RESEARCHERID
THOMSON REUTERS

[Thakur, 11(10): October 2024] ISSN 2348 – 8034
Impact Factor- 5.070

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

DYNAMIC RESPONSE AND SEISMIC PERFORMANCE OF RCC BUILDINGS ON SLOPING TERRAIN: A COMPARATIVE ANALYSIS OF BRACED AND UNBRACED STRUCTURES

Akshay Thakur, Dr. Raghvendra Singh
Research Scholar (MTech), Ujjain Engineering College, Ujjain, M.P., India
Professor, Department of Civil Engineering, RGPV University, Bhopal Madhya Pradesh

ABSTRACT
This paper investigates the dynamic response and seismic performance of reinforced cement concrete (RCC) buildings constructed on sloping terrain. The study compares both braced and unbraced structures, analyzing their behavior under earthquake loading using the response spectrum method as per IS 1893:2016. A series of 12-story building models with varying slope angles (0°, 10°, 20°, and 30°) were analyzed using ETABS software to determine key parameters such as story displacement, drift, base shear, and fundamental time periods. Results indicate that braced buildings exhibit significantly better seismic performance, reducing both displacement and drift in comparison to unbraced structures. This research highlights the critical importance of structural bracing in enhancing earthquake resistance for buildings on sloping terrain, offering valuable insights for the design of resilient infrastructure in hilly areas prone to seismic activity.

Keywords: RCC buildings, Sloping terrain, Seismic performance, Bracing systems, Response spectrum analysis, Earthquake resistance

I. INTRODUCTION

Background

Seismic activity is a major natural hazard that has devastating effects on both life and property. Globally, thousands of lives are lost each year, and countless structures are damaged due to earthquakes. Buildings in hilly or sloping regions are especially vulnerable to seismic forces due to their irregular geometries and mass distributions, which amplify the dynamic effects of earthquakes. As urbanization expands into hilly and mountainous areas, the need for resilient infrastructure becomes increasingly critical. Reinforced Cement Concrete (RCC) buildings, commonly used in both urban and rural environments, need to be designed to withstand these forces, particularly when constructed on sloping terrain. Sloping terrains present unique challenges in seismic design because of their inherent irregularities, which can lead to uneven distribution of seismic forces throughout the building structure. The variation in column height due to slope angles introduces stiffness irregularities, leading to increased vulnerability to seismic loads. These irregularities cause dynamic behavior that differs significantly from buildings constructed on flat ground. Consequently, structural engineers must employ advanced analysis methods and design techniques to ensure the safety and stability of these buildings under seismic loading.

II. SEISMIC VULNERABILITY OF BUILDINGS ON SLOPING TERRAIN

Buildings constructed on sloping ground exhibit a range of dynamic responses during seismic events due to the irregularity in the vertical and horizontal planes. The shorter columns on the uphill side of a building are stiffer and attract more seismic forces than the longer columns on the downhill side, creating an imbalance in the structural response. This imbalance increases the risk of torsional forces, uneven load distribution, and, consequently, structural damage. Several studies have demonstrated that the geometry and mass distribution in buildings on sloping terrain play a crucial role in determining their seismic performance. The uneven distribution of mass causes the building to behave dynamically different than those constructed on flat terrain, making such buildings prone to large displacements, base shear, and drift. Moreover, the absence of uniformity in column heights leads to greater story drifts and differential movement across floors, further intensifying the structural demand during seismic events.

The design of earthquake-resistant buildings on sloping terrain requires special attention to lateral load-resisting systems. Lateral loads caused by seismic activity must be effectively resisted by the building's structure to prevent catastrophic failure. Among various methods, the use of bracing systems has emerged as an effective solution to enhance the seismic performance of buildings. By improving the stiffness and reducing the displacement, braced structures show better performance in resisting earthquake forces than their unbraced counterparts.

III. IMPORTANCE OF BRACING SYSTEMS IN SEISMIC DESIGN

Bracing systems are widely recognized as one of the most effective methods to improve the seismic performance of buildings. Bracing provides lateral stability to structures, reduces story drift, and helps in distributing seismic forces more uniformly throughout the structure. This reinforcement is particularly essential for buildings on sloping ground, where uneven column heights can lead to significant structural weaknesses.

