

Investigation of Ground Settlement in a Residential Area: A Case Study of Ekosodin Community, Benin City, Nigeria.

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Abstract

This study investigates ground settlement in residential structures along Ogurobo Street in Ekosodin, Benin City, Nigeria. Field reconnaissance surveys and laboratory tests were conducted to evaluate the geotechnical properties of the soil and identify the causes of structural distress. Laboratory analyses were performed in accordance with ASTM standards and included natural moisture content, specific gravity, particle size distribution, Atterberg limits, compaction, triaxial shear strength, and consolidation tests. The results indicate that the soil is predominantly fine-grained with relatively high moisture content ranging from 17% to 23%. The soils exhibit moderate plasticity, with plasticity index values between 17.86% and 26.13%, and specific gravity ranging from 2.29 to 2.55. Compaction results show optimum moisture content values between 10.6% and 16.4% and maximum dry density ranging from 1.74 to 2.48 g/cm³. Shear strength parameters show cohesion values between 2.74 and 3.43 kN/m² and angles of internal friction between 18° and 24°. The calculated safe bearing capacity ranges from approximately 93 to 158 kN/m², indicating low to moderate load-bearing capacity. These properties suggest that the soil is highly susceptible to settlement due to its compressibility and moisture sensitivity. The findings highlight the need for proper foundation design, adequate drainage, and ground improvement measures to mitigate differential settlement and structural failure in the study area.

Keywords

Ground settlement, Clay soil, Ekosodin, Foundation failure, Bearing capacity

Introduction

Ground settlement refers to the gradual sinking or subsidence of the ground surface, often resulting in damage to civil engineering structures such as buildings and roads. Settlement occurs when the supporting soil lacks sufficient strength or stability due to natural or human-induced factors

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(Amadi et al., 2012; Fagbenle et al., 2010). In Nigeria, it is a major contributor to structural failures, particularly in residential areas.

The case study at Ogurobo Street, Ekosodin, highlights the effects of settlement, including cracking, partial collapse, and structural instability, posing risks to residents and property. These problems are often linked to inadequate site investigation, poor foundation design, and weak regulatory enforcement (Phoon & Ching, 2021). Previous studies have shown that high moisture content, clayey composition, and groundwater fluctuations significantly influence settlement behavior (Amadi et al., 2012; Arora, 2008).

However, limited studies have specifically examined the geotechnical properties responsible for settlement in Ekosodin, particularly along Ogurobo Street. This study aims to evaluate the geotechnical characteristics of the soil and assesses their suitability for foundation support.

Methodology

Study Area

The study was conducted at No. 34 Ogurobo Street, Ekosodin community, within the Ovia North-East Local Government Area of Edo State, Nigeria. The area lies within the rainforest belt and is located between longitudes $5^{\circ}37'7.89''$ to $5^{\circ}37'37.75''$ E and latitudes $6^{\circ}24'29.92''$ to $6^{\circ}25'31.35''$ N as shown in Figure 1. The region is underlain by the sedimentary formations of the Southern Sedimentary Basin, characterized by reddish lateritic clayey sand (kayode-Ojo, et al., 2023). The area serves as a residential and commercial hub, making soil behavior critical for sustainable development.

