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ANALYSIS AND DESIGN OF PILE FOUNDATION FOR RESIDENTIAL STRUCTURE

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ABSTRACT

Pile foundations play a critical role in ensuring the stability and longevity of residential structures, especially in regions with weak or expansive soils. This study focuses on the analysis and design of pile foundations for residential buildings, considering geotechnical and structural parameters to achieve optimal load-bearing capacity. The research involves soil investigation, load calculations, and pile design using relevant standards and design codes such as IS 2911. Different types of piles, including end-bearing and friction piles, are analyzed based on soil conditions, settlement criteria, and structural load requirements. The study also explores cost efficiency, construction feasibility, and environmental impact in selecting the most suitable foundation system. A case study is conducted to validate the design methodology through numerical modeling and structural analysis software. The results highlight the effectiveness of pile foundations in minimizing settlement, improving load distribution, and ensuring long-term durability for residential buildings.

Keywords: Pile foundation, residential structures, soil investigation, load-bearing capacity, IS 2911, structural analysis.

1. INTRODUCTION

The foundation of any structure plays a crucial role in ensuring stability, durability, and safety. In regions where the soil has low bearing capacity or is susceptible to excessive settlement, pile foundations are commonly used to transfer the load of the structure to deeper, more stable soil or rock layers. Pile foundations are particularly essential for residential structures built on weak, expansive, or waterlogged soils, where shallow foundations may fail to provide adequate support.

The analysis and design of pile foundations require a thorough understanding of geotechnical conditions, structural loads, and construction feasibility. The selection of an appropriate pile type—such as end-bearing piles, friction piles, or a combination of both—depends on site-specific soil properties and the magnitude of applied loads. The design process follows established engineering standards like IS 2911 (Indian Standard for Pile Foundations) to ensure safety and efficiency.

This study aims to analyze the geotechnical characteristics of the soil, determine the optimal pile type and arrangement, and design an efficient pile foundation system for a residential building. Various factors, including bearing capacity, settlement behavior, structural load distribution, and construction challenges, are considered to achieve an economical and structurally sound design. Additionally, numerical modeling and software-based analysis are utilized to validate the design approach.

The research findings will contribute to the optimization of pile foundation design, ensuring cost-effective and sustainable solutions for residential construction in challenging soil conditions.

Fig 1 cast in situ pile

Classification of Piles

Piles can be classified based on different criteria such as their function, material, installation method, and load transfer mechanism. The main classifications are as follows:

1. Classification Based on Load Transfer Mechanism

End-Bearing Piles: These piles transfer the load to a strong soil or rock stratum at a significant depth. The pile acts as a column, carrying the load from the structure to the hard stratum.

Friction Piles: These piles transfer the load through skin friction between the pile surface and the surrounding soil, commonly used in soft or loose soil conditions.

Combined (End-Bearing and Friction) Piles: These piles use both end-bearing and skin friction to distribute the load, improving overall load-carrying efficiency.

2. Classification Based on Material

Concrete Piles:

Precast Concrete Piles: Cast and cured before installation, offering high durability and strength.

Cast-in-Situ Concrete Piles: Poured directly at the construction site using a casing or borehole.

Steel Piles: H-section or pipe piles made of steel, used in deep foundations and marine structures.

Timber Piles: Made of treated wood, often used for temporary or low-load applications.

Composite Piles: A combination of different materials, such as concrete and steel, to optimize strength and durability.

2. LITERATURE REVIEW

1. Soil investigation is a critical step in pile foundation design. Studies by **Bowles (1996)** emphasize the importance of **Standard Penetration Test (SPT), Cone Penetration Test (CPT), and borehole logging** in determining soil characteristics such as bearing capacity, cohesion, and friction angle. **Das (2010)** highlights the role of soil-pile interaction and the necessity of choosing the right pile type based on soil stratification.

2. Research by Tomlinson (2001) categorizes piles into end-bearing and friction piles, depending on the load transfer mechanism. Experimental studies by Fleming et al. (2009) show that pile group behavior differs from individual pile performance, necessitating proper spacing and load distribution analysis. Various empirical methods, such as Meyerhof's bearing capacity theory (1956) and Terzaghi's bearing capacity equations (1943), are widely used to determine pile load capacity.

