan Jia, Yongsheng Song, Xi Chen, Shunqing Liu & Binsheng Zhang (2022)

The authors evaluated the seismic performance of a 14-storey high-rise building having both plan and vertical irregularities. Response Spectrum Analysis, Elastic Time History Analysis, and Elastic-Plastic Time History Analysis

were carried out under different earthquake intensities. They confirmed that the structural design satisfied the required performance levels while identifying critical regions susceptible to damage. This study demonstrates advanced seismic evaluation methods that can be adopted for validating structural safety.

10. Shubham S. Bhile & Uttam R. Awari (2022) The authors compared the seismic response of symmetrical and unsymmetrical RC buildings subjected to earthquake loading. The study focused on displacement, stiffness, and structural irregularity. It concluded that symmetrical buildings perform better because of uniform mass and stiffness distribution, whereas unsymmetrical buildings experience greater torsional effects and displacement. This paper supports the importance of maintaining structural regularity for improved seismic behavior.

III. METHODOLOGY

- (1) Analysis of G+10 RC building with unsymmetrical shape with different positions of shear wall on sloping ground and flat ground using response spectrum method in Etabs software.
- (2) Estimate story displacement, story drift, base shear.
- (3) Analysis and results for the different models and conclusion based on analysis and results.

IV. RESEARCH OBJECTIVES

- (1) To analyze multistory unsymmetric RC building with shear wall at different positions with variation in slope i.e., 0° and 20° using Etabs software.
- (2) To compare the behavior of unsymmetric RC building with shear wall and without shear wall on Flat & sloping ground.
- (3) To find the suitable positions of shear wall for unsymmetric RC building with sloping ground and flat ground.

V. MODELING

In this study G+10 unsymmetric RC building was used for the analysis. Also, there were flat ground and sloping ground was considered. For the sloping ground 20 degree slope considered. The building models are modeled and analyzed by ETABS v18.0.2 software by response spectrum analysis method as per IS 1893:2016. For the Analysis results of the structure the following parameters are considered :

- (1) Maximum Story Displacement
- (2) Base Shears
- (3) Maximum Story Drifts.

The columns of the building are considered as 400 mm x 400 mm and short column considered as 750 mm x 750 mm, while all the beams considered as 300 mm x 400 mm. the size of shear wall used as 150 mm in size. For the center position of shear wall considered two panels which are approximately at center which include Center of mass of building area. First four models are at flat ground while last four models are at sloping ground of 20 degree slope. The different positions of shear wall were planned for the analysis. The following cases of building were considered for analysis:

