"SEISMIC RESPONSE OF RC BUILDING ON SLOPING GROUND USING SAP2000"

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ABSTRACT:

Typically, structures are constructed on flat terrain; however, with limited availability of level ground, construction on slopes has become more prevalent. Two primary configurations are employed for buildings on sloped land: the step-back and the step-back setback designs. This study examines an RCC building of G+8 stories situated on slopes with angles of 15°, 30°, 45°, and 60°, assessing its stability and performance. Both versions of the building—those with and without an infill wall—were analyzed. Using SAP2000, the building was modelled to evaluate how variations in bottom-storey column height and the presence of an infill wall influence structural behaviour during seismic events. Comparative analysis was conducted on buildings with and without infill walls, focusing on seismic response factors such as top-storey displacement, drift, base shear, and natural period. Linear static analysis and response spectrum analysis were carried out as per IS:1893 (Part 1):2002 standards. Findings indicate that shorter columns are more susceptible to earthquake impacts, and the step-back setback configuration, with or without infill walls, is suitable for sloping terrain.

Keywords: Sloping ground, Step back, Step back setback, Linear static analysis, response spectrum analysis, Displacement, Base Shear, Bending moment, Time Period and SAP2000.

1.INTRODUCTION:

Real estate development has accelerated significantly in hilly areas due to economic growth and urban expansion, leading to a sharp increase in population density in these regions. Consequently, the demand for multi-story buildings on slopes near urban areas has risen considerably. Mountainous regions, such as northeast India, experience higher levels of seismic activity. Buildings constructed with masonry and mud or cement mortar in these areas often fail to meet seismic standards when subjected to earthquake forces, resulting in severe loss of life and property.

Seismic analysis refers to evaluating a structure's reaction to earthquake forces and forms a critical component of structural design, earthquake-resistant engineering, or retrofitting practices in regions vulnerable to earthquakes. Past earthquakes have shown that reinforced concrete (RC) frame buildings with columns of unequal heights within a single level tend to incur greater damage in the shorter columns compared to taller ones on the same floor. Figure-1 illustrates examples of buildings with shorter columns on inclined terrain as well as structures featuring mezzanine floors.

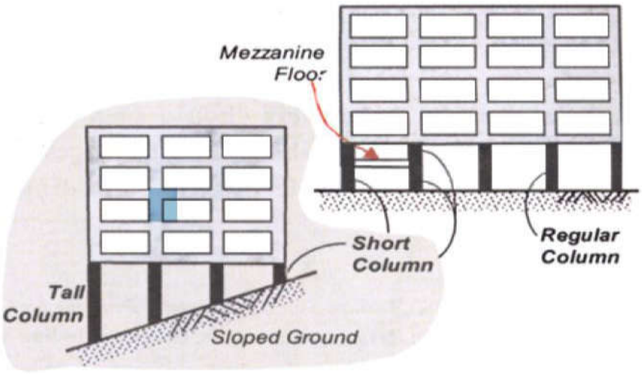


Fig No 1: short columns in buildings on a sloping ground and buildings with a mezzanine floor

Seismic analysis involves calculating a structure's response to earthquake forces, forming a critical aspect of structural design, earthquake-resistant engineering, and structural assessment or retrofitting in seismically active regions. This study aims to explore how RC structures respond when built on sloping terrain, as seismic reactions on slopes vary considerably from those on flat ground. In designing RC buildings, the impact of infill walls during seismic events is often overlooked. In countries like India, multi-story buildings commonly use reinforced concrete frames, with masonry infill walls added after the frame is completed. These infill walls contribute significantly to the building's strength and rigidity, thereby impacting the overall seismic response. It is well-established that frames with infill walls possess higher strength and stiffness than bare frames; neglecting these characteristics has unfortunately contributed to failures in several multi-story buildings.

2. REASERCH METHODOLOGY

Problem Statement for Various Building Analysis Configurations

The aim of this project is to examine G+8 story structures with various configuration types and slopes. As mentioned in section 5.1, four design models are currently being developed. The primary focus of this investigation is the use of SAP2000 software to evaluate multistory buildings located in seismic zone III. The selected designs exhibit a unique architectural layout, serving as an architectural design rather than representing an actual or intended building. The analysis of these structures has been conducted to assess their response to dynamic seismic forces and gravity loads.

