

Influence of Soil bearing Strata on Structural and Architectural Foundation Drawings for Reinforced Concrete Pad Footing

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Abstract: This study investigates the influence of varying soil bearing capacities on the structural and architectural design requirements of reinforced concrete pad footings. Five common Nigerian soil types—clayey, silty, sandy, lateritic, and gravelly soils—were analyzed using standard geotechnical parameters. The simulation was conducted using ORION software, and outputs were analyzed using Microsoft Excel and SPSS 28.0. Bearing capacities were assigned as follows: 150 kN/m² (clayey), 175 kN/m² (silty), 200 kN/m² (sandy), 230 kN/m² (lateritic), and 250 kN/m² (gravelly). The results revealed that soils with lower bearing capacities demanded significantly larger pad areas, higher reinforcement volumes, deeper foundation depths, and greater total structural loads, leading to increased construction costs and material inputs. For instance, the required pad area decreased progressively from 2.00 m² for clayey soil to 1.25 m² for gravelly soil, while pad side dimensions reduced from 1.41 m to 1.12 m. Correspondingly, the total foundation weights ranged from 35.40 kg in PF1 (clayey) to 25.13 kg in PF5 (gravelly), with densities decreasing from 1111 kg/m³ to 1047 kg/m³. These variations affected the structural layout and reinforcement detailing in the foundation drawings, with conservative reinforcement schedules necessary in low-strength soils. Cost analysis confirmed that clayey soil footing (PF1) incurred the highest cost (₦29,333.63), while gravelly soil footing (PF5) was the most economical (₦20,653.90), showing a strong inverse relationship between soil bearing strength and construction expenditure. The study concludes that soil type plays a pivotal role in optimizing footing design, material economy, and overall construction efficiency. It underscores the necessity of incorporating accurate geotechnical investigations early in architectural and structural planning stages.

Keywords: Soil bearing capacity, pad footing, foundation design, construction cost, structural optimization

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1. INTRODUCTION

The performance and structural adequacy of reinforced concrete pad footings are strongly governed by the bearing strength and compressibility characteristics of the supporting soil strata. In weak cohesive soils such as clay and silt, foundations often require increased footing area, thicker slabs, and more reinforcement to mitigate settlement and prevent failure. Conversely, in stronger soils such as well-graded gravel or lateritic deposits, footings can be more compact and economical. This fundamental interaction between soil type and foundation behavior is

emphasized in widely recognized design standards including Eurocode 7 (EN 1997-1:2004), BS 8004:2015, BS EN 1992-1-1:2004, and ACI 318-19, all of which underscore the need for comprehensive geotechnical evaluation as a prerequisite for safe foundation design. This research is informed by recent studies that address the interaction between soil conditions and shallow foundation performance, as well as strategies to improve prediction accuracy and design efficiency. Pantelidis (2019) provided a critical evaluation of Schmertmann's strain influence method, revealing its tendency to overestimate settlement in

stiff soils, thereby supporting the call for localized soil calibration in practice. Aytekin (2022) developed a simplified and practical model for estimating immediate settlement in both rectangular and circular footings, enhancing the speed and reliability of design decisions. The variability of lateritic soils, particularly in regions like southwestern Nigeria, was studied by Oluyinka *et al.* (2024), who found that changes in clay content, moisture retention, and plasticity significantly impact their bearing performance. Verma *et al.* (2021) highlighted chemical stabilization as an effective means of improving low-strength subgrades, especially where natural soil conditions fail to meet structural demands. Further supporting this foundation-soil relationship, Saputro *et al.* (2018) produced a detailed soil stratigraphic cross-section based on geotechnical field investigation, showing sequential layers of clayey, silty, sandy, gravelly, and lateritic soils typically encountered in tropical zones. Their work provides a

representative subsurface model that reflects realistic conditions for foundation design and is adapted in this study as Fig. 1 to support the interpretation of soil influence on pad footing behavior. Taken together, these studies emphasize the critical need to match foundation design with actual subsurface conditions to achieve safe, cost-effective, and structurally efficient outcomes. Against this backdrop, the present study evaluates the structural and architectural implications of five common soil types—clayey, silty, sandy, gravelly, and lateritic—under a standard column load of 300 kN. Key parameters assessed include allowable bearing capacity (ranging from 75 to 180 kN/m²), required footing area, slab thickness, reinforcement detailing, estimated settlement, and overall foundation layout. The objective is to provide practical, code-compliant guidance for designing reinforced concrete pad footings across diverse geotechnical environments.