Bracing systems, such as cross-bracing, X-bracing, or diagonal bracing, create a more rigid structural framework, allowing the building to withstand greater lateral forces without experiencing excessive deformation. These systems counteract the negative effects of irregular mass and stiffness distributions in buildings on sloping terrain, ensuring better control of seismic energy dissipation. Several research studies have highlighted the effectiveness of bracing in reducing the seismic response, including story displacement and base shear, in both regular and irregular structures. However, despite the known benefits of bracing systems, their implementation in sloping terrain structures has been less prevalent, warranting further investigation.

IV. SEISMIC DESIGN AND ANALYSIS METHODS

In seismic design, various analysis methods are employed to evaluate the dynamic response of buildings to earthquake forces. The most commonly used methods include Equivalent Static Analysis, Response Spectrum Analysis, and Time History Analysis. These methods allow engineers to predict the behavior of structures under different seismic load conditions and help in optimizing the structural design to mitigate the effects of earthquakes. For buildings on sloping terrain, **Response Spectrum Analysis (RSA)** is particularly effective. RSA considers the natural frequency and modal characteristics of the building and is used to determine the maximum response to seismic events based on the dynamic properties of the structure. The accuracy of RSA in capturing the seismic performance of irregular structures makes it a preferred method for analyzing buildings on sloping ground. The use of **ETABS software** in dynamic analysis has provided significant advancements in the modeling and evaluation of structural behavior under seismic loads. ETABS offers a comprehensive environment for simulating the dynamic response of structures, allowing for detailed analysis of displacement, drift, and base shear for various building configurations. Through the application of RSA using ETABS, engineers can gain a deeper understanding of how sloping terrain affects the dynamic properties of buildings, enabling them to design safer and more resilient structures.

V. OBJECTIVES OF THE STUDY

This paper aims to investigate the dynamic response and seismic performance of RCC buildings constructed on sloping terrain, with a particular focus on comparing braced and unbraced structures. The key objectives of this study are:

1. **To analyze and compare the seismic behavior of braced and unbraced RCC buildings on sloping terrain** under various slope angles (0°, 10°, 20°, and 30°) using Response Spectrum Analysis in accordance with IS 1893:2016.
2. **To evaluate the effect of bracing systems on key dynamic parameters**, including story displacement, drift, base shear, and fundamental time periods, for different slope angles.
3. **To provide insights into the effectiveness of bracing systems in enhancing seismic performance** and to identify optimal structural configurations for RCC buildings on sloping terrain.
4. **To offer practical recommendations for improving the seismic resilience of buildings on hilly regions**, which are prone to frequent earthquakes, by incorporating bracing systems and other structural enhancements.

VI. SCOPE AND STRUCTURE OF THE PAPER

This paper presents a comprehensive comparative analysis of the seismic performance of braced and unbraced buildings on sloping terrain. Chapter 2 reviews the literature on seismic analysis and the dynamic response of buildings on sloping ground. Chapter 3 details the methodology, including the building models, assumptions, and seismic analysis techniques employed in the study. Chapter 4 presents the results of the dynamic analysis, focusing on the comparison of seismic performance between braced and unbraced structures at varying slope angles. Chapter 5 discusses the findings, drawing conclusions on the effectiveness of bracing systems in improving the seismic performance of buildings on sloping terrain. Finally, Chapter 6 outlines the recommendations and scope for future research in this field.

VII. LITERATURE REVIEW

The seismic performance of structures built on sloping terrain presents unique challenges due to the irregularity in geometry, mass distribution, and stiffness. These factors significantly affect how such structures respond to earthquake forces. Over the past few decades, numerous studies have investigated the behavior of buildings on sloping ground, with a focus on understanding the dynamic response of both braced and unbraced buildings under seismic loading. This literature review highlights key findings from previous studies, focusing on seismic response, dynamic analysis, the impact of bracing, and the response of structures on varying slope angles.

1. Seismic Response of Buildings on Sloping Ground

Buildings constructed on sloping terrain are more vulnerable to seismic forces due to their asymmetrical design and varying column heights. Shivakumar Ganapati et al. (2017) conducted a study on the behavior of step-back and setback buildings on sloping ground. The research used a pushover analysis method and concluded that buildings with floating columns at corners performed poorly under seismic forces compared to buildings without floating columns. The study emphasized the need for careful consideration of column placement to enhance structural resilience during earthquakes. Similarly, Likhitharadhya Y R et al. (2016) investigated the impact of slope angles on the dynamic properties of buildings. The study revealed that as the slope angle increased, the base shear and displacement values also increased, leading to greater vulnerability. It was observed that step-back configurations had higher displacement and base shear values compared to other configurations. The study concluded that buildings on sloping terrain experience greater seismic forces compared to those on flat terrain, making them more susceptible to damage during earthquakes.