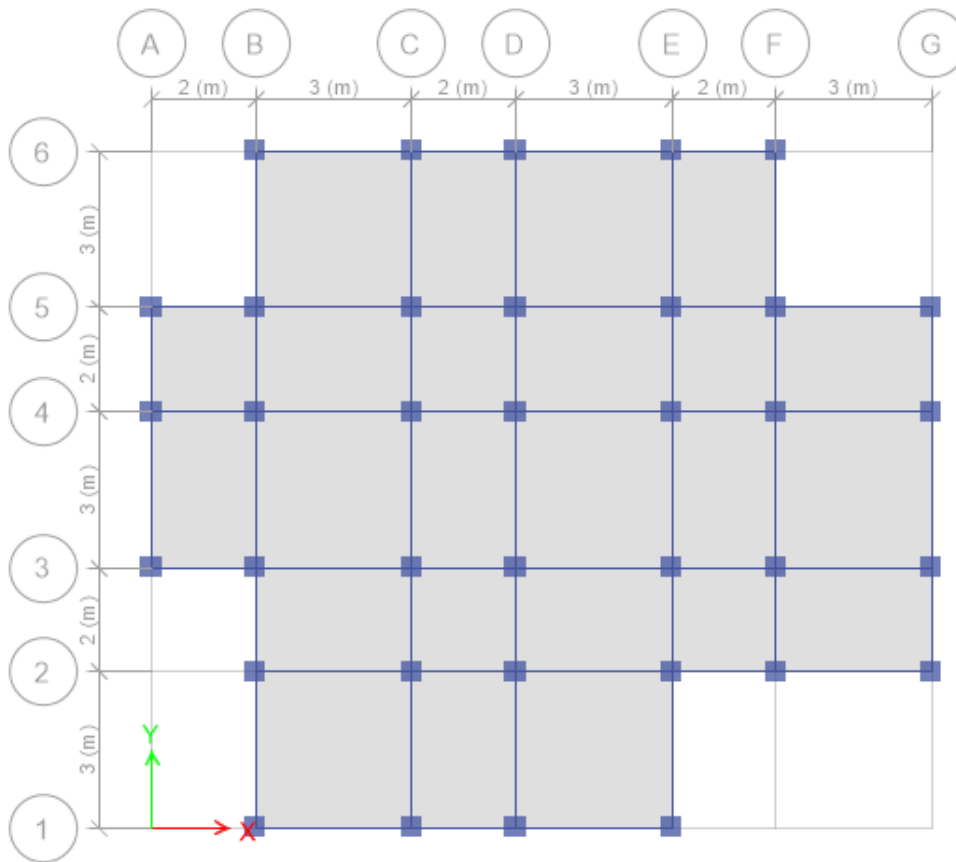


Fig -1 : Plan View of Modeling Building

- ❖ Flat ground building without Shear wall : [model-1]
- ❖ Flat ground building with Shear wall at alternative positions : [model-2]
- ❖ Flat ground building with Shear wall at center : [model-3]
- ❖ Flat ground building with Shear wall at Internal corner : [model-4]
- ❖ Sloping ground building with no Shear wall : [model-5]
- ❖ Sloping ground building with Shear wall at alternative positions : [model-6]
- ❖ Sloping ground building with Shear wall at center : [model-7]
- ❖ Sloping ground building with Shear wall at Internal corner : [model-8]

Table -1 : Building Parameter :

BUILDING PARAMETERS	DISCRIPTION
Type of frame	RCC structure
Plan size	15m X 13m
No. of stories	G+10 (11 stories)
Floor height	3m
Column size	450mm X 450mm
Short Column	750mm X750mm

Beam size	230mm X 400 mm
Slab thickness	200mm
Shear wall size	150mm
Live load	3 KN/m ²
Super Dead Load (F.F + C.P)	2 KN/m ²
Grade of concrete	M30
Grade of steel	Fe500
Density of concrete	25 KN/m ²
Seismic zone	IV
Type of soil	Medium (type II)
Damping %	5%
Importance factor	1
Response reduction factor	5
Basic wind speed	44 m/s
Terrain Category	2
Risk Coefficient (k1)	1.07
Topography (K3)	1
RCC design code	IS 456:2000
Steel design code	IS 800:2007
Wind design code	IS 875:2015
Seismic design code	IS 1893:2016