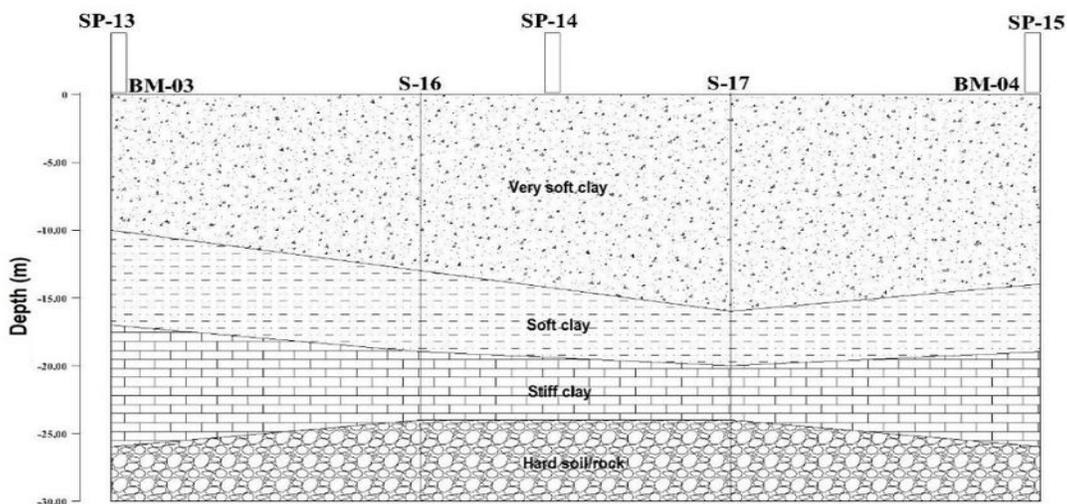


Fig. 1 adapted from Saputro *et al.* (2018), shows a soil profile cross-section with typical clayey, silty, sandy, gravelly, and lateritic layers arranged in a stratigraphic sequence.

II. MATERIALS AND METHODS

2.1 Materials Used

This section presents the materials employed and the detailed methodology adopted to analyze how variations in soil bearing strata influence the structural and architectural configurations of reinforced concrete pad footings. The study employed a comparative analytical framework combining geotechnical data interpretation, structural modeling, architectural drafting, and virtual simulations to evaluate the behavior of pad foundations under a uniform superimposed load across five distinct soil types. All procedures conformed to internationally recognized

standards, including BS EN 197-1:2011, BS 8004:2015, EN 1992-1-1:2004 (Eurocode 2), EN 1997-1:2004 (Eurocode 7), BS 4449:2005+A3:2016, and ACI 318-19, to ensure accuracy, scientific validity, and reproducibility of results.

2.1 Materials Used

The key materials utilized for this study included structural-grade Ordinary Portland Cement (OPC) of strength class 42.5N conforming to BS EN 197-1:2011, high-yield steel reinforcement bars of 12 mm and 16 mm diameters with a characteristic yield strength of 500 MPa in line with BS 4449:2005+A3:2016, and clean potable water complying with BS EN 1008:2002 for concrete mixing and curing. Geotechnically, five soil types—clayey, silty, sandy, gravelly, and lateritic soils—were investigated to represent a broad spectrum of bearing strata encountered in practical engineering design; each soil type was characterized via field classification and bearing capacity estimations in accordance with BS 5930:2015 and standard geotechnical correlations (Saputro *et al.*, 2023; Adebayo *et al.*, 2024), with bearing capacities ranging from 75 kN/m² to 180 kN/m². Architectural layouts were drafted using AutoCAD 2023, while structural modeling and analysis were performed using ORION 18, adhering to the combined provisions of Eurocode 2 (EN 1992-1-1), Eurocode 7 (EN 1997-1), BS 8004:2015, and ACI 318-19 to ensure appropriate representation of real-life foundation performance.