Model Details for the Analysis of a Symmetric Shape Multi-Storey (G+8) Building:

Table 1. Parameters for building design

No.ofstorey's	G+8
Storeyheight	3.5m
Buildingframesystem	SMRF
Seismiczone	ZoneType-III
Soiltype	I
Importancefactor	I
Response reduction factor	5(SMRF)
Dampingpercent	5%
MaterialProperties	
Gradeofconcrete	M25
Gradeofsteel	Fe500
Young's modulus ofM25concrete, E	25x106kN/m2
Densityofconcrete	25kN/m2
Density of brickmasonry	20kN/m2
Structuralmembers	
Thicknessofslab	225mm
AllBeamsize	300X530mm
AllColumnsize	300X680mm

Thicknessofwall	230mm
Rooffinishes	1.5kN/m2
Floorfinishes	1.5kN/m2
Wallloadoneachfloor	13.66kN/m
Wallloadonroof floor	5.52kN/m
Liveloadoneachfloor	4kN/m2
Liveloadonrooffloor	2kN/m2

5.3.3D Model Views of Structure:

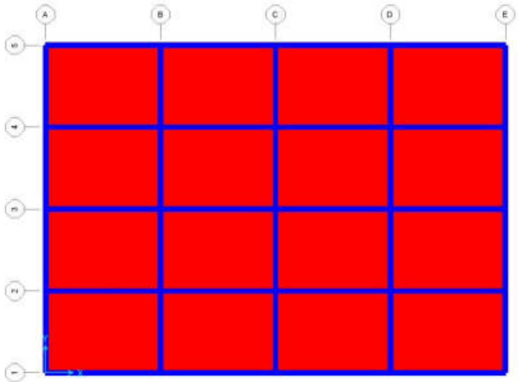


Fig.12. Plan view.

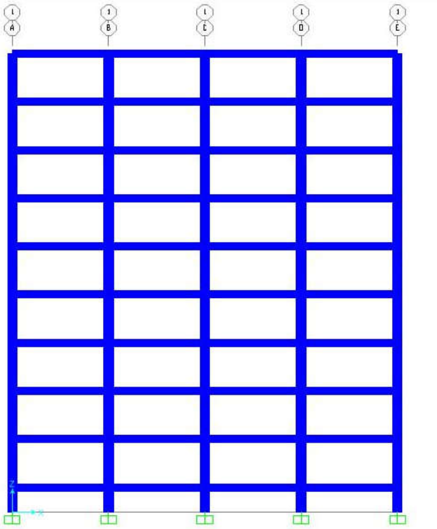


Fig.13. 3D Elevation View

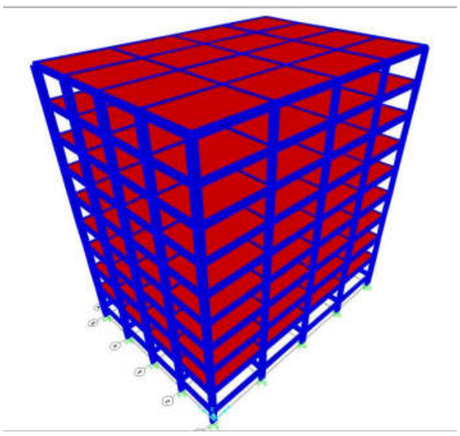


Fig.14. 3D View for Bare Frame

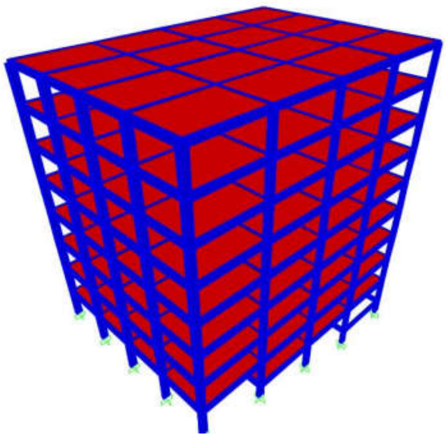


Fig.15. 3D View for Braced Frame

MODELING PARAMETERS:

Different types of model is categorized in below table to display result.