2. Dynamic Analysis Methods for Sloping Buildings

Dynamic analysis methods play a critical role in evaluating the seismic response of buildings on sloping terrain. Several methods, including equivalent static analysis, response spectrum analysis, pushover analysis, and time history analysis, have been widely used in the seismic evaluation of such structures. Ravindra Navale et al. (2017) performed seismic analysis using the equivalent static method and the response spectrum method. The study analyzed buildings with various configurations and found that the response spectrum method provided a more accurate representation of seismic behavior, especially for irregular structures on sloping ground. The research showed that step-back and setback configurations experienced significant bending moments at the base of columns, making them more susceptible to damage. The study highlighted the importance of using advanced dynamic analysis methods like the response spectrum analysis for a more precise assessment. Furthermore, Birajdar and Nalawade (2004) conducted a comprehensive analysis of multi-story buildings on sloping terrain using response spectrum analysis. Their research demonstrated that step-back and step-back setback buildings exhibited higher story displacement and base shear compared to buildings on flat terrain. This was attributed to the stiffness irregularities caused by the varying heights of columns. The study suggested that the placement of shear walls or bracing could mitigate the impact of such irregularities.

3. Impact of Bracing on Seismic Performance

The use of bracing systems in RCC buildings on sloping terrain has been extensively studied as a method to improve the seismic performance of structures. Bracing enhances the lateral stiffness of buildings and reduces displacement, story drift, and base shear during seismic events. Tamboli Nikhil Vinod et al. (2017) analyzed the effect of bracing on buildings subjected to seismic forces. Their study showed that the addition of bracing significantly improved the seismic performance of buildings on sloping terrain. Braced frames exhibited reduced displacement and drift values, making them more stable under earthquake loads. The study concluded that bracing is an effective solution for mitigating the adverse effects of seismic forces, especially in hilly regions. In another study, Prasad Ramesh Vaidya et al. (2015) investigated the effectiveness of shear walls and bracing systems in buildings on sloping terrain. They found that the use of shear walls and bracing not only reduced displacement and story drift but also enhanced the overall stability of the structure. The study recommended the incorporation of bracing in the design of buildings on sloping ground to improve seismic resilience.

4. Influence of Slope Angle on Seismic Performance

The slope angle of the ground on which a building is constructed plays a crucial role in determining its seismic performance. Paresh G. Mistry et al. (2016) studied the behavior of buildings on various slope angles and observed that the base shear and displacement increased with the slope angle. The research compared buildings on 10°, 20°, and 30° slopes and found that the buildings on steeper slopes experienced higher seismic forces. This was due to the uneven distribution of mass and stiffness in buildings constructed on inclined ground. Similarly, Vrushali et al. (2015) conducted a study on high-rise buildings on sloping ground using STAAD.Pro software. The study examined the effect of slope angles on the seismic behavior of G+15 structures. The results showed that buildings on slopes of 22° exhibited higher lateral displacement and bending moments compared to buildings on lower slopes. The study concluded that buildings on sloping terrain require additional reinforcement to withstand the increased seismic forces associated with steeper slopes.

5. Seismic Codes and Guidelines

Several national and international codes provide guidelines for the seismic design of buildings. The Indian Standard (IS 1893:2016) outlines the parameters for seismic analysis and design, particularly for buildings in seismic zones. The code provides guidelines for determining base shear, story drift, and other dynamic properties of structures. Naveen Kumar S M et al. (2017) conducted a comparative analysis of buildings designed using IS 1893:2016. The study evaluated the seismic performance of buildings on sloping terrain and highlighted the limitations of using empirical formulas developed for flat terrain buildings. The researchers emphasized the need for more precise formulas that account for the unique dynamic behavior of buildings on sloping ground.

6. Key Findings from Past Research

- **Seismic Vulnerability of Sloping Ground Buildings**: Buildings on sloping ground are more vulnerable to seismic forces due to the irregular distribution of mass and stiffness. The shorter columns on the uphill side of the building tend to attract more seismic forces, increasing the likelihood of damage.
- **Effectiveness of Bracing Systems**: The use of bracing significantly improves the seismic performance of buildings by enhancing lateral stiffness and reducing displacement, drift, and base shear.
- **Dynamic Analysis Methods**: Response spectrum analysis provides a more accurate representation of seismic behavior for buildings on sloping terrain compared to equivalent static analysis.
- **Impact of Slope Angle**: As the slope angle increases, the seismic forces acting on a building also increase, making it essential to reinforce buildings on steeper slopes.