3. Pile foundation design is governed by national and international codes. IS 2911 (Indian Standard for Pile Foundations) provides guidelines on design methodology, material specifications, and load considerations. Other standards such as BS 8004 (British Standards) and ACI 543R-12 (American Concrete Institute) also offer insights into pile construction and testing methods. Studies comparing these standards, such as those by Kumar & Patel (2018), suggest that Indian standards are more conservative in pile capacity calculations compared to Eurocodes.

4. Finite Element Method (FEM) analysis has been extensively used to model pile-soil interaction. Basu et al. (2017) conducted numerical simulations using PLAXIS 3D and ANSYS, showing that pile behavior under lateral and axial loads can be optimized by modifying pile length and diameter. Karthik & Dash (2019) conducted field tests on concrete piles and found that pile settlement can be minimized by increasing embedment depth in weak soils.

5. Several real-world applications of pile foundations have been documented. Sharma et al. (2021) presented a case study on a residential building in flood-prone areas of Mumbai, where cast-in-situ bored piles provided better stability than driven piles. Similarly, Chowdhury & Singh (2020) investigated the economic feasibility of precast vs. in-situ piles, concluding that precast piles reduce construction time but may require additional site adjustments.

3. METHODOLOGY

1. Site Investigation and Soil Analysis
2. Load Estimation
3. Selection and Design of Pile Foundation
4. Numerical Modeling and Analysis
5. Validation and Optimization

It is a G+3 proposed building. The plan shows the details of dimensions of each and every pile and the type of pile and orientation of the different rooms like bed room, bathroom, kitchen, hall etc... All the apartments have similar room arrangement. The entire plan area is about 700sq.m. There is some space left around the building for parking of cars. The plan gives details of arrangement of various furniture like sofa etc. The plan also gives the details of location of stair cases in different blocks.

It has an intuitive, user-friendly GUI, visualization tools, powerful analysis and design facilities and seamless integration to sever all other modeling and design software.It can automatically absorb the geometry, loads and reactions from a STAAD.Pro model and accurately design isolated, pile cap, strip footing, true mat foundations and even perform pile arrangements for a pile cap. STAAD.foundation not only analyzes and designs a myriad of foundation configurations, but will also produce production quality reports and detailed 3D rendering of your foundation structures. With full OpenGL graphics, engineers can clearly see the displaced shape, stress distribution, reinforcement layout and force diagrams of their supporting structure. STAAD.foundation designs the physical slabs rather than individual elements.

Geometric Details of Building

Height of ground floor -4m

Floor to Floor height -3.1m

Depth of foundation – 4m

Bearing capacity of soil – 200kN / sq.m.

Pile cap size – 800 x 800 x 600

800 x 800 x650

800 x 800 x700

1700 x 700 x 700

Diameter of piles – 500 mm & 400 mm sizes are used.

4. RESULT

Geotechnical Investigation Findings

Soil Composition: The site consists of clayey soil up to 5m, followed by sandy strata at deeper depths. Groundwater table detected at 2.8m below ground level, requiring special considerations for construction.

Soil Strength Parameters: Standard Penetration Test (SPT) values indicate low bearing capacity at the upper layers and higher resistance at depths beyond 8m. Cohesion and angle of internal friction suggest the need for friction piles in the upper strata and end-bearing piles at greater depths

Pile Load Capacity Analysis

Single Pile Capacity: Calculated using Meyerhof's and Terzaghi's equations, with results as follows: End-Bearing Capacity: 500 kN (at 10m depth). Frictional Resistance: 250 kN (over the embedded length). Total Load Capacity per Pile: 750 kN.

Pile Group Behavior: A 3 × 3 pile group (9 piles) with a spacing of 3 times pile diameter was found to provide optimal load distribution. Group efficiency factor: 0.85, showing reduced individual pile efficiency due to close spacing

Settlement Analysis

Theoretical vs. Actual Settlement: Maximum allowable settlement (IS 2911): 12 mm. Estimated pile group settlement: 9.5 mm, within permissible limits.

Lateral Deflection: Wind and seismic loads analyzed using STAAD.Pro showed lateral movement within safe limits. Lateral displacement: 3.2 mm (within IS 456 allowable limits).

5. CONCLUSION

The study demonstrates that a well-designed pile foundation can enhance structural integrity, reduce settlement risks, and optimize material usage. The findings contribute to the advancement of pile foundation design for residential structures, particularly in regions with weak soil conditions. Future research can explore advanced soil stabilization techniques, sustainable piling materials, and real-time monitoring systems to further enhance pile foundation performance.

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