Sr. No.	Model	Frame Type	Structure variation	Bay variation	Beam depth variation in (mm)
1	Model-I	Step back buildings with infill wall	G+8	4	300X530
2	Model-II	Step back buildings without Infill wall.	G+8	4	300X530
3	Model-III	Step back- set back building with infill wall.	G+8	4	300X530
4	Model-IV	Step back- set back building without Infill wall.	G+8	4	300X530
5	Model-I 15	Typical Setback building model on 15-degree slope	G+8	4	300X530
6	Model-I 30	Typical Setback building model on 30-degree slope	G+8	4	300X530
7	Model-I 45	Typical Setback building model on 45-degree slope	G+8	4	300X530
8	Model-I 60	Typical Setback building model on 60-degree slope	G+8	4	300X530
9	Model-II 15	Typical Step back set back building model on 15-degree slope.	G+8	4	300X530
10	Model-II 30	Typical Step back set back building model on 30-degree slope.	G+8	4	300X530
11	Model-II 45	Typical Step back set back building model on 45-degree slope.	G+8	4	300X530

12	Model-II 60	Typical Step back set back building model on 60-degree slope.	G+8	4	300X530

Table 2. Modelling Parameters.

3. RESULTS AND DISCUSSIONS

3.1 Example 1: Comparable Static Approach

This is the most straightforward process available to a structural engineer to conduct a seismic study and produce appropriate findings. It is frequently employed, especially for buildings and other common structures that meet specific regularity standards, and is required by any applicable code for seismic analysis**.**

Base shear: Based on the building's examination, the base shear for the four previously mentioned configurations is determined. A comparison of base shears with and without infill wall construction is made. As the slope angle increases, the base shear decreases. In contrast to step back-set back buildings, step back buildings exhibit a larger base shear when compared across different configurations. Additionally, as the stiffness of the construction models increases, the base shear of the infilled models also increases.

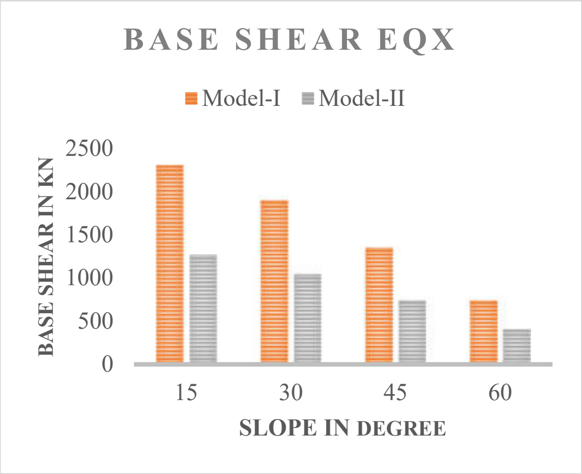


Fig.16:Base shear in the X direction for models I and II

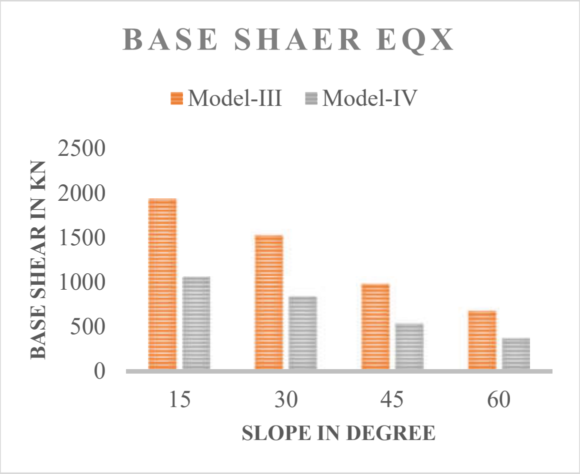


Fig.17:Base shear in the X direction for models III and IV

The base shear versus slope angle is displayed in Figs. 16 and 17. In the X direction for Models I, II, III, and IV, base shear increases with increasing slope angles in the Response Spectrum Analysis (RSA) for 15°, 30°, and 45°. However, base shear decreases for a slope angle of 60°. This occurs because, while base shear increases with an increasing bay count, it falls when the bay count decreases at a 60° slope.

- Storey Displacement –
- Analyzing storey displacement in the X direction (EQX case) for Models I, II, III, and IV at slope angles of 15°, 30°, 45°, and 60° reveals the following trends:

- At a slope of 15°, all models demonstrate a relatively uniform displacement pattern, with Model I showing the least displacement due to its infill wall.
- As the slope angle increases to 30°, displacement increases for all models, indicating heightened vulnerability to seismic forces.
- At 45°, the trend continues, with significant increases in storey displacement, particularly noted in Models II and IV, which lack infill walls, resulting in less rigidity.
- Finally, at a slope of 60°, displacement is at its peak across all models, suggesting that the steep incline exacerbates the structural response to seismic activity. Models without infill walls demonstrate the most significant increases in displacement, further emphasizing the importance of infill walls in enhancing structural stability under dynamic loading conditions.

