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Seismic Analysis of Multistorey Building on Sloping Ground Using ETABS

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Abstract

Buildings constructed on sloping terrain exhibit significant mass and stiffness irregularities, resulting in complex seismic behavior compared to structures on flat ground. This study evaluates the seismic performance of a G+10 reinforced-concrete (RC) building on sloping ground using ETABS 2022. Three structural configurations—(i) building on sloping ground, (ii) sloping ground with shear walls and boundary elements, and (iii) building without shear walls—are modeled and analyzed using the Response Spectrum Method as per IS 1893 (Part 1): 2016, considering Zone V seismicity and medium soil conditions. The study investigates key seismic response parameters, including storey displacement, inter-storey drift, base shear, mode shapes, and hinge behavior, to assess structural stability and lateral load resistance. Results indicate that buildings on slopes experience greater lateral displacement, torsional response, and uneven base shear distribution due to column height variation. However, the inclusion of shear walls and boundary elements significantly enhances structural stiffness, reducing displacement, drift, and base shear in both X and Y directions. Comparative evaluation demonstrates that the dual system offers improved seismic performance by minimizing lateral deformation and strengthening energy dissipation capacity. The findings highlight the importance of incorporating lateral-resisting systems for safer and ductile design of multistorey buildings in seismically active hilly regions.

Keywords: Seismic analysis, Sloping ground, ETABS, Shear wall, Response spectrum method, Base shear

1. INTRODUCTION

Earthquakes are among the most destructive natural phenomena, capable of causing severe damage to the built environment within seconds. Their effects are particularly critical for multistorey reinforced-concrete (RC) buildings, which must safely resist lateral ground motions through adequate strength, stiffness, and ductility. In India, large portions of the northern and northeastern regions—including Himachal Pradesh, Uttarakhand, Sikkim, and Arunachal Pradesh—lie in Seismic Zone V, the highest hazard category defined in *IS 1893 (Part 1): 2016*. These areas are also predominantly hilly, where construction commonly takes place on natural slopes due to topoFigureical constraints. Buildings constructed on sloping ground differ fundamentally from those on level terrain. The variation in foundation elevations causes columns in the same storey to have different effective heights, resulting in non-uniform stiffness distribution and unsymmetrical mass geometry. When subjected to seismic excitation, such irregularities lead to complex three-dimensional behavior characterized by torsional coupling, short-column effects, and uneven lateral-force distribution. The shorter uphill columns attract higher shear and bending moments, while the longer downhill columns experience larger displacements, making the structure more susceptible to localized damage or even partial collapse during strong earthquakes. Traditional seismic design approaches—largely developed for regular, flat-ground buildings—do not always capture these irregularities accurately. Hence, there is an increasing need to analyze and understand the seismic response of buildings resting on slopes using advanced dynamic methods such as the Response Spectrum Method (RSM) or Time-History Analysis. These approaches help quantify key response parameters including base shear, storey shear, lateral displacement, and inter-storey drift, allowing engineers to assess structural performance and identify critical weaknesses. With rapid urbanization expanding into hilly terrains, the safe and economical design of multistorey RC structures on sloping ground has become a pressing engineering challenge. Modern computational tools like ETABS and STAAD Pro make it possible to model slope geometry, mass irregularity, and lateral-resisting systems with precision. Incorporating additional elements such as shear walls and boundary elements can significantly enhance stiffness and ductility, leading to improved seismic resilience. This study therefore focuses on the seismic analysis of a multistorey RC building located on sloping ground, comparing its performance with equivalent models on flat terrain and with integrated shear-wall systems. The findings aim to contribute toward safer design practices and better code-based understanding of slope-induced irregularities in Indian seismic conditions.

1.1 Problem Statement

Buildings constructed on sloping ground exhibit complex and irregular behavior under seismic loading due to the variation in column heights, non-uniform mass distribution, and unequal stiffness along both vertical and horizontal axes. These geometric and structural irregularities introduce torsional effects, uneven lateral-force distribution, and stress concentration in shorter uphill columns, making such structures more vulnerable to damage during earthquakes. Conventional seismic design provisions and analytical methods prescribed in design codes have primarily been developed for regular buildings on flat ground, where mass and stiffness are symmetrically distributed. As a result, they may not fully capture the dynamic response characteristics of buildings situated on inclined terrains. The inadequacy of such conventional approaches can lead to underestimation of seismic demands and unsafe design in hilly regions. Therefore, it becomes essential to carry out a detailed seismic analysis of multistorey buildings on sloping ground, in accordance with *IS 1893 (Part 1): 2016 – Criteria for Earthquake Resistant Design of Structures*, to accurately evaluate their base shear, fundamental natural period, storey displacement, and inter-storey drift. This study aims to investigate how slope geometry and structural configuration influence seismic performance and to develop recommendations that ensure the safe, ductile, and economical design of buildings in seismically active hilly terrains of India.

2. LITERATURE REVIEW

A literature review is an essential component of any scientific study, providing an overview of existing research and helping to establish the theoretical and analytical foundation of the present work. In the context of seismic engineering, understanding previous investigations on the behavior of buildings subjected to earthquake forces is crucial for identifying gaps and developing improved analytical approaches.

Several studies have been conducted on the seismic performance of reinforced-concrete (RC) buildings; however, most focus on structures resting on flat ground where mass and stiffness are uniformly distributed. In contrast, buildings constructed on sloping ground display geometric and structural irregularities due to variation in column heights and stepped foundations, resulting in complex dynamic behavior during earthquakes. These irregularities often cause torsional effects, short-column behavior, and non-uniform lateral-force distribution, increasing vulnerability to seismic damage. This study reviews previous national and international studies related to seismic response of multistorey buildings on flat and sloping ground, the influence of slope geometry and soil conditions, and the effectiveness of lateral-load-resisting systems such as shear walls and dual systems. The objective is to understand the evolution of analytical models, highlight key findings, and identify research gaps that justify the need for the present study.

2.1 Related Work

Khatri *et al.* (2025) carried out a comparative seismic study of reinforced-concrete buildings constructed on flat and sloping terrain using ETABS v22.0.0 in compliance with *NBC 105:2020*. The analysis covered seven structural configurations, including step-back, step-back set-back, and flat-ground buildings, positioned on slopes of 0°, 15°, 25°, and 35°. Using the Response Spectrum Method, the researchers examined parameters such as fundamental time period, top-storey displacement, drift, and storey stiffness. The results revealed that as slope inclination increases, fundamental period and base shear decrease, while stiffness irregularity and torsional effects intensify. The study concluded that steeper slopes, though reducing base shear, lead to greater torsional response and soft-storey formation, necessitating careful design consideration in hilly regions. **Anuradha *et al.* (2025)** emphasized the importance of combining modern software-based analysis tools with conventional design methods to enhance the seismic safety of multistorey structures. Their study involved a comprehensive seismic analysis of a multistorey RC building located on sloping ground with a soft-storey configuration, using ETABS software. The analysis focused on evaluating storey displacement, drift, and base shear to assess seismic performance. The incorporation of bracing systems at soft-storey levels was explored as a strategy to minimize deflections within the permissible limits specified by IS standards. The authors concluded that integrating ETABS with traditional design approaches significantly improves accuracy, efficiency, and structural resilience in earthquake-prone regions.

Veera Babu *et al.* (2023) investigated the seismic behavior of multistorey RC buildings on flat and sloping ground using the Response Spectrum Method in ETABS. Considering rapid urbanization in hilly regions, the study analyzed models with two different slope angles under Seismic Zone II conditions to compare their performance with level-ground buildings. Key parameters such as storey shear, drift, bending moments, and displacement were evaluated. The results revealed that buildings on sloping terrain experience higher lateral displacements, torsional effects, and irregular force distribution due to asymmetry in stiffness and geometry. The authors concluded that slope-specific design configurations are essential to enhance seismic safety and minimize earthquake-induced damage in hilly regions. **Supraja Parsa *et al.* (2022)** examined the seismic behavior of irregular multistorey RC buildings constructed on sloping and flat ground using the Response Spectrum Method. The study considered two slope inclinations—5° and 10°—and analyzed the models under Seismic Zone V conditions to compare their dynamic responses. Key parameters such as storey displacement, base shear, bending moments, and storey drift were evaluated. The findings revealed that buildings on sloping ground exhibit greater lateral displacements, torsional coupling, and irregular force distribution due to asymmetry in stiffness and mass. The authors concluded that slope configuration significantly affects seismic performance and emphasized the need for slope-adaptive structural design in hilly regions.

Puri *et al.* (2021) performed a seismic analysis of a G + 5 reinforced-concrete building situated on different slope angles of 0°, 15°, and 30° using ETABS 18.0.2. The study employed a linear static analysis approach following *IS 1893 (Part 1): 2016* to evaluate the structural response under earthquake loading. Key parameters such as storey drift, storey shear, overturning moment, and maximum storey displacement were compared for all slope conditions. The results showed that as the slope angle increases, storey shear and displacement values rise, indicating greater seismic vulnerability. The study concluded that slope inclination significantly affects stability and should be carefully addressed in seismic design. Ratnakala et al. (2021) investigated the seismic performance of G + 12 multistorey RC buildings located on both flat and sloping ground (20° inclination) using the Equivalent Static Method of analysis. The study considered ten analytical models, including variations with infill walls, different shear wall arrangements, and soft-storey configurations. The results demonstrated that slope inclination significantly influences the structural response, causing higher base shear, displacement, and storey drift in sloping-ground models compared to flat-ground ones. The inclusion of shear walls and infill panels effectively enhanced lateral stiffness, reduced drift, and improved overall seismic stability, making them essential for earthquake-resistant design in hilly terrains. **Abu Zafar Mohammed Irfan *et al.* (2018)** presented a review on the seismic behavior of multistorey buildings constructed on sloping ground, focusing on the combined effects of earthquake-induced ground shaking and landslides. The study referenced observations from the 2011 Sikkim earthquake, which revealed poor seismic performance of RC buildings located on hill slopes even under moderate shaking. It emphasized that buildings on slopes, with foundations at varying levels, exhibit mass and stiffness irregularities, leading to torsional responses and greater lateral displacements. The review concluded that such buildings experience higher base shear and displacement than those on flat ground, with short columns attracting larger forces and being more prone to seismic damage, especially in step-back configurations. **Ikhitharadhya *et al.* (2016)** analyzed the seismic performance of a G + 10 reinforced-concrete building constructed on sloping ground with slope angles ranging from 10° to 30°, comparing the results with those of an equivalent building on flat terrain. The modeling and analysis were performed in ETABS 2015 using the Response Spectrum Method as per *IS 1893 (Part 1): 2002*. The study evaluated key response parameters such as top-storey displacement, storey acceleration, base shear, and mode period. The results indicated that the short columns on the uphill side experienced higher shear and bending moments during seismic loading, confirming that slope-induced irregularity significantly increases vulnerability to earthquake damage.