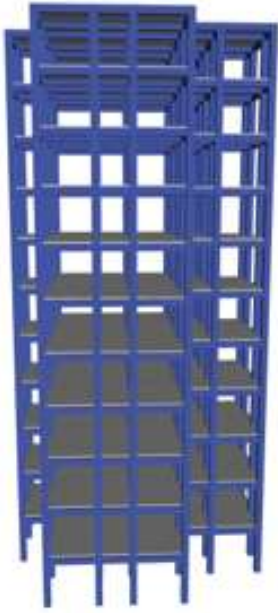


Fig -2 : Model 1

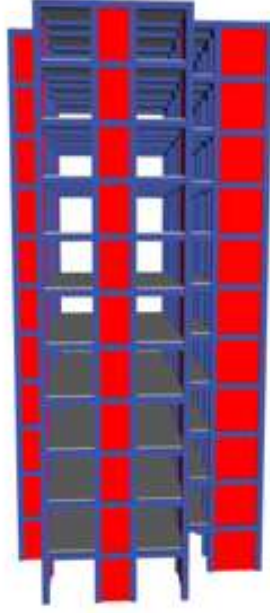


Fig -3 : Model 2

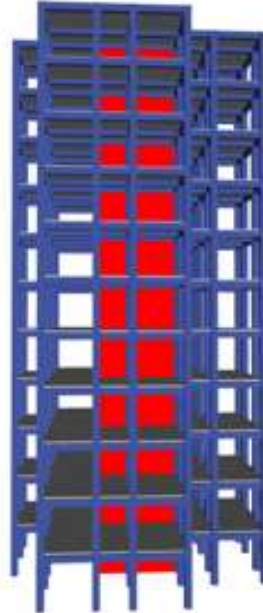


Fig -4 : Model 3

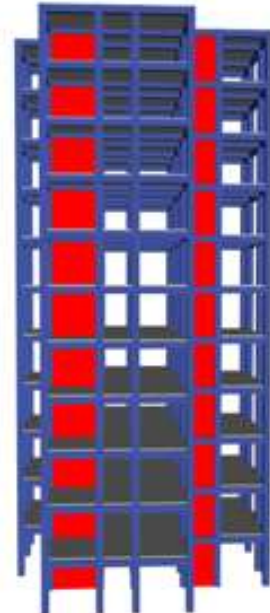


Fig -5 : Model 4



Fig -6 : Model 5

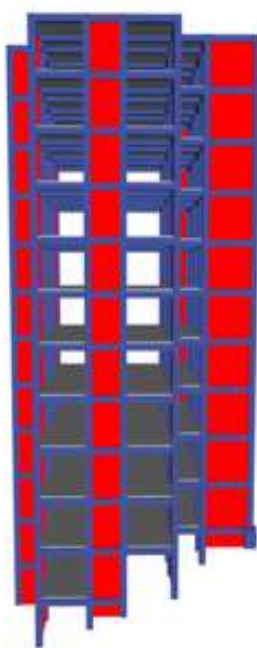


Fig -7 : Model 6

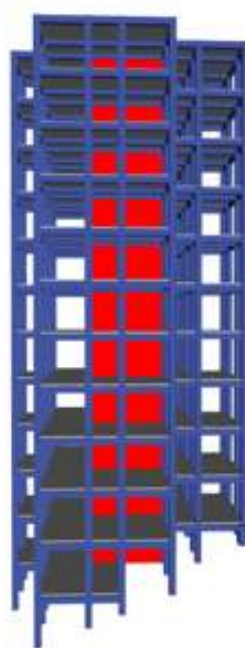


Fig -8 : Model 7

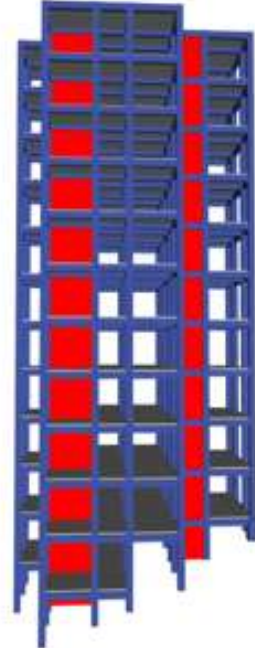


Fig -9 : Model 8

VI. RESULT AND DISSCUSION

Table -2 : Analysis results for story displacement

Story No.	Displacement (mm)							
	Flat Ground				Sloping Ground			
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
10	77.17	38.14	17.70	43.56	65.54	32.62	18.33	39.47
9	74.29	34.51	15.92	39.59	63.00	29.59	16.55	36.23
8	69.84	30.66	14.03	35.34	59.23	26.35	14.67	32.72
7	63.99	26.61	12.08	30.80	54.33	22.89	12.71	28.94
6	57.01	22.39	10.10	26.04	48.52	19.23	10.71	24.94
5	49.16	18.09	8.14	21.14	41.98	15.48	8.71	20.77
4	40.68	13.83	6.25	16.26	34.90	11.73	6.75	16.54
3	31.79	9.78	4.49	11.58	27.47	8.16	4.90	12.40
2	22.70	6.12	2.91	7.32	19.83	4.95	3.22	8.50
1	13.63	3.08	1.58	3.74	12.22	2.33	1.77	5.04
G	5.14	0.93	0.58	1.16	5.22	0.58	0.62	2.28
Base	0	0	0	0	0	0	0	0

