

Assessment of Geotechnical Properties and Bearing Capacity of Subsurface Soils for Shallow Foundation Design in Port Harcourt, Nigeria

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DOI: <https://doi.org/10.5281/zenodo.18919283>

Published Date: 09-March-2026

Abstract: This study evaluates the geotechnical properties of subsurface soils for shallow foundation design in Port Harcourt, Rivers State, Nigeria. Soil samples obtained from five locations—RSU Campus, Iwofe, Eneka, Rukpokwu, and Egbelu—were subjected to laboratory tests including natural moisture content, specific gravity, Atterberg limits, triaxial compression, and one-dimensional consolidation. Results indicate that the soils are predominantly fine-grained and classified as A-7-5 clayey soils under the AASHTO system. Natural moisture content ranged from 22.41% to 25.36%, while specific gravity varied between 2.54 and 2.62. Plasticity characteristics show mostly medium plastic clays, with relatively higher plasticity at Iwofe. Shear strength parameters yielded cohesion values of 37–118 kPa and friction angles of 11.55°–20.55°. The estimated ultimate bearing capacity ranged from 169–214 kN/m², indicating moderate load-bearing capacity. Consolidation analysis predicted settlements between 0.44 and 3.61 mm, suggesting that the soils are generally suitable for shallow foundations for low- to medium-rise structures with proper design considerations.

Keywords: geotechnical characterization, shallow foundation, soil properties, bearing capacity, consolidation, Port Harcourt.

I. INTRODUCTION

The stability and durability of civil engineering structures largely depend on the engineering characteristics of the soils supporting their foundations. Foundations function as load-transferring elements that distribute structural loads safely to the underlying ground. When the geotechnical properties of the supporting soil are not properly evaluated, excessive settlement, shear failure, or differential movement may occur, often resulting in structural damage or collapse. Consequently, adequate site investigation and soil characterization are fundamental requirements for the safe and economical design of foundations [1], [2].

Shallow foundations, including isolated footings, strip footings, and raft foundations, are commonly adopted for low- to medium-rise structures because of their simplicity and cost effectiveness. The design of these foundations requires accurate determination of soil parameters such as moisture content, particle size distribution, plasticity characteristics, shear strength, compressibility, and bearing capacity. These parameters provide essential information for evaluating the load-bearing capability of soils and estimating the magnitude of settlement that may occur under structural loads [1], [3]. Reliable geotechnical data therefore play a crucial role in ensuring that foundations perform satisfactorily throughout the service life of a structure.

In many developing countries, including Nigeria, numerous cases of structural distress have been associated with inadequate geotechnical investigations and improper assessment of subsurface soil conditions. Rapid urbanization and increased demand for infrastructure have intensified construction activities, particularly in major urban centres such as Port Harcourt. However, the subsurface soils in the Niger Delta region are generally characterized by unconsolidated sands, silts, and clay deposits with relatively high groundwater levels. These conditions often influence the bearing capacity, shear strength, and settlement behaviour of soils supporting foundations [4].

Previous studies on the engineering characteristics of soils in the Niger Delta have revealed significant spatial variability in their geotechnical properties. Investigations by Akpokodje identified the superficial soils of the region as predominantly sandy and clayey deposits with variable plasticity and compressibility, which may affect foundation performance if not adequately considered during design [4]. Similarly, Abam and Okogbue emphasized that the geotechnical properties of Niger Delta soils vary considerably with location and depth, highlighting the need for detailed site-specific investigations prior to construction [5]. Other studies have also reported that high moisture content and clayey soil composition can significantly reduce soil strength and increase settlement potential under structural loads [6].

Port Harcourt, located within the Niger Delta sedimentary basin, has experienced rapid urban and industrial development in recent decades. This growth has led to increased construction of residential, commercial, and infrastructural facilities, thereby increasing the need for reliable geotechnical data for foundation design. Due to the heterogeneous nature of soils in the area, detailed evaluation of subsurface soil properties is necessary to determine their suitability for shallow foundation construction.

The purpose of this study is to assess the geotechnical properties of soils obtained from selected locations in Port Harcourt and evaluate their suitability for shallow foundation systems. Laboratory tests including natural moisture content, specific gravity, particle size distribution, Atterberg limits, triaxial compression, and consolidation tests were conducted to determine key engineering parameters of the soils. The contribution of this study lies in providing reliable geotechnical data on soil stratification, strength characteristics, compressibility, and bearing capacity of soils within the study area. The findings are expected to support safe and economical foundation design for engineering structures in Port Harcourt and similar geologic environments.