Sontakke *et al.* (2015) conducted a seismic analysis of 48 reinforced-concrete buildings with three configurations step-back, step-back set-back, and set-back commonly adopted in hilly regions of northern India. Using three-dimensional response spectrum analysis that incorporated torsional effects, the study examined key response parameters such as fundamental time period, top-storey displacement, and base shear in columns to evaluate the suitability of each configuration on sloping ground. The results indicated that irregular geometry and mass–stiffness variations lead to torsional coupling and uneven force distribution. Among all configurations, the step-back set-back building showed the most favorable seismic performance, making it the most suitable form for construction on hilly terrain. **Birajdar and Nalawade (2004)** conducted a seismic analysis of 24 reinforced concrete buildings with three configurations—step-back, step-back set-back, and set-back constructed on sloping ground. Using three-dimensional response spectrum analysis including torsional effects, they examined parameters such as fundamental time period, top-storey displacement, and base shear in columns. The results showed that slope-induced irregularity significantly affects structural behavior, leading to uneven force distribution and higher stresses in shorter columns. Among the configurations, the step-back set-back building performed best, showing balanced stiffness, reduced displacement, and uniform base shear. The study concluded that this configuration provides superior seismic performance and is most suitable for construction on hilly terrains.

2.2 Research Gap

Previous studies have extensively analyzed the seismic performance of buildings resting on plain ground; however, limited research has been conducted on multistorey structures constructed on sloping terrain, which exhibit complex behavior under lateral seismic forces. Most existing literature focuses on regular and symmetric buildings, often neglecting the irregularity in mass and stiffness distribution that occurs on sloping ground conditions. Moreover, while conventional analytical approaches such as the equivalent static or response spectrum methods have been widely applied, fewer studies have utilized advanced modeling software like ETABS to simulate the nonlinear behavior of such structures with varying slope geometries. The influence of slope inclination, soil-structure interaction, and the placement of shear walls or boundary elements are also not sufficiently explored. Furthermore, comparative assessments between buildings on flat and sloping sites, particularly in the context of displacement, story drift, and base shear response, remain inadequate. This gap indicates the need for a detailed numerical analysis to evaluate the seismic response of multistorey buildings on sloping ground using ETABS, thereby contributing to a more comprehensive understanding of structural behavior and aiding in the formulation of improved design guidelines for earthquake-resistant construction in hilly regions.

3. RESEARCH METHODOLOGY

The research methodology outlines a systematic approach to evaluate the seismic performance of G+10 RC buildings on sloping ground. Since sloped buildings exhibit mass and stiffness irregularities, a quantitative comparative analysis is performed using the Response Spectrum Method (RSM). Three structural configurations. (i) flat ground, (ii) sloping ground, and (iii) sloping ground with a dual system of shear walls and boundary elements are modeled and analyzed in ETABS 2022. The analysis follows IS 1893 (Part 1): 2016, IS 456:2000, IS 875 (Parts 1–5):1987, and IS 13920:2016 considering Zone V (Z = 0.36) and medium soil conditions. All models are analyzed under identical material, geometry, and loading parameters for accurate comparison. The study evaluates key seismic responses including base shear, time period, storey displacement, and drift to assess the impact of slope and lateral load–resisting systems, ultimately supporting safer design practices for hilly regions.

3.1 Research Approach

The present research adopts an analytical and comparative approach to evaluate the seismic behavior of multistorey reinforced-concrete (RC) buildings resting on sloping ground. The methodology is based on linear dynamic analysis using the Response Spectrum Method (RSM), which is widely recognized for assessing the dynamic characteristics of structures subjected to earthquake loading. This approach enables the study of multiple structural configurations under identical boundary conditions, thereby providing an accurate comparison of their seismic performance.

Three distinct building models are considered for analysis:

1. A G + 10 RC Moment Resisting Frame (MRF) building on flat ground.
2. A G + 10 RC MRF building on sloping ground with an inclination of approximately 27°.
3. A G + 10 Dual System comprising an RC MRF with shear walls and boundary elements.

Each model is developed in ETABS 2022 and analyzed using the Response Spectrum Method as per IS 1893:2016, IS 456:2000, IS 13920:2016, and IS 875 load combinations. Dynamic parameters including time period, base shear, storey displacement, and drift are extracted to assess seismic performance. Results are compared to evaluate slope effects and shear wall efficiency, ensuring a code-compliant identification of the most stable configuration for hilly seismic regions.

3.3 Model Description

The study considers a G + 10 reinforced-concrete (RC) multistorey building to examine the influence of sloping ground on seismic performance. The analysis and modeling are carried out using ETABS 2022, which performs three-dimensional finite element analysis based on the Response Spectrum Method. The building has a plan dimension of 20 m × 20 m, with a storey height of 3.2 m, resulting in an overall height of 35.2 m above ground level. The beam and column cross-sections are 300 × 450 mm and 450 × 600 mm respectively, while the slab thickness is 150 mm. The building is modeled as a moment-resisting frame (MRF) with rigid diaphragm action at each floor to distribute lateral loads evenly.

Three distinct configurations are analyzed to evaluate the effect of slope geometry and lateral stiffness:

1. Case 1: G + 10 RC MRF on flat ground (regular configuration).
2. Case 2: G + 10 RC MRF on sloping ground with an inclination of 27°.
3. Case 3: G + 10 dual system comprising MRF with shear walls and boundary elements.

Material properties are consistent across all models with M30 concrete and Fe500 steel. Seismic parameters are taken as per *IS 1893 (Part 1): 2016*—Zone V (Z = 0.36), Importance Factor (I = 1.0), and Response Reduction Factor (R = 3 for MRF, 5 for dual system). The base is assumed fixed, and medium soil (Type II) conditions are considered. All models are analyzed dynamically to ensure at least 90% modal mass participation, enabling reliable comparison of slope and configuration effects.

3.4 Load Considerations

Loads are defined as per IS 875 and IS 1893. Dead load includes self-weight, masonry, and finishes; live load is 4 kN/m² (floor) and 1.5 kN/m² (roof), with 25% considered for seismic mass. Seismic parameters include Zone V (0.36), medium soil, I=1.0, R=3 (MRF) and 5 (dual). Load combinations like 1.5(DL±EQ) and 1.2(DL+LL±EQ) ensure realistic gravity and seismic representation.

3.5 Analysis Methodology

Seismic analysis is performed using the Response Spectrum Method as per IS 1893:2016 for G+10 RC models—flat, sloping, and dual system—in ETABS 2022. Zone V, medium soil, and 5% damping are considered. Modal analysis determines natural period and modes, base shear is computed and scaled per code, and results for displacement, drift, and shear are compared to assess slope and shear wall effects.

3.6 Modeling in ETABS

Modeling and analysis of flat, sloping, and dual RC frames are performed in ETABS 2022 using 3D frame elements, rigid diaphragms, fixed supports, M30 concrete, Fe500 steel, IS 1893 loads, 27° slope, and Response Spectrum results for displacement and base shear.

4. ETABS MODELLING

This study presents the detailed modeling process of the multistorey reinforced concrete (RC) building using ETABS 2022. The software provides a powerful platform for three-dimensional analysis and design of structures under static and dynamic loading conditions. The modeling process involves defining the building geometry, material properties, section dimensions, loading patterns, boundary conditions, and response spectrum functions in accordance with the Indian Standards—IS 1893 (Part 1): 2016, IS 456: 2000, IS 875 (Parts 1–5): 1987, and IS 13920: 2016.

Three models of a G + 10 RC building were developed to analyze the influence of ground slope and lateral-load-resisting systems on seismic performance:

- **Model 1:** G + 10 RC MRF on flat ground (regular configuration)
- **Model 2:** G + 10 RC MRF on sloping ground with an inclination of 27°.
- **Model 3:** G + 10 Dual System comprising an RC MRF with shear walls and boundary elements.

Each model was created under identical geometric and loading conditions, ensuring that observed variations in response parameters are solely due to differences in slope and structural configuration.

5.1 Modeling Procedure

The modeling process in ETABS was performed systematically as per the following steps:

1. **Creation of Grid System and Geometry:**

   A 20 m × 20 m plan was established with a storey height of 3.2 m, giving a total height of 35.2 m. A 5 × 5 grid layout was generated to define column and beam locations.

2. **Assignment of Material Properties:**
   Concrete of grade M30 and reinforcement steel of grade Fe500 were defined. Material properties, including modulus of elasticity, Poisson's ratio, and unit weight, were entered as per IS 456: 2000.

3. **Definition of Structural Sections:**
   - Beam: 300 mm × 450 mm
   - Column: 450 mm × 600 mm
   - Slab thickness: 150 mm
   - Shear wall: 250 mm thick (in Model 3)

4. **Modeling of Sloping Ground Condition:**
   For Model 2 and Model 3, the base level was inclined at a 27° slope. Column heights were adjusted in accordance with the natural ground profile, resulting in shorter uphill and longer downhill columns. This setup simulated realistic topoFigureical irregularity and torsional stiffness variation.

5. **Assignment of Loads:**
   - **Dead Load (DL):** Self-weight automatically considered by ETABS, plus floor finishes (1.0 kN/m²) and wall loads (13.8 kN/m external, 9.2 kN/m internal).
   - **Live Load (LL):** 3.0 kN/m² on typical floors and 1.5 kN/m² on the roof (IS 875 Part 2: 1987).
   - **Seismic Load (EQ):** Defined automatically using IS 1893 (Part 1): 2016 parameters (Zone V, medium soil, I = 1.0, R = 3 for MRF, R = 5 for dual system).

