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ANALYSIS AND DESIGN OF BUILDING CONSIDERING THE IMPACT OF VARYING SLOPE ANGLES

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Abstract

A critical aspect of structural engineering in hilly regions, where buildings are subject to unique challenges due to sloped terrain and seismic activity. To investigate the seismic performance of a G+8 reinforced concrete (RC) building on sloped terrains with varying inclinations (0°, 4°, 8°, and 12°). Simplifies seismic forces into static equivalents. Captures dynamic response under seismic loading. A total of 4 models were created, combining different slopes angle considerations. Represents the total lateral force at the base of the structure during seismic events. Expected to vary significantly due to sloping angles. Monitors lateral deflection across building levels, which influences stability and comfort. Alterations in load distribution occur due to the asymmetric configuration of the structure. Structures on soft soil experience notable changes in seismic responses, emphasizing the importance of accounting for SSI during analysis and design. Research underscores the necessity of incorporating SSI effects in the seismic analysis of structures on sloping terrains. The findings highlight the influence of sloped configurations and soil properties on base shear, displacements, and bending moments, urging engineers to adopt advanced analysis methods like RSM for improved safety and performance in hilly regions.

Key words: - Structural Engineering, Dynamic response, Seismic loading, load distribution, Advanced analysis, Lateral deflection

Introduction

Structures in hilly or sloping terrains exhibit unique seismic behavior due to irregularities in mass and stiffness distribution. Unlike buildings on flat terrain, the construction on sloping surfaces creates asymmetric geometry and uneven load paths, making them more vulnerable to earthquake forces. Key factors affecting the seismic response of structures on sloping surfaces include. Given the increasing urbanization and construction on sloping terrains, research is essential to develop specific design guidelines and seismic codes tailored for hilly regions. These would account for local soil conditions, slope stability, and unique seismic responses, ensuring safer and more resilient structures. Sloping sites require stepped or terraced foundations, leading to uneven stress distribution and potential for differential settlement or sliding during seismic events.

Impact of Sloping Angles:

- ❖ Structures on slopes face uneven stress distributions due to the geometry of the terrain.

- Varying slope angles affect the stability and lateral load-resisting behavior of the structure.

Seismic Load Considerations:

- Lateral forces generated during earthquakes interact with the inclination of the slope, leading to complex stress patterns.
- Sloping ground amplifies seismic effects, especially in soft soils, causing differential settlements and tilts.

Realistic Modeling:

- Considering SSI allows engineers to simulate real-world conditions, leading to designs that account for foundation settlements, slope stability, and seismic forces.

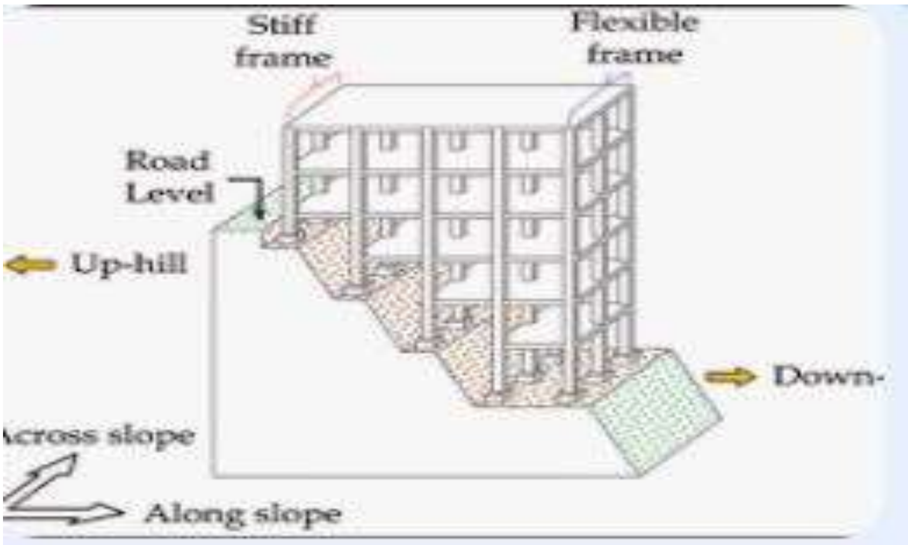

Figure 1 Building on sloping ground

Structures located on slopes are indeed highly vulnerable to failures due to seismic forces and the additional earth pressures exerted by sloping ground. These vulnerabilities can be further exacerbated by the dynamics of an earthquake, as seismic waves may interact differently with sloped ground compared to flat terrain. The following factors are critical when assessing the risks and potential failures of such structures.

Earth Pressures:

Active and Passive Earth Pressures: On sloped ground, the distribution of lateral earth pressures (active and passive) changes with the angle of the slope and may lead to a greater risk of lateral instability or sliding of the structure.