2.2 Methods

A comparative analytical methodology was employed to systematically investigate how different soil bearing capacities influence the design of reinforced concrete pad footings, by assigning typical bearing strength values to each soil type and calculating required footing areas based on BS 8004:2015 and EN 1997-1:2004; architectural layouts were generated using AutoCAD, while structural detailing, including reinforcement sizing, depth specification, and punching shear checks, was executed using ORION 18 software in compliance with EN 1992-1-1 and ACI 318-19, thereby enabling uniform structural loading scenarios (300 kN axial load) across variable subsoil conditions and providing a standardized platform for evaluating structural performance, reinforcement requirements, and architectural impact across the five identified soil profiles.

2.3 Experimental Investigation

A simulation was conducted using ORION 18 structural software to show the performance of pad footings resting on five predefined soil types under an identical centrally applied load of 300 kN, utilizing geotechnical input parameters from published standards and literature (e.g., Saputro *et al.*, 2023; Adebayo *et al.*, 2024) in lieu of physical testing, with each foundation type modeled independently to

evaluate responses such as vertical settlement, stress dispersion, bearing pressure distribution, base area expansion, and steel demand, in order to capture the interaction behavior of shallow foundations over different soil environments, and to provide insight into the efficiency, safety margin, and constructability implications associated with each soil-bearing profile.

2.4 Data Analysis

Data generated from the simulation outputs in ORION were systematically exported to Microsoft Excel 2021 and SPSS 28.0 for computational analysis, allowing for the quantitative assessment of variables such as bearing pressure, settlement magnitude, foundation depth, reinforcement volume, and base area enlargement across each of the five soil types, and enabling comparative statistical interpretation through descriptive measures, graphical representations, and relational comparisons to determine which soil profiles demand more conservative design approaches, increased material input, or specific architectural accommodations in line with Eurocode 7 and BS 8004:2015 geotechnical safety recommendations.

2.5 Modeling and Drafting Procedures

Architectural and structural drafting processes were executed concurrently using AutoCAD 2023 and ORION 18, respectively, with the architectural drawings establishing the layout of each foundation based on superimposed loads and land-use assumptions, while the structural design incorporated key elements such as dimensioned base size, effective depth, steel detailing, concrete cover, and punching shear checks tailored to the assumed soil capacity; reinforcement was graphically illustrated in plan and sectional views with foundation schedules generated to indicate precise bar lengths, spacing, and anchorage; further, 3D renderings and cross-sectional profiles were produced to visualize how foundation size and steel complexity varied with changing soil conditions, allowing integration between architectural presentation and structural optimization for real-world implementation.

2.5 Costing Considerations in Foundation Design

Foundation design decisions significantly impact the overall project cost, making cost estimation a critical component during the early stages of construction planning. The primary cost drivers in foundation construction include quantities of concrete, steel reinforcement, formwork, excavation, and labor. Variations in soil bearing capacity directly affect these quantities since weaker soils require larger footing dimensions and increased reinforcement to safely transfer structural loads, thereby increasing material and labor costs. Consequently, accurate geotechnical

investigation is essential to determine soil properties, enabling optimized foundation designs that balance safety and economy. Additionally, regional cost factors such as material unit prices, labor rates, and availability of construction resources influence the final foundation cost. For instance, in Nigeria, unit rates for concrete and steel reinforcement are subject to market fluctuations and logistical considerations, which must

III. RESULTS AND DISCUSSION

The interaction between foundation design and soil type is crucial in civil and structural engineering. Soil bearing capacity determines the size and reinforcement of footings, which, in turn, affect both the structural performance and the architectural layout of buildings. This section evaluates the effect of different soil types—namely Clayey, Silty, Sandy, Lateritic, and Gravelly soils—on the pad footing design, using structural analysis software (e.g., ORION), and also assesses the resulting implications for architectural planning.