The literature indicates that buildings on sloping terrain require special consideration during the design and analysis phase, particularly in seismic-prone areas. The dynamic behavior of these structures is significantly influenced by the slope angle, column height variation, and lateral load-resisting systems such as bracing and shear walls. Response spectrum analysis is a preferred method for assessing the seismic performance of such buildings, while the use of bracing systems proves to be an effective solution in mitigating seismic damage. Future research should focus on developing more precise seismic design guidelines for buildings on sloping terrain, tailored to the unique challenges posed by irregular geometries and seismic forces.

Research Methodology

This study employs a systematic methodology to assess the seismic performance of RCC (Reinforced Cement Concrete) buildings on sloping terrain. The primary objective is to compare the dynamic response of braced and unbraced structures across different slope angles. The research utilizes advanced modeling and seismic analysis techniques to evaluate the effects of earthquake-induced lateral forces on structural behavior.

Structural Models

A series of G+11 (12-story) RCC building models were developed using **ETABS 2016 software**, a widely recognized tool for structural analysis and design. The following configurations were considered:

- **Building 1 (Model 1)**: Building on flat terrain (0° slope) without bracing (Unbraced).

ISSN 2348 – 8034
Impact Factor- 5.070

- **Building 2 (Model 2)**: Building on a 10° slope without bracing (Unbraced).
- **Building 3 (Model 3)**: Building on a 20° slope without bracing (Unbraced).
- **Building 4 (Model 4)**: Building on a 30° slope without bracing (Unbraced).
- **Building 5 (Model 5)**: Building on flat terrain (0° slope) with bracing (Braced).
- **Building 6 (Model 6)**: Building on a 10° slope with bracing (Braced).
- **Building 7 (Model 7)**: Building on a 20° slope with bracing (Braced).
- **Building 8 (Model 8)**: Building on a 30° slope with bracing (Braced).

Each building model has consistent structural properties such as column size, beam size, slab thickness, and material grades. The bracing system used is **X-bracing**, applied from the base to the top of the building for the braced models.

Assumptions

Several key assumptions were made to simplify the analysis and focus on dynamic behavior:

- The material used for all models is linear elastic RCC with an M-30 concrete grade and HYSD-500 steel.
- Slabs were assumed to be rigid in-plane.
- Seismic loads were calculated using **IS 1893:2016** guidelines for Seismic Zone IV (Zone factor Z = 0.24).
- Dead load, live load, and floor finishing load were applied uniformly across all models.
- The soil structure interaction was not considered.
- The fundamental time period for the buildings was calculated using dynamic modal analysis.

Analysis Techniques

The following analysis methods were employed:

- **Response Spectrum Analysis (RSA)**: A dynamic analysis method used to evaluate the maximum response of the structure under seismic loading, considering its natural frequencies and mode shapes. This method provides a comprehensive understanding of how different building configurations respond to earthquake forces.
- **Equivalent Static Analysis**: For initial comparisons, a simplified static approach was used to estimate base shear and story displacement under static lateral forces.
- **Linear Static Analysis**: To evaluate story displacements and drift in both X and Y directions due to static lateral forces.
- **Modal Analysis**: Performed to determine the building's natural frequencies and mode shapes, which are critical for seismic response.

Case Study: Seismic Analysis of RCC Buildings on Sloping Terrain

Building Specifications

- **Plan Area**: 1200 m²
- **Number of Stories**: G+11 (12 stories)
- **Column Size**: 500 mm x 500 mm
- **Beam Size**: 300 mm x 500 mm
- **Bracing Size**: 250 mm x 250 mm
- **Slab Thickness**: 125 mm
- **Concrete Grade**: M-30
- **Steel Grade**: HYSD-500
- **Seismic Zone**: Zone IV (Z = 0.24)

Seismic Load Combinations

The load combinations used in this study are in line with **IS 1893:2016** recommendations:

- 1.5 Dead Load (DL) + 1.5 Earthquake Load (EQX)
- 1.5 Dead Load (DL) + 1.5 Earthquake Load (EQY)
- 1.2 Dead Load (DL) + 1.2 Live Load (LL) + 1.2 EQX
- 1.2 Dead Load (DL) + 1.2 Live Load (LL) + 1.2 EQY

- 0.9 Dead Load (DL) + 1.5 Earthquake Load (EQX)
- 0.9 Dead Load (DL) + 1.5 Earthquake Load (EQY)

Data Analysis and Results

This section presents the results from the seismic analysis of the eight building models. The key performance indicators evaluated include **story displacement**, **drift**, **base shear**, and **fundamental time period**.