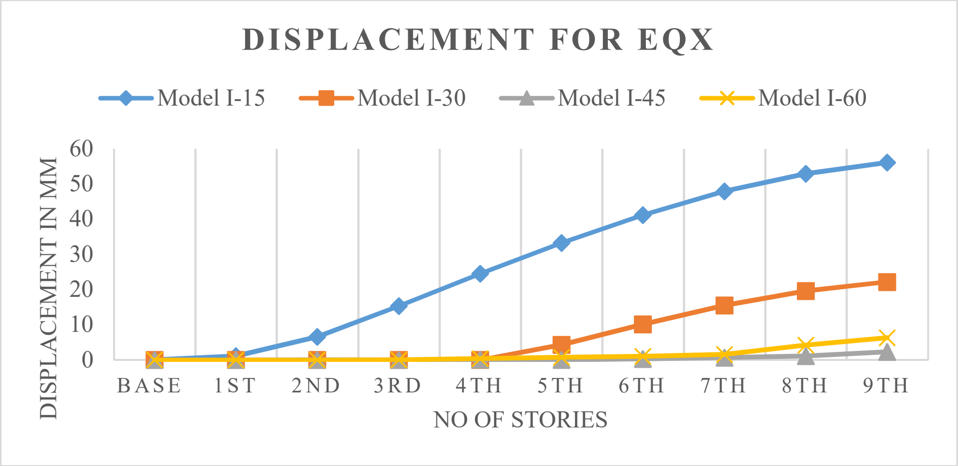


Fig.18: Model I displacement in the X direction.

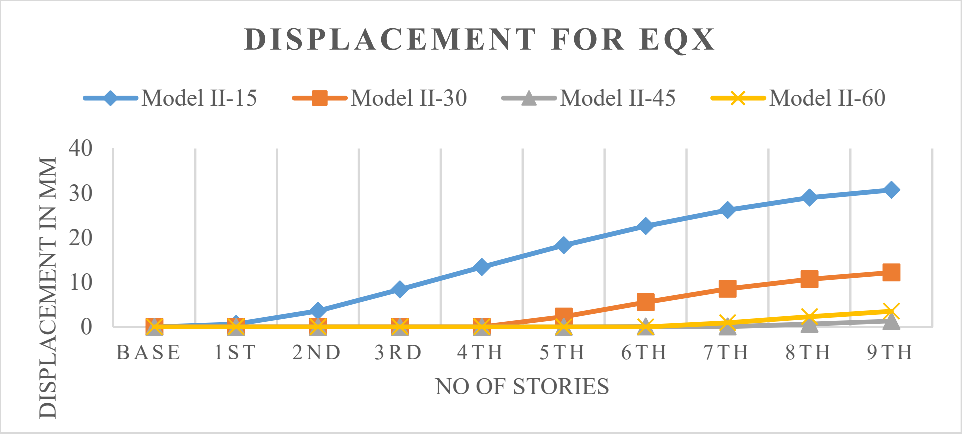


Fig.19: Model II displacement in the X direction

Figures 18 and 19 illustrate the relationship between displacement and storey count for step-back buildings, both with and without infill walls, in the X direction. For slope angles of 15°, 30°, and 45°, displacement decreases as the hill grade increases, indicating improved stability with lower slope angles. However, at a 60° slope, displacement increases sharply due to the steep incline, which significantly affects the building's lateral stability. This increase is also linked to the reduction in the number of bays at higher slopes, which leads to reduced structural stiffness and, consequently, greater displacement.

Figure 18 displays 55% more displacement data than Figure 19, highlighting that step-back buildings without infill walls exhibit notably higher displacement compared to those with infill walls, underscoring the importance of infill walls in maintaining structural stability under seismic loading.

