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ANALYTICAL STUDY ON SEISMIC PERFORMANCE OF BUILDINGS WITH SHEAR WALL IN HILLY REGIONS

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CANDIDATE'S DECLARATION

I, GIRISH BHARDWAJ, 23/STE/24, of MTech (Structural Engineering), hereby declare that the project Dissertation titled "**SEISMIC PERFORMANCE OF BUILDINGS WITH SHEAR WALL IN HILLY REGIONS**" 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 the 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.

Place: Delhi **GIRISH BHARDWAJ**

Date:

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CERTIFICATE

I hereby certify that the Project Dissertation titled "SEISMIC PERFORMANCE OF BUILDINGS WITH SHEAR WALL IN HILLY REGIONS" which is submitted by GIRISH BHARDWAJ, 23/STE/24, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the 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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ABSTRACT

Because of their inherent geometric irregularities—such as vertical and plan abnormalities brought about by step back and setback configurations—structures situated in hilly areas are particularly vulnerable to seismic impacts. Because of the uneven distribution of mass and stiffness caused by these flaws, these buildings are more susceptible to earthquake damage. The seismic performance of setback-step back structures on hilly terrain is carefully examined in this thesis, with an emphasis on how shear wall placement affects the structural response to seismic stress.

The analysis was conducted using ETABS software, with M30 grade concrete and Fe500 grade reinforcement consistently employed across all models. The first model represents a structure with setback and step back. The second model setback and step back with shear walls placed at the two corners of the buildings to enhance the strength and performance of the building during the earthquake response. The 3rd model incorporates four shear walls at the four corners of the building to reduce the maximum story drift and displacement, furthermore a model with the same configuration of the terrain is analysed with shear wall at the core of the structure. Key seismic response parameters such as maximum storey displacement in both X and Y directions, modal participating mass ratio, base reaction, and maximum storey drift were evaluated.

This addition aims to assess the impact of shear walls on improving seismic resilience. Comparative analysis across the different models provides valuable insights into the effectiveness of design strategies for buildings in hilly regions, contributing to safer and more efficient construction practices in such challenging environments. As per IS 1893 the building located in zone 4 and 5 the modal participating mass ratio should be greater than 65 percent for the for the first 3 modes together in each principal direction, as per IS 1893 the maximum storey in the structure should be less than 0.004.

In the ETABS the model which we created consist of a 5-storey building with the each of 3-meter height which accumulate total height of the structure to 15 meter and beam of span 6 meter in the both axis with the plan area of 36-meter x 36 meter with the equal spacing in both the axis.

A response spectrum analysis was conducted in accordance with IS 1893 (Part 1): 2016 for seismic Zone IV, presuming medium soil conditions and a damping ratio of 5%.

The analysis revealed that Model 3, which had shear walls at all four corners, exhibited the most favourable seismic performance. It effectively resisted lateral loading and exhibited the lowest displacement and drift values. Although it performed well, Model 4's central core walls were marginally less successful than Model 3 at regulating edge displacements. The most displacements and drifts were seen in the control model without shear walls, underscoring the crucial function that shear walls play in improving seismic resistance.

According to the study's findings, carefully positioned shear walls enhances the seismic behaviour of hillside structures, and corner placement provides enhanced performance because of increased lateral stiffness and torsional stability. The results offer structural engineer helpful ideas for creating earthquake-resistant structures in challenging hilly environments.

ACKNOWLEDGEMENT

I, GIRISH BHARDWAJ feel a great sense of gratitude and accomplishment as the project “seismic performance of buildings with shear wall in hilly regions” comes to its completion stage and it wouldn’t have been possible without the support of my mentor and all my colleagues.

I would like to offer my heartfelt appreciation to everyone who helped me finish this academic project. This journey wouldn’t be this swift without the guidance of my mentor; she not only helped and guided me with the project work but also introduce each and every one of us to the practical world by giving us numerous opportunities to interact with the different experts of the structural engineering world.

This project has increased my knowledge multifold by understanding the response of the structure situated in the hilly regions and would also enhance importance of this topic in the structural engineering world.

First and foremost, I want to sincerely thank our mentor and guide, **Prof. Shilpa Pal**, for her unwavering support, knowledgeable advice, and helpful criticism during the project. We were able to move confidently and clearly through each step thanks to your assistance.

I also want to express my gratitude to the DTU civil engineering department HOD and all respected academic staff, whose timely assistance and resources were crucial in completing this work. Our technical personnel and lab helpers deserve special recognition for their assistance with the software and tools, particularly the use of ETABS for our modelling and analysis.

GIRISH BHARDWAJ

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CHAPTER 1

INTRODUCTION

1.1GENERAL

The swift expansion of infrastructure in hilly areas has sparked serious worries about the structural stability and seismic safety of buildings built on sloping terrain. Because of the combined effects of varied heights, complicated soil conditions, and uneven topography, earthquakes in these areas are a serious concern. Buildings in mountainous regions, as opposed to flat terrain, may have foundations at varying levels, which causes structural abnormalities in both plan and elevation. These anomalies have a major impact on the buildings' seismic performance and increase their susceptibility to lateral stresses during seismic activity.

The shear wall is one of the best structural components utilized to increase a building's seismic resistance. Vertical components called shear walls are made to withstand lateral forces brought on by earthquakes and wind. Shear walls improve overall stability during earthquake stress by increasing lateral stiffness and decreasing sway when positioned strategically within a building. However, depending on the terrain's geometry and the structural arrangement, the number, size, and placement of shear walls can have a variety of effects.

With a focus on comparative behaviour under various circumstances, this thesis examines and assesses the seismic performance of buildings with shear walls in hilly areas. Using industry-standard design codes, mainly IS 1893:2016 for earthquake-resistant design and IS 875 (Part 3) for wind load analysis, the study models and analyses multi-story reinforced concrete (RC) buildings built on sloping terrain with and without shear walls and irregular configuration and the dynamic analysis is done using response spectrum method.

The following configurations are considered for comparison:

1 Model**:** A setback and step structure placed in the Zone-V as per IS 1893:2016.

2 Model: A setback and step back structure with shear walls placed at the two corners of the structure placed in the Zone-V as per IS 1893:2016.

3 Model: A setback and step structure with shear walls placed at the four corners of the structure placed in the Zone-V as per IS 1893:2016.

4 Model: A setback and step structure with shear walls placed at the core of the structure placed in the Zone-V as per IS 1893:2016.

For each model, a comprehensive seismic analysis is carried out to evaluate parameters such as:

- **Maximum story displacement in X and Y directions**
- **Base shear and its distribution**
- **Story drift and inter-story drift ratios**
- **Modal participation mass ratios**
- **Fundamental time period of vibration**
- **Base reactions due to seismic forces**

In order to make judgments about how well shear walls reduce seismic susceptibility in hilly areas, a thorough comparison of these factors across several models will be carried out. It is anticipated that the findings will influence future design procedures and help create stronger, safer structural solutions for hill regions that are vulnerable to earthquakes.

By concentrating on a regionally and geologically specific problem the seismic performance of buildings in sloped terrains this study fills a critical void in structural engineering and assesses the role of shear walls as a workable and efficient seismic-resistant design element.

1.2OBJECTIVES OF THE STUDY

This thesis's main goal is to assess and contrast the seismic performance of reinforced concrete (RC) structures built on sloping terrain with and without shear walls. The goal of the study is to determine efficient design techniques for enhancing earthquake protection while addressing the particular structural difficulties presented by mountainous terrain. The following are the study's particular goals:

To comprehend how buildings built on sloping terrain will behave structurally under seismic loading circumstances, taking into account the anomalies in elevation and plan brought about by the terrain.

To use ETABS software to model and analyse multi-story RC buildings on hilly terrain, taking into account pertinent Indian Standard codes like IS 875 (Part 3) for wind load and IS 1893:2016 (Part 1) for seismic load using response spectrum analysis method with the help of ETABS.

To assess how well shear walls work as a lateral load-resisting mechanism to lessen the negative impacts of seismic forces in buildings that are sloping

1.3OVERVIEW OF THESIS

Chapter 1 - Deals with the description about an introduction to the topic, its application and significance.

Chapter 2- Discusses some of the literature and previous work on seismic performance of buildings in hilly regions

Chapter 3 – Discusses the methodology followed along with details of the analytical work done through the software ETABS.

Chapter 4 - Discusses the results and discussion related to performance of buildings in hilly regions.

Chapter 5 – Deal with the conclusion of the present study.

CHAPTER 2

LITERATURE REVIEW

2.1GENERAL

The present chapter involves the detailed literature study to comprehend the benefits of the shear walls in the buildings in hilly regions, it explains how the building dynamic behavior changes significantly merely by addition of shear walls in the building. The shear wall not only reduces the various critical parameters to make the structure safe and sound. Different papers have also been published where it is proven that the shear wall does increase the strength of the existing structure therefore various literature review have been summarized below.

- **Jarapala et al.** ***(2023)*** There is a dearth of research specifically designed for sloping ground RC buildings, particularly in 3D modelling, irregularity assessment, and retrofit solutions, despite the literature's substantial understanding of seismic vulnerabilities and the performance of irregular buildings. Validating or creating new descriptors and assessment frameworks that are relevant to these typologies is urgently needed.
- **Bush Rc et al. (2024)** Buildings on sloped terrain provide special seismic issues that are not entirely addressed by current standards, according to the body of literature. Torsional abnormalities, short-column effects, and inadequate infill wall stiffness are major contributing contributors to susceptibility. In order to assure safer construction in hilly locations, the review emphasizes the necessity of region-specific seismic design regulations, improved modelling techniques that incorporate soil–structure interaction, and a more deliberate use of URM infill walls in design analysis.

- **Singh et al. (2015)** A comprehensive seismic risk assessment approach designed for hilly areas is urgently needed, according to the examined literature. Although some international codes make an effort to account for topographic impacts, they are nonetheless unduly basic. In instance, Indian codes don't account for structural typologies and terrain-specific amplification. As a result, the seismic demand and extreme fragility of hill buildings have been systematically underestimated. For mountainous urban communities to be resilient, a new framework that incorporates geotechnical, structural, and topographical criteria is necessary.