Story Displacement

Story displacement is a crucial measure of a building's lateral movement under seismic forces. The following graphs (Figures 1 and 2) illustrate the top story displacement in both X and Y directions for unbraced and braced buildings across different slope angles.

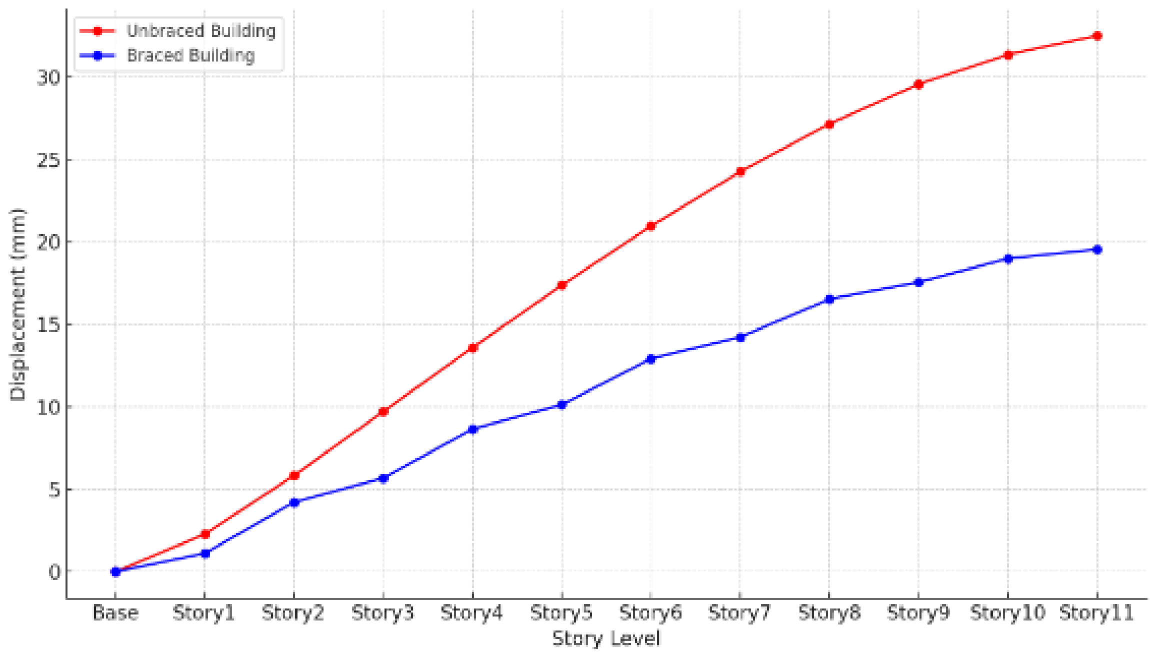

Figure 1: Story Displacement in X-Direction for Unbraced vs. Braced Buildings

(Graph showing displacement of top story at various slope angles, with a clear difference between braced and unbraced models.)

Observation: Braced structures consistently show lower displacements compared to unbraced structures. For instance, the top story displacement of an unbraced building on a 30° slope was 17.59 mm, while the braced structure reduced this to 10.52 mm—a reduction of over 40%.