II. METHODOLOGY

This study involved field sampling, laboratory testing, and analytical evaluation to characterize subsurface soils for shallow foundation design in Port Harcourt, Nigeria. Soil samples were collected from five locations—RSU Campus, Iwofe, Eneka, Rukpokwu, and Egbelu—using hand augers and core samplers at depths corresponding to typical shallow foundations. Both disturbed and undisturbed samples were obtained, labelled, and transported to the laboratory to preserve their natural state.

In the laboratory, the soils were subjected to standard geotechnical tests, including natural moisture content, specific gravity, Atterberg limits, triaxial compression, and one-dimensional consolidation. Soils were classified under the AASHTO and USCS systems, and shear strength parameters were used to estimate ultimate bearing capacity for shallow strip foundations using Terzaghi's equation:

$$q_u = cN_c + qN_q + 0.5\gamma BN_\gamma \quad (1)$$

where q_u is the ultimate bearing capacity (kPa), c is the soil cohesion (kPa), q is the surcharge at foundation level (kPa), γ is the soil unit weight (kN/m³), B is the foundation width (m), and N_c , N_q , N_γ are bearing capacity factors based on the soil friction angle (ϕ). Consolidation tests were used to predict settlements, and all laboratory data were statistically analyzed to evaluate spatial variation in geotechnical properties and assess the suitability of the soils for low- to medium-rise structures.

III. RESULTS AND DISCUSSIONS

A. Index Properties of Soil

Table I presents the index properties of soils obtained from the five study locations. The natural moisture content ranges from 22.41% at RSU to 25.36% at Iwofe, indicating moderately wet soils across the sites. Specific gravity values vary slightly between 2.54 and 2.62, reflecting the predominance of fine-grained mineral constituents. Liquid and plastic limits suggest medium plasticity, with Iwofe exhibiting relatively higher plasticity, while Egbelu shows lower values, indicating

less cohesive soil behavior. The plasticity index ranges from 12.8% to 23.3%, further confirming that the soils are mainly clayey and of medium plasticity. Overall, these index properties provide a foundational understanding of the soils' consistency, compressibility potential, and behavior under loading, which are critical for shallow foundation design.

TABLE I: Index Properties of Soil Samples

Location	RSU	Iwofe	Eneka	Rukpokwu	Egbelu
Natural moisture content (%)	22.41	25.36	22.80	23.57	24.61
Specific gravity	2.62	2.60	2.54	2.55	2.58
Liquid limit (%)	0.4	0.477	0.295	0.45	1.171
Plastic limit (%)	14.6	19.15	15.92	15.92	9.61
Flow index (%)	40	25	26	31	8
Plasticity index (%)	19.5	13	23.3	17	12.8

B. Shear Strength Parameters and Bearing Capacity

Table II and Fig. 1 present the shear strength characteristics and estimated ultimate bearing capacities of soils from the five study locations.

TABLE II: Shear Strength Parameters and Estimated Ultimate Bearing Capacity

Location	Cohesion value(kpa)	Angle of internal friction	Soil bearing capacity(KN/m ²)
RSU Campus	118	14.445	214
Iwofe	50	20.55	189
Eneka	53	17.483	181
Rukpokwu	37	11.545	173
Egbelu	42	12.406	169

Cohesion values range from 37 kPa at Rukpokwu to 118 kPa at RSU Campus, indicating significant variability in soil cohesiveness. The internal friction angle (ϕ) varies between 11.55° at Rukpokwu and 20.55° at Iwofe, reflecting differences in soil texture and density. Consequently, the estimated ultimate bearing capacity (q_u) ranges from 169 kN/m² at Egbelu to 214 kN/m² at RSU Campus, suggesting that RSU and Iwofe soils possess relatively higher load-bearing potential. The results indicate that while all soils are generally suitable for shallow foundations supporting low- to medium-rise structures, careful foundation design is necessary at locations with lower cohesion and friction values to limit settlement and ensure stability.

