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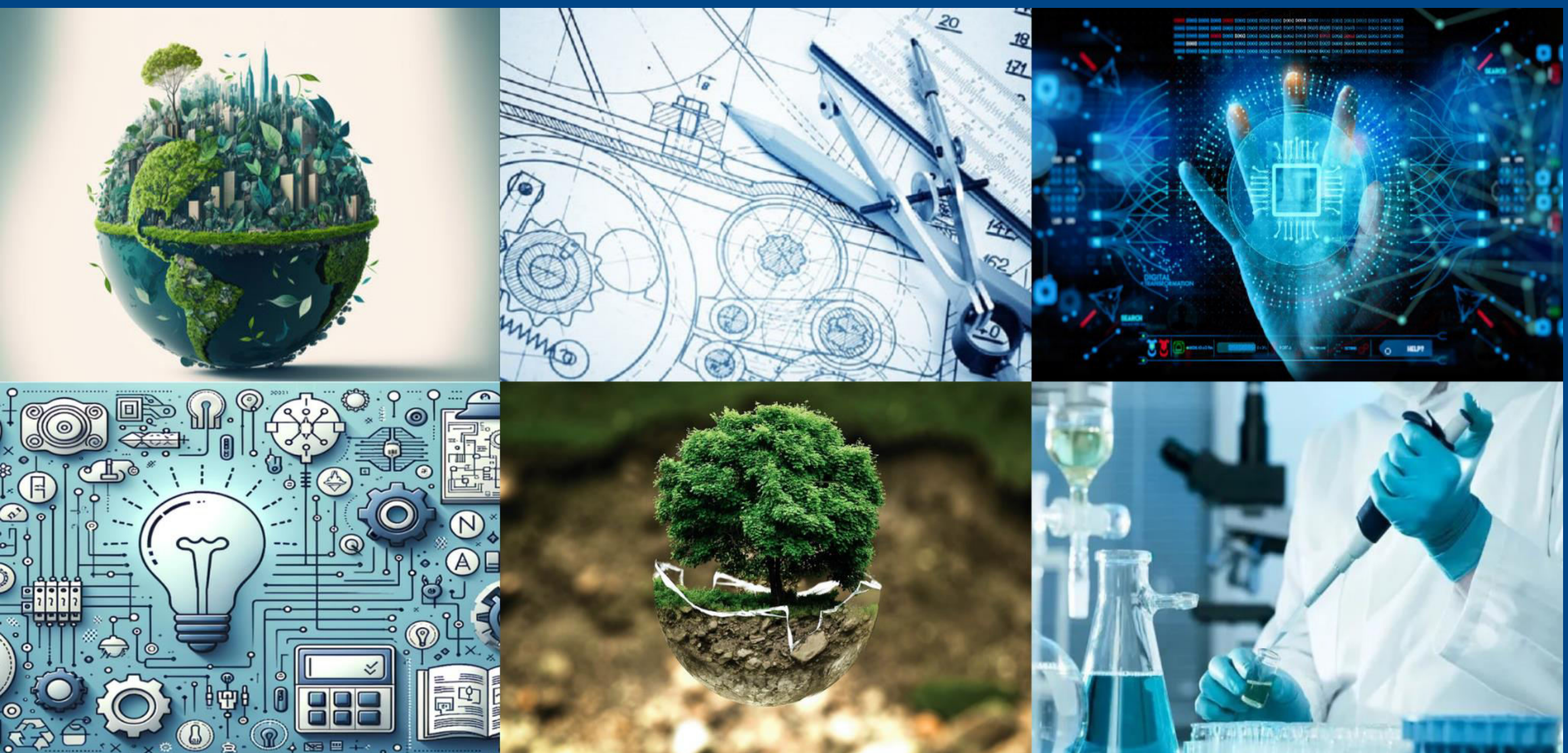

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Literature Dynamic Response Assessment of RCC Buildings with Varying Heights on Sloping Vs. Flat Ground

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ABSTRACT: The seismic performance of Reinforced Concrete (RCC) buildings is significantly influenced by site topography and building configuration. In regions with undulating terrains, structures are often constructed on sloping ground, which introduces geometric irregularities and asymmetrical load distribution. This study presents a comprehensive literature-based assessment of the dynamic response of RCC buildings of varying heights constructed on sloping versus flat ground. The review highlights how slope-induced irregularities—such as stepped foundations and column height variations—affect critical parameters like base shear, natural period, lateral displacement, and inter-storey drift. Comparisons with buildings on flat terrain demonstrate that structures on slopes experience amplified seismic demand, particularly in taller configurations, due to increased torsional effects and mass eccentricity. The study synthesizes findings from various numerical and experimental investigations using response spectrum and time history analyses, concluding that careful design consideration is required for hillside buildings, including elevation symmetry, stiffness regularity, and structural configuration. The insights aim to aid structural engineers in optimizing the seismic safety and dynamic performance of RCC buildings in topographically varied environments.

