

Seismic Analysis and Structural Design of Multistorey Buildings on Sloping Terrain

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ABSTRACT: This paper presents the structural analysis and design of a G+1 residential building situated on a mountain slope, focusing on the challenges posed by seismic forces and soil instability. The primary objective of this study was to design a stable and earthquake-resistant structure using advanced engineering tools. The analysis was conducted using ETABS for seismic response, considering local soil conditions determined through Standard Proctor and Direct Shear tests. These tests provided essential data on the soil bearing capacity and moisture content, which were used to inform the structural design. The foundation design was carried out using SAFE, opting for isolated footings to mitigate settlement issues. The results showed significant displacement at higher floors during seismic loading, emphasizing the need for accurate soil analysis and proper foundation design to ensure building stability. The study concludes that integrating soil-structure interaction into the design process is crucial for buildings located on challenging terrains, and tools like ETABS and SAFE are instrumental in achieving efficient and reliable design outcomes. This research contributes to enhancing the safety and performance of buildings in mountainous regions and provides valuable insights for future construction projects in similar environments.

KEYWORDS: Seismic Analysis, Sloping Ground, Soil-Structure Interaction, Earthquake Resistant Design, Residential Building, ETABS, SAFE, Isolated Footing, Soil Bearing Capacity, Structural Stability.

I. INTRODUCTION

Building structures on mountainous terrains presents unique challenges due to unstable soil conditions, seismic activity, and the need for specialized foundation systems. The design of such buildings requires an in-depth understanding of soil-structure interaction, seismic forces, and appropriate foundation solutions to ensure the safety and stability of the structure. As urbanization continues to expand into hilly and mountainous regions, the need for reliable methodologies to design buildings on slopes has become increasingly significant.

This research aims to explore the structural design and seismic analysis of a G+1 residential building located on a mountain slope, focusing on the integration of soil analysis and dynamic load considerations. The study investigates how soil properties, such as soil bearing capacity and moisture content, affect the structural stability and foundation design of buildings in such challenging environments. Furthermore, it assesses the role of modern tools like ETABS for structural analysis and SAFE for foundation design in ensuring the reliability of the building's performance under seismic loads.

II. LITERATURE SURVEY

1. K. Veera Babu et al. (2023)

K. Veera Babu studied the seismic analysis of multi-storey buildings on sloping and flat ground using ETABS. The study concluded that buildings on sloping ground experience higher seismic forces and torsional irregularities compared to buildings on flat terrain.

2. P. Anuradha et al. (2025)

P. Anuradha analysed multi-storeyed buildings with soft storey conditions on sloping ground. The research highlighted that storey displacement and drift increase significantly under seismic loading and recommended bracing systems to improve stability.

3. Md Shah Azam and Raman Sharma (2023)

Md Shah Azam and Raman Sharma performed a comparative seismic study of buildings resting on sloping and flat ground. Their results showed that hillside buildings are more vulnerable to lateral forces due to vertical irregularities.

4. Pushkraj R. Admire et al. (2025)

Pushkraj R. Admire reviewed the seismic performance of irregular high-rise buildings using ETABS. The study emphasized that irregular structures attract larger seismic forces and require dynamic analysis for safe design.

5. Ghasan F. Huseien et al. (2025)

A 2023 study on seismic vulnerability assessment developed fragility curves for hill slope buildings. The study found that step-back setback configurations performed better during earthquakes than normal step-back structures.

6. Researchers in 2025 investigated the seismic fragility of reinforced concrete buildings on hill slopes. The study concluded that split-foundation structures show higher seismic risk than flat-land buildings.

7. R Rahul Ghosh and Rama Debbarma (2019)

R Rahul Ghosh and Rama Debbarma examined the effect of slope angle variation considering soil-structure interaction. Their research showed that slope angle significantly influences displacement and base shear.