6. **Boundary Conditions:**
   Fixed supports were assigned at the base for all models, assuming negligible foundation flexibility. Rigid diaphragm action was provided at each floor level to distribute lateral loads evenly.

7. **Load Combinations:**
   The following combinations were defined in accordance with IS 456 and IS 1893:
   - 1.5 (DL + LL)
   - 1.5 (DL ± EQx)
   - 1.5 (DL ± EQy)
   - 1.2 (DL + LL ± EQx)
   - 1.2 (DL + LL ± EQy)
   - 0.9 DL ± 1.5 EQx
   - 0.9 DL ± 1.5 EQy

5.2 Response Spectrum Definition

A design response spectrum for Zone V and medium soil conditions was defined in ETABS using 5% damping, as per IS 1893 (Part 1): 2016, Clause 6.4.5. The spectrum was input in terms of acceleration coefficient (Sa/g) versus natural period (T). The dynamic analysis considered both X and Y directions, automatically combining modal responses using the Square Root of Sum of Squares (SRSS) method.

5.3 Model Validation

The following checks were conducted to validate the ETABS models:

- **Modal Mass Participation:** Verified to exceed 90% in both X and Y directions as required by Clause 7.8.4.2 of IS 1893.
- **Natural Period Comparison:** Analytical periods were compared with empirical values from IS 1893, showing good agreement.
- **Base Shear Check:** Total modal base shear was verified to be ≥ 0.8 times the static base shear.
- **Drift Limit Check:** Maximum inter-storey drift was below the permissible $0.004h_s$ limit as per Clause 7.11.1 of IS 1893.

5.4 Modelling

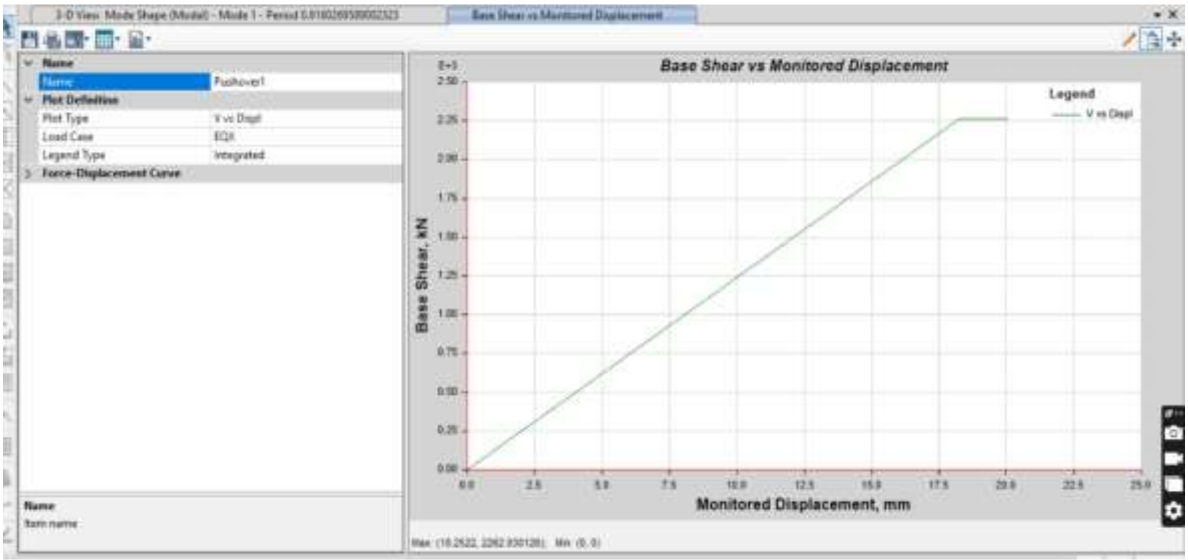

Fig 1 Base Shear vs Monitored Displacement Curve from Pushover Analysis

The Figure 1. shows a linear increase in base shear with monitored displacement up to around 18 mm, indicating elastic behavior. Beyond this point, the curve flattens, suggesting that the structure has reached its yield limit and entered the plastic deformation stage.

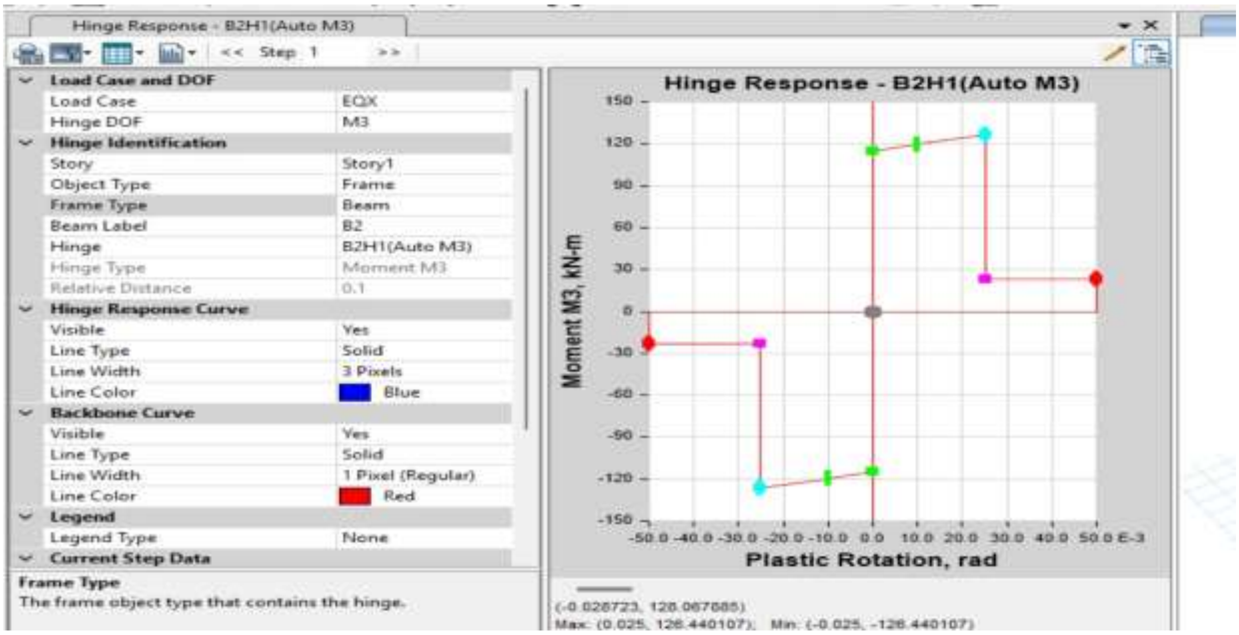

Fig .2. Hinge Response Curve for Beam B2 at Story 1 (Moment M3)

The hinge response curve illustrates the moment (M3) versus plastic rotation behavior of Beam B2. The plot shows that the hinge undergoes elastic deformation initially, followed by yielding and limited plastic rotation, indicating that the beam section develops controlled inelastic behavior without significant strength degradation.

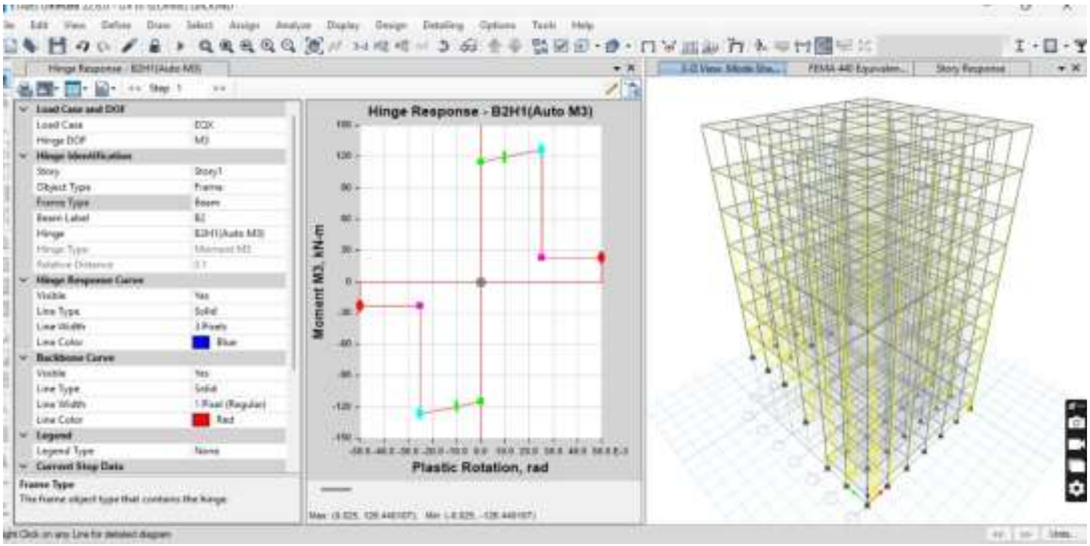

Fig 3. Hinge Response (Moment M3) and 3D Structural Model under EQX Load Case

The hinge response curve represents the moment–plastic rotation behavior of Beam B2, showing elastic to plastic transition under seismic loading. The adjoining 3D model highlights the structural framework with hinge formations, indicating that the building exhibits localized plastic behavior while maintaining overall structural stability.

