Analysis and Design of a Multistorey Building on Sloped and Flat Grounds (Stilt + Ground + 4)

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Abstract - This project focuses on the planning, static analysis, and structural design of a (Stilt + Ground + 4) residential building, located on both sloping and flat ground, using ETABS software. The primary goal is to study the impact of ground conditions on the structural behavior and design considerations of the building. The project incorporates planning principles to create a functional and efficient layout, ensuring compliance with Indian Standard codes for beams, columns, slabs, and other structural elements.

Key aspects such as load distribution, stability, reinforcement detailing, and member sizing are thoroughly examined to ensure the building's safety and adherence to IS guidelines. A comparative analysis between sloping and flat ground conditions highlights the differences in design parameters, such as member forces, moments, and reinforcement requirements, with particular attention to the unique challenges posed by sloping ground.

The findings of the study aim to offer insights into cost-effective and optimized design strategies that cater to different site conditions. By exploring these variations, the study contributes to the development of advanced modeling techniques for structural analysis and design. It also emphasizes the importance of adaptable strategies to ensure safe, resilient, and efficient residential buildings, regardless of topography.

This research enhances the understanding of how varying ground conditions influence the design process and promotes the development of residential structures that are both safe and cost-efficient across diverse terrains.

Keywords: Residential Building Design, Sloping Ground, Flat Ground, ETABS, Static Analysis, Structural Components, Indian Standards, Comparative Study, Planning Principles, Reinforcement Detailing.

1.INTRODUCTION

Urbanization and population growth have significantly increased the demand for multi-story residential buildings, especially in regions with diverse terrains, including sloping grounds. Designing structures on such varied terrains poses unique challenges related to load distribution, stability, and cost. This project focuses on the planning, static analysis, and design of a (Stilt+G+4) residential building situated on both sloping and flat ground using ETABS software, a widely used tool in structural engineering.

The main objective is to evaluate and compare the structural performance of the building on different terrains, considering factors such as soil characteristics, seismic loads, and overall stability. Adhering to Indian Standard codes, the design ensures safety, durability, and compliance with regulatory guidelines while addressing functional aspects such as space optimization and user requirements. Special attention is given to structural components like beams, columns, and slabs, ensuring the building's integrity under varying ground conditions.

The study also examines the dynamic interaction between the structure and foundation, particularly on sloping terrain, where uneven load distribution can significantly affect stability. By comparing design complexities and material utilization for sloping and flat ground conditions, the research provides valuable insights into optimizing cost-efficient and sustainable design strategies. The findings aim to guide architects, engineers, and developers in addressing terrain-specific challenges, contributing to the development of safe, efficient residential buildings across diverse topographies.

1.1 Scope of work

The scope of this project encompasses the planning, static analysis, and design of a residential building on sloping and flat ground using ETABS. It includes evaluating structural components like beams, columns, and slabs based on Indian Standard codes. The project investigates terrain-specific challenges, ensuring functional and stable designs. A comparative analysis highlights the variations in structural performance between the two terrains. The findings aim to assist in designing cost-effective, safe, and durable structures while addressing the complexities of construction on sloping grounds, making this study relevant for engineers, architects, and urban developers.

1.2 Objectives

1.The Principal Objective of this Project is to Plan, Static analysis and Design a (Stilt+ G+4) Residential Building on Sloping Ground and Flat Ground using ETABS.
2.To understand the basic concepts of principles of planning which are required for functional design of building.

3.To understand the parameters for the design of beams, columns, slabs and other structural components using Indian standard codes.
4.To understand the variation in results in the final output between the structure in Sloping ground and flat ground

2. STATEMENT OF THE PROJECT

Type of building :R.C. Frame building
Number of floors:Stilt + G + 4
Location of building: Hyderabad
Total number of columns:32
Depth of foundation :1.5m below ground level
Type of footing :Isolated footing & Combined footings
Plinth level :0.5m above ground level
Size of beams :0.23m x 0.3m
Size of columns :0.3m x 0.3m
Thickness of slab:150mm
Type of walls :Ordinary clay brick walls
Wall thickness :6" (outer wall) and 4.5" (inner wall)
Type of Staircase:Dog legged Staircase
Front offset :3.00m
Rear offset :3.50m
Left side offset :3.50m
Right side offset :3.50m
Width of road :30'-0"
Grade of concrete:M 30
Grade of Steel :Fe 500