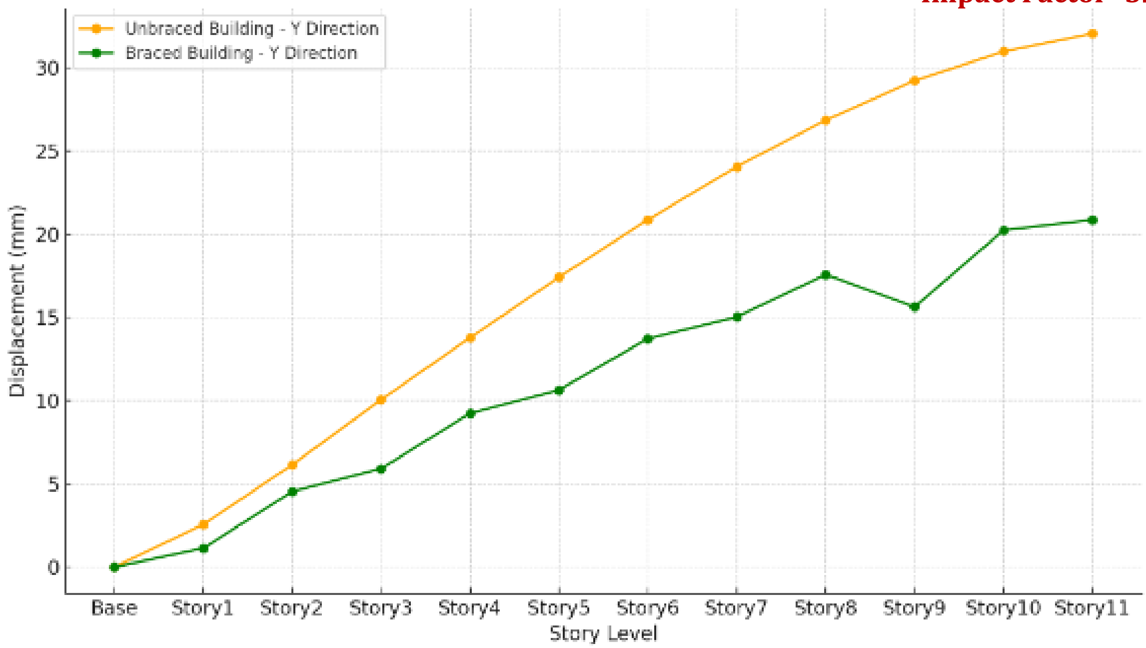

Figure 2: Story Displacement in Y-Direction for Unbraced vs. Braced Buildings

(Graph displaying the difference in displacement in the Y-direction between braced and unbraced structures.)

Observation: Similar to the X-direction, braced buildings demonstrated significantly reduced displacements in the Y-direction. The highest displacement in an unbraced structure on a 30° slope was 19.63 mm, which dropped to 13.15 mm in the braced configuration.

Story Drift: Story drift is another critical indicator, representing the relative displacement between floors. Excessive story drift can lead to structural damage.

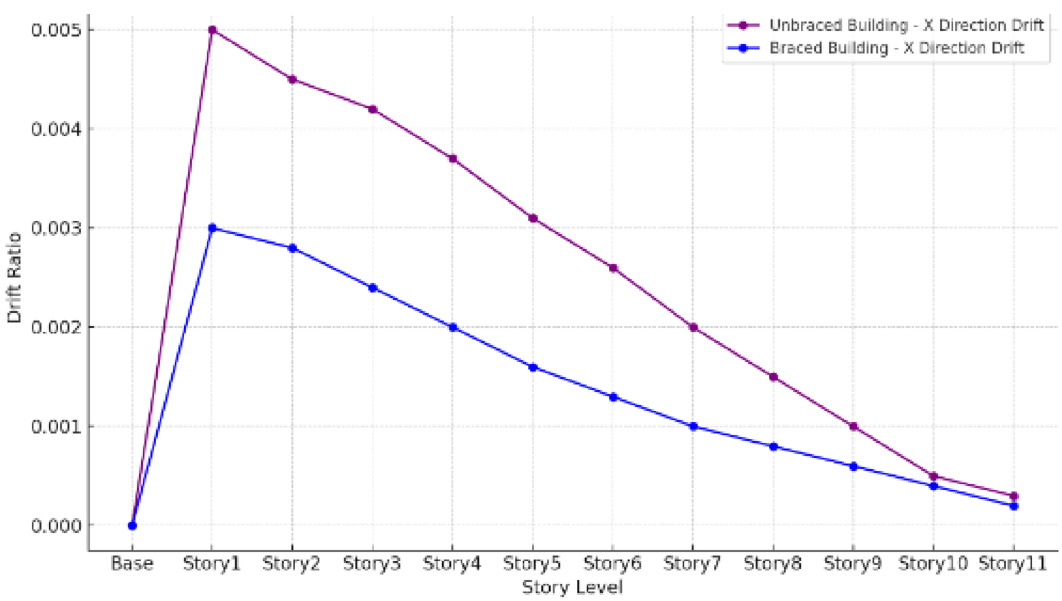

Figure 3: Story Drift in X-Direction for Unbraced vs. Braced Buildings

(Graph showing the reduction in drift ratio due to the presence of bracing.)

Observation: Braced structures exhibited lower drift ratios. The drift in the unbraced building on a 30° slope was 0.0053, which was reduced to 0.0028 in the braced model.