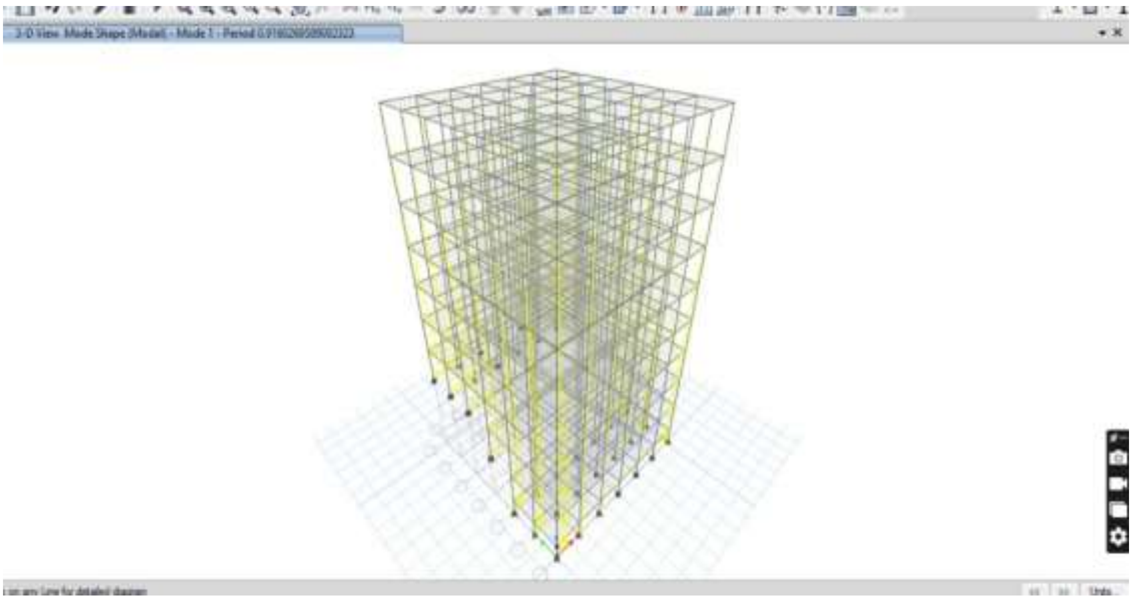

Fig 4. 3D View of Mode Shape (Modal Analysis) – Mode 1

The figure 4 illustrates the first mode shape of the building model, representing its fundamental vibration pattern. The maximum displacement occurs at the top, indicating lateral sway due to seismic excitation, while the base remains fixed, showing typical dynamic behavior of multi-storey frames.

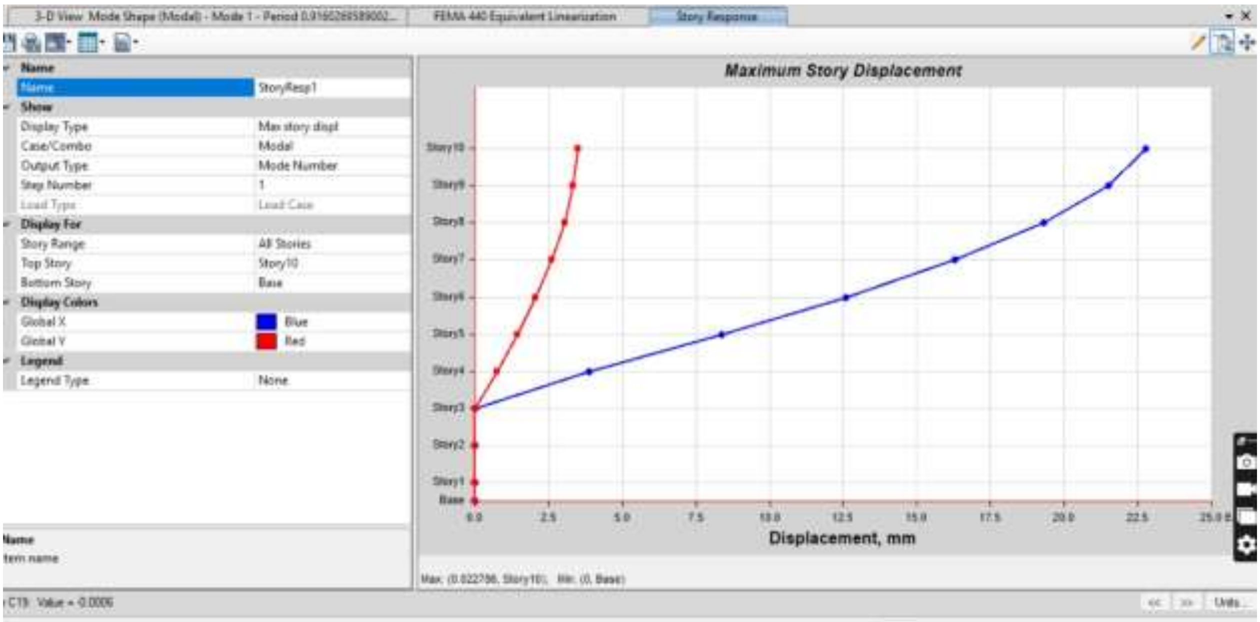

Fig 5. Maximum Story Displacement Curve

The figure 5. illustrates the first mode shape of the building model, representing its fundamental vibration pattern. The maximum displacement occurs at the top, indicating lateral sway due to seismic excitation, while the base remains fixed, showing typical dynamic behavior of multi-storey frames.

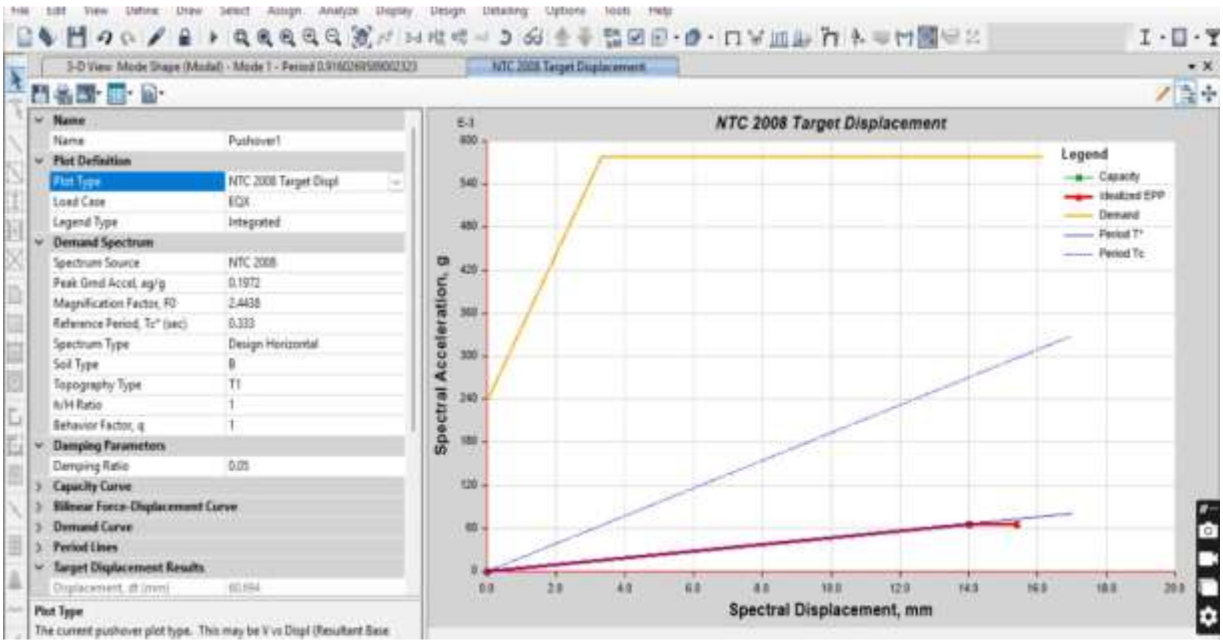

Fig 6. NTC 2008 Target Displacement Curve

The figure 6 represents the relationship between spectral acceleration and spectral displacement under the NTC 2008 standard. The intersection point of the capacity and demand curves defines the target displacement, indicating the structure's performance level. The Figure shows that the building maintains stability within the expected displacement limits under the applied seismic demand.

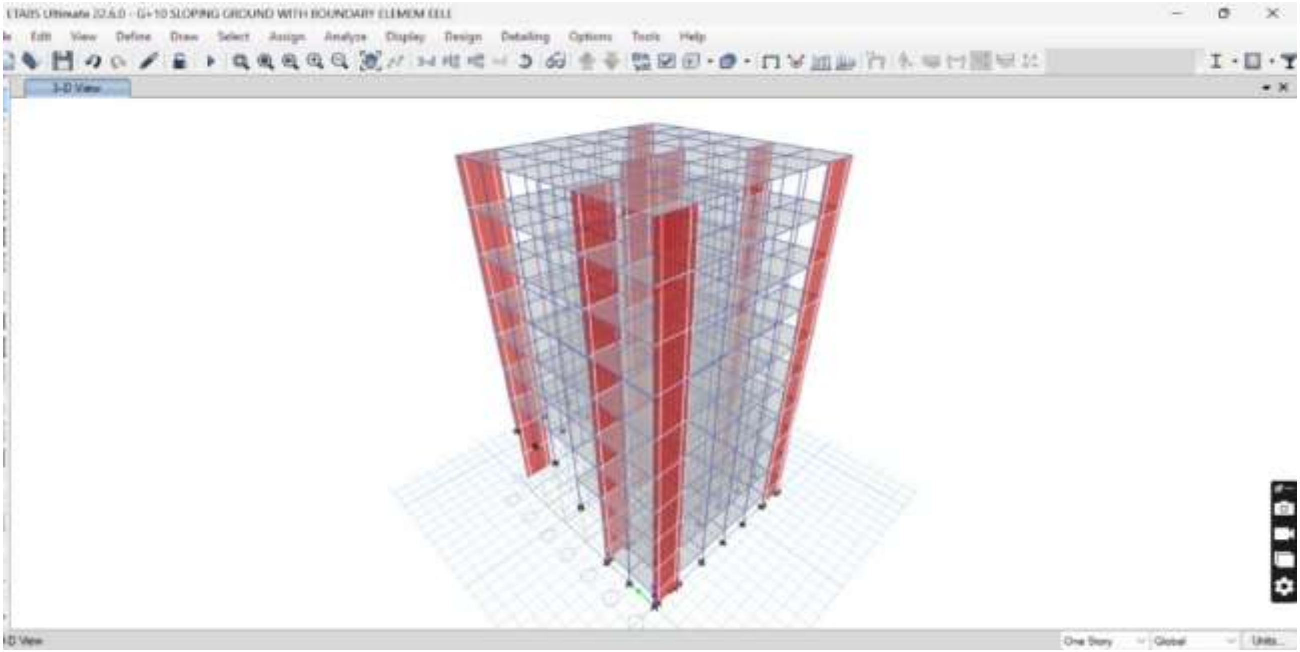

Fig 7. 3D View of G+10 Building Model on Sloping Ground with Boundary Elements

The figure 7 shows a 3D ETABS model of a G+10 building designed on sloping ground, incorporating boundary elements for enhanced structural stiffness and strength. The red-colored boundary elements indicate shear walls that provide lateral stability and improve the building's resistance against seismic and wind forces.