- **Joshi et al. (2021)** According to the literature, structures situated on sloping terrain are more susceptible to earthquakes because of their uneven geometry, eccentric mass distribution, and short-column effects. Infill and shear walls, as well as step-back set-back designs, can improve performance; however, more dynamic behaviour modelling and terrain-specific design standards are desperately needed for these structures.

- **Dubey et al. (2021)** All of the previous study has showed us that because of abnormalities in the plan and elevation, structures on sloped ground are more vulnerable to earthquakes. By lowering displacement, drift, and torsional effects, the addition of L-shaped shear walls, shear wall cores, and RCFST columns improves seismic performance. For safety, the ideal arrangement and positioning are still essential.
- **Narayana et al. (2012)** The study combines structural analysis and field data to support findings from earlier research: buildings on hill slopes are subject to increased seismic demands because of their geometry, subpar design, and insufficient foundation fixity. If strict design principles and terrain-specific requirements are not followed, the performance of such buildings is severely hampered.
- **Akhtar et al. (2019)** Buildings on sloping terrain are particularly vulnerable to seismic damage because of uneven geometry and short column effects. By lowering internal forces, drift, and storey displacement, shear walls placed correctly greatly enhance earthquake performance. The influence of different slope angles in 3D models has not yet been thoroughly studied or experimentally investigated, which is a gap that this research aims to fill.

2.2OBJECTIVE

From the literature study, it was concluded that:

1. Most design codes (including IS 1893) are developed for flat terrain and do not address the unique behavior of buildings on inclined or terraced sites.
2. Real-world 3D anomalies like torsional response and out-of-plane behavior are frequently overlooked from research that rely on linear or simplified 2D models**.**
3. Although acknowledged, the nonlinear failure modes of short columns in hilly buildings have not been thoroughly studied statistically.
4. A few basic shear wall positions are tested in a number of articles, but there is a lack of systematic optimization of placement, shape, and interaction with frame structure.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

The strategy used to assess the seismic performance of reinforced concrete (RC) structures built on sloping terrain is given in this chapter. ETABS, a structural analysis program, is used for the study's structural modelling, seismic load application, and performance comparison of different configurations. The main goal is to look into how building layout, shear wall placement, and slope inclination affect seismic response metrics as base reaction, displacement, story drift, and modal mass participating ratio.

3.2 SOFTWARE AND OTHER PARAMETERS

ETABS software is used for the analysis of the structure, it is one of the most versatile and sophisticated software available in the market for commercial and learning purpose. ETABS is used to find the various aspects of the structure.

3.3 MODELS CONSIDER FOR STUDY

ETABS: Software for Structural Analysis and Design, it is used for structural response parameter extraction, static and dynamic (response spectrum) analysis, load assignment, and 3D modelling.

Important Features Employed: Analysis of Response Spectrum (per IS 1893:2016), automatic synthesis of combinations of seismic loads, calculation of base shear, calculation of story displacement and drift.

Model description:

Structural Elements	**Specifications**
Number of stories	G+5
Story height	3m
Column Size	600*600 mm
Beam Size	600* 300 mm
Slab thickness	150 mm