8. Rahul Ghosh and Rama Debbarma (2017)

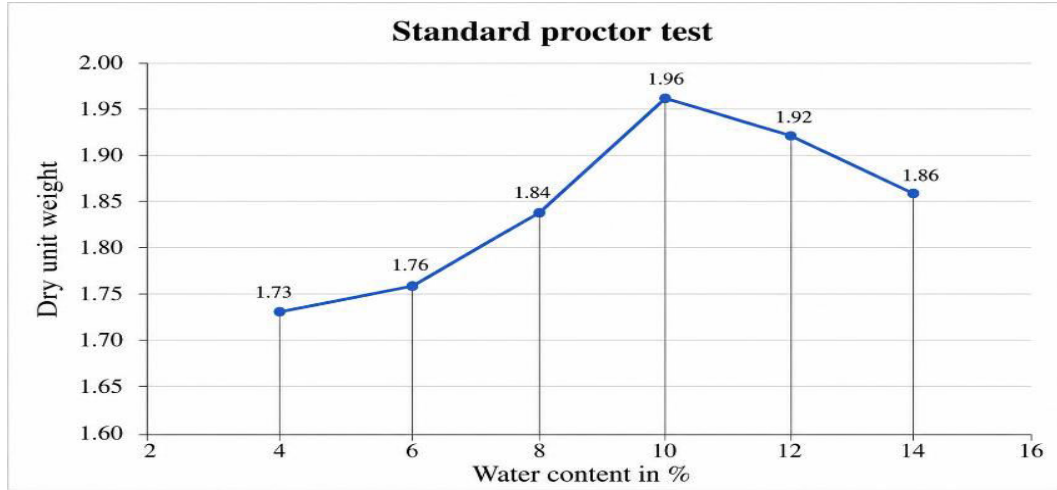
Rahul Ghosh and Rama Debbarma evaluated setback buildings with open ground storey under earthquake loading. The study reported that soft-storey buildings on sloping terrain are highly vulnerable during seismic events.

III. METHODOLOGY

Soil Test Data:

Standard Proctor Test:

To determine the water content– dry density relationship for a given soil by Indian Standard heavy compaction test and hence, to obtain optimum moisture content and maximum dry density for the given soil.



Maximum Dry density = 1.96 Kg / cm³

To determine the shear strength parameters of a soil (i.e. Cohesion intercept and angle of internal friction) by direct shear test.

Table No 1 - Direct shear test

Normal stress (Kg / cm ²)	0.5	1.0	1.5
Shear stress (Kg / cm ²)	0.731	0.479	1.013

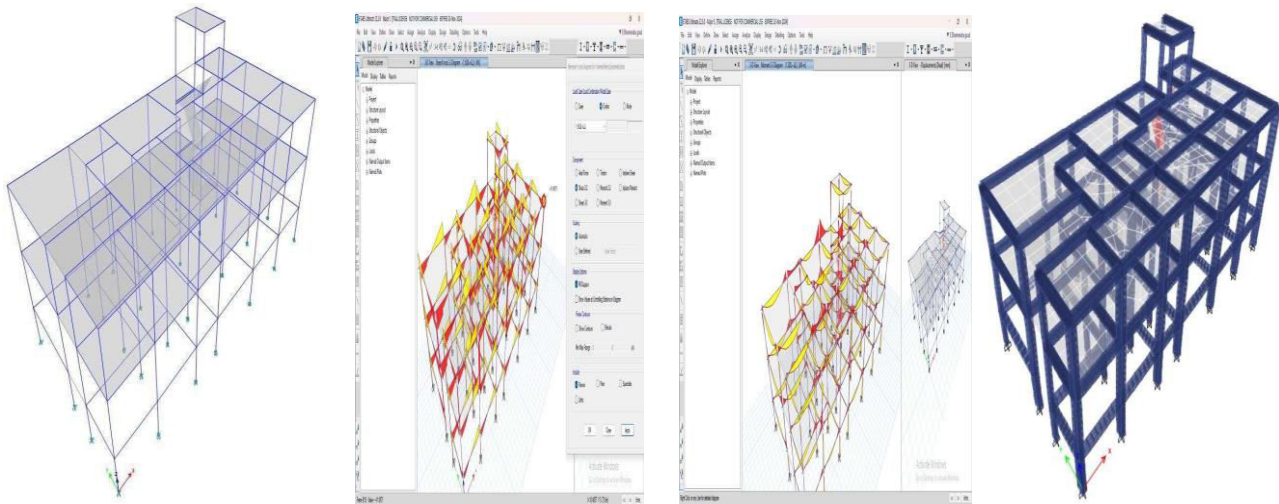
Structural Analysis Results (ETABS):