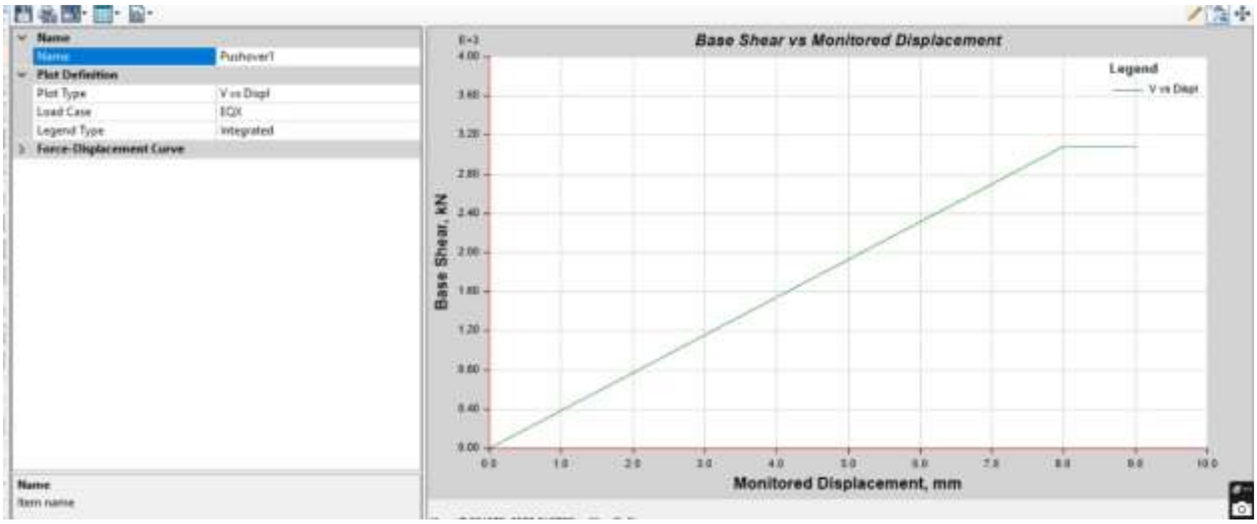

Fig 8. Base Shear vs Monitored Displacement Curve

The Figure 8. illustrates the relationship between base shear and monitored displacement during the pushover analysis. Initially, the base shear increases linearly with displacement, indicating elastic behavior. Beyond a certain point, the curve flattens, showing the structure entering the plastic range where stiffness reduces and yielding begins.

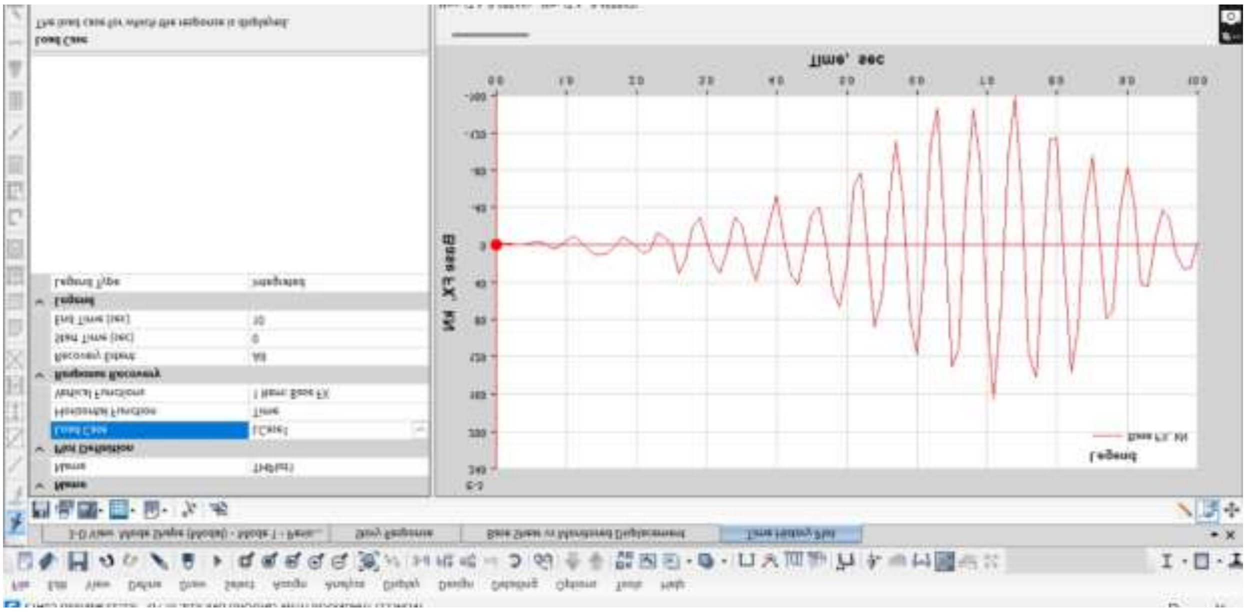

Fig 9. Time History Plot of Base Shear (Base FX)

The figure 9 shows the variation of base shear with time during a dynamic time history analysis. The oscillations indicate the structure's response to seismic loading, with peak shear forces occurring between 6 to 8 seconds. The gradual decay of amplitude after the peak suggests energy dissipation and stabilization of structural vibrations over time.

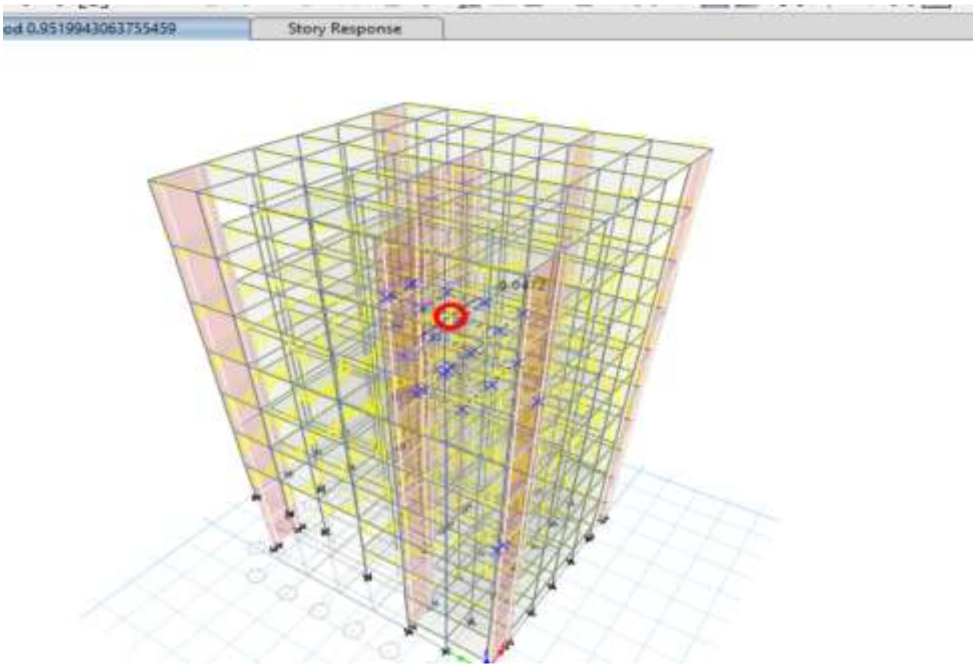

Fig 10. 3D Structural Model Showing Story Response in ETABS

The figure 10. represents the deformation response of a multistory building model under lateral loading in ETABS. The highlighted red circle indicates the point of maximum displacement, suggesting the building's peak lateral drift occurs at that location.

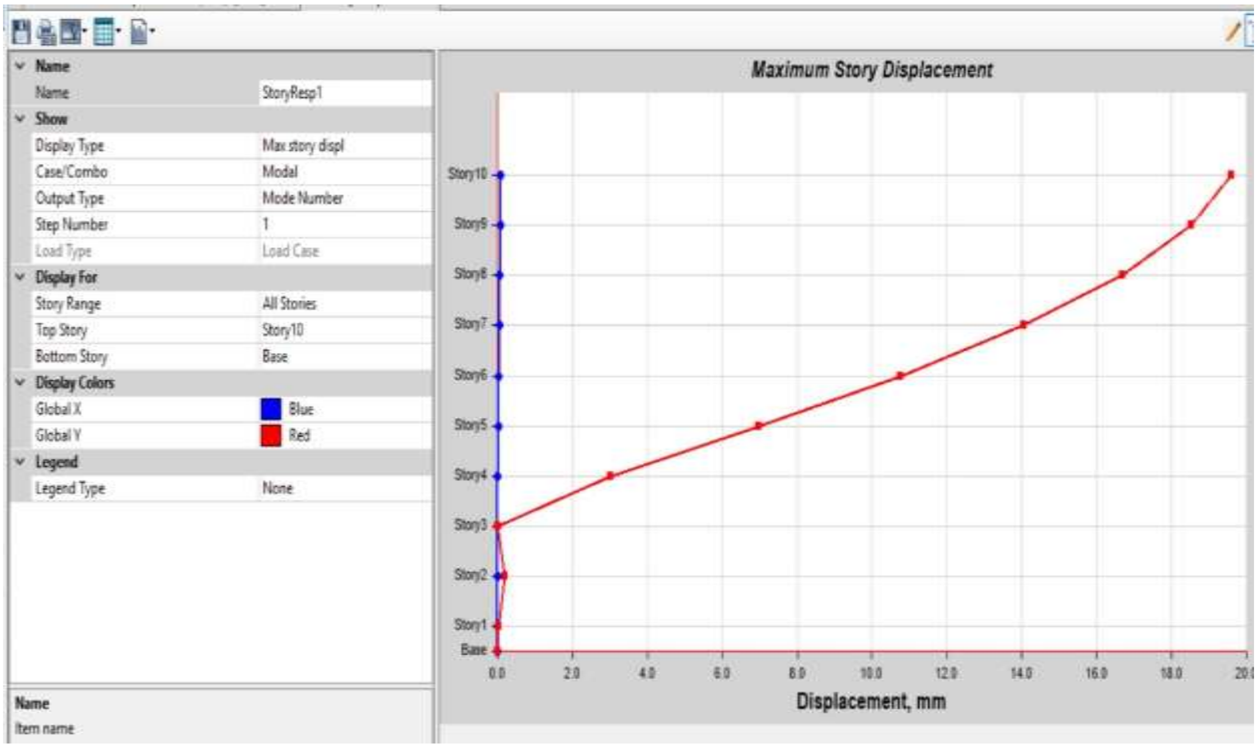

Fig 11. Maximum Story Displacement Curve

The Figure 11 illustrates the variation of maximum lateral displacement along the building height. The displacement increases gradually from the base to the top story, indicating typical flexible building behavior under lateral (modal) loading, with the highest deformation occurring at the roof level.