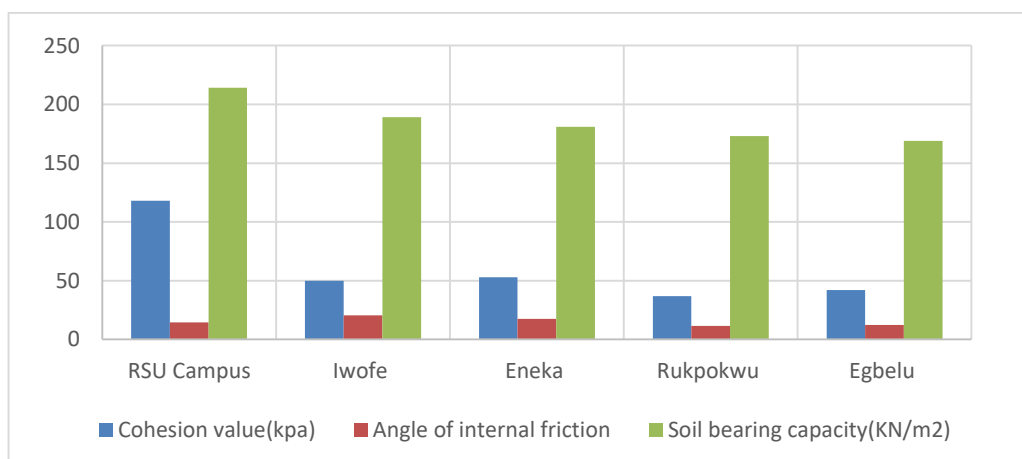


Fig 1: Shear Strength Parameters and Estimated Bearing Capacity of Soils at Selected Locations in Port Harcourt

Fig. 1 illustrates the variation of cohesion, friction angle, and bearing capacity across the five locations, clearly showing RSU Campus soils as the strongest in terms of load-bearing capacity, while Rukpokwu and Egbelu show comparatively lower values.

C. Consolidation Characteristics of Soils

Table III presents the consolidation properties of soil samples from the five study locations.

TABLE III: Consolidation Properties of Soil Samples

Location	Coefficient of volume compressibility(m ² /KN)	Consolidation index	Consolidation settlement(mm)	Pre-consolidation pressure(KN/m ²)
RSU	4.95x10 ⁴	0.0629	0.44mm	1.442
Iwofe	4.06x10 ⁻³	0.6078	3.61mm	1.447
Eneka	5.97x10 ⁻³	0.2306	1.56	1.459
Egbelu	4.65x10 ⁴	0.229	1.44mm	1.342
Rukpokwu	5.77x10 ⁻³	0.2106	1.96	1.349

The coefficient of volume compressibility (a_v) varied from 4.06×10^{-3} m²/kN at Iwofe to 5.97×10^{-3} m²/kN at Eneka, indicating moderate compressibility across the sites. Consolidation index values ranged from 0.0629 at RSU to 0.6078 at Iwofe, suggesting that Iwofe soils are more prone to compression under applied loads. Predicted settlement values were generally low, between 0.44 mm at RSU and 3.61 mm at Iwofe, implying that the soils are largely suitable for shallow foundations with minimal settlement concerns. Pre-consolidation pressures ranged narrowly from 1.342 kN/m² at Egbelu to 1.459 kN/m² at Eneka, confirming that the soils have not been subjected to excessive past loading. Overall, the results indicate that while slight variations exist among locations, the soils exhibit acceptable compressibility for low- to medium-rise structures.

IV. CONCLUSION

This study has evaluated the geotechnical properties of subsurface soils at five locations in Port Harcourt—RSU Campus, Iwofe, Eneka, Rukpokwu, and Egbelu—to assess their suitability for shallow foundation design. Laboratory tests on natural moisture content, specific gravity, particle size distribution, Atterberg limits, triaxial compression, and one-dimensional consolidation revealed that the soils are predominantly fine-grained, clayey in nature, and exhibit medium plasticity. Shear strength parameters indicated moderate cohesion and friction angles, while estimated ultimate bearing capacities ranged from 169 kN/m² to 214 kN/m². Consolidation analysis predicted settlements between 0.44 and 3.61 mm, suggesting limited compressibility under typical shallow foundation loads.

The main advantage of this study lies in providing site-specific geotechnical data that can guide the design of low- to medium-rise structures in Port Harcourt, potentially reducing foundation-related failures and ensuring safe and cost-effective construction. However, the study is limited to five locations and shallow depths, which may not capture deeper soil variations or extreme weather impacts. Despite this limitation, the results offer valuable insights into spatial variability in soil properties, highlighting areas like RSU campus with higher load-bearing capacity and Egbelu with relatively lower strength.

In conclusion, the research demonstrates that the soils in the study area are generally suitable for shallow foundations, provided that proper design considerations—such as allowable bearing capacity and predicted settlements—are incorporated. The findings can serve as a reference for geotechnical engineers, urban planners, and construction professionals in foundation design, soil improvement strategies, and risk assessment for future developments in Port Harcourt.

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