Table -3 : Analysis results for story drift

Story No.	Story Drift							
	Flat Ground				Sloping Ground			
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
10	0.000978	0.00121	0.000594	0.001322	0.00088	0.001017	0.000591	0.001146
9	0.001481	0.001281	0.000629	0.001419	0.001296	0.001083	0.000629	0.001243
8	0.00195	0.001351	0.00065	0.001511	0.001688	0.001154	0.000653	0.001338
7	0.002328	0.001407	0.000659	0.001589	0.002011	0.001217	0.000667	0.001421
6	0.002618	0.001434	0.000654	0.001632	0.002265	0.001253	0.000667	0.001472
5	0.002826	0.001419	0.000631	0.001627	0.002452	0.001248	0.000651	0.001478
4	0.002962	0.001351	0.000589	0.00156	0.002579	0.001191	0.000616	0.001426
3	0.003032	0.001219	0.000526	0.001421	0.002642	0.001071	0.000561	0.001301
2	0.003024	0.001012	0.000442	0.001193	0.002599	0.000872	0.000484	0.001152
1	0.002828	0.000716	0.000335	0.00086	0.002102	0.000582	0.000383	0.00092
G	0.001714	0.00031	0.000192	0.000386	0.000992	0.000452	0.000484	0.000646
Base	0	0	0	0	0	0	0	0

Table -2 : Analysis results for base shear

Base Shear (KN)			
Flat Ground		Sloping Ground	
Model 1	1412.17	Model 5	1568.57
Model 2	1634.54	Model 6	1808.54
Model 3	1571.01	Model 7	1740.76
Model 4	1555.12	Model 8	1724.61

Result :

(1) For Model 1, the maximum story displacement was 77.17 mm at Story 10, indicating the highest lateral deformation among all flat ground models. The displacement gradually increased from the base to the roof, producing the typical deflected shape of a multi story building. The corresponding maximum story drift was 0.003032 at Story 3, while the base shear was 1412.17 kN.

(2) For Model 2, the maximum story displacement reduced significantly to 38.14 mm, representing approximately 50.6% reduction compared to Model 1. The maximum story drift also decreased to 0.001434 at Story 6, indicating considerable improvement in lateral stiffness. However, the base shear increased to 1634.54 kN, which is about 15.7% higher than Model 1 due to the increased structural stiffness.

(3) For Model 3, the story displacement further reduced to 17.70 mm, which is approximately 77.1% lower than Model 1 and represents the minimum displacement among all flat ground models. The maximum story drift was only 0.000659 at Story 7, demonstrating excellent drift control throughout the building height. The base shear was 1571.01 kN, which is higher than Model 1 but slightly lower than Model 2.

(4) For Model 4, the maximum story displacement was 43.56 mm, showing a 43.6% reduction compared with Model 1. The maximum story drift was 0.001632 at Story 6, which is higher than Models 2 and 3 but still much lower than the conventional model. The base shear was 1555.12 kN, indicating improved lateral resistance while maintaining moderate structural stiffness.

(5) For Model 5 (Conventional Sloping Ground Building), the maximum story displacement was 65.54 mm at Story 10. Although the displacement was lower than the flat ground conventional building, the base shear increased to 1568.57 kN due to the influence of sloping ground conditions. The maximum story drift reached 0.002642 at Story 3.

(6) For Model 6, the maximum roof displacement reduced to 32.62 mm, corresponding to approximately 50.2% reduction compared with Model 5. The maximum story drift also decreased significantly to 0.001253 at Story 6. However, the base shear increased to 1808.54 kN, which is approximately 15.3% greater than Model 5, indicating enhanced lateral stiffness.

(7) For Model 7, the story displacement further reduced to 18.33 mm, representing approximately 72.0% reduction relative to Model 5 and the minimum displacement among all sloping ground models. The maximum story drift was only 0.000667 at Stories 6 and 7, indicating excellent seismic performance with minimum inter-story deformation. The corresponding base shear was 1740.76 kN, which was slightly lower than Model 6.

(8) For Model 8, the maximum story displacement was 39.47 mm, showing approximately 39.8% reduction compared to Model 5. The maximum story drift reached 0.001478 at Story 5, while the base shear was 1724.61 kN. Although the displacement and drift were higher than Model 7, the overall seismic performance remained considerably better than the conventional sloping ground building.