Table 3.1-ETABS model

3.4 ETABS MODEL PLAN ELEVATION AND 3D VIEW

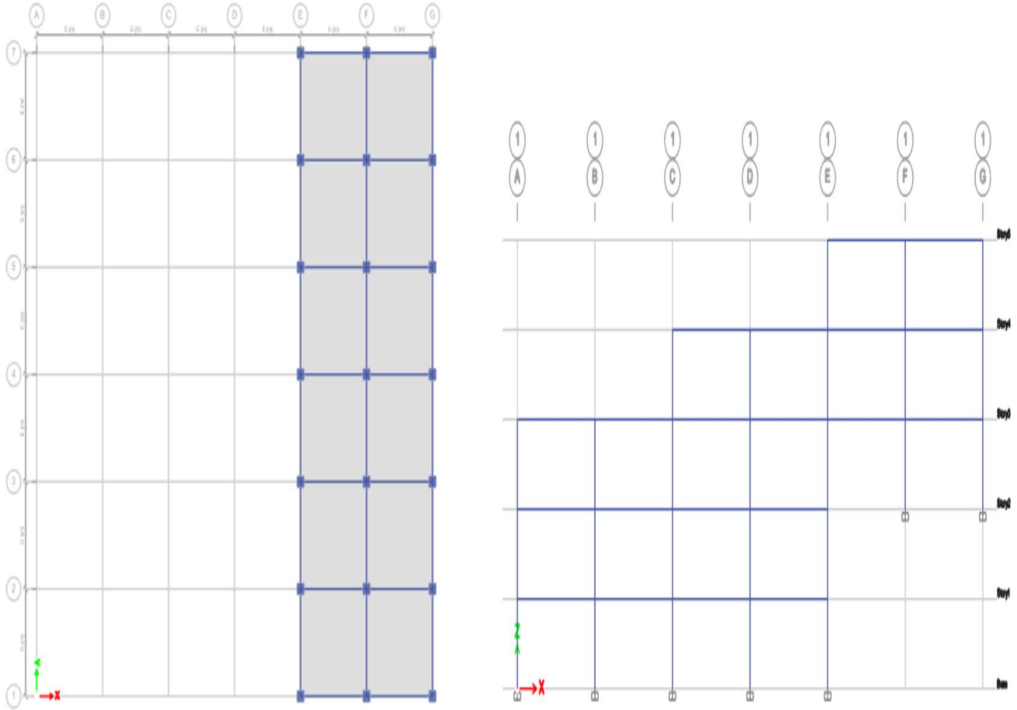

Fig 3.1-Plan and elevation of setback and step back building

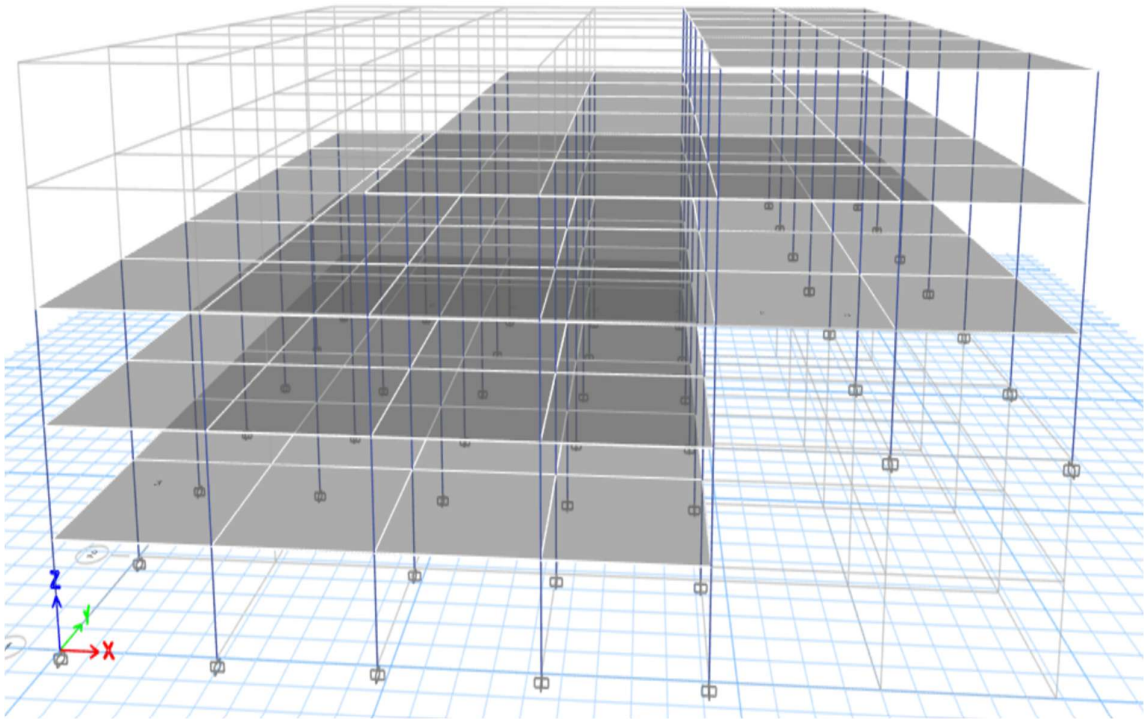

Fig 3.2-3D view of the setback and step back building

3.4 ETABS MODEL PLAN ELEVATION AND 3D VIEW

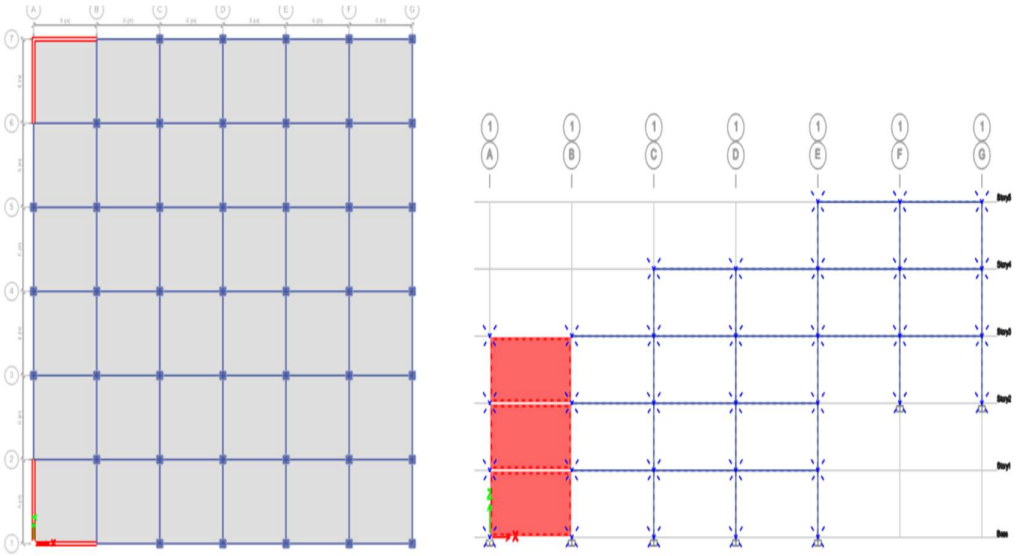

Fig 3.3-Plan and elevation of setback and step back building with 2 shear walls

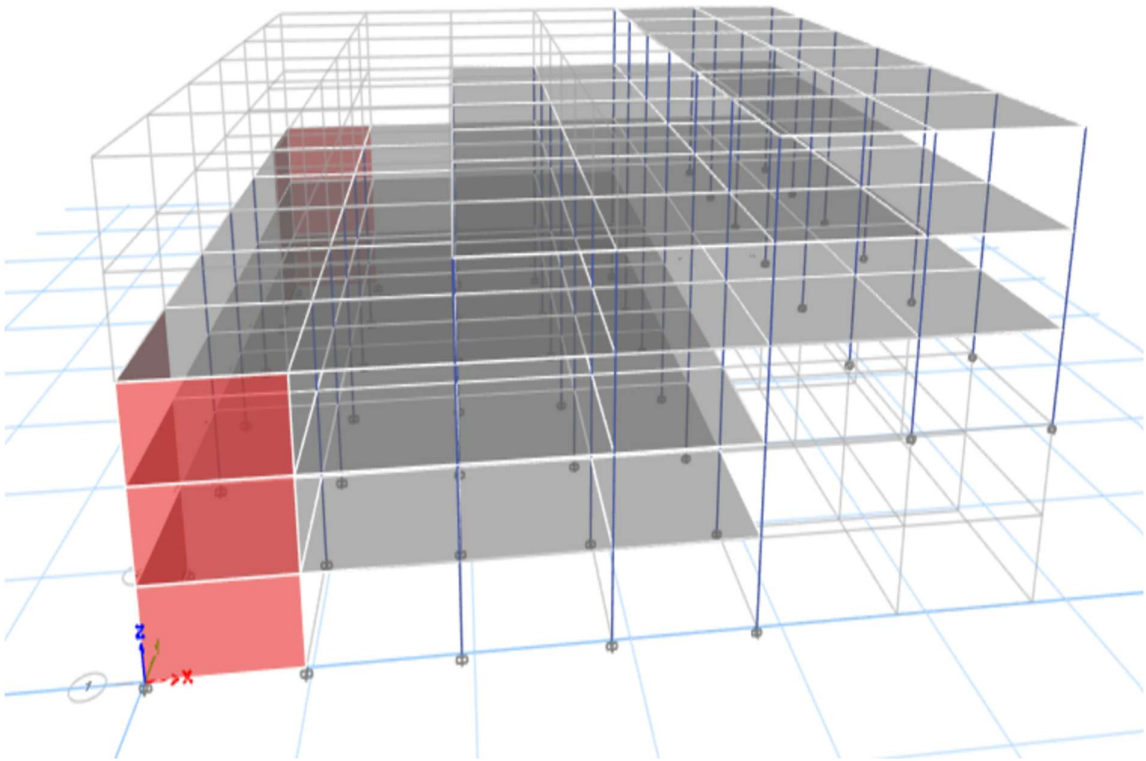

Fig 3.4-3D view of the setback and step back building with 2 shear walls

3.4 ETABS MODEL PLAN ELEVATION AND 3D VIEW

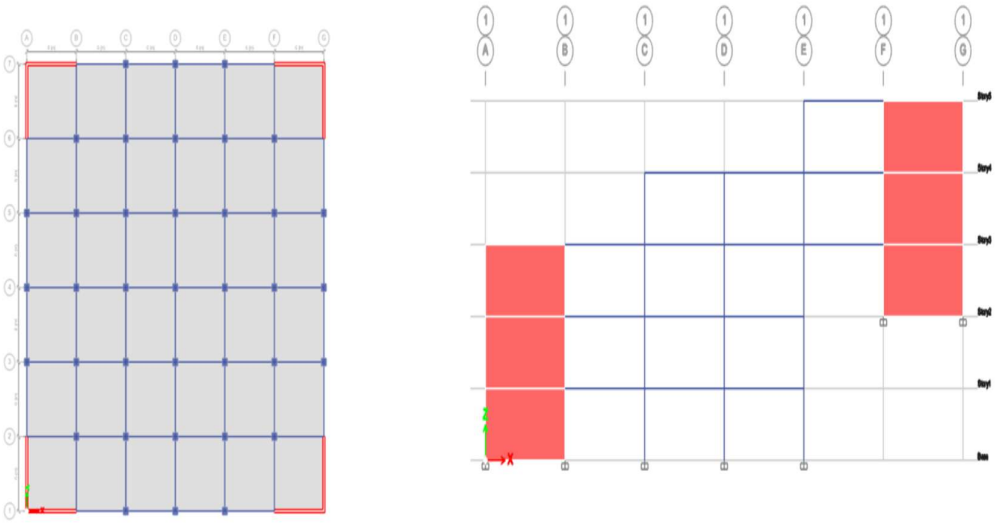

Fig 3.5-Plan and elevation of setback and step back building with 4 shear walls

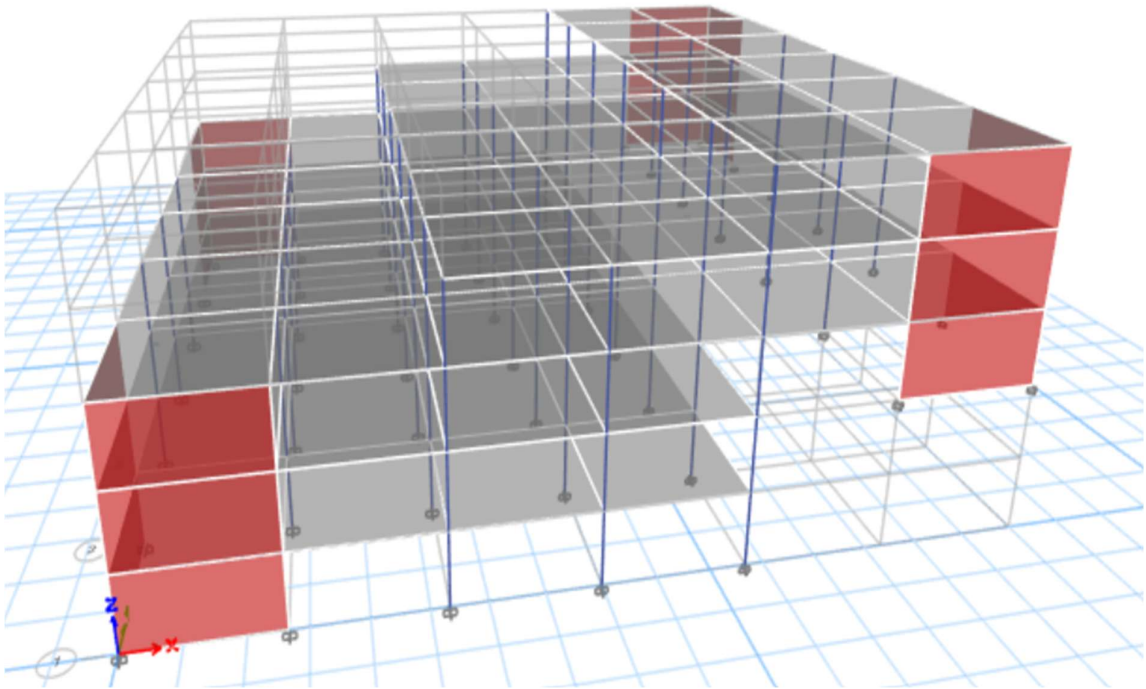

Fig 3.6-3D view of the setback and step back building with 4 shear walls

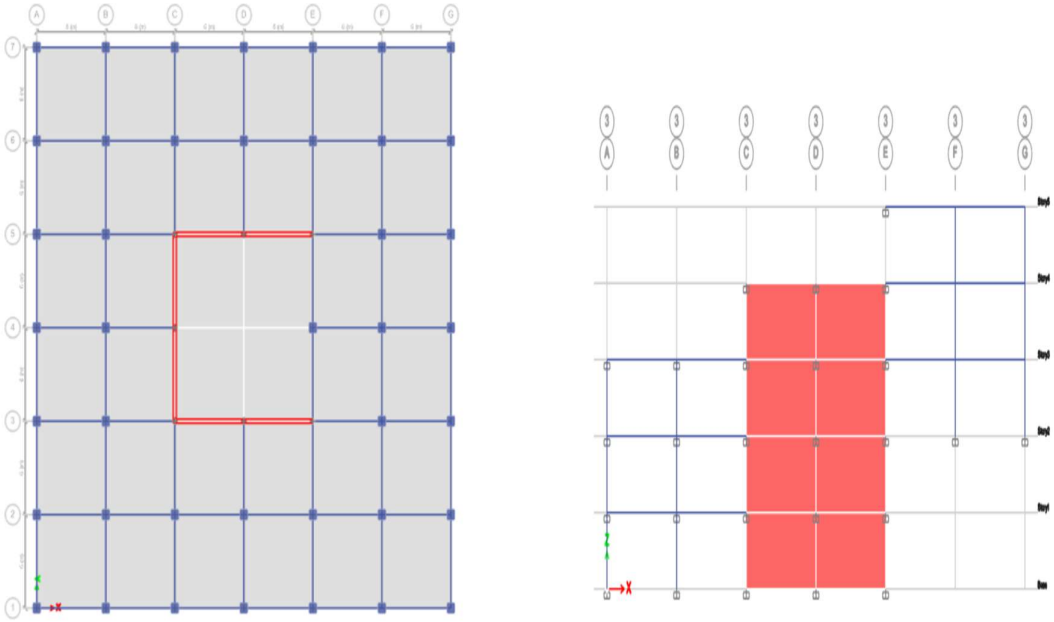

Fig 3.7-Plan and elevation of setback and step back building with shear walls at the core