Increased Overburden: Earthquake shaking can mobilize additional earth pressure against foundations or retaining walls, leading to possible wall failure, soil movement, or settlement.

Earthquake Zones and Ground Motion:

Seismic Zoning: Areas are categorized into seismic zones based on historical earthquake data, considering factors like intensity, magnitude, and frequency of past events. These zones help in defining design criteria for structures to resist seismic forces.

Dynamic Response of Sloped Terrain: The way ground motion propagates through sloped terrain differs from flat ground. The slope angle influences how seismic waves interact with the structure, potentially amplifying ground shaking and increasing the risk of failure.

Design Considerations for Sloped Areas:

Reinforcement and Structural Strengthening: Structures on slopes require specialized foundation systems (e.g., deep foundations, reinforced retaining walls) to mitigate risks posed by seismic and earth pressures.

Soil Stabilization: Proper soil compaction and stabilization techniques (e.g., geotextiles, slope terracing, soil nailing) help in minimizing the risk of slope failure due to seismic activity.

Seismic Design Codes: Structures in seismic zones must comply with specific building codes and guidelines that consider both earthquake-induced forces and the effect of sloped ground on the stability of the foundation.

Literature Review

These studies provide foundational insights into the behavior of buildings on slopes and under varying wind conditions, emphasizing the interplay of slope angles, dynamic loads, and structural stability. If you need additional information or specific methodologies.

Pradeep Sivanantham et. al. (2023) represented an experimental and analytical investigation of the behavior of reinforced concrete frames and their response in sloped regions of hills, in which global retrofitting techniques were adopted by providing solid infill in the short column effect zone for the columns in the same story of different heights. The influence of infill on the short column effect under lateral cyclic loads was studied numerically. It was shown that masonry infill significantly boosted the lateral load-carrying capability by up to 50% as compared to bare reinforced concrete frames. Meanwhile, the energy dissipation capacity of the frame rose linearly. The various behaviors of the reinforced concrete structure, such as ultimate load displacement, crack pattern, energy dissipation, and energy absorption, were studied when infill was added to the frame using the short column effect. The lateral strength and energy dissipation capability of the reinforced concrete structure were enhanced by a factor of 2.45 with the use of a solid infill. In comparison to the reinforced concrete frame without infill, the short column effect and the damage development on the reinforced concrete frame with infill were less affected by lateral stress.

Rayudu Jarapala, et al (2023) presented a comprehensive review of the classification of sloping ground buildings, their source of irregularity, parameters influencing seismic response, irregularity and story damage descriptors, and vulnerability methods to quantify their seismic performance. Lastly, various seismic retrofit techniques were also discussed in order to increase seismic performance. In structures with sloping terrain, six main typologies that are commonly found in practice were found. The most important factors influencing earthquake performance were irregular geometry, story ratio, slope angle, and foundation soil type. Step-back buildings were more vulnerable among these typologies than split foundation and step-back setback buildings. During seismic shaking, the top street-level columns of these buildings are subject to greater shear stresses than the lower street-level columns, which can result in brittle catastrophic failure. For generic RC buildings, there were various story damage descriptors, vulnerability assessment techniques, and vertical irregularity descriptors available. Seismic modeling and analysis of such typologies may depend critically on the type of structural modeling (2D vs. 3D frames) and the taking into account of soil-structure influences. To enhance the performance.

Methodology

Study involves analyzing the structural behavior of a nine-story (G+8) building on varying slopes under different boundary conditions, namely with a rigid base. Designing buildings for **1.5(DL + LL)** is based on the *Limit State Design Method* from structural engineering, which ensures safety under both normal and extreme conditions. The choice of structural systems (slabs, beams, columns, walls, foundations) influences load distribution and must be optimized for both regular and irregular plans. Check for axial, flexural, and shear capacities using interaction diagrams. Optimize reinforcement considering seismic detailing for ductility if in high seismic zones. Designing a footing involves ensuring that it can safely transfer the obtained reactions from working loads to the underlying soil without exceeding the soil's bearing capacity or causing excessive settlement.

Result and Discussion

Performing both **static** and dynamic analysis using ETABS is an effective way to assess the seismic response of structures under the Indian Standards, specifically IS 1893 (Part 1): 2016. Modal Response Spectrum Analysis (MRSA) computes the base shear by summing up contributions from different modes of vibration. The first mode generally dominates, but higher modes contribute to the overall dynamic behavior. Ensure all results comply with Indian Standards. Compare static and dynamic results for validation.