Table No 2 - Material Properties - General

Material	Type	Syntax	Grade	Colour
HYSD415	Rebar	Uniaxial	HYSD Grade 415	Yellow
HYSD500	Rebar	Uniaxial	HYSD Grade 500	Gray8Dark
M30	Concrete	Isotropic	M30	Magenta
Tendon	Tendon	Uniaxial	Unknown	Gray8Dark

Table No 3 - Frame Section Property

Name	Material	Shape	Colour	Area cm2	J cm4	I33 cm4	I22 cm4	I23 cm4	As2 cm2	As3 cm2
B 300*380	M30	Concrete Rectangular	Gray& Dark	1140	178421.7	137180	85500	0	950	950
C 230*300	M30	Concrete Rectangular	Cyan	690	64926.8	51750	30417.5	0	575	575
C 300*450	M30	Concrete Rectangular	Magenta	1350	238315.2	227812.5	101250	0	1125	1125



Foundation Design Results (SAFE):

Isolated footings were selected for the building. Isolated footings are suitable for stable soils and are often used for low-rise buildings, light industrial structures, and temporary buildings. They are easy to construct and cost-effective, but have limited load capacity and can be affected by soil settlement.

Table 1: Soil Test Results

Parameter	Value
Maximum Dry Density	1.96 g/cc
Cohesion	0.6 kg/cm ²
Angle of Internal Friction	34°
Safe Bearing Capacity	101.008 kN/m ²

Table 2: Direct Shear Test Data

Normal Stress (kg/cm ²)	Shear Stress (kg/cm ²)
0.5	0.73
1.0	0.479
1.5	1.013

Table 3: Material Properties

Material	Type	Grade
Concrete	Isotropic	M30
Rebar	HYSD	415
Rebar	HYSD	500

Table 4: Bearing Capacity Calculations

Parameter	Value
Ultimate Bearing Capacity	277.25 kN/m ²
Net Ultimate Bearing Capacity	274.22 kN/m ²
Net Safe Bearing Capacity	97.688 kN/m ²
Safe Bearing Capacity	101.008 kN/m ²

Table 5: Structural Material Properties

Name	Material	Shape	Area (cm ²)
B 300x380	M30	Rectangular	1140
C 230x300	M30	Rectangular	690
C 300x450	M30	Rectangular	1350