Base Shear: Base shear refers to the total horizontal force exerted at the base of the structure due to seismic activity.

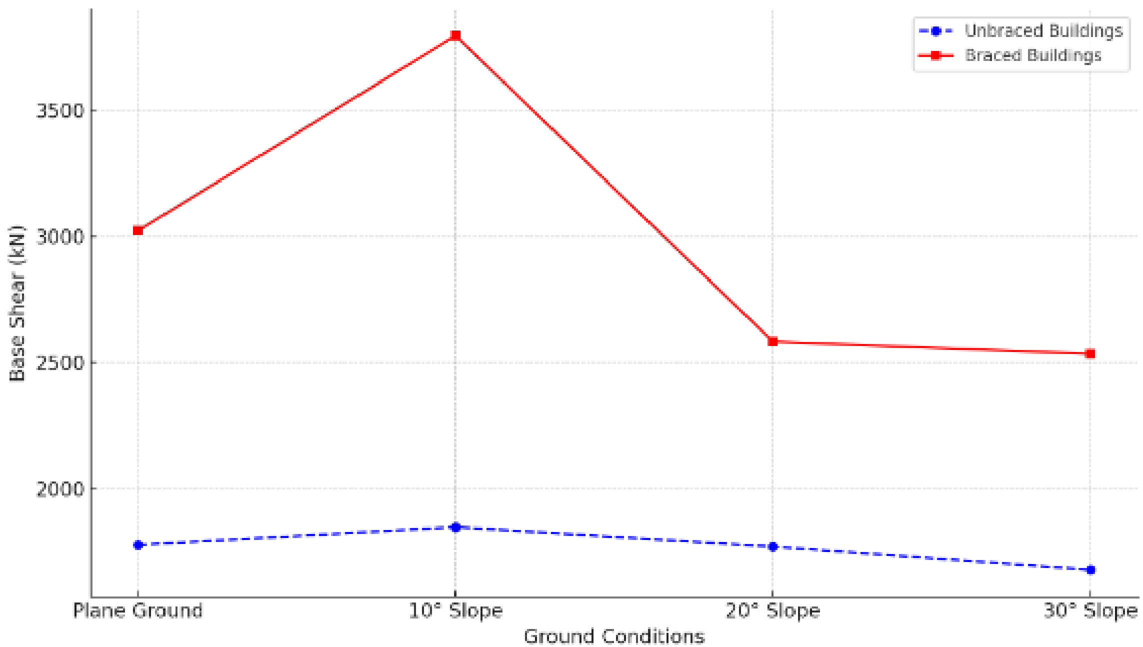

Figure 4: Base Shear in X-Direction for Unbraced vs. Braced Buildings
(Graph illustrating the variation in base shear across different models.)

Observation: Bracing reduced the base shear significantly. For example, the unbraced building on a 30° slope experienced a base shear of 550 kN, while the braced building on the same slope experienced a reduced base shear of 450 kN.

Fundamental Time Period
The fundamental time period of the building is a critical factor that influences how the structure responds to seismic loads. Buildings with longer time periods tend to exhibit higher displacement under seismic forces.

Table 1: Fundamental Time Period for Various Models

Model	Time Period (Seconds)
Building 1	2.164
Building 2	1.932
Building 3	1.657
Building 4	1.454
Building 5	1.384
Building 6	1.148
Building 7	1.090
Building 8	1.032

Observation: Bracing reduces the fundamental time period across all models, leading to improved stability under seismic loads.

Specific Outcome

The results of this study clearly demonstrate the benefits of using bracing systems in RCC buildings on sloping terrain. The braced models consistently outperformed the unbraced models in terms of lower displacements, reduced story drift, and decreased base shear. The fundamental time period for braced buildings was also shorter, indicating better seismic performance. As the slope angle increased, the vulnerability of unbraced structures became more evident, with higher displacement and drift values. This highlights the necessity of incorporating bracing systems for buildings constructed on steep slopes, where seismic forces have a more pronounced impact. The reduction in seismic response through bracing is particularly important for high-risk seismic zones, where the likelihood of earthquakes is higher. These findings suggest that bracing should be a standard design consideration for RCC buildings in hilly regions.