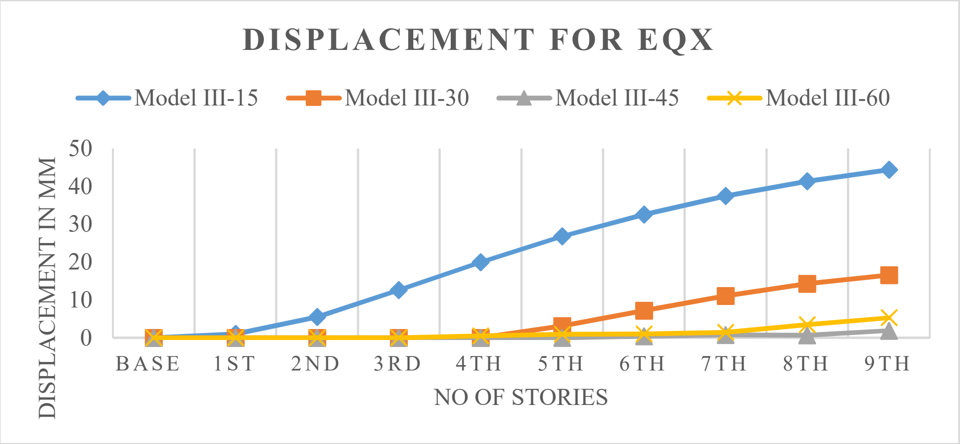


Fig.20: Model III displacement in the X direction

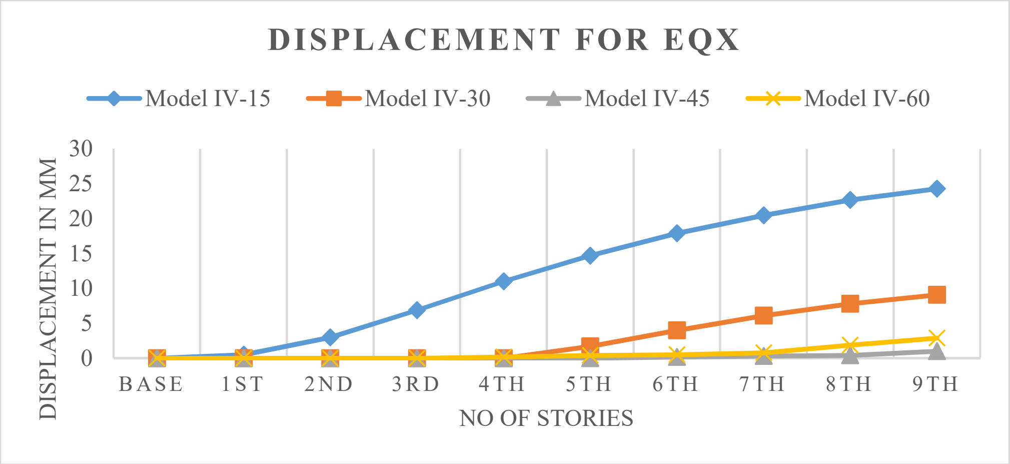
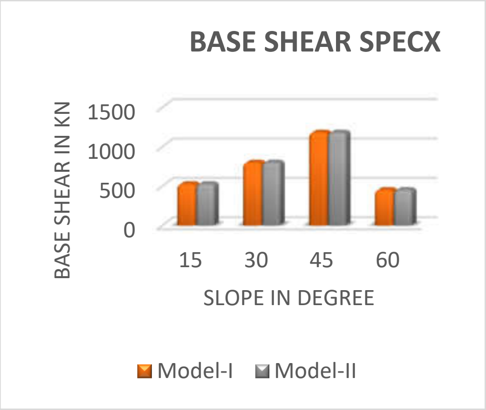


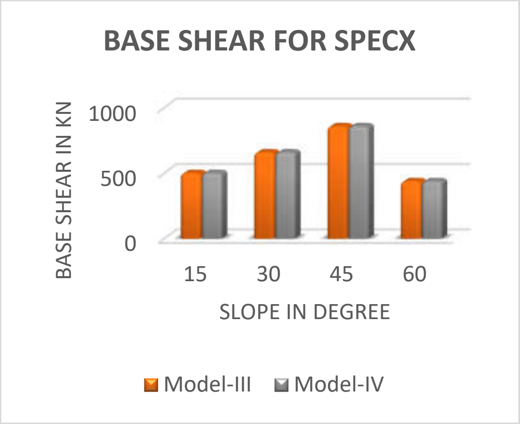
Fig.21: Model IV displacement in the X direction

The storey-wise displacement for step back-set back buildings, both with and without an infill wall, along the X direction is illustrated in Figures 20 and 21. For slopes of 15°, 30°, and 45°, displacement decreases as the hill slope increases, showing enhanced stability at these moderate incline levels. However, at a 60° slope, displacement increases substantially due to the steep gradient, which poses a structural challenge. As the number of bays decreases at the 60° slope, the displacement increases, highlighting the influence of fewer bays on the building's lateral flexibility.