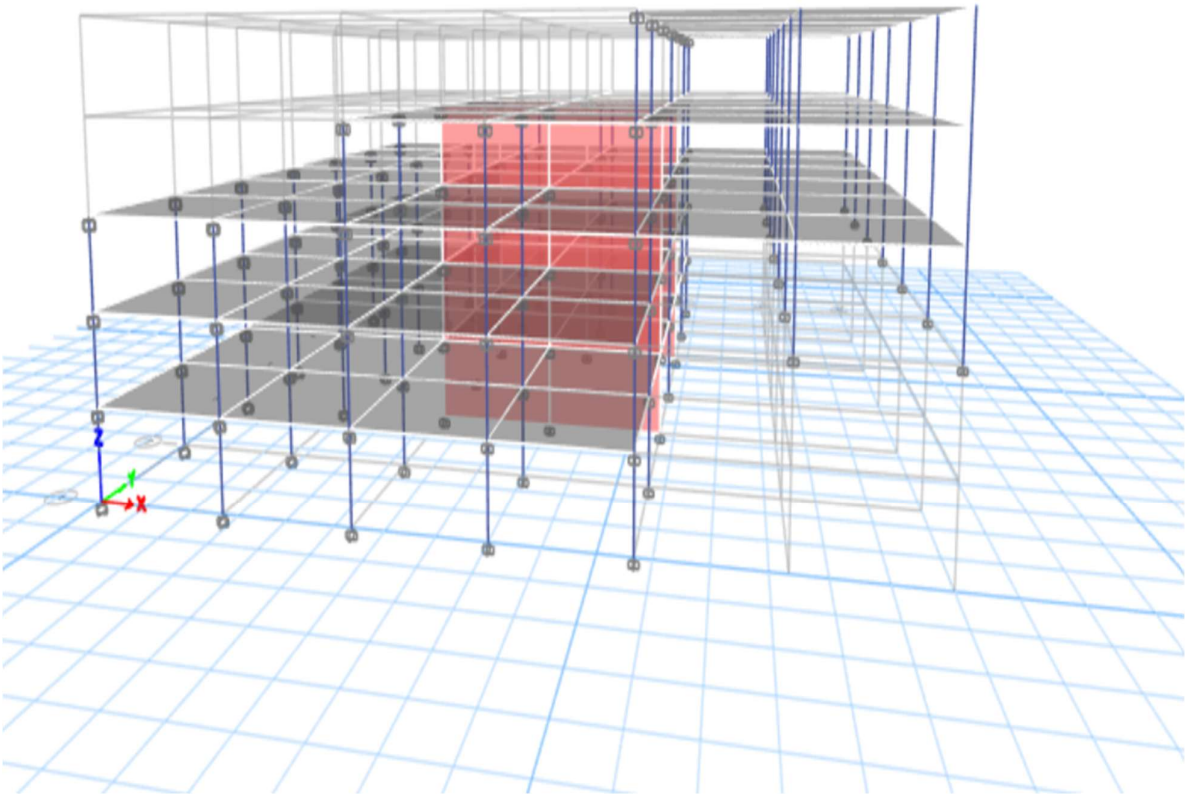

Fig 3.8-3D view of the setback and step back building with walls at the core

3.5 ETABS MODEL DATA INPUT

Table 3.2: Material Properties

Structural Properties	Specifications
Grade of Concrete	M30
Grade of steel	Fe500
Shear wall thickness	250 mm

Table 3.3: Wind load parameters

Wind speed	50m/s
Terrain category	3
Windward Coefficient	+0.86
Leeward coefficient	-0.5
Structure class	C
Risk coefficient(k1)	1
Topography(k3)	1
Importance factor	1.15

Table 3.4: Earthquake load parameters

Zone	V
Site type	II
Importance factor	1
Response reduction factor	5
Story range	Base to five
Direction and eccentricity	X and Y respectively
Time period	Program calculated
Seismic zone factor	0.36

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 GENERAL

The findings of the seismic study of G+5 story RC structures with and without shear walls that are located on sloping terrain are presented in this chapter. Response spectrum analysis (per IS 1893:2016) was used in ETABS to examine the models.

4.2 Results to be discussed are as follows

1.Modal mass participating ratio- The Indian standard for designing structures that are earthquake-resistant, IS 1893 (Part 1): 2016, lays forth standards for seismic analysis, including modal participation in dynamic analysis like Response Spectrum Analysis (RSA). The number of modes to be used in the analysis should be such that the cumulative modal mass participation factor is at least 65% of the total seismic mass in each principal direction (X and Y).

The modal participating mass ratio (MPMR) is an important concept in structural dynamics and earthquake engineering. It indicates the portion of a structure's total mass that actively participates in a certain mode of vibration during dynamic stress, such as an earthquake.

2. **Maximum story drift**- The greatest inter-storey displacement in the building, observed between any two consecutive floors during dynamic or static lateral loads. As per IS1893:2016 With a partial load factor of 1.0, the storey drift in any storey caused by the minimum required design lateral force cannot be greater than 0.004 times the storey height.

3. **Maximum story displacement-** During an earthquake, it is the whole horizontal movement of a story typically the top story with respect to the earth.

4. **Base shear-** The entire horizontal force that an earthquake's tremors cause at a building's base is known as base shear.

4.4 ETABS results of Setback and step back model with no shear walls

Units: As Noted Hidden Columns: No Sort: None Modal Participating Mass Ratios
Filter: None

	Case	Mode	Period sec	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ
▶	Modal	1	0.349	0.0002	0.7241	0	0.0002	0.7241	0	0.0954	4.704E-05	0.0768
	Modal	2	0.332	0.7442	0.0002	0	0.7443	0.7243	0	0.0001	0.2846	7.868E-06
	Modal	3	0.3	2.995E-05	0.0666	0	0.7444	0.791	0	0.2568	2.063E-05	0.6809
	Modal	4	0.153	0.0008	0.0792	0	0.7452	0.8701	0	0.3282	0.0021	0.0298
	Modal	5	0.152	0.2093	0.0004	0	0.9545	0.8705	0	0.0015	0.5067	0.0001
	Modal	6	0.124	1.755E-05	0.0722	0	0.9545	0.9428	0	0.1015	1.979E-05	0.1581
	Modal	7	0.1	0.0208	8.169E-07	0	0.9753	0.9428	0	2.26E-06	0.1109	1.861E-06
	Modal	8	0.099	6.913E-07	0.0248	0	0.9753	0.9676	0	0.1113	2.141E-06	0.0219
	Modal	9	0.09	2.483E-06	0.004	0	0.9753	0.9716	0	0.0034	4.214E-06	0.0034
	Modal	10	0.071	0	0.008	0	0.9753	0.9797	0	0.0437	0	0.0054
	Modal	11	0.066	0.0036	0	0	0.9789	0.9797	0	0	0.0453	0
	Modal	12	0.057	0	1.343E-05	0	0.9789	0.9797	0	0.0104	0	0.0001

Fig 4.1-Modal participating mass ratio for setback and step back model

	Output Case	Case Type	Step Type	Step Number	FX kN	FY kN	FZ kN	MX kN-m	MY kN-m	MZ kN-m
▶	Dead	LinStatic			-202	-202	27607.8855	498630.4528	-501945.008	-490
	Live	LinStatic			0	0	10800	194400	-194400	0
	Modal	LinModEigen	Mode	1	0.2137	-14.554	0	139.2666	2.1944	-195.4841
	Modal	LinModEigen	Mode	2	-16.2475	-0.2609	0	2.6944	-171.0588	287.0919
	Modal	LinModEigen	Mode	3	0.1263	-5.9602	0	92.8447	1.4306	-400.4219
	Modal	LinModEigen	Mode	4	2.5942	-25.1203	0	14.023	5.862	-267.4958
	Modal	LinModEigen	Mode	5	-41.3879	-1.8373	0	1.7497	-97.7584	725.5089
	Modal	LinModEigen	Mode	6	0.5667	-36.3613	0	136.535	2.3906	-1488.3554
	Modal	LinModEigen	Mode	7	30.0472	-0.1883	0	0.3691	-14.0983	-548.9072
	Modal	LinModEigen	Mode	8	0.1772	33.5905	0	-8.5367	0.2829	124.878
	Modal	LinModEigen	Mode	9	0.4018	16.1832	0	-76.9666	1.3315	58.1979
	Modal	LinModEigen	Mode	10	-0.0867	-36.8855	0	-20.4476	-0.0195	-207.745
	Modal	LinModEigen	Mode	11	28.6982	-0.0526	0	-0.4294	-145.3041	-518.0187
	Modal	LinModEigen	Mode	12	-0.4009	2.3584	0	226.7645	-1.6377	-65.949
	eq x	LinStatic			-2462.8065	0	0	0	-27587.3157	44333.3432
	eq y	LinStatic			0	-2462.8065	0	27587.3157	0	-56188.108
	w x	LinStatic			-1063.7848	0	0	0	-8994.5925	19148.1269
	w y	LinStatic			0	-743.7685	0	6051.9766	0	-13026.5179
	SIDL	LinStatic			0	0	5184	93312	-93312	0
	DConS1	Combination			-303	-303	49187.8282	887913.6792	-892885.512	-735
	DConS2	Combination			-303	-303	65387.8282	1179513.6792	-1184486	-735
	DConS3	Combination			-1518.9418	-242.4	52310.2626	943610.9433	-958381.9205	22389.7522

Fig 4.2-Base reaction for setback and step back model

Note-Blue color graph line depicts displacement in X axis and red color line depicts displacement in Y axis.