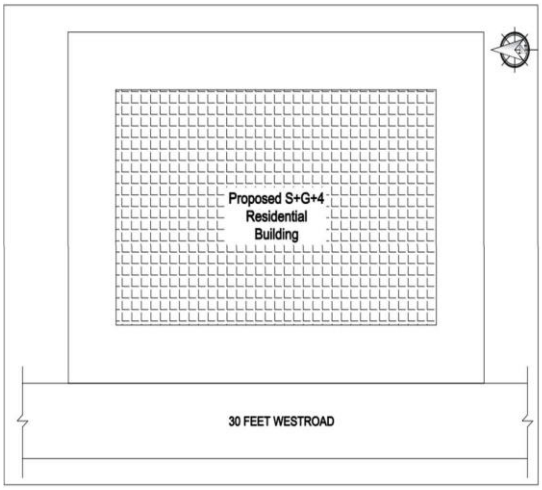

Fig. 1. Site plan

2.1 Software used

ETABS (Extended Three-Dimensional Analysis of Building Systems) is a leading engineering software used for the analysis and design of multi-story buildings, developed by Computers and Structures, Inc. (CSI). It is widely employed for structural analysis, 3D modeling, and multi-material design, particularly in the fields of civil and structural engineering. ETABS is a comprehensive Building Information Modeling (BIM) tool that aids in the simulation of both steel and reinforced concrete (RC) structures, providing an efficient approach to handling complex building designs.

The software's advanced features allow for the creation of 3D models, applying various load cases such as dead, live, wind, seismic, and temperature loads, with accurate and automated calculations. ETABS integrates several advantages, such as seamless integration with CAD software, which enables the conversion of CAD drawings directly into ETABS models. It also supports the concept of "similar stories" to expedite the design process for buildings with similar floor layouts, thus saving considerable time. Additionally, it automates load calculation, beam and column design, as well as the reinforcement detailing, and supports construction sequence analysis and pushover analysis for seismic assessment.
Despite its strengths, ETABS does have certain drawbacks. For example, the software can be slow in processing large models, which may lead to high memory consumption and longer analysis times. Editing input files directly is not possible, and certain load cases may be inadvertently omitted in large, complex models. Additionally, some users find the shear design results difficult to interpret, as they are provided in terms of ASV/SV. Overall, ETABS remains a powerful and user-friendly tool, offering engineers a reliable solution for the efficient design of complex structures, although it does come with certain limitations that need to be considered in large-scale projects.

3.METHODOLOGY

The analysis and design process in ETABS follows a systematic approach. The first step is model generation, where a 3D model of the building is created using methods like the snap node, coordinate, copy-paste, or structural wizard methods. Once the model is generated, materials and supports are assigned to the structure. After this, load definitions are inputted, including dead loads, live loads, wind loads, earthquake loads, and other relevant forces. These are then combined into load combinations as per design codes like IS 1893-2002 for earthquake analysis.
Next, the analysis is performed, which calculates the response of the structure under various loads. This analysis considers different modes and factors like seismic zone, soil type, and damping. Finally, design verification is carried out, ensuring that the structure's beams, columns, and other elements meet the required safety and performance criteria. The results are then reviewed, and any necessary adjustments are made before finalizing the design.