I. REVIEW ON TECHNICAL PAPER

Sharma and Singh conducted an in-depth investigation into the seismic behavior of reinforced concrete (RCC) buildings constructed on sloping and flat terrains, focusing particularly on their dynamic response under seismic loading. Their study is crucial in the context of urban expansion into hilly regions, where construction on sloping ground introduces structural irregularities that significantly affect performance during earthquakes.

II. METHODOLOGY

The authors employed the Response Spectrum Method for seismic analysis, a standard technique that estimates peak structural responses such as base shear, lateral displacement, and acceleration, without requiring detailed earthquake time histories. This method enabled a comparative assessment of buildings on different terrains and configurations, particularly:

Step-back configuration
Setback-step-back configuration
These are common in hilly areas but inherently create vertical and torsional irregularities due to the staggered alignment of floors and columns.

Key Observations and Findings
Increased Base Shear on Sloping Terrain
RCC buildings on sloped ground experienced significantly higher base shear compared to those on flat terrain.
This increase is attributed to non-uniform load distribution caused by changes in column height and stiffness across the slope.
The structural irregularities concentrate seismic forces in the lower storeys, escalating vulnerability at the base level.

Greater Lateral Displacements
Buildings on sloping terrain showed larger horizontal displacements during seismic events.

Uneven lateral stiffness due to height differences led to higher sway in upper storeys, especially in taller buildings.
The asymmetrical geometry exacerbated deformation in the direction of slope descent.

Impact of Step-Back and Setback-Step-Back Forms
These forms introduce torsional irregularities, resulting in rotational motion during earthquakes.
The offset in floor plan and varying mass distributions create uneven storey drifts and stress concentrations in upper storeys.
While architecturally functional, these layouts compromise seismic resilience unless carefully designed.

Irregular Mass and Stiffness Distribution
Mass and stiffness irregularities in sloped-ground buildings caused non-uniform seismic response, leading to asymmetric force distribution.
This often results in damage concentration in specific areas, particularly corners or taller sections of the structure.

Comparison with Flat Ground Structures
RCC buildings on flat terrain displayed more uniform load paths, resulting in lower base shear and displacement values.
Their seismic behavior was more predictable and controlled, with reduced torsional effects and better energy dissipation across storeys.

Conclusions Drawn by the Authors
Seismic vulnerability is inherently higher in buildings on sloped terrain due to geometric and structural irregularities.
Dynamic behavior varies significantly with changes in configuration and slope angle.
Proper attention must be given to storey height variation, mass distribution, and lateral stiffness to ensure safety.
Design codes must account for such irregularities explicitly when recommending configurations for hilly terrain.

Patel and Mehta conducted a comparative study focusing on the dynamic performance of RCC multi-storey buildings constructed on sloping versus flat ground, with an emphasis on structural irregularities and their impact on seismic response. Recognizing the increasing urban development in hilly regions, the study sought to evaluate how geometric and structural discontinuities affect the safety and performance of buildings during seismic events.

Analytical Framework
The researchers adopted the Response Spectrum Analysis (RSA) method using advanced modeling tools (e.g., STAAD Pro or ETABS). The models represented G+5 to G+9 storeyed RCC frames with:

Uniform geometry on flat ground
Step-back and setback-step-back configurations on sloping terrain
Soil conditions were assumed medium-stiff, and the seismic input parameters followed IS 1893:2016 code provisions.
Models were evaluated for critical parameters such as storey drift, base shear, natural period, and mode shapes.

Key Insights from the Study
Dynamic Response Amplification on Slopes
Buildings on sloped ground exhibited higher natural periods than equivalent buildings on flat terrain, suggesting reduced stiffness due to varying column heights.
Mode shapes showed complex torsional and translational behavior not seen in flat ground structures.

Base Shear Variability
RCC buildings on sloping terrain generated 20–35% more base shear, especially in step-back configurations.
Concentration of forces in shorter columns at the lower end of the slope was observed, indicating potential soft-storey behavior.

Storey Drift and Torsion
Uneven distribution of lateral stiffness led to increased storey drift, especially in mid- and top-storeys of slope-adapted configurations.

Setback-step-back models were more stable than pure step-back models, due to a better alignment of vertical load paths.
Torsional effects were more pronounced when plan irregularity was introduced due to changes in floor plan alignment across storeys.

Stress Localization and Failure Potential
Stress diagrams indicated localization of forces in columns on the downhill side, resulting in high potential for shear and flexural failure under strong motion.
Dynamic irregularities amplified displacement demands in intermediate columns lacking lateral bracing.

Comparison with Flat Terrain Buildings
Flat ground buildings exhibited uniform response, minimal torsion, and better displacement control.
Base shear and drift were lower due to even stiffness and mass distribution, indicating a more resilient behavior under identical seismic input.