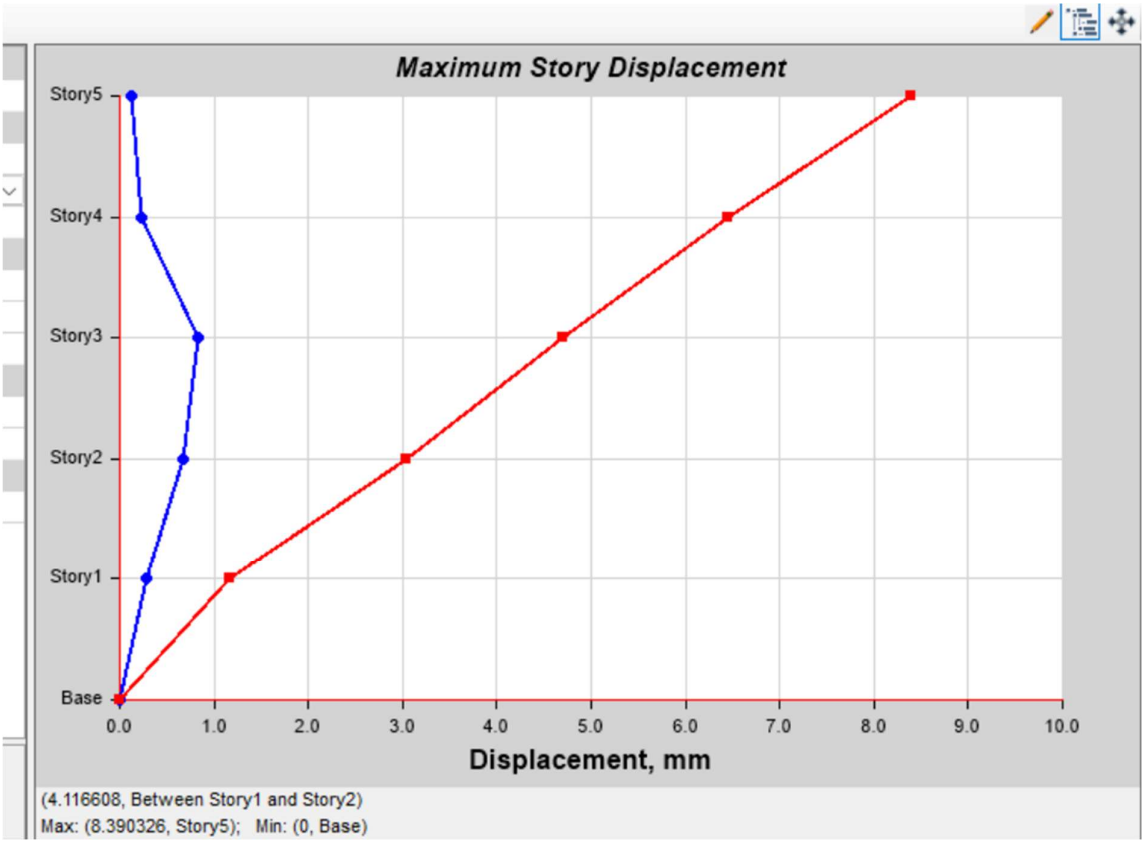

Fig 4.3-Maximum story displacement for setback and step back

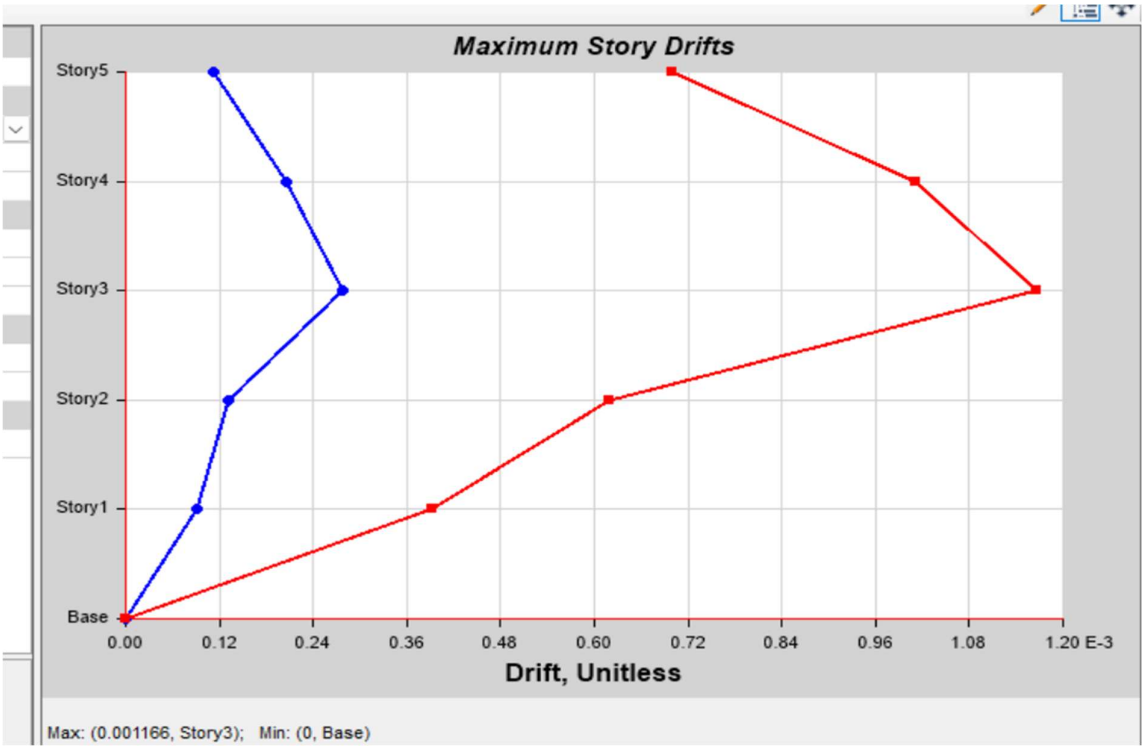

Fig 4.4-Maximum story drift for model setback and step back

4.5 ETABS results of Setback and step back model with two shear walls at the corners.

Units: As Noted Hidden Columns: No Sort: None Modal Participating Mass Ratios
Filter: None

Case	Mode	Period sec	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ
Modal	1	0.296	0	0.4893	0	0	0.4893	0	0.3937	0	0.2438
Modal	2	0.254	0.5694	0	0	0.5694	0.4893	0	0	0.4251	0
Modal	3	0.175	0	0.0917	0	0.5694	0.581	0	0.0273	0	0.1653
Modal	4	0.114	0.2654	3.876E-06	0	0.8348	0.581	0	2.974E-06	0.1181	0
Modal	5	0.113	5.267E-06	0.2209	0	0.8348	0.8019	0	0.1466	2.24E-06	0.002
Modal	6	0.084	0	0.0176	0	0.8348	0.8195	0	0.0002	0	0.266
Modal	7	0.073	0	0.1021	0	0.8348	0.9216	0	0.0925	0	0.089
Modal	8	0.069	0.0659	0	0	0.9007	0.9216	0	0	0.0681	0
Modal	9	0.058	0	0.0029	0	0.9007	0.9244	0	0.0256	5.908E-07	0.1372
Modal	10	0.049	0	0.0387	0	0.9007	0.9631	0	0.1798	1.039E-06	0.0016
Modal	11	0.04	0.0839	0	0	0.9847	0.9631	0	6.384E-07	0.3358	0
Modal	12	0.028	0	0.0205	0	0.9847	0.9837	0	0.0682	0	0.0013

Fig 4.5-Modal mass participating ratio for setback and step back with 2 shear walls

Units: As Noted Hidden Columns: No Sort: None Base Reactions
Filter: None

Output Case	Case Type	Step Type	Step Number	FX kN	FY kN	FZ kN	MX kN-m	MY kN-m	MZ kN-m	X m
Dead	LinStatic			-202	-202	28342.0686	511845.7492	-503437.3972	-490	
Live	LinStatic			0	0	10800	194400	-194400	0	
Modal	LinModEigen	Mode	1	0.0116	16.7264	0	-191.8082	0.129	478.095	
Modal	LinModEigen	Mode	2	24.6443	-0.0145	0	0.1721	279.5571	-443.9765	
Modal	LinModEigen	Mode	3	0.004	20.7211	0	-210.259	0.0633	-61.9681	
Modal	LinModEigen	Mode	4	82.6483	0.3159	0	-1.5169	461.8125	-1482.7155	
Modal	LinModEigen	Mode	5	-0.3774	77.2928	0	-389.0048	-2.1303	1262.5895	
Modal	LinModEigen	Mode	6	-0.0961	-39.801	0	339.6027	-0.5202	1682.3002	
Modal	LinModEigen	Mode	7	0.0075	-124.3792	0	561.8564	0.0093	-412.5024	
Modal	LinModEigen	Mode	8	-112.6957	-0.0137	0	0.0692	-481.6345	2030.7879	
Modal	LinModEigen	Mode	9	0.3501	-33.9433	0	-106.5204	1.0011	-4229.8495	
Modal	LinModEigen	Mode	10	-0.4936	168.5501	0	1.5447	-0.7129	2467.7206	
Modal	LinModEigen	Mode	11	-375.9655	-0.4574	0	-0.1951	-216.6915	6775.7479	
Modal	LinModEigen	Mode	12	0.141	378.3679	0	-471.1598	0.5972	5219.1806	
eq x	LinStatic			-2513.4976	0	0	0	-28071.0764	45245.8186	
eq y	LinStatic			0	-2513.4976	0	28071.0764	0	-56962.4284	
w x	LinStatic			-1063.7848	0	0	0	-8994.5925	19148.1269	
w y	LinStatic			0	-743.7685	0	6051.9766	0	-13026.5179	
SIDL	LinStatic			0	0	5184	93312	-93312	0	
DConS1	Combination			-303	-303	50289.1029	907736.6238	-895124.0957	-735	
DConS2	Combination			-303	-303	66489.1029	1199336.6238	-1186724	-735	
DConS3	Combination			-1518.9418	-242.4	53191.2824	959469.2991	-960172.7876	22389.7522	