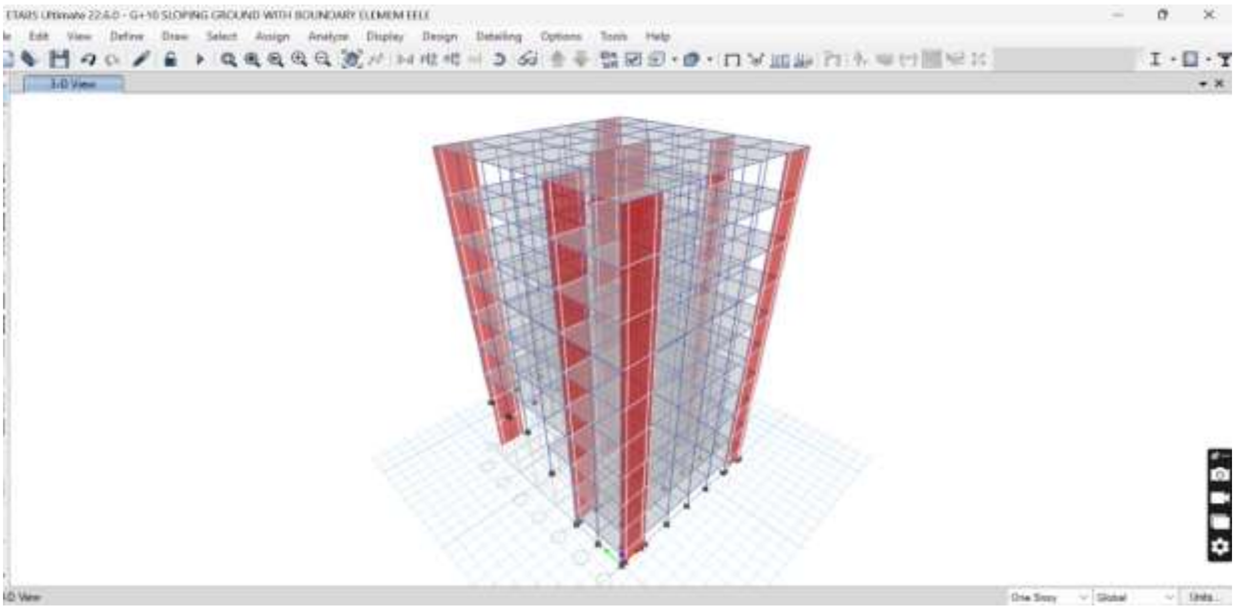

Fig 12. 3D ETABS Model of G+10 Building with Shear Walls on Sloping Ground

The figure 12 shows the structural model of a G+10 building analyzed on sloping ground, incorporating boundary elements along the shear walls. The red-highlighted regions represent shear walls that enhance the building's lateral stiffness and resistance against seismic or wind loads.

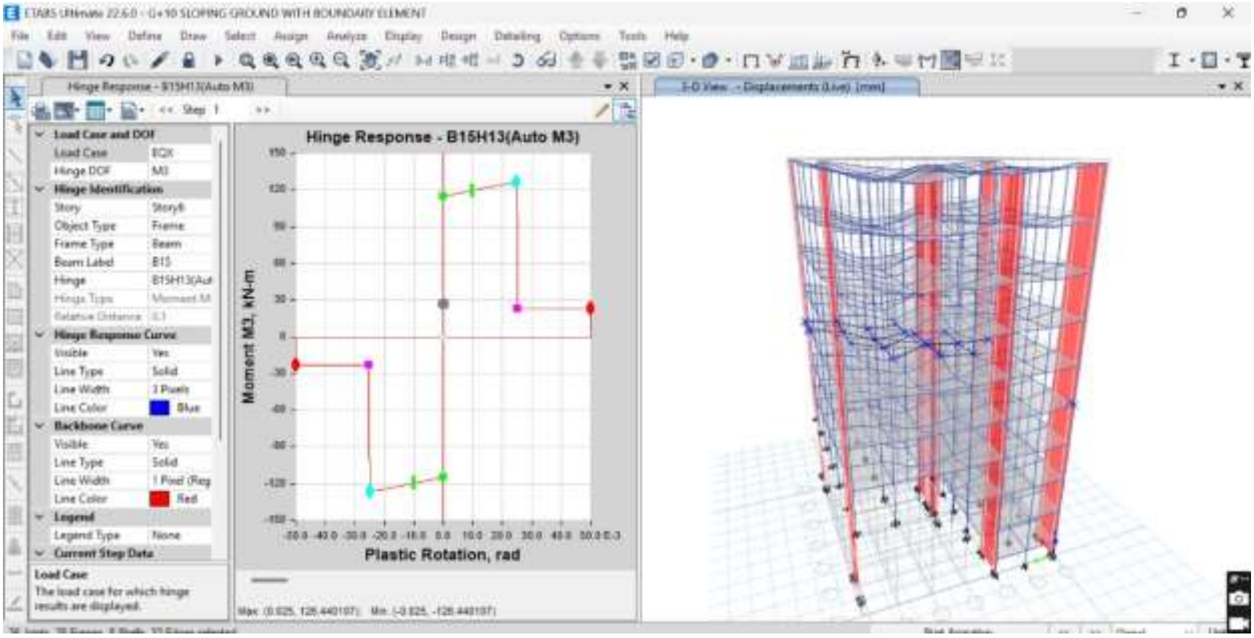

Fig 13. Hinge Response Curve and Structural Deformation in ETABS

The figure 13 displays the hinge response curve for a beam element alongside the 3D model of the building under lateral loading. The moment–rotation Figure shows the nonlinear behavior of the hinge, indicating the onset and progression of plastic deformation, which helps assess the structure's ductility and performance under seismic conditions.

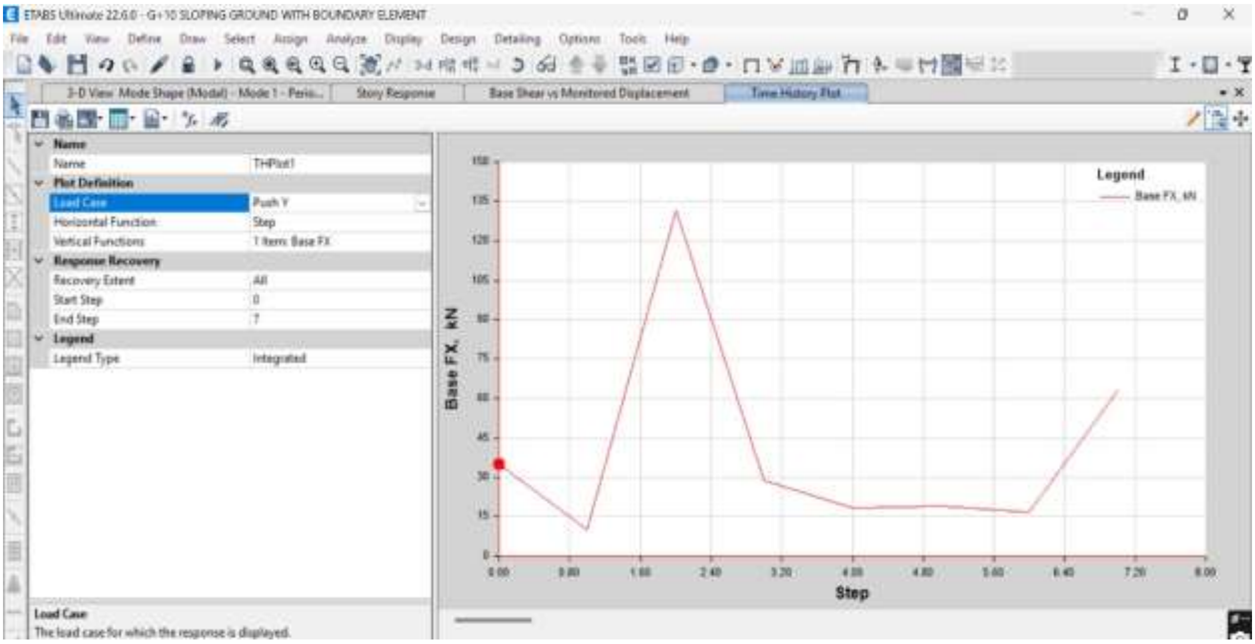

Fig 14. Time History Plot of Base Shear (FX) for Push Y Load Case

The Figure 14 shows the variation of base shear (FX) in kN over time steps during the Push Y load case. The base shear initially decreases, peaks sharply around Step 2.4, and then drops before slightly rising again—indicating nonlinear structural behavior and possible energy dissipation during the loading process.