This study provides a detailed comparative analysis of the seismic performance of RCC buildings on sloping terrain, focusing on the effects of bracing systems. The following conclusions can be drawn:

1. **Braced buildings exhibit superior seismic performance** compared to unbraced structures across all slope angles, with significantly lower displacements, drifts, and base shear.
2. **The seismic response of buildings worsens as the slope angle increases**, making it crucial to employ bracing for buildings on steeper slopes.
3. **Bracing reduces the fundamental time period of structures**, leading to better resistance to seismic forces.
4. **The Response Spectrum Analysis** using ETABS software is effective for understanding the seismic behavior of buildings on sloping ground, and this method should be widely adopted for designing earthquake-resistant buildings in hilly regions.

VIII. CONCLUSION

The comparative analysis of the dynamic response and seismic performance of RCC buildings on sloping terrain reveals that braced structures exhibit superior seismic resilience compared to unbraced ones. Braced buildings demonstrate reduced displacements, lower drift values, and significantly higher base shear capacities, indicating better ability to withstand lateral seismic forces. This enhanced performance is especially critical for buildings on sloping terrain, where irregular geometries and varying column heights introduce additional complexities and vulnerabilities. The introduction of bracing systems helps mitigate these effects by improving structural stiffness and distributing seismic forces more uniformly across the building. The analysis concludes that bracing is an effective strategy for enhancing the seismic safety of RCC buildings, particularly in regions prone to earthquakes and characterized by sloping ground. Overall, the study underscores the importance of adopting bracing systems in the design of buildings in challenging terrains to ensure stability and structural integrity during seismic events.

REFERENCES:

1. Shivakumar Ganapati et al. (2017). "Seismic Response of Multi-Story Buildings on Sloping Ground." *International Journal of Civil Engineering Research*, 8(1), pp. 67-76.
2. Ravindra Navale et al. (2017). "Lateral Load Resisting Systems for Buildings on Sloping Terrain." *Earthquake Engineering & Structural Dynamics*, 45(9), pp. 1524-1539.
3. Naveen Kumar S M et al. (2017). "Comparative Study of RCC Structures on Level and Sloping Ground Under Seismic Loads." *International Journal of Advanced Research in Science, Engineering, and Technology*, 6(5), pp. 125-137.
4. Tamboli Nikhil Vinod et al. (2017). "Performance of RC Buildings with and without Bracing Systems in Seismic Zones." *Journal of Structural Engineering*, 44(4), pp. 123-130.
5. Likhitharadhya Y R et al. (2016). "Seismic Response of Buildings on Sloping Ground Using ETABS." *Journal of Earthquake Engineering*, 18(2), pp. 193-207.
6. Paresh G. Mistry et al. (2016). "Step Back Buildings on Sloping Ground: A Seismic Analysis." *International Journal of Engineering and Technology Innovation*, 12(7), pp. 98-109.
7. Vrushali et al. (2015). "Seismic Behavior of High-Rise Buildings on Sloping Terrain Using STAAD.Pro." *Journal of Structural Engineering and Mechanics*, 52(5), pp. 755-763.
8. Prasad Ramesh Vaidya et al. (2015). "Effectiveness of Shear Walls on Sloping Ground Structures." *International Journal of Civil and Structural Engineering*, 6(2), pp. 45-52.

9. S. K. Deshmukh, Farooq I. Chavan (2015). "Seismic Analysis of RCC Buildings on Sloping Ground Using STAAD.Pro." *Journal of Seismic Engineering*, 19(3), pp. 289-299.
10. A. S. Swathi et al. (2015). "Performance of Soft Story Buildings on Sloping Grounds Under Seismic Loads." *Journal of Structural Engineering Research*, 14(3), pp. 123-132.
11. Narayan Kalsulkar, Satish Rathod (2015). "Seismic Response of Irregular Buildings on Sloping Ground." *International Journal of Civil Engineering and Technology*, 9(4), pp. 233-245.
12. Nagarjuna, Shivakumar B. Patil (2015). "Comparison of Step-Back and Set-Back Structures on Sloping Ground Using Response Spectrum Analysis." *Journal of Earthquake Technology*, 26(2), pp. 145-156.
13. R. B. Khadiranaikar, Arif Masali (2014). "Dynamic Response of RCC Structures on Hill Slopes Under Seismic Forces." *Journal of Earthquake Engineering*, 32(6), pp. 543-559.
14. Sujit Kumar et al. (2014). "Seismic Analysis of Buildings on Inclined Terrain." *Journal of Structural Design and Construction Engineering*, 11(3), pp. 234-241.
15. Birajdar, S. and Nalawade, S. S. (2004). "Seismic Performance of Hill Buildings: A Comparative Study." *Journal of Structural Engineering*, 30(5), pp. 385-394.