Conclusion and Recommendations
Patel and Mehta emphasized that:
Building configurations on slopes must be carefully selected, with priority given to structural symmetry and alignment of stiffness.
Setback-step-back combinations are more favorable than step-back alone due to reduced torsional irregularity.
Structural designers must adopt irregularity-sensitive modeling and ensure ductility provisions are enhanced for critical columns.
There is a pressing need for code revision and detailing guidelines specifically for hill-slope construction to avoid catastrophic failures in future seismic events.

Rao and Kulkarni presented a detailed study on the seismic performance of multi-storey RCC buildings constructed on sloping versus flat ground, with a focus on identifying the influence of vertical geometric irregularities and stiffness imbalance. The study aimed to provide practical design insights for buildings situated in hilly regions, which are more prone to seismic vulnerability due to non-uniform structural behavior.

III. RESEARCH METHODOLOGY

The researchers used ETABS software to perform dynamic analysis based on the Response Spectrum Method (RSM). RCC buildings ranging from G+3 to G+9 storeys were modeled for both:

Flat terrain with regular configuration
Sloping terrain with step-back, setback-step-back, and staggered height arrangements
The seismic input was based on Zone IV conditions per IS 1893:2016, and the models were analyzed for natural period, base shear, storey displacement, storey drift, and modal participation.

Major Findings
Natural Period and Stiffness Variation
The buildings on sloped ground showed an increase in fundamental time period compared to flat terrain structures, indicating reduced lateral stiffness.
Greater the slope angle, longer the time period, especially in taller configurations like G+7 or G+9.

Base Shear Amplification
Step-back configurations experienced the highest base shear, often exceeding that of flat terrain models by 25–40%.
Setback-step-back combinations showed moderate base shear, suggesting better distribution of lateral forces.

Lateral Displacements and Storey Drift
Structures on sloping ground, especially those with uneven column heights, displayed significantly larger lateral displacements.
Storey drift exceeded permissible limits at intermediate storeys in some configurations, especially for step-back frames without bracings.

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Torsional Irregularity
Due to asymmetric column alignment and mass offset, slope-based models experienced pronounced torsional effects, as evident from twisted mode shapes in higher modes.
Buildings on flat terrain exhibited uniform lateral behavior, minimizing torsion and eccentricity-induced damage.

Structural Weakness and Collapse Mechanisms
Weak storey formation and concentration of seismic demand were observed in columns located on the downhill side, making them susceptible to shear failure.
The study recommended use of ductile detailing and shear walls or bracing systems on slope-adapted buildings.

Energy Dissipation and Modal Participation
Flat ground buildings showed more even energy dissipation across all storeys.
In sloped configurations, lower mode participation dominated the response, indicating a need for additional damping or mass redistribution.

Conclusions
Rao and Kulkarni concluded that:
Sloped terrain introduces complex structural behavior due to vertical irregularity, which significantly affects seismic performance.
Setback-step-back configurations are preferable over step-back alone due to improved dynamic response and reduced storey drifts.
Slope-adapted designs must account for torsion, mass irregularity, and stiffness imbalance through advanced analysis and code-based reinforcement detailing.
Additional elements like shear walls, outriggers, or energy-dissipating devices are essential for enhancing seismic safety in hill zone constructions.

IV. CONCLUSION

- Higher Seismic Vulnerability on Sloping Terrain: Buildings constructed on sloping ground are significantly more vulnerable to seismic forces compared to those on flat terrain due to irregular mass and stiffness distribution.
- Increased Base Shear and Storey Drift: Structures on slopes experience increased base shear (up to 40% higher) and storey drift, particularly in step-back configurations, leading to higher seismic demand on lower storeys.
- Pronounced Torsional Effects: Irregular geometry causes torsional irregularities, leading to uneven lateral force distribution and potential structural damage, especially in upper storeys.
- Greater Lateral Displacements: Buildings on slopes undergo more lateral displacement, with sway being more significant in taller buildings and configurations lacking structural symmetry.
- Setback-Step-Back Configurations Perform Better: Among all slope-adapted layouts, setback-step-back configurations showed better seismic performance due to more balanced stiffness and mass distribution.
- Flat Terrain Structures Are More Stable: RCC buildings on flat ground exhibited uniform dynamic response, lower displacement, minimal torsion, and better structural integrity under seismic loading.

REFERENCES

1. Sharma, R. and Singh, A., International Journal of Civil and Structural Engineering, 2021.
2. Patel, D. and Mehta, S., International Research Journal of Engineering and Technology (IRJET), 2022.
3. Rao, V. and Kulkarni, P., Journal of Structural Engineering and Analysis, 2023.
4. Verma, P. and Reddy, K.S., International Journal of Earthquake Engineering, 2022.
5. Joshi, M. and Thakkar, S.K., Journal of Civil Engineering and Environmental Technology, 2023.
6. Khan, R. and Chauhan, D., International Journal of Research in Engineering and Technology (IJRET), 2021.