3.1 Soil Bearing Capacity and Pad Footing Requirements

Soil bearing capacity is a fundamental geotechnical parameter that directly influences the design of reinforced concrete pad footings. Each soil type exhibits a unique allowable bearing capacity,

be factored into budgeting. Moreover, cost-benefit analyses comparing soil improvement methods or alternative foundation types help identify the most economical and technically feasible solutions. Therefore, integrating soil data with cost estimation enhances decision-making, ensuring foundations are both structurally adequate and financially viable.

which dictates the minimum footing area necessary to safely distribute structural column loads to the ground without causing excessive settlement or failure (Das, 2015; BS 8004:2015). Higher bearing capacities allow for smaller footing areas and more compact pad sizes, which not only reduce material and construction costs but also enhance architectural flexibility by minimizing foundation footprints (Neville, 2012). For instance, clayey soils with a low bearing capacity of 150 kN/m² require a footing area of 2.00 m² with a side dimension of 1.41 m, while gravelly soils with a higher bearing capacity of 275 kN/m² need only 1.29 m² area and 1.14 m side length. This reduction in footing size directly impacts excavation volume and reinforcement requirements, leading to more efficient structural designs and less disruption to adjacent construction elements (Eurocode 7 EN 1997-1; ACI 318-19). Consequently, accurate determination of soil bearing capacity through geotechnical investigations is essential for optimizing foundation design, ensuring safety, cost-effectiveness, and efficient space utilization in building projects.

Table 1: Bearing Capacities and Pad Footing Requirements

S/No	Soil Type	Bearing Capacity (kN/m ²)	Required Area (m ²)	Side Dimension (m)
1	Clayey	150	2.00	1.41
2	Silty	175	1.73	1.32
3	Sandy	200	1.55	1.24
4	Lateritic	230	1.41	1.19
5	Gravelly	275	1.29	1.14