3.2 Case 2: Response Spectrum Approach

This approach is suitable for structures significantly affected by higher modes beyond the fundamental one. Typically, a response spectrum is used alongside this method to assess peak responses across modes. By applying smooth design spectra, representing averages of multiple earthquake motions, this approach calculates only the maximum displacement and member force values for each mode. This method allows for a more nuanced understanding of the building's peak responses under seismic forces across various modes, thus enhancing the accuracy of the structural analysis.





Tabl mod

Fig.22:Base shear in the X direction for models I and II

een base she slope angle

Fig.23:Baseshearformodel–IIIandmodel-IV alongXdirection

spectrum analysis (RSA). However, for a 60° slope angle, the base shear decreases. This reduction occurs because, although base shear generally rises with an increasing number of bays, it decreases when the bay count diminishes on the steep 60° slope. This pattern emphasizes the impact of slope angle and bay configuration on base shear values across different structural models.

Storey Displacement

A comparative analysis of Models I, II, III, and IV for storey displacement in the X-direction (SPECX case) across slope angles of 15°, 30°, 45°, and 60° reveals distinct patterns in structural response.

For slopes of 15°, 30°, and 45°, the displacement generally decreases with increasing slope angle, indicating enhanced stability at these inclinations. However, at a 60° slope, displacement increases due to the structural challenges associated with such a steep gradient.

The increase in displacement at a 60° slope reflects the reduced bay count, which contributes to decreased stability under seismic and gravitational forces. This pattern underscores the importance of slope and bay configurations in determining displacement characteristics across varying structural models.

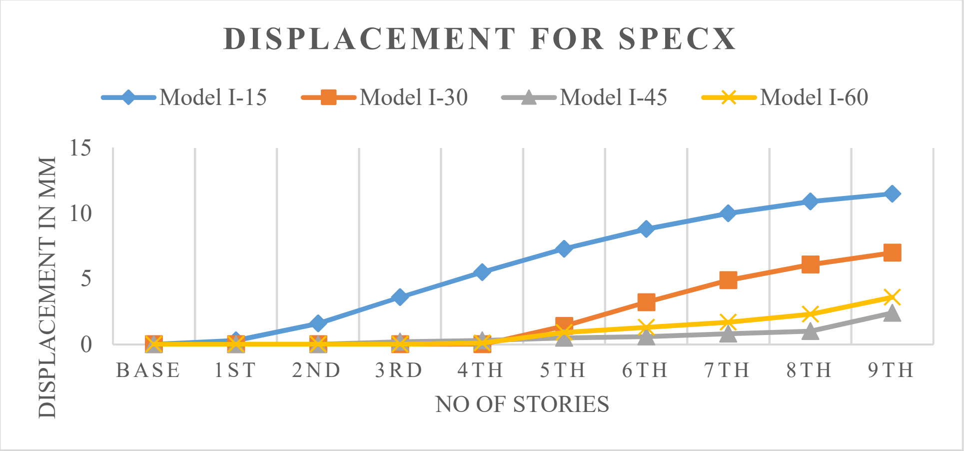


Fig.24: Model I displacement along the X axis

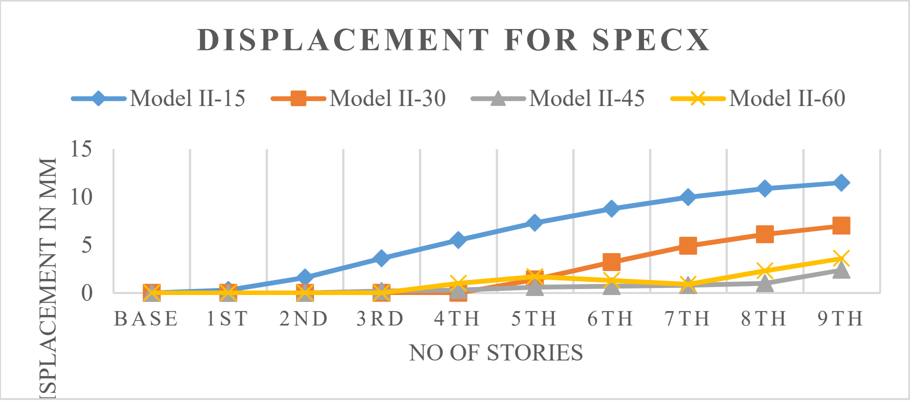


Fig.25: Model II displacement in the X direction.