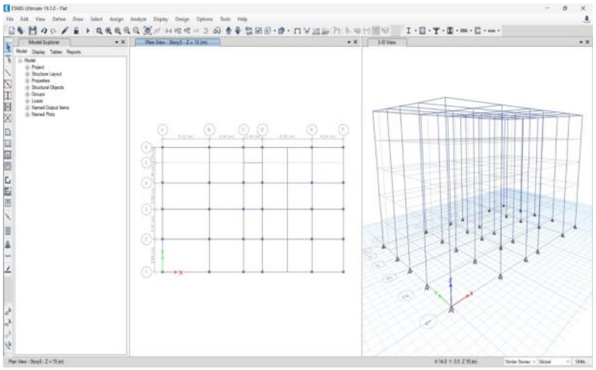

Fig.2 Model Generation

4.Result and discussion

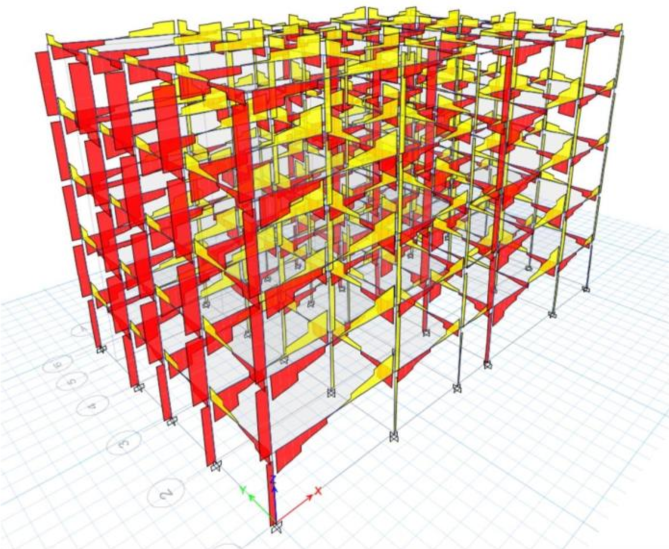

Fig.3 bending moment

The process of designing a combined footing using STAAD Foundation involves several key steps, ensuring that all necessary parameters are defined and the design is executed correctly.

Adding Load Factors and Strip Beams: Load combinations are generated by selecting the appropriate code for the loads. Once the load combinations are defined, strips are added to combine footings, linking the necessary supports.

Assigning Properties: Once the job is set up, the concrete and reinforcement parameters are specified, followed by the soil properties. These details include concrete strength, rebar sizes, soil bearing capacity, and more, ensuring the foundation's design will meet the required specifications.

Design: After inputting all parameters, the design process is initiated. The software performs the design calculations and provides output, which includes reinforcement details, design calculations, and summary drawings. If any errors occur, the design must be corrected and executed again.

Output Details: For the given footing, the output includes the dimensions, reinforcement details, and design calculations. For instance, the footing's dimensions are 16.56 m in length, 2.50 m in width, and 0.90 m in thickness. The main steel reinforcement includes Ø25 bars at 105 mm c/c on the top and Ø20 bars at 250 mm c/c at the bottom. Secondary reinforcement consists of Ø16 and Ø20 bars.

Footing and Soil Properties: The soil's unit weight is 22 kN/m³ with a bearing capacity of 160 kN/m². The footing's self-weight, including the pedestal, is 894.24 kN, and there is no soil weight above the footing.

The calculated final footing dimensions, reinforcement details, and soil parameters ensure that the designed combined footing will provide adequate support for the structure based on the specified loads and conditions.

The load combinations for the design of the foundation include various scenarios based on different load cases, such as Dead Load (DL), Live Load (LL), Wind Load (W), and their combinations with different factors. For instance, Load Combinations 1 and 2 consider only Dead Load and Live Load with multipliers of 1.00, while combinations like 9 and 14 involve combinations of Dead Load, Live Load, and Wind Load (both positive and negative). Additionally, service stress level combinations (1001–1005) are provided with multipliers for Dead Load, Live Load, and Wind Load based on Indian design codes, ensuring comprehensive load analysis for the foundation design.

The provided data outlines the shear forces, resisting sliding forces, and the required factors of safety (FOS) for various load cases. Each load case specifies shear forces in the X and Z directions (in kN), the resisting sliding force, and the ratio of these forces along the X and Z axes. The required factor of safety for all cases is consistently 1.500.

Load Case 1 shows a shear force of 1.645 kN in X, -4.543 kN in Z, with a resisting sliding force of 1181.568 kN. The ratio values for X and Z are 718.467 and -260.110, respectively.