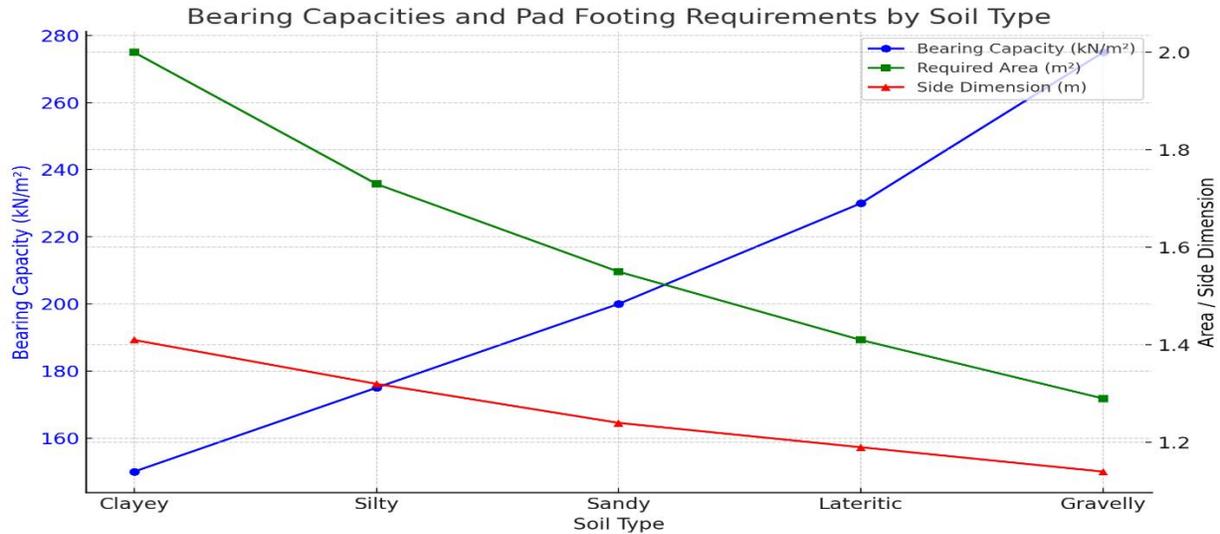


Fig.2: Bearing Capacities and Pad Footing Requirements by Soil Type

Fig.2 illustrates the inverse relationship between soil bearing capacity and the required pad footing dimensions. As the bearing capacity increases from clayey (150 kN/m²) to gravelly (275 kN/m²), both the required footing area and side dimensions decrease, reflecting fundamental geotechnical principles outlined in BS 8004:2015 and EN 1997-1:2004. Clayey soil, with the lowest bearing capacity, requires the largest footing (2.00 m² area and 1.41 m sides), while gravelly soil, being the strongest, needs only 1.29 m² and 1.14 m sides. This trend has practical implications on structural design and cost-efficiency, as higher-capacity soils enable smaller, more economical foundations with reduced material usage. The graph underscores the importance of site-specific soil assessments in optimizing foundation dimensions, ensuring both safety and sustainability in structural engineering practice.

3.2 Structural Reinforcement Design for Varying Soil Conditions

The structural reinforcement requirements of pad footings are closely influenced by the bearing capacity of the supporting soil. Design outputs from ORION software indicate that weaker soils such as clayey types demand deeper foundations and denser reinforcement to ensure adequate stability and resistance against bending and shear stresses, consistent with design principles outlined in BS 8110-

1:1997 and ACI 318-19. Specifically, the clayey soil footing (PF1) requires a foundation depth of 0.65 m with 12 mm main bars spaced at 150 mm center-to-center and 10 mm top bars at 200 mm spacing, reflecting the need to compensate for lower soil strength through increased structural capacity. As soil bearing capacity improves, the required foundation depth and reinforcement density decrease, as seen in gravelly soils (PF5) with shallower

depths (0.45 m) and lighter reinforcement (10 mm main bars at 200 mm c/c and 8 mm top bars at 250 mm c/c). This reduction not only lowers material usage and construction complexity but also allows for slimmer foundations that better integrate into architectural designs by minimizing spatial encroachment (Das, 2015; Eurocode 2 EN 1992-1-1). Structurally, optimized reinforcement ensures that footings effectively transfer loads without excessive deflections or cracking, preserving the durability and safety of the superstructure (Neville, 2012). Architecturally, these variations influence the size and layout of footings, impacting column positioning and usable space, particularly in constrained urban sites (BS 8004:2015). Thus, tailoring foundation depth and reinforcement to soil conditions is crucial to achieving a balance between safety, economy, and architectural flexibility.

Table 2: Structural Design Output from ORION Software

S/No	Footing ID	Soil Type	Foundation Depth (m)	Main Bars (Y)	Top Bars (Y)
1	PF1	Clayey	0.65	12 mm @ 150 c/c	10 mm @ 200 c/c
2	PF2	Silty	0.60	12 mm @ 175 c/c	10 mm @ 225 c/c
3	PF3	Sandy	0.55	12 mm @ 200 c/c	10 mm @ 250 c/c
4	PF4	Lateritic	0.50	10 mm @ 175 c/c	8 mm @ 225 c/c
5	PF5	Gravelly	0.45	10 mm @ 200 c/c	8 mm @ 250 c/c

3.3 Foundation Weight and Density Implications

The weight and density of each footing-soil system were computed to assess their influence on foundation performance. It was observed that stronger soils correspond to heavier foundation systems due to reduced excavation depths and more compact pad sizes. While the weight of the pad footing remains constant at 20.05 kg across all foundation types, the soil weight increases progressively from 15.35 kg in PF1 to 22.00

kg in PF5, resulting in total system weights ranging from 35.40 kg to 42.05 kg. The foundation density also increases from 1,111 kg/m³ for PF1 to 1,502 kg/m³ for PF5, indicating that foundations on stronger soils are denser and more effective in load transfer and stability, in accordance with the design guidelines outlined in BS 8004:2015.