The storey-wise displacement for step-back buildings, with and without infill walls, is shown in Figs. 24 and 25. Displacement in these configurations increases progressively from the bottom to the top story. For slope angles of 15°, 30°, and 45°, displacement generally decreases as the slope angle increases, suggesting improved structural resistance at these inclinations. However, for the 60° slope, displacement rises due to the reduced number of bays, which diminishes lateral stability on such a steep gradient. This increase highlights the influence of bay count and steepness, as displacement tends to increase when the bay count is lower at a 60° slope.

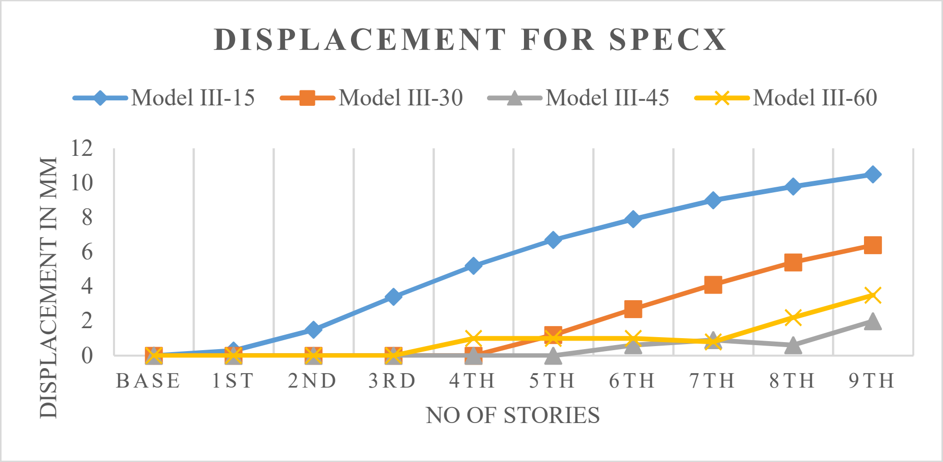


Fig.26: Model III displacement in the X direction

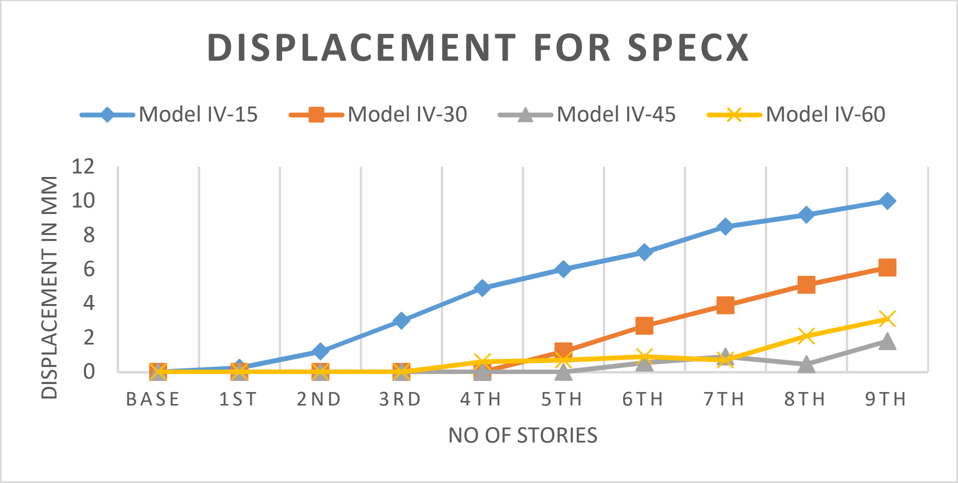


Fig.27: Model IV displacement in the X direction

The storey-wise displacement for Step Back-Set Back buildings, both with and without infill walls, is illustrated in Figs. 26 and 27. For slopes of 15°, 30°, and 45°, displacement tends to decrease as the hill slope increases, indicating a stabilizing effect on the structure at these angles. However, at a slope of 60°, displacement increases due to the reduced number of bays, which compromises lateral stability on the steeper slope. This trend suggests that a steep 60° incline, combined with fewer bays, leads to greater displacement, emphasizing the structural challenges associated with such configurations.

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