Similarly, Load Case 9 has a shear force of 3.709 kN in X and -49.569 kN in Z with a resisting sliding force of 2220.728 kN. In all cases, the required factor of safety is 1.500, indicating the foundation's ability to resist sliding and shear forces under different loading conditions, ensuring stability and safety.

Overall, these calculations contribute to assessing the foundation's capacity to withstand various load scenarios, including dead loads, live loads, and wind loads, while maintaining the required safety margin.

Load Case	Shear X (kN)	Shear Z (kN)	Resisting Sliding Force (kN)	Ratio X	Ratio Z	Required FOS
1	1.645	-4.543	1181.568	718.467	-260.110	1.500
2	0.828	-28.504	775.845	936.654	**-27.219**	1.500
7	-0.001	-0.006	357.655	-652655.707	-60825.736	1.500
8	0.004	0.002	357.723	90265.736	195050.765	1.500
9	3.709	-49.569	2220.728	**598.688**	-44.800	1.500
10	2.967	-39.662	1848.073	622.917	-46.595	1.500
11	2.972	-39.653	1848.154	621.810	-46.608	1.500
12	2.968	-39.648	1848.171	622.674	-46.614	1.500
13	2.963	-39.658	1848.089	623.784	-46.601	1.500
14	2.967	-39.655	1848.122	622.795	-46.605	1.500
15	2.466	-6.823	1593.443	646.158	-233.551	1.500
16	2.473	-6.811	1593.545	644.431	-233.963	1.500
17	2.468	-6.805	1593.565	645.777	-234.175	1.500
18	2.461	-6.817	1593.464	647.510	-233.762	1.500
19	2.467	-6.814	1593.504	645.967	-233.863	1.500
20	1.479	-4.097	1099.120	743.006	-268.266	1.500
21	1.486	-4.086	1099.222	739.693	-269.050	1.500
22	1.481	-4.079	1099.242	742.263	-269.456	1.500
23	1.474	-4.091	1099.140	745.600	-268.669	1.500
24	1.480	-4.088	1099.181	742.635	-268.859	1.500
1001	1.645	-4.543	1181.568	718.467	-260.110	1.500
1002	2.473	-33.046	1599.717	646.904	-48.409	1.500
1003	1.648	-4.547	1181.555	716.970	-259.876	1.500
1004	1.645	-4.543	1181.568	718.467	-260.110	1.500

5.Conclusion

The foundation design, in compliance with IS 456:2000 standards, ensures safety and structural integrity under critical load conditions. The design accounts for key factors such as moments, shear stresses, and punching shear, all of which fall within permissible limits. The governing sagging moment is 242.70 kNm, and the hogging moment is 3610.98 kNm, both of which are well below the respective moment capacities (6693.24 kNm and 6571.37 kNm). The shear stress along the foundation width is 469.68 kN/m², well within the concrete strength of 497.89 kN/m², confirming the foundation's safety. Punching shear stresses around critical columns are also within acceptable limits, with the highest stress being 364.83 kN/m², far below the capacity of 1369.31 kN/m². The reinforcement design consists of Ø25 bars at 105 mm c/c (top) and Ø20 bars at 250 mm c/c (bottom), meeting all code requirements and ensuring robust support. Stability checks confirm that the foundation has a sufficient factor of safety (FOS) of 1.5 against overturning, with resisting moments exceeding applied moments across all load cases. For example, in Load Case 9, the applied moments are 96.160 kNm (X) and -162.029 kNm (Z), while the resisting moments are 6939.649 kNm and 45968.234 kNm, respectively, demonstrating a stable design.

5.1 Scope for Further Studies

Future studies could focus on optimizing the foundation design to improve material efficiency while maintaining structural safety. Advanced analysis techniques, such as finite element modeling (FEM), could provide a more detailed understanding of stress distribution and identify potential areas for further optimization. Additionally, the incorporation of seismic load analysis and dynamic response studies would enhance the design's resilience in earthquake-prone regions. Exploring alternative materials, such as high-strength concrete or fiber-reinforced composites, could improve durability and reduce overall construction costs. Lastly, conducting a sustainability analysis to evaluate the environmental impact of the materials and construction methods could align the design with green building standards, enhancing the project's overall efficiency and environmental responsibility.

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