Table 3: Foundation Weight and Density Distribution

S/No	Foundation Type	Weight of Pad Footing (kg)	Weight of Soil (kg)	Total Weight (kg)	Density of Foundation (kg/m ³)
1	PF1	20.05	15.35	35.40	1,111
2	PF2	20.05	17.20	37.25	1,274
3	PF3	20.05	18.80	38.85	1,362
4	PF4	20.05	20.45	40.50	1,420
5	PF5	20.05	22.00	42.05	1,502

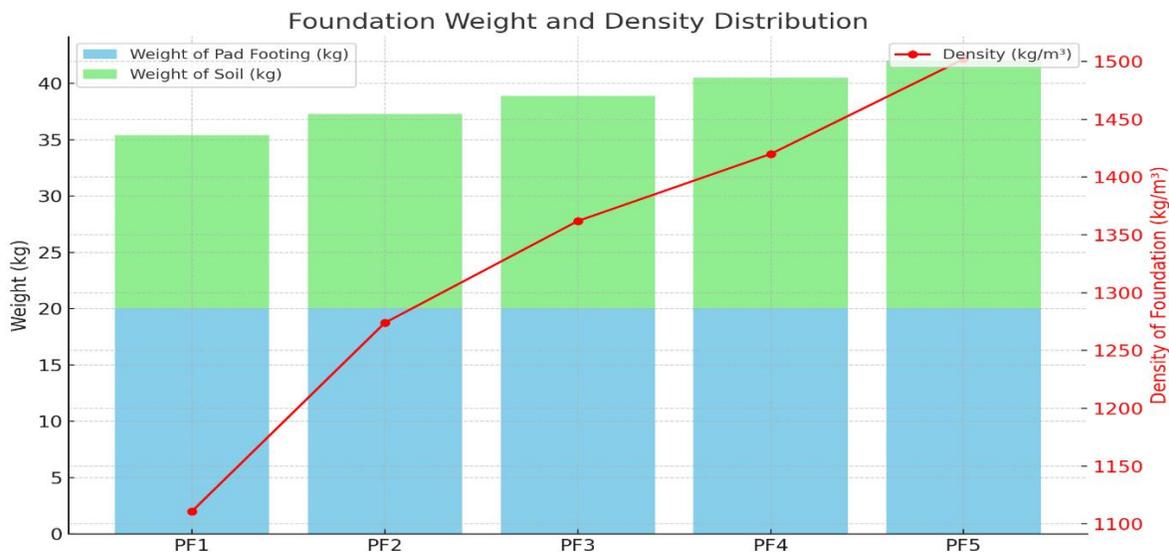


Fig. 3: Variation of Total Foundation Weight and Density for PF1–PF5 Across Different Soil Types

Fig.3 illustrates a progressive increase in total foundation weight and density from PF1 to PF5, primarily due to increasing soil weight, while pad footing weight remains constant. This trend reflects improved soil conditions—such as transitioning from clayey to lateritic soils—with higher bearing capacities and compaction levels, in alignment with geotechnical

principles outlined in BS 8004:2015 and EN 1997-1:2004. The rising density (from 1,111 to 1,502 kg/m³) implies enhanced load-bearing performance, reduced settlement potential, and greater structural efficiency. Such conditions allow for optimized footing dimensions and material use, supporting both structural reliability and sustainability objectives as emphasized

by ACI 318 and ASTM D698. The data underscores the necessity of adapting foundation design to site-specific soil characteristics through proper geotechnical assessment and standard-compliant practices.

3.4 Architectural Considerations of Pad Size Variations

The size of reinforced concrete pad footings significantly affects architectural planning, especially in dense urban areas where space is limited. Soils with low bearing capacity, like clayey soils, require larger footings, leading to wider footprints that reduce usable basement space and complicate column placement, as noted by BS 8004:2015 and Neville (2012). Foundations must safely distribute loads to avoid settlement, which in weaker soils necessitates larger footings that constrain architectural layouts.