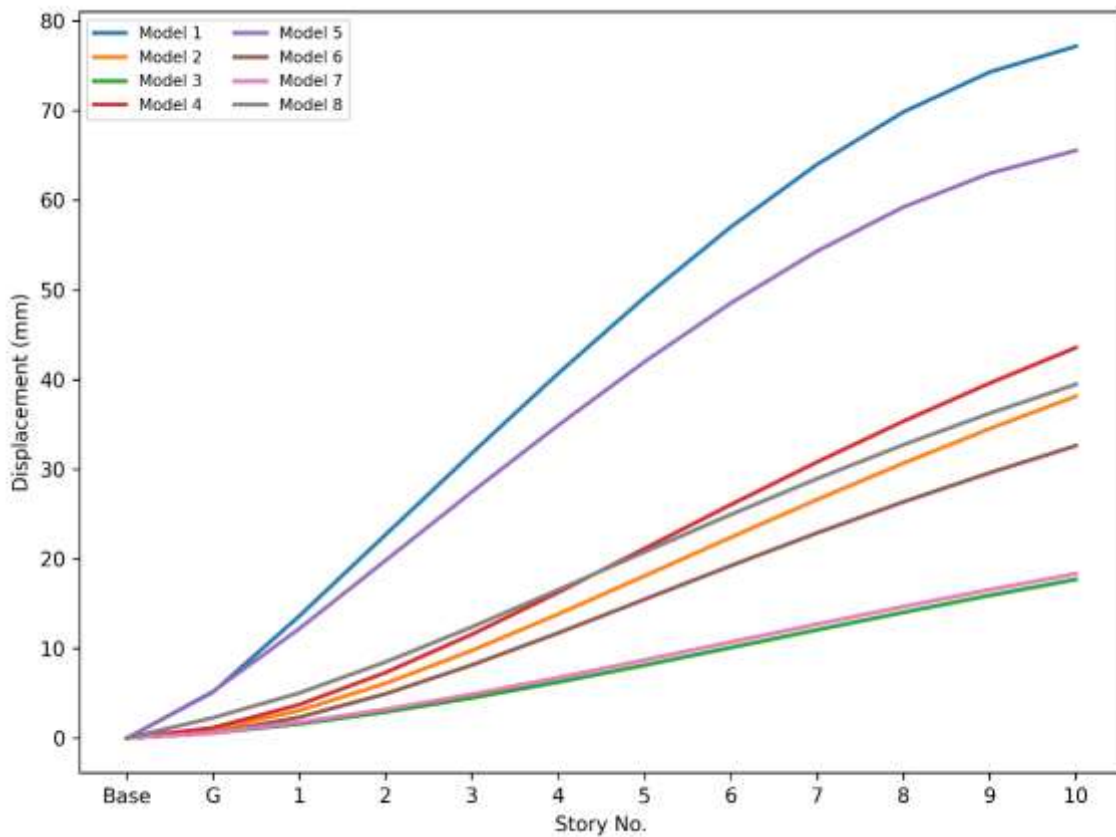


Fig -10 : Story Displacement

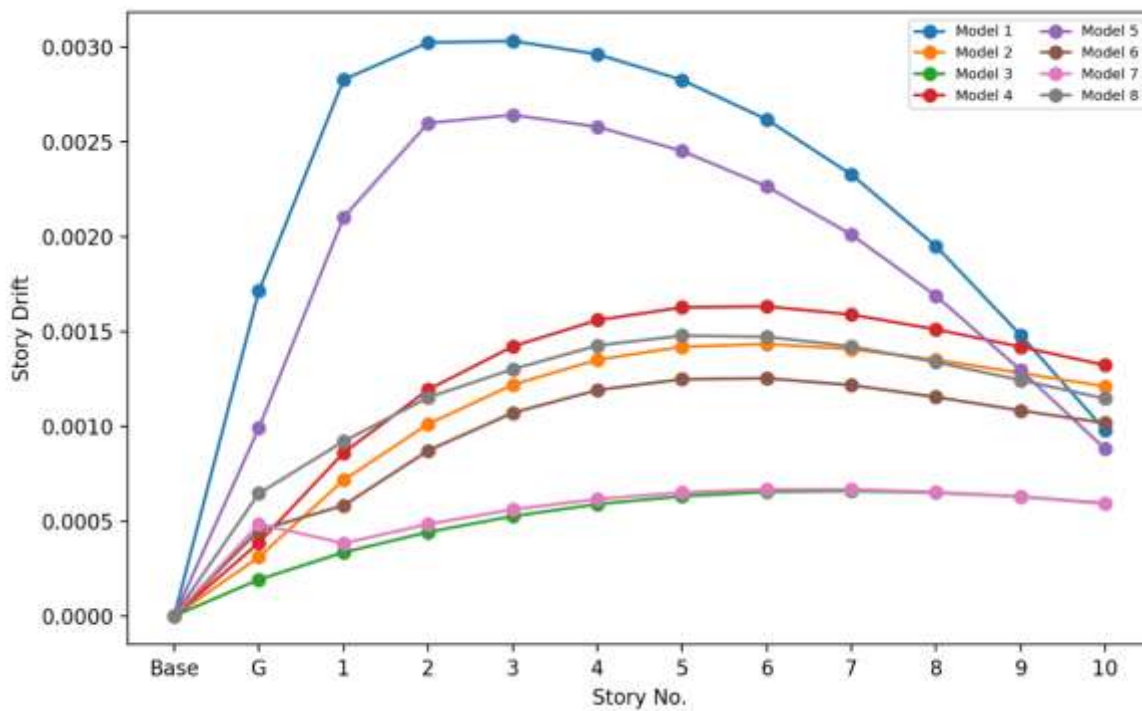


Fig -11 : Story Drift

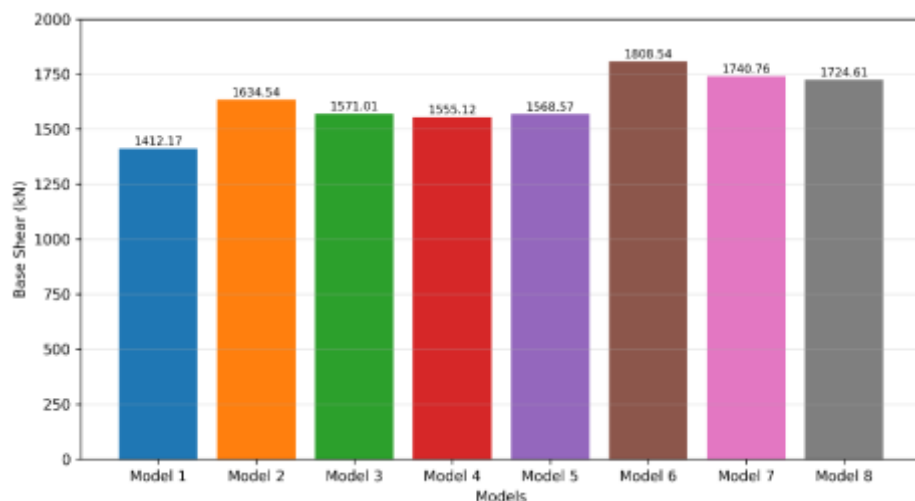


Fig -12 : Base Shear

Comparative Discussion

Comparison between flat and sloping ground buildings indicates that the conventional sloping ground model (Model 5) developed higher base shear (1568.57 kN) than the conventional flat ground model (1412.17 kN), primarily due to the irregular stiffness distribution caused by the slope. However, the roof displacement of the sloping ground model (65.54 mm) was lower than that of the flat ground model (77.17 mm).

Among all eight models, Model 3 exhibited the minimum story displacement (17.70 mm) for flat ground, whereas Model 7 showed the best performance for sloping ground with a roof displacement of 18.33 mm. Both models also recorded the lowest story drift values, demonstrating superior seismic behaviour and effective control of lateral deformation.

The increase in base shear observed in Models 2, 3, 4, 6, 7 and 8 indicates increased structural stiffness, which resulted in substantial reductions in both displacement and inter-story drift. Overall, Models 3 and 7 provided the most balanced seismic response by minimizing lateral displacement while maintaining acceptable base shear values.

VII. CONCLUSION

- (1) The conventional flat ground building (Model 1) exhibited the highest story displacement (77.17 mm) and maximum story drift (0.003032), indicating lower lateral stiffness.
- (2) Model 3 showed the best seismic performance for flat ground by reducing story displacement by approximately 77.1% and significantly decreasing story drift compared with Model 1.
- (3) The conventional sloping ground building (Model 5) experienced higher base shear (1568.57 kN) than the conventional flat ground building, demonstrating the influence of ground slope on seismic response.
- (4) Model 7 provided the best performance among the sloping ground models, reducing story displacement by approximately 72.0% and limiting the maximum story drift to 0.000667.
- (5) The increase in base shear in the modified models indicates improved structural stiffness, which effectively controlled lateral displacement and inter story drift.
- (6) Overall, Model 3 for flat ground and Model 7 for sloping ground exhibited the most efficient seismic behavior and can be considered the optimum configurations among the models analyzed.

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