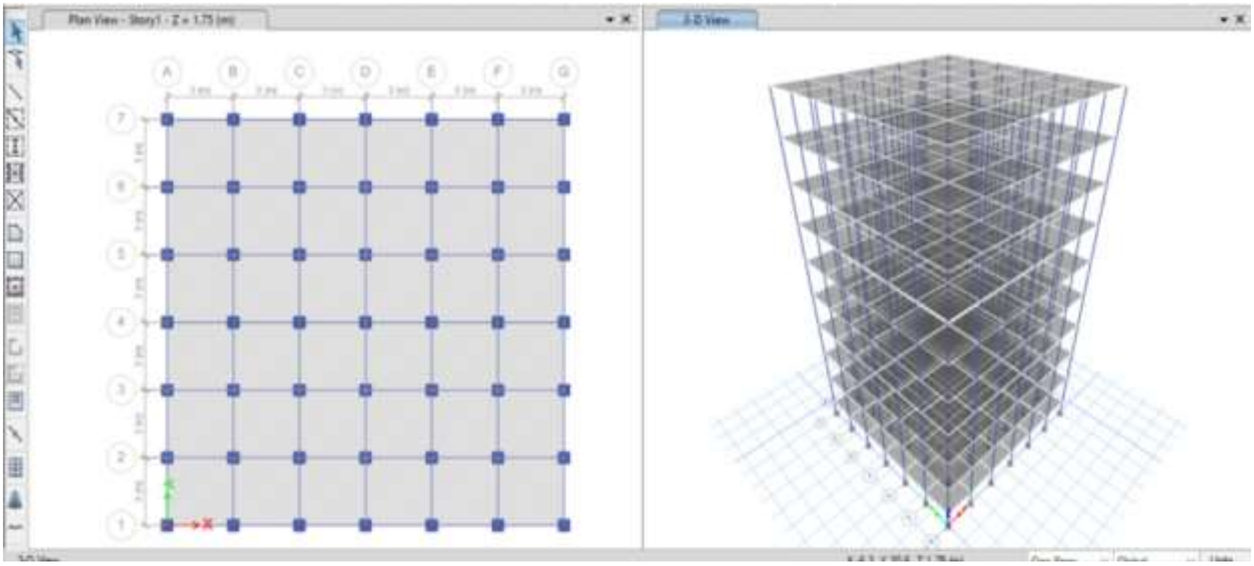

Fig 15. Plan and 3D View of the Structural Model

The figure 15 illustrates the structural configuration of a multi-storey building modeled in ETABS. The left side shows the plan view with a regular grid layout (7×7 bays), while the right side presents the 3D view, displaying the overall geometry and interconnection of beams, columns, and floors in the structure.

Fig 16. Maximum Story Displacement Curve

The figure 16 shows the variation of maximum story displacement along the building height in both the X (blue) and Y (red) directions. It can be observed that displacement increases gradually from the base to the top story, indicating the building's lateral flexibility and overall deformation behavior under the applied modal load case.

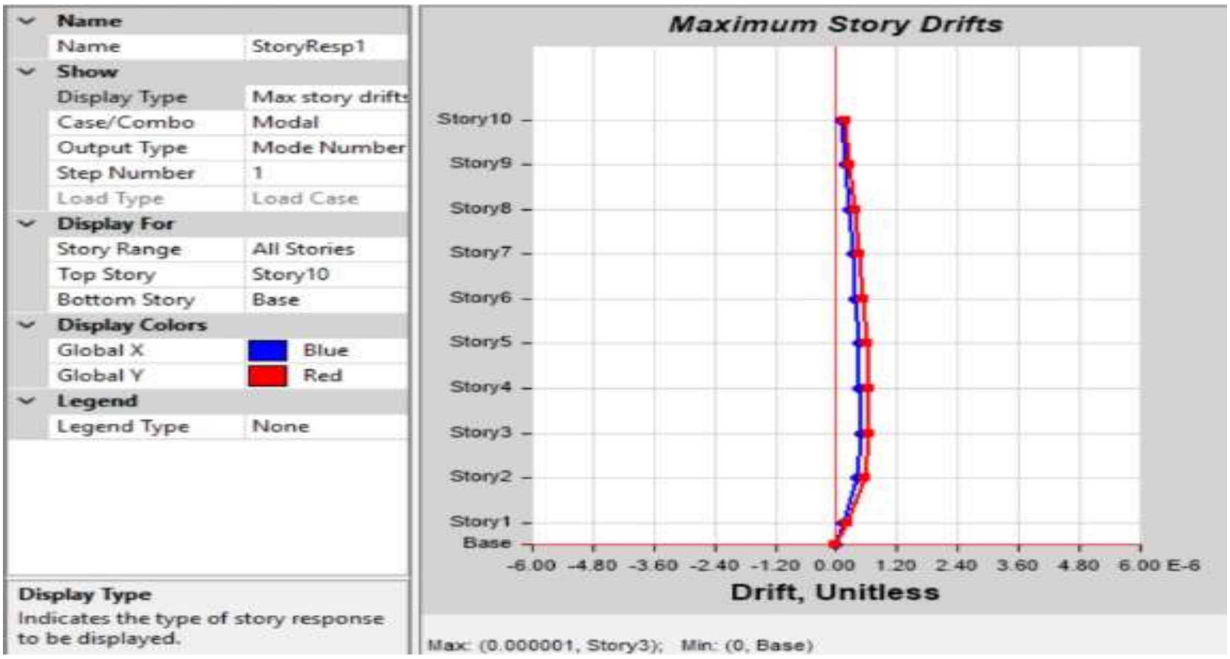

Fig 17. Maximum Story Drift Curve

The figure 17 represents the maximum story drift distribution along the building height in both X (blue) and Y (red) directions. The drift values are minimal and remain within permissible limits, indicating that the structure exhibits adequate lateral stiffness and stability under the applied modal load conditions.

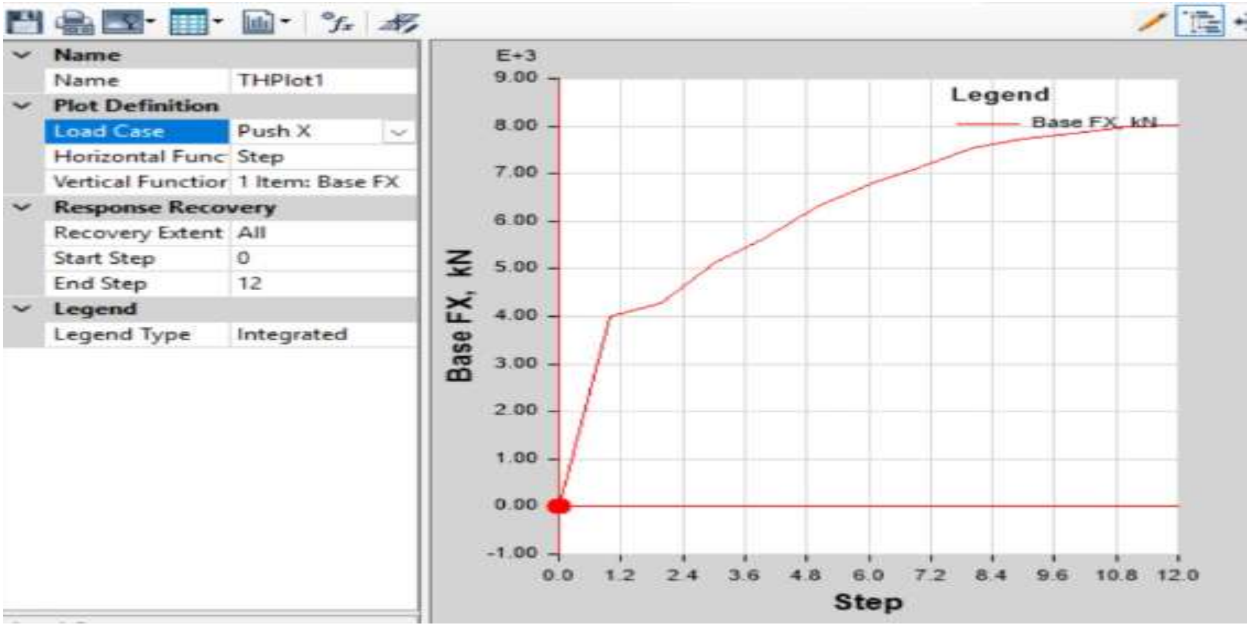

Fig 18. Base Shear versus Load Step Curve (Push X Direction)

The figure 18 depicts the variation of base shear with respect to load steps in the X direction obtained from pushover analysis. The increasing trend of base shear indicates that the structure effectively resists lateral loads, with stiffness gradually reducing as loading progresses, signifying the nonlinear behavior of the building under applied forces.

6. RESULT AND DISCUSSION

This section presents the findings of the seismic analysis conducted on a multistorey building situated on sloping ground, comparing the effects of sloping ground, sloping ground with a boundary element, and a scenario without a shear wall. The results include the story displacement and drift in both the X and Y directions, as well as the base shear in both directions. Tables and figures illustrate the variations in displacement, drift, and shear for each condition across different story levels, from the base to Story 10. These results provide valuable insights into the structural behavior under various loading conditions and contribute to understanding the impact of different design modifications on the building's performance.

6.1 Story Displacement

Fig 19. Story Displacement in X Direction (mm)

The figure 19 illustrates the story displacement in the X direction for a multistorey building under three conditions: sloping ground, sloping ground with a boundary element, and without a shear wall. The displacement increases with each story level, with the highest displacement observed in the "Sloping Ground" condition, followed by "Without Shear Wall," and the lowest in the "Sloping Ground with Boundary Element" condition, demonstrating the effectiveness of the boundary element in reducing lateral displacement.

Fig 20. Story Displacement in Y Direction (mm)

The figure 20 shows the story displacement in the Y direction for a multistorey building under three conditions: sloping ground, sloping ground with a boundary element, and without a shear wall. Displacement increases with story level, with the highest values observed in the "Sloping Ground" condition. The "Sloping Ground with Boundary Element" condition results in the lowest displacements, indicating the effectiveness of the boundary element in reducing lateral displacement.