Fig 4.6-Base reaction for setback and step back with 2 shear wall

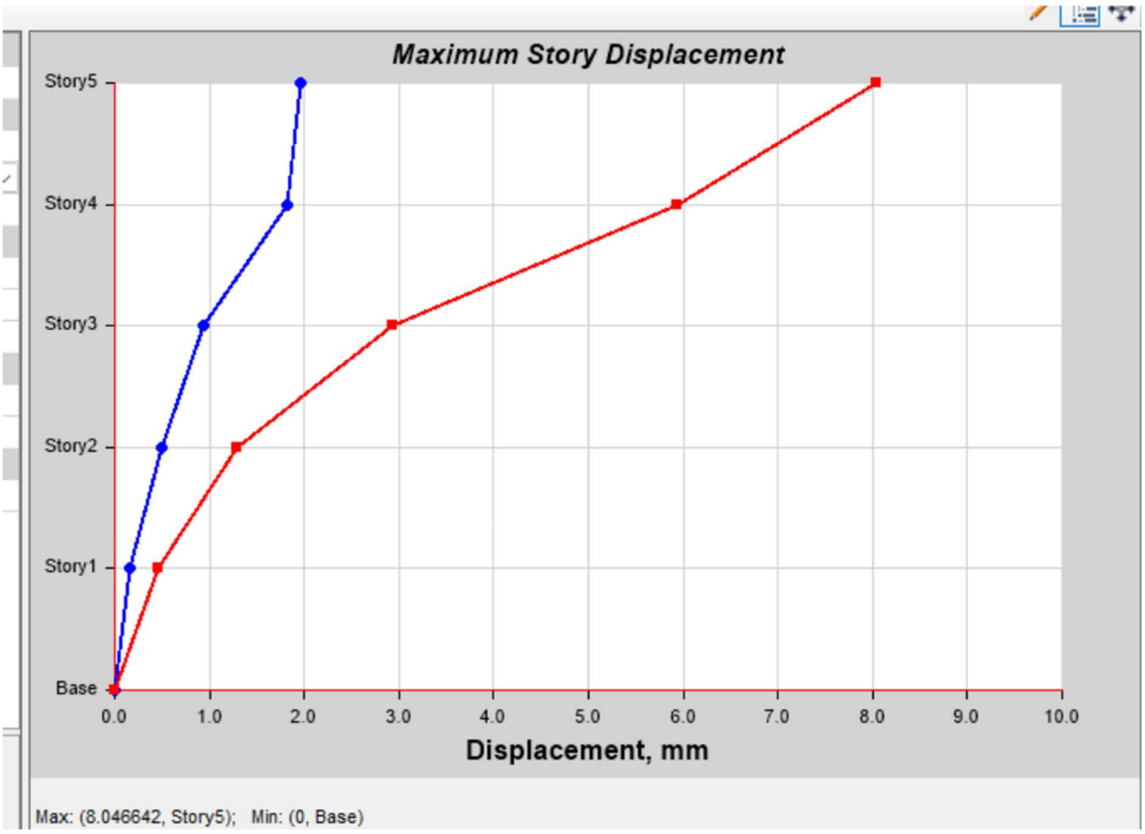

Fig 4.7- Maximum displacement for setback and step back with 2 shear walls

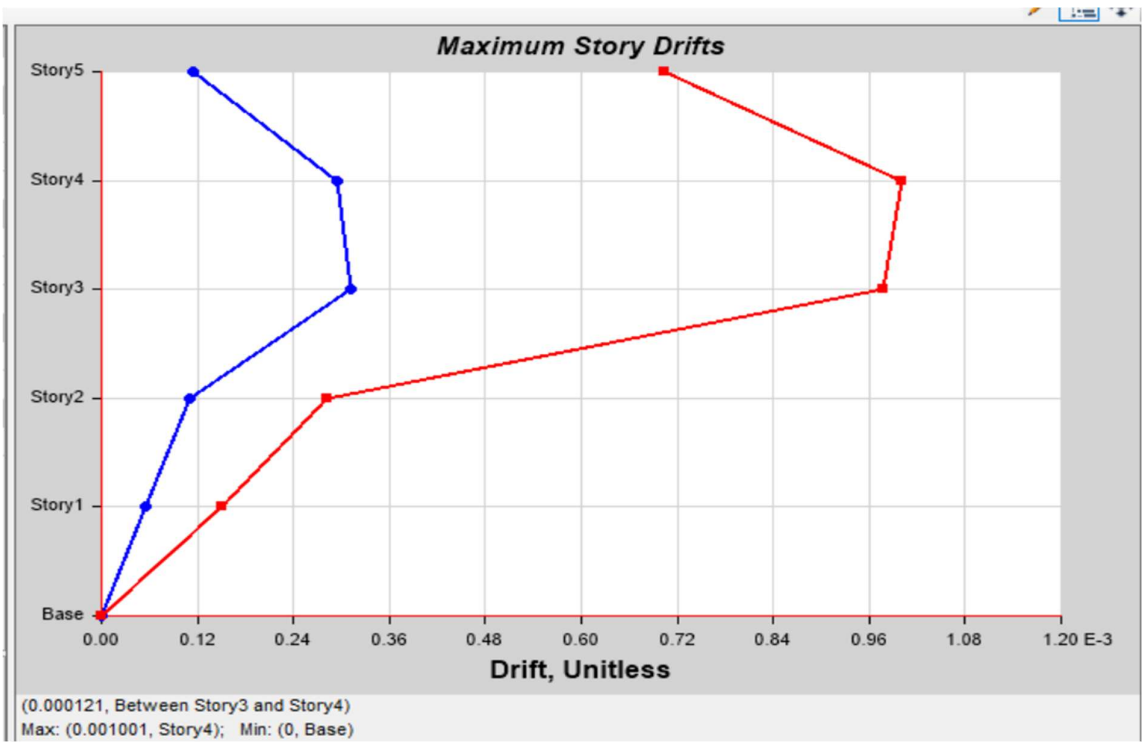

Fig 4.8-Maximum story drift for setback and step back with 2 shear walls

4.6 ETABS results of Setback and step back model with four shear walls at the corners.

Units: As Noted Hidden Columns: No Sort: None Modal Participating Mass Ratios
Filter: None

Case	Mode	Period sec	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ
Modal	1	0.136	0	0.5661	0	0	0.5661	0	0.3324	0	4.345E-05
Modal	2	0.113	0.6394	0	0	0.6394	0.5661	0	0	0.3734	0
Modal	3	0.069	0	0.1746	0	0.6394	0.7407	0	0.4245	0	0.3694
Modal	4	0.062	0	0.2046	0	0.6394	0.9453	0	0.0173	0	0.3532
Modal	5	0.053	0.3386	0	0	0.9779	0.9453	0	0	0.4746	0
Modal	6	0.048	0	0.0071	0	0.9779	0.9525	0	0.0844	0	0.0108
Modal	7	0.036	6.5E-07	0	0	0.9779	0.9525	0	0	0.0893	1.367E-06
Modal	8	0.032	0	1.653E-05	0	0.9779	0.9525	0	0.0073	0	0.1393
Modal	9	0.029	0	0.0177	0	0.9779	0.9702	0	0.0818	0	0.0256
Modal	10	0.025	6.212E-06	0.0008	0	0.9779	0.971	0	0.0055	3.847E-05	0.0828
Modal	11	0.025	0.0049	2.232E-06	0	0.9829	0.971	0	1.295E-06	0.0411	0.0001
Modal	12	0.022	0.0171	4.163E-06	0	1	0.971	0	5.17E-06	0.0216	2.201E-06

Fig-4.9 Modal mass participating ratio for setback and step back with 4 shear walls

Units: As Noted Hidden Columns: No Sort: None Base Rea
Filter: None

Output Case	Case Type	Step Type	Step Number	FX kN	FY kN	FZ kN	MX kN-m	MY kN-m	MZ kN-m
Dead	LinStatic			-190	-190	28958.69	522884.9345	-524812.749	-286
Live	LinStatic			0	0	10800	194400	-194400	0
Modal	LinModEigen	Mode	1	0.0074	-86.4839	0	952.1163	0.0938	-1574.4024
Modal	LinModEigen	Mode	2	133.6571	0.0171	0	-0.1597	1470.3967	-2405.6355
Modal	LinModEigen	Mode	3	-0.0402	188.5266	0	-429.4892	-0.0957	-869.6004
Modal	LinModEigen	Mode	4	0.1991	-247.9319	0	1745.6501	0.6611	-9562.7232
Modal	LinModEigen	Mode	5	445.3916	0.2234	0	-2.5052	1641.9551	-8022.3971
Modal	LinModEigen	Mode	6	0.454	-78.3527	0	1650.4895	2.9437	79.9471
Modal	LinModEigen	Mode	7	1.315	0.1417	0	2.5124	-1819.7346	-50.8609
Modal	LinModEigen	Mode	8	0.328	8.2141	0	579.473	4.1523	-11618.4339
Modal	LinModEigen	Mode	9	-0.1497	-335.6142	0	24.7064	-0.1527	227.2887
Modal	LinModEigen	Mode	10	-8.4584	95.5829	0	-1723.1964	10.2527	17107.1231
Modal	LinModEigen	Mode	11	-246.8928	-5.2441	0	57.6419	665.1068	3888.5601
Modal	LinModEigen	Mode	12	-568.9231	-8.8722	0	35.0229	-2229.1373	9985.3872
eq x	LinStatic			-2567.9135	0	0	0	-28691.395	46225.2888
eq y	LinStatic			0	-2567.9135	0	28691.395	0	-59026.2171
w x	LinStatic			-1063.7848	0	0	0	-8994.5925	19148.1269
w y	LinStatic			0	-743.7685	0	6051.9766	0	-13026.5179
SIDL	LinStatic			0	0	5184	93312	-93312	0
DConS1	Combination			-285	-285	51214.0351	924295.4018	-927187.1235	-429
DConS2	Combination			-285	-285	67414.0351	1215895.4018	-1218787	-429
DConS3	Combination			-1504.5418	-228	53931.228	972716.3214	-985823.2098	22634.5522