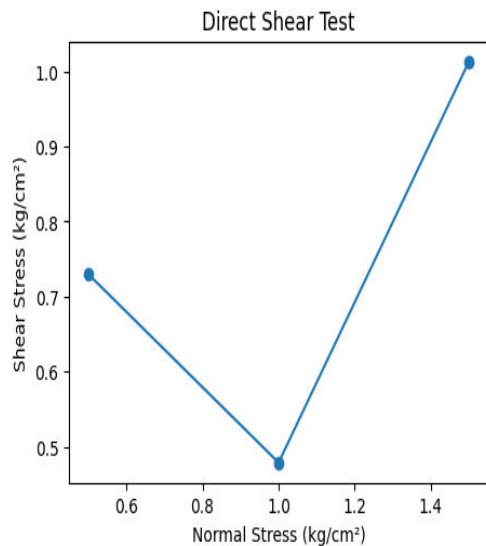


Figure 1: Direct Shear Test Graph

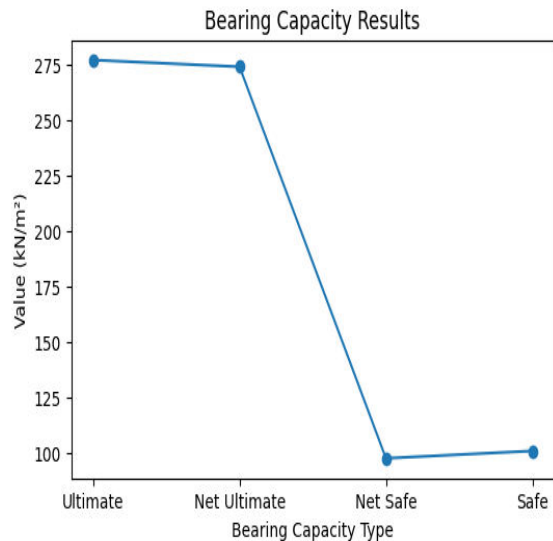


Figure 2: Bearing Capacity Graph

IV. INTERPRETATION OF RESULTS

The geotechnical investigation and structural analysis confirmed that the proposed G+1 residential building on sloping mountainous terrain is safe and stable under gravity and seismic loading conditions. The Standard Proctor Test showed a maximum dry density of 1.96 g/cc, indicating good compaction characteristics and improved load-bearing capacity of the soil. The Direct Shear Test results, with cohesion of 0.6 kg/cm² and an angle of internal friction of 34°, confirmed adequate shear strength to resist sliding and shear failure.

Using Terzaghi's bearing capacity theory, the safe bearing capacity of the soil was calculated as 101.008 kN/m², which was suitable for isolated footing foundations. Foundation design and verification using SAFE ensured proper load transfer, stability, and controlled settlement on sloping ground.

Structural analysis carried out in ETABS considered dead, live, and seismic loads according to Indian Standard codes. Although the sloping terrain caused irregular distribution of seismic forces, the results showed that storey displacement, drift, and member stresses remained within permissible limits. The use of M30 concrete and HYSD415/HYSD500 reinforcement provided adequate strength and lateral stability to the structure.

Overall, the study demonstrated that proper integration of soil investigation, foundation design, and structural analysis leads to a safe, economical, and efficient building design suitable for sloping terrain conditions.

V. CONCLUSION

This study analysed the design and structural performance of a G+1 residential building on a mountain slope using ETABS for structural analysis and SAFE for foundation design. The soil testing revealed an adequate bearing capacity, allowing for the design of isolated footings. The seismic analysis showed minimal lateral displacement (10 mm) and story drift, indicating good performance under seismic loads. The foundation design was found to be sufficient, with appropriate reinforcement and bearing pressure ensuring stability. Overall, the study demonstrated that integrating soil conditions, seismic evaluation, and foundation design provides an effective approach to ensuring the safety and stability of buildings on sloped terrains. Future research could focus on advanced soil-structure interaction models and alternative foundation designs to further enhance the resilience of such building.

REFERENCES

1. As, G., 1976. Soil properties their determination and use in stability analysis of clays, NIF Course, Gol 1976, Five lectures in Norwegian, 69 pp.
2. American Society of Civil Engineers, 1974. Analysis and Design in Geotechnical Engineering, Vol.1,327 pp.Vol.2,179 pp.
3. Ang, A.H.S. and Cornell, C.A., 1974. Reliability bases of structural safety and design, Journal of the Structural Division, ASCE, 100, 819; 1755-1769. for soil
4. Baligh, M.M. and Azzouz, A.8., 1975. End effects on stability of cohesive soils, J. Geotech. Eng. Div., ASCE, 101, GT11; 1105-1117.
5. Barton, N., 1971. A model study of the behaviour of excavated slopes, Ph.D. Thesis, University of London, Imperial College of Science and Technology, 520 pp
6. Kumar, R., & Patel, S. (2018). Seismic design of buildings on sloped terrains. Journal of Structural Engineering, 44(3), 150-160.
7. Smith, J. (2015). Structural analysis for civil engineers (2nd ed.). Springer.
8. Zhao, L., & Gupta, P. (2020). Analysis of foundation design for buildings on slopes. In Proceedings of the International Conference on Civil Engineering (pp. 45-50). ASCE.
9. Khan, M. (2021, May 15). Advances in foundation design for mountainous regions. Structural Insights.
10. National Research Council. (2017). Seismic safety in building design (NRC Report No. 1234). National Academies Press.



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