6.2 Story Drift

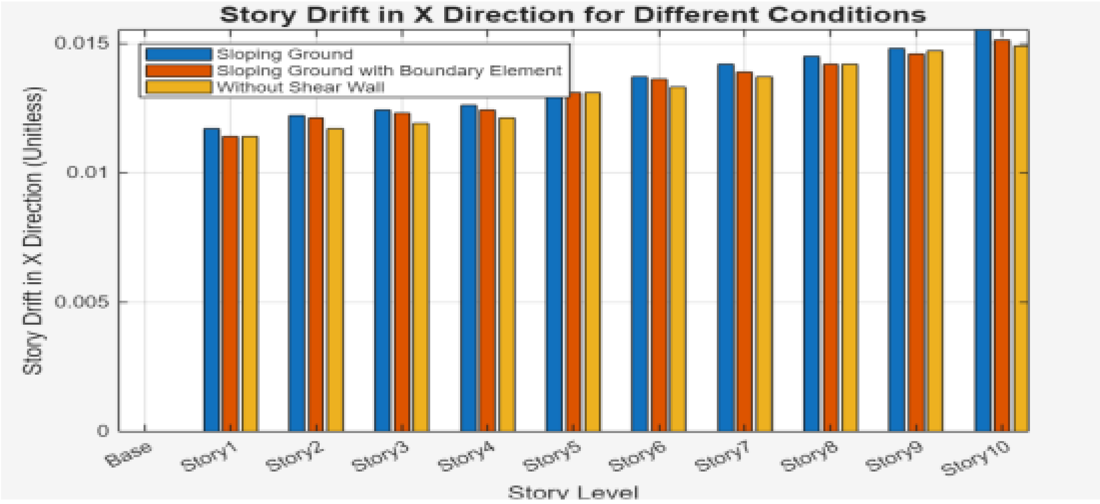

Fig 21. Story Drift in X Direction (Unitless)

The figure 21 displays the story drift in the X direction for a multistorey building under three conditions: sloping ground, sloping ground with a boundary element, and without a shear wall. The drift values are similar across all conditions for each story level, with only slight variations observed. The "Sloping Ground" and "Sloping Ground with Boundary Element" conditions exhibit almost identical drift values, while the "Without Shear Wall" condition shows slightly higher drift, indicating the effectiveness of the boundary element and shear wall in reducing lateral drift.

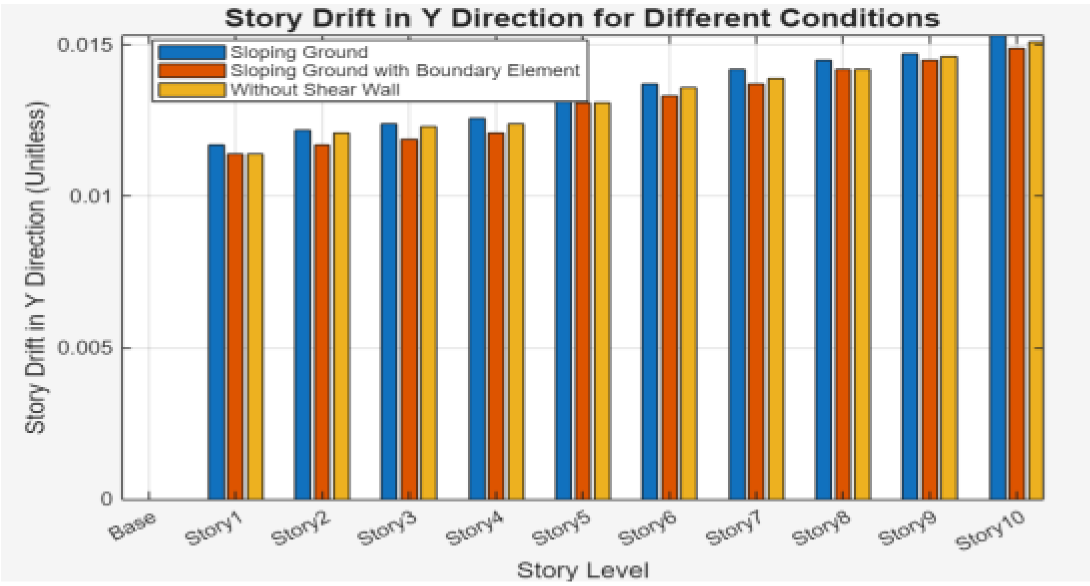

Fig 22. Story Drift in Y Direction (Unitless)

The Fig 22. shows the story drift in the Y direction for a multistorey building under three different conditions: sloping ground, sloping ground with a boundary element, and without a shear wall. The drift values remain almost identical across all conditions for each story level, with slight variations observed. The "Sloping Ground with Boundary Element" and "Sloping Ground" conditions exhibit nearly the same drift, while "Without Shear Wall" shows marginally higher drift, highlighting the boundary element's effectiveness in reducing lateral drift.

5.3 Base Shear

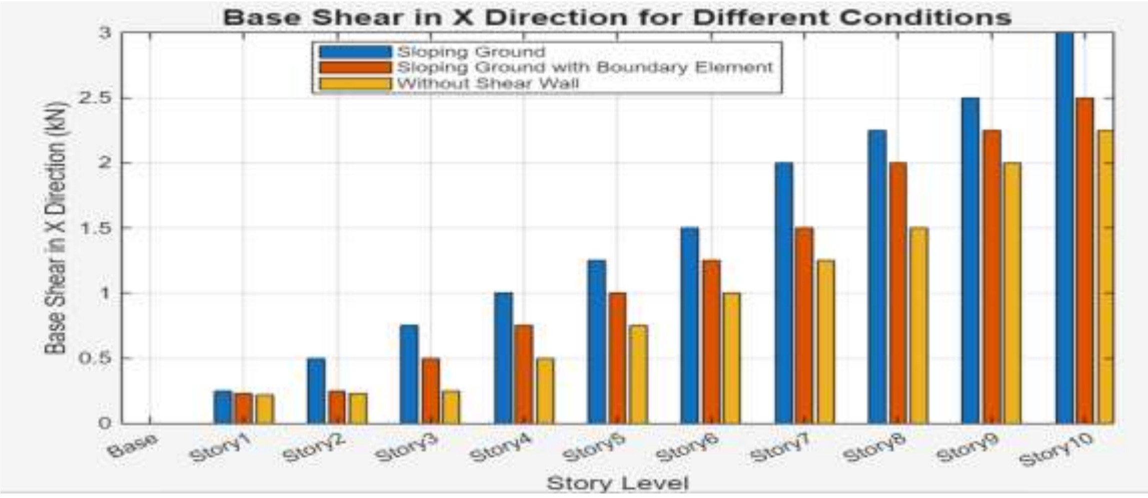

Fig 23. Base Shear in X Direction (kN)

The figure 23 illustrates the base shear in the X direction (kN) for a multistorey building under three different conditions: sloping ground, sloping ground with a boundary element, and without a shear wall. The base shear increases with higher story levels for all conditions, with the "Without Shear Wall" condition showing the highest base shear values, followed by "Sloping Ground," and the lowest values observed in the "Sloping Ground with Boundary Element" condition. This indicates that the boundary element reduces the lateral force distribution across the structure.

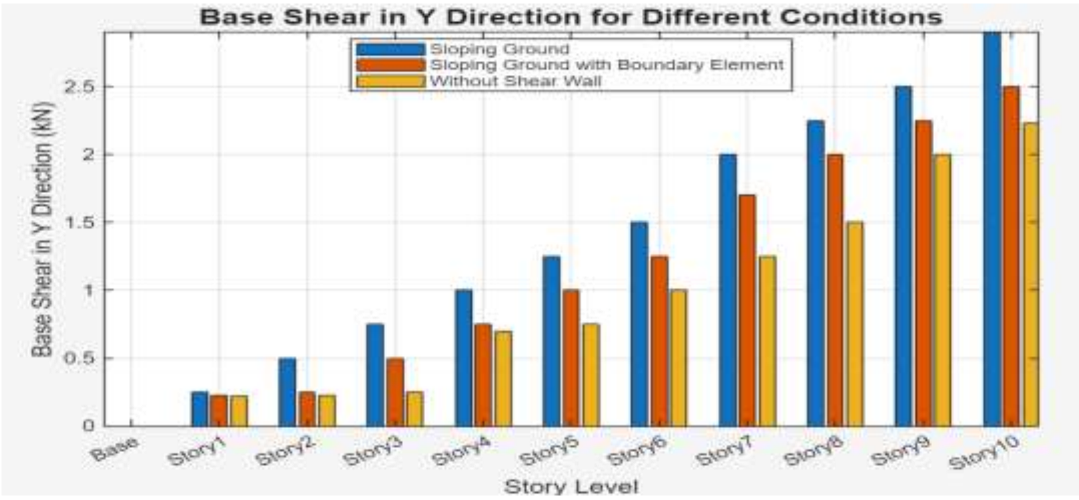

Fig 24. Base Shear in Y Direction (kN)

The figure 24 illustrates the base shear in the Y direction (kN) for a multistorey building under three conditions: sloping ground, sloping ground with a boundary element, and without a shear wall. The base shear increases as the story level rises for all conditions, with the "Without Shear Wall" condition showing the highest values, followed by "Sloping Ground," and the lowest values observed in the "Sloping Ground with Boundary Element" condition. This suggests that the boundary element effectively reduces the lateral force in the Y direction.

7. CONCLUSION

The seismic analysis of the multistorey building situated on sloping ground has provided valuable insights into its structural behavior under various loading conditions. The study compared three different scenarios: sloping ground, sloping ground with a boundary element, and a scenario without a shear wall. The results indicate that the inclusion of a boundary element significantly reduces lateral displacement, drift, and base shear in both the X and Y directions. In the X and Y direction displacement, it was observed that as the story level increases, displacement also increases for all conditions, with the highest displacement observed at Story 10. However, the displacement in the "Sloping Ground with Boundary Element" condition was notably lower compared to both the "Sloping Ground" and "Without Shear Wall" conditions. This demonstrates the boundary element's effectiveness in reducing lateral displacement.Similarly, the drift values were lowest in the "Sloping Ground with Boundary Element" condition across all story levels, indicating that the boundary element helps minimize lateral drift. The drift values for the "Sloping Ground" and "Sloping Ground with Boundary Element" conditions were nearly identical, while the "Without Shear Wall" condition exhibited slightly higher drift values.

Regarding the base shear, the "Sloping Ground with Boundary Element" consistently resulted in the lowest base shear values across all story levels, followed by the "Sloping Ground" condition, and the highest values were seen in the "Without Shear Wall" scenario. This trend was observed in both the X and Y directions, with the boundary element playing a critical role in reducing the lateral forces on the building structure. In conclusion, the analysis strongly supports the notion that incorporating boundary elements and shear walls significantly improves the seismic performance of multistorey buildings on sloping ground. These structural modifications help reduce displacement, drift, and base shear, thereby enhancing the building's stability in seismic zones. The findings provide valuable insights for designing earthquake-resistant buildings in sloping terrains and contribute to optimizing building performance in areas prone to seismic activity.

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