Fig 4.10- Base reaction for setback and step back with 4 shear wall

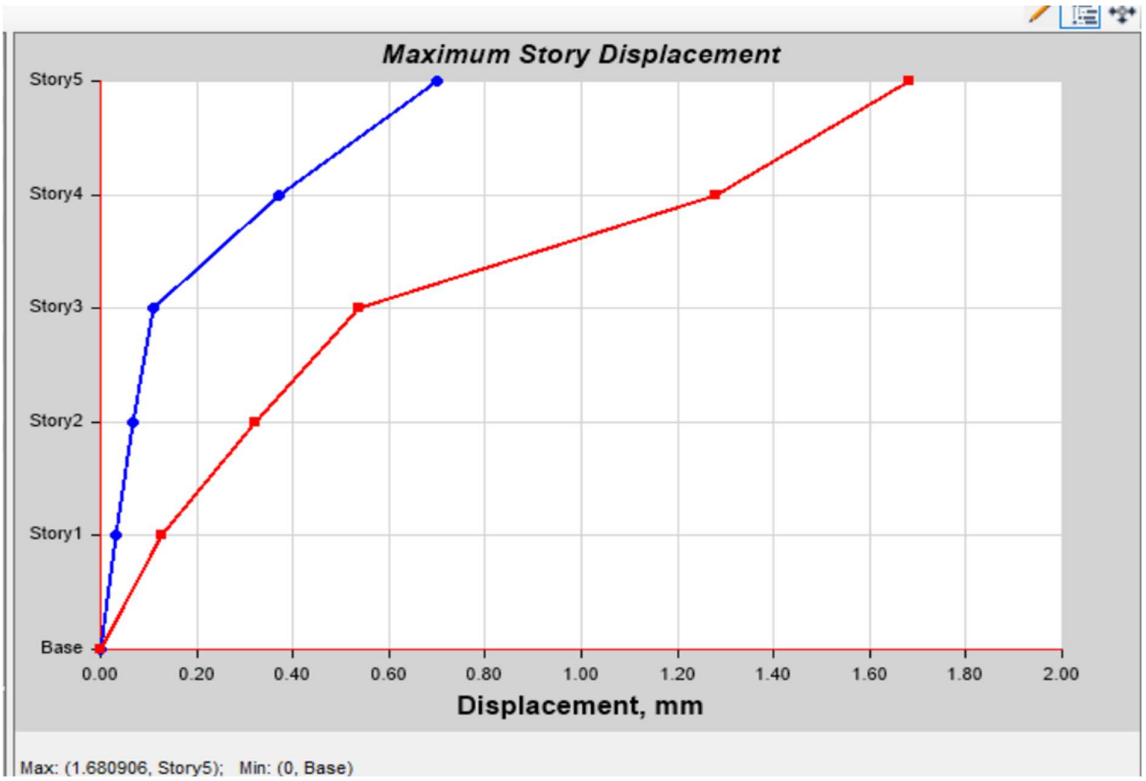

Fig 4.11- maximum story displacement for setback and step back with 4 shear wall

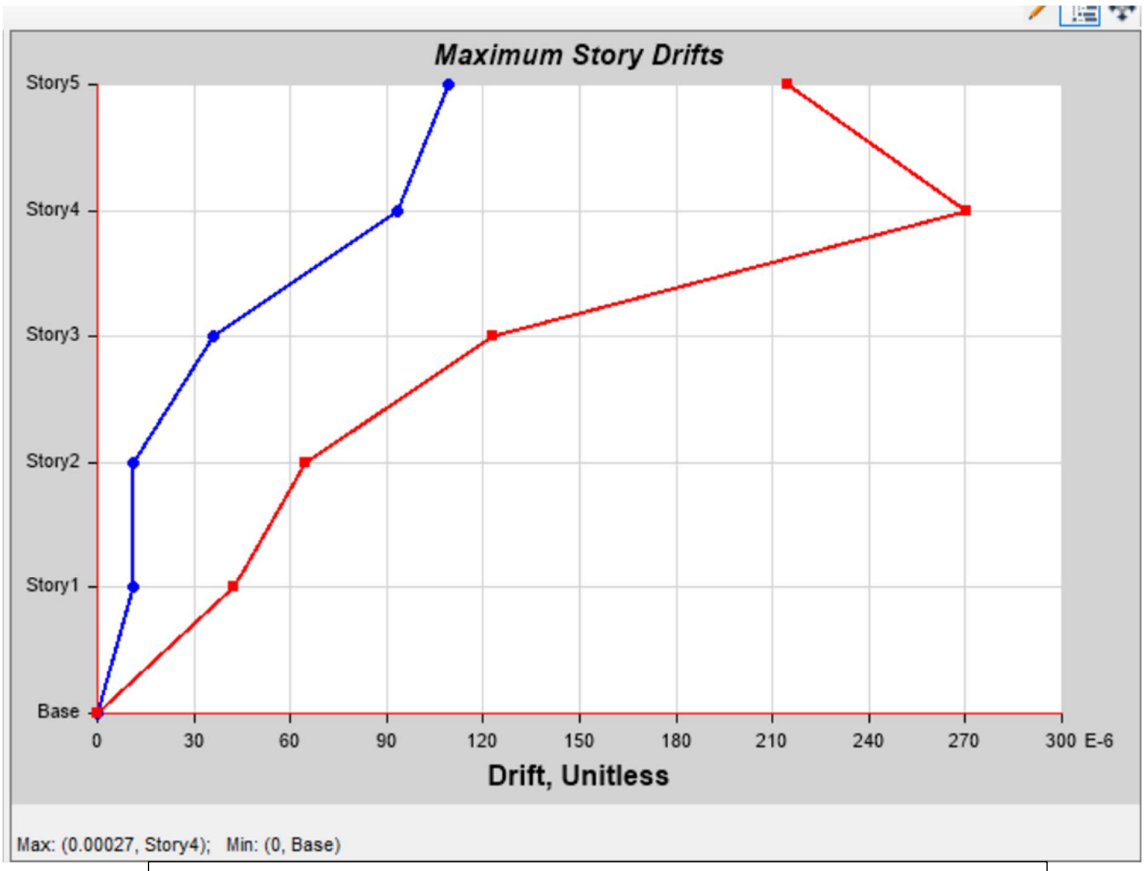

Fig 4.12-Maximum story drift for model on hilly terrain with shear wall

4.7 ETABS results of Setback and step back model with shear walls at the core.

Units: As Noted Hidden Columns: No Sort: None
Filter: None

Modal Participating Mass Ratios

	Case	Mode	Period sec	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ
▶	Modal	1	0.246	0	0.317	0	0	0.317	0	0.3425	0	0.4515
	Modal	2	0.142	0.501	0	0	0.501	0.317	0	0	0.3754	0
	Modal	3	0.131	0	0.363	0	0.501	0.68	0	0.0322	0	0.3163
	Modal	4	0.1	0	0.0547	0	0.501	0.7347	0	0.0219	0	0.1275
	Modal	5	0.098	0	0.1437	0	0.501	0.8784	0	0.0721	0	0.0218
	Modal	6	0.09	0.3648	0	0	0.8659	0.8784	0	0	0.0225	0
	Modal	7	0.061	0	0.0289	0	0.8659	0.9073	0	0.0298	0	0.0432
	Modal	8	0.044	0	0.028	0	0.8659	0.9353	0	0.1271	0	0.0163
	Modal	9	0.039	0	0.0469	0	0.8659	0.9821	0	0.3204	0	0.0072
	Modal	10	0.034	0.1079	0	0	0.9737	0.9821	0	0	0.5108	0
	Modal	11	0.031	0	1.312E-05	0	0.9737	0.9822	0	0.0001	0	0.014
	Modal	12	0.025	0	0.0128	0	0.9737	0.995	0	0.026	0	0.0015

Fig-4.13 Modal mass participating ratio for setback and step back with shear wall at core

Units: As Noted Hidden Columns: No Sort: None
Filter: None

Base Reactions

	Output Case	Case Type	Step Type	Step Number	FX kN	FY kN	FZ kN	MX kN-m	MY kN-m	MZ kN-m
▶	Dead	LinStatic			-190	-190	28740.0548	518657.9857	-516904.2924	-286
	Live	LinStatic			0	0	10800	194400	-194940	0
	Modal	LinModEigen	Mode	1	0	19.6548	0	-234.0725	0	704.2335
	Modal	LinModEigen	Mode	2	-73.9968	0	0	0	-833.1193	1331.9418
	Modal	LinModEigen	Mode	3	0	74.115	0	-677.0705	0	287.361
	Modal	LinModEigen	Mode	4	0	-49.2516	0	278.6123	0	247.8691
	Modal	LinModEigen	Mode	5	0	-82.91	0	445.5723	0	-1969.595
	Modal	LinModEigen	Mode	6	-156.3873	0	0	0	-1109.2948	2814.971
	Modal	LinModEigen	Mode	7	0	-97.792	0	412.8543	0	-3546.8603
	Modal	LinModEigen	Mode	8	0	-185.8039	0	10.0528	0	-1197.456
	Modal	LinModEigen	Mode	9	0	308.0281	0	539.5061	0	3705.674
	Modal	LinModEigen	Mode	10	609.6127	0	0	0	-69.5689	-10973.0278
	Modal	LinModEigen	Mode	11	0	8.2032	0	1.8871	0	-3882.4586
	Modal	LinModEigen	Mode	12	0	-374.6648	0	1007.544	0	-4791.2868
	eq x	LinStatic			-2538.1143	0	0	0	-28201.6193	45686.0576
	eq y	LinStatic			0	-2538.1143	0	28201.6193	0	-57182.5169
	w x	LinStatic			-1063.7848	0	0	0	-8994.5925	19148.1269
	w y	LinStatic			0	-743.7685	0	6051.9766	0	-13026.5179
	SIDL	LinStatic			0	0	5184	93312	-93571.2	0
	DConS1	Combination			-285	-285	50886.0821	917954.9785	-915713.2386	-429
	DConS2	Combination			-285	-285	67086.0821	1209554.9785	-1208123	-429
	DConS3	Combination			-1504.5418	-228	53668.8657	967643.9828	-977292.1019	22634.5522