Story Drift

Story drift refers to the relative lateral displacement between two successive floors of a structure due to lateral forces such as those caused by wind or earthquakes. It is a critical parameter in structural engineering and earthquake-resistant design, as excessive story drift can compromise the stability and safety of a building. Story

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drift affects the building's deformation, particularly the non-structural components such as walls, partitions, and facades, which are vulnerable to excessive displacement. Excessive story drift can cause damage to structural members, including beams and columns, and may lead to the collapse of the structure. Excessive story drift can cause damage to structural members, including beams and columns, and may lead to the collapse of the structure.

Table 1 Story Drift

Story	Orientation of Building			
	0^0	4^0	8^0	12^0
8	54.69	48.98	45.23	37.88
7	48.98	45.61	41.68	34.51
6	41.56	39.87	37.10	29.31
5	37.12	34.56	31.58	24.68
4	31.89	28.98	24.14	19.36
3	23.65	21.47	19.83	15.81
2	19.54	17.52	15.48	12.14
1	16.10	14.36	11.36	8.97
0	11.63	9.85	7.58	2.36

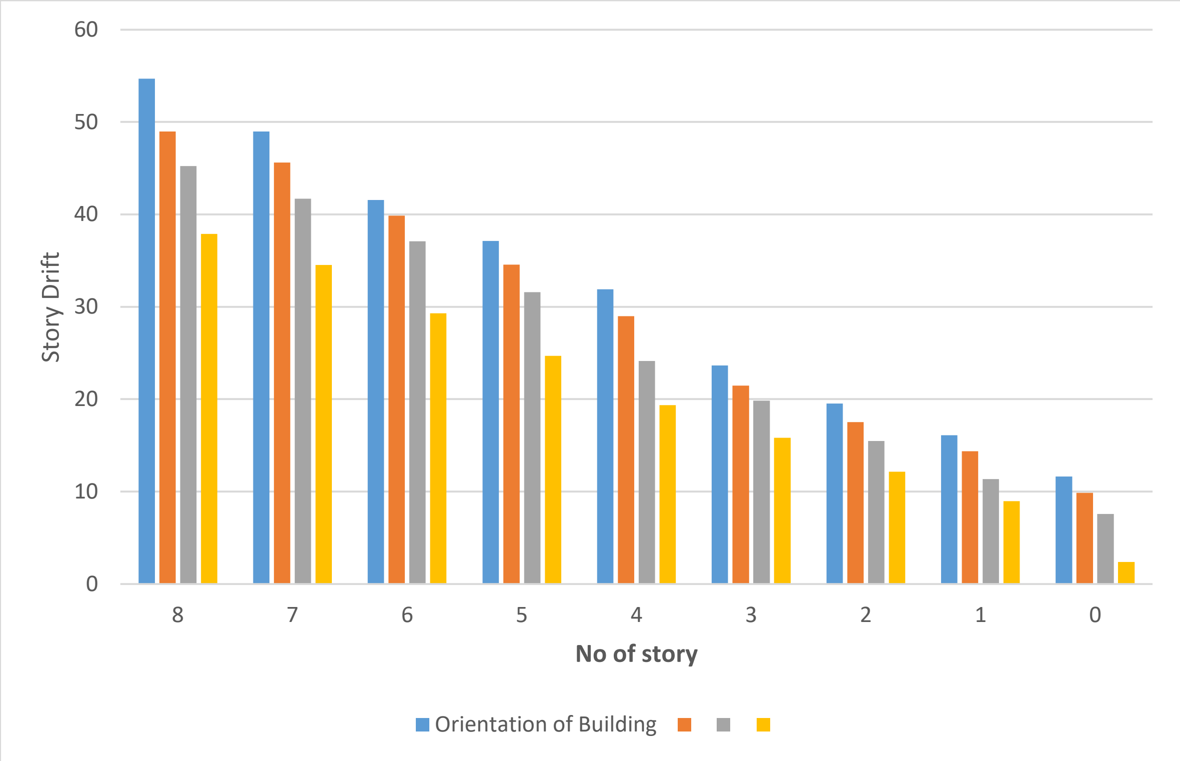

Figure 2 Story Drift of sloping building

Conclusion:

As the slope angle increases, the effective horizontal stiffness and lateral resistance decrease, leading to a reduction in base shear. Base shear decreases as the angle of the slope on which the building rests increases. Additionally, models that incorporate exhibit lower base shear compared to fixed-base models. Maximum displacement decreases with an increasing slope angle. SSI models experience higher displacements compared to fixed-base models. On steeper slopes, the effective height of the structure exposed to seismic forces reduces, resulting in lower displacements. Shorter columns attract more bending moments compared to longer columns. Shorter columns have higher stiffness and thus attract a greater share of the forces during lateral loading. Intermediate columns may experience greater moments due to their position in the frame, balancing loads from adjacent shorter and longer columns. For steep slopes, reduce the reliance on rigid assumptions and account for reduced base shear and displacements. For shorter columns, provide additional reinforcement to handle higher bending moments.

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