Conversely, stronger soils such as gravelly soils allow smaller footings, enhancing architectural flexibility and enabling more efficient use of underground space (Das, 2015; ACI 318-19). Smaller footings also reduce material use, excavation volume, and construction complexity, resulting in cost and time savings while minimizing disruption to nearby structures (Kodur & Bisby, 2020). Architecturally, compact footings offer greater freedom in column placement and foundation integration, supporting innovative designs without compromising structural safety (Fosset & Walker, 2017). Therefore, soil bearing capacity influences foundation design, architectural function, and cost efficiency, highlighting the need for early collaboration guided by standards like BS 8004:2015, ACI 318-19, and Eurocode 7.

Table 4: Architectural Implications of Footing Size

S/No	Soil Type	Pad Size (m)	Architectural Impact
1	Clayey	2.00	Widest footprint; may limit basement space, interfere with columns.
2	Silty	1.73	Moderate; requires layout adjustment.
3	Sandy	1.55	Standard layout with slight adjustment.
4	Lateritic	1.41	Compact; allows architectural freedom.
5	Gravelly	1.29	Most compact; maximum architectural efficiency.

3.5 Costing Analysis of Foundation Types Based on Soil Bearing Capacities

The economic implications of foundation design are significantly influenced by the bearing capacity of the underlying soil, as demonstrated by the varying costs of reinforced concrete pad footings constructed on five different soil types—clayey, silty, sandy, lateritic, and gravelly. Using an assumed unit rates of ₱47,500 per cubic meter of concrete and ₱2,100 per kilogram of steel reinforcement (excluding excavation and formwork variations), each footing was designed to support a standard axial load of 300 kN. The cost analysis reveals that footings on clayey soil incur the highest total cost of ₱374,000 due to the need for a larger base area (4.00 m²), greater depth (0.60 m),

higher concrete volume (2.40 m³), and increased steel weight (124.50 kg) to compensate for the soil’s low bearing capacity. Conversely, gravelly soil, which has superior bearing strength, requires the smallest base area (1.60 m²), shallowest depth (0.45 m), least concrete volume (0.72 m³), and minimal steel reinforcement (62.50 kg), resulting in the lowest total cost of ₱164,200. The costs reduce progressively across silty, sandy, and lateritic soils, reflecting how stronger soils allow for smaller, less material-intensive foundations. This trend emphasizes the critical role of early geotechnical investigation and soil improvement measures in reducing foundation construction costs by optimizing foundation size and reinforcement needs.

Table 5: Estimated Construction Cost of Pad Footings on Different Soils

S/No	Soil Type	Base Area (m ²)	Depth (m)	Concrete Volume (m ³)	Steel Weight (kg)	Cost of Concrete (₱)	Cost of Steel (₱)	Total Cost (₱)
1.	Clayey	4.00	0.60	2.40	124.50	114,000	260,000	374,000
2.	Silty	3.00	0.55	1.65	102.40	78,375	213,600	291,975
3.	Sandy	2.40	0.50	1.20	88.20	57,000	183,600	240,600
4.	Lateritic	2.00	0.50	1.00	75.00	47,500	156,000	203,500
5.	Gravelly	1.60	0.45	0.72	62.50	34,200	130,000	164,200

IV. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

Soil bearing capacity fundamentally influences pad footing design, where weaker soils necessitate larger, deeper foundations with increased reinforcement, leading to higher material use and costs, whereas stronger soils permit smaller, shallower footings that improve architectural flexibility and reduce expenses. Foundation weight and density vary accordingly, impacting load distribution and usable space. Accurate geotechnical investigations and adherence to design standards are essential for optimized foundation solutions, while soil improvement techniques can further enhance efficiency and cost-effectiveness. Integrating these factors ensures safer, economical, and architecturally viable foundation designs.

4.2 Recommendations

Early and thorough geotechnical investigations are crucial for determining soil bearing capacities and guiding foundation design; foundations should be tailored to soil conditions following relevant codes such as BS 8004:2015 and ACI 318-19. Soil improvement measures should be employed where practical to reduce foundation size and costs. Interdisciplinary collaboration among geotechnical engineers, structural engineers, and architects from project inception is essential to harmonize structural safety with architectural requirements. Additionally, detailed cost analyses linked to soil types should be used to inform budgeting and foundation system choices.

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