Fig 4.14- Base reaction for setback and step back with shear wall at the core

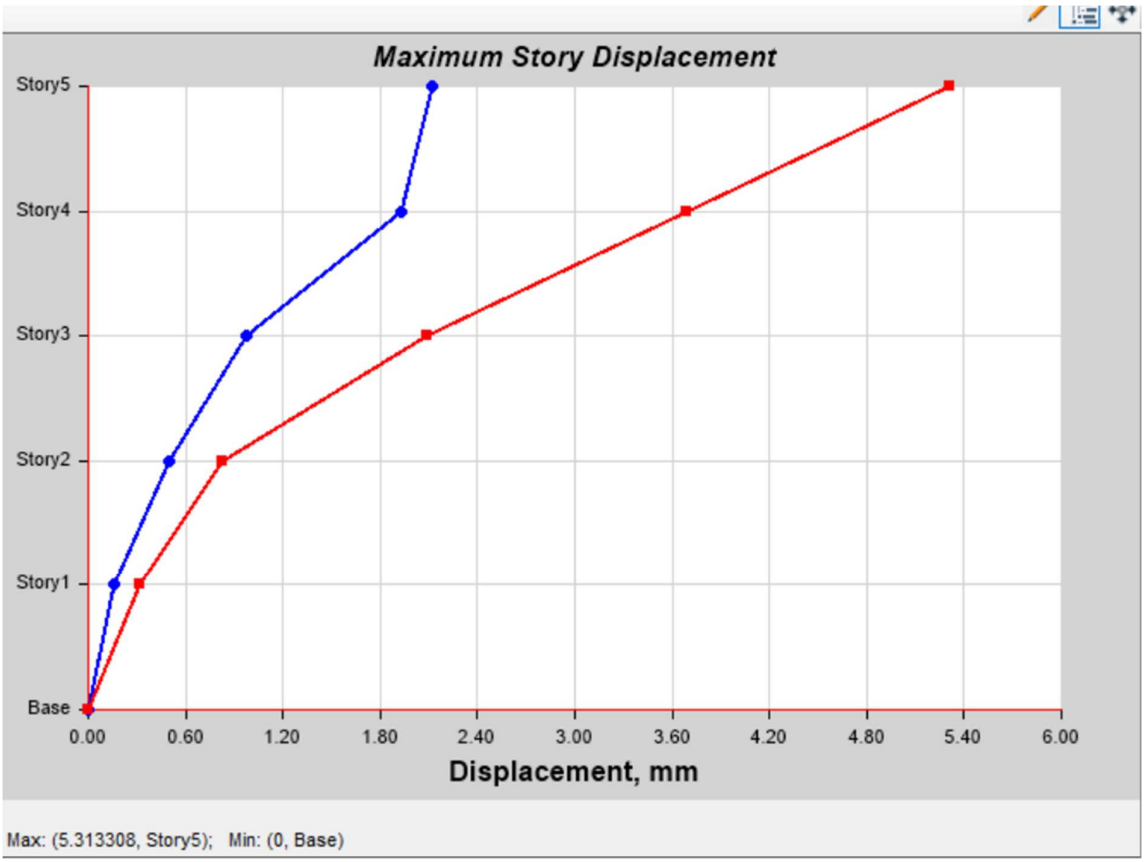

Fig 4.15- maximum story displacement for setback and step back with shear wall at the core

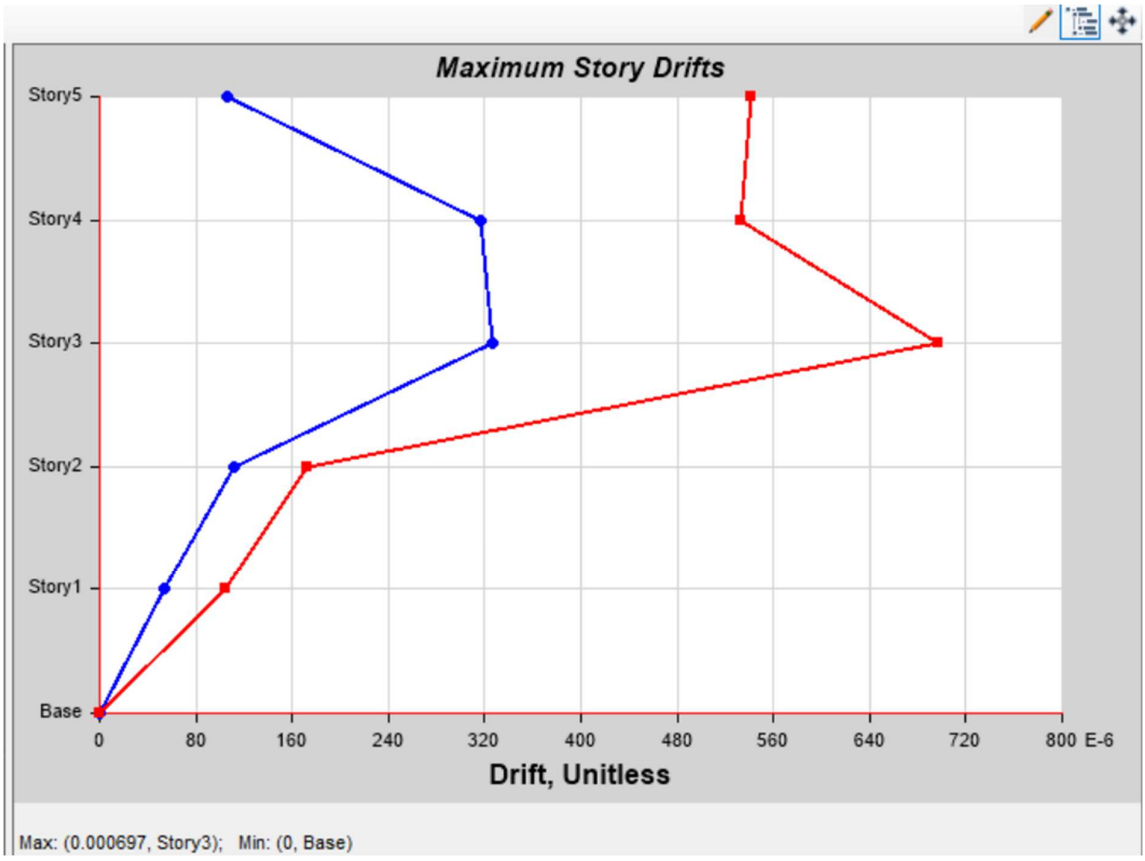

Fig 4.16-Maximum story drift for setback and step back with shear wall at the core

4.8 Results obtained for modal mass participating ratio

Modal participating mass ration for no shear wall	72%
Model participating ratio with 2 shear walls	56%
Model participating ratio with 4 shear walls	63%
Model participating ratio with 4 shear walls	53%

Table 4.1 Modal mass participating ratio

4.9 Results obtained for maximum drift

Maximum story drift no shear wall	0.0012
Maximum story drift for shear wallls at the two corners	0.0010
Maximum story drift for shear wallls at the four corners	0.0003
Maximum story drift for shear wallas at the core	0.0007

Table 4.2 Maximum story drift

Modal	Base reaction (KN)	Maximum displacement (mm)	MPMR (%)	Maximum drift
M1	2462	8.4	72	0.0012 on 3rd story
M2	2513	8.1	56	0.0010 on 4th story
M3	2567	1.2	63	0.0003 on 4th story
M4	2538	5.3	53	0.0007 on 3rd story

NOTE
M1- It depicts set back and step back model without shear wall.
M2 – It depicts model with shear walls at the two corners.
M3- It depicts model with four shear walls at the four corners.
M4- It depicts model with shear wall at the core.

Key conclusions:

1.**M1**

- Highest MPMR (72%) → Captures most of the seismic mass in lesser modes.
- Drift = 0.0011 (within IS 1893 limit of 0.004) → shows good overall seismic performance.
- Suitable for hilly regions with terraced topography.

2. **M2**

- Lower MPMR (56%) → Less effective in mobilizing seismic mass.
- Drift = 0.0012 → Slightly higher than step back, still within safe limits.
- Asymmetric geometry could contribute to lower dynamic performance.

3. **M3**

- MPMR = 63% → Strong dynamic response, though not the highest.
- Drift = 0.00027 → Lowest among all models, shows excellent stiffness and control.
- Best performing model overall – ideal for seismic zones.

4. **M4**

- MPMR = 53% → Least modal mass captured.
- Drift = 0.00069 → Better than step back/setback, but higher than four-corner shear wall.
- Performs well in drift control but slightly less dynamically efficient.

Though it is axiomatic from the results that the shear walls at the four corners of the buildings performs well in the dynamic analysis of the building yet it also proves that the placement of the shear wall plays a significant role in the analysis of the structure, because shear walls not placed symmetrically didn't perform well.

CHAPTER 5

Conclusion

- The seismic integrity of structures with shear walls in hilly areas, where uneven terrain and seismic vulnerability pose particular structural difficulties, has been investigated in this work. The results unequivocally show that adding shear walls greatly improves a building's ability to withstand tremors, particularly when they are positioned carefully and properly to take into account the slope shape.

- According to the analysis, shear walls improve energy dissipation during seismic events, increase lateral stiffness, and decrease inter-story drift. Shear walls, which offer even load distribution and enhanced structural symmetry, assist lessen the consequences of torsional abnormalities, which are more likely to occur in buildings situated on sloping terrain. Additionally, the comparative analysis of various shear wall configurations indicates that shear wall continuity, orientation, and placement are important variables affecting total seismic behaviour Compared to traditional vertical layouts utilized in flat terrains, stepped or staggered shear wall layouts tailored to terrain profiles function better in mountainous areas.
- In conclusion, adding shear walls to a building's structural structure in a hilly area is a workable and efficient way to increase earthquake resistance. However, building configuration, dynamic properties, and slope geometry must all be carefully taken into account for the best possible design. To further increase seismic resilience in these susceptible places, future research should concentrate on creating region-specific design standards and performance-based evaluation techniques.

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