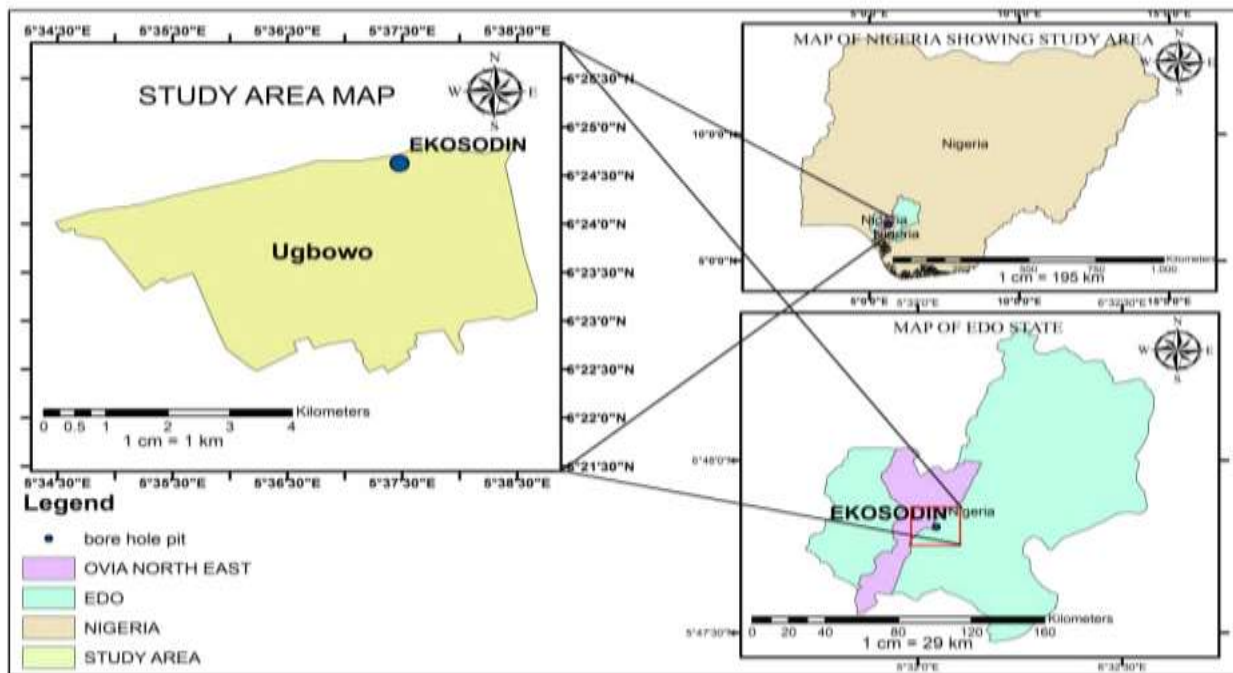


Figure 1. Location map of the study area (ArcGIS)

A total of eight soil samples were collected from four boreholes (BH1–BH4) at depths ranging from 0.5 m to 2.0 m using a hand auger. Samples were air-dried and prepared in accordance with BS 1377 (1990). A reconnaissance survey was conducted to assess ground settlement conditions using visual inspection and elevation measurements with a builder’s level. Observations included wall cracks, floor depressions, uneven settlement, and structural distortions. Poor drainage, seasonal flooding, and erosion channels were also identified as contributing factors.

Geotechnical laboratory tests were conducted to determine soil properties, including natural moisture content, specific gravity, particle size distribution, Atterberg limits, compaction, triaxial shear strength, and consolidation. BS 1377 (1990) was used for sample preparation, while ASTM standards were adopted for laboratory testing to ensure consistency, reliability, and international comparability of results. The results obtained formed the basis for subsequent analysis.

Results and Discussion

The Classification of the Soil Based on its Index and Engineering Properties

The soil in its natural (non-stabilized) state was evaluated using index and engineering properties, including moisture content, specific gravity, particle size distribution, Atterberg limits, compaction, shear strength and consolidation test as shown in Table 1 – 3.

Table 1. Index properties of the soil samples

| Borehole | Depth (m) | Moisture Content (%) | specific gravity | Liquid limit (%) | Plastic limit (%) | Plasticity index (%) | Sand (%) | Silt + Clay (%) | USCS Class |
|----------|-----------|----------------------|------------------|------------------|-------------------|----------------------|----------|-----------------|------------|
| BH1 | 1.0 | 19 | 2.35 | 39.30 | 19.47 | 19.83 | 39.40 | 60.60 | CL--ML |
| BH1 | 2.0 | 17 | 2.55 | 41.16 | 11.24 | 23.92 | 37.66 | 62.34 | CL |
| BH2 | 0.5 | 19 | 2.44 | 39.43 | 15.10 | 24.33 | 43.52 | 56.48 | CL |
| BH2 | 1.5 | 18 | 2.47 | 44.72 | 18.60 | 26.13 | 37.48 | 62.52 | CL |
| BH3 | 0.7 | 18 | 2.49 | 33.71 | 15.85 | 17.86 | 49.10 | 50.90 | CL--ML |
| BH3 | 1.2 | 22 | 2.43 | 41.67 | 19.70 | 21.97 | 42.32 | 57.68 | CL |
| BH4 | 0.9 | 23 | 2.33 | 38.10 | 19.58 | 18.52 | 44.23 | 55.77 | CL--ML |
| BH4 | 1.8 | 21 | 2.29 | 41.40 | 20.90 | 20.50 | 38.56 | 61.44 | CL |

Index Properties

Refer to Table 1, the natural moisture content ranged from 17–23% with an average of 19.63%, indicating moderately high moisture conditions typical of fine-grained soils. The specific gravity values ranged from 2.29 to 2.55 with a mean value of 2.42, which falls within the standard range for clayey soils ($\approx 2.60 \pm 0.3$), suggesting normal mineral composition. The liquid limit (33.71–44.72%, average $\approx 39.2\%$) and plasticity index (17.86–26.13%, average $\approx 22.0\%$) indicate low to intermediate plasticity, consistent with CL–ML soils under the Unified Soil Classification System (USCS).

The Sieve analysis shows 50.90–62.52% fines with an average of 56.7%, confirming that the soil is predominantly fine-grained. Such soils are typically associated with low permeability and high compressibility, which reduce drainage efficiency and increase susceptibility to volume change. These findings are consistent with previous studies on lateritic and clayey soils in tropical regions (Maduka et al., 2016).

Overall, the combined effect of high fines content, moderate plasticity, and elevated moisture levels contributes to reduced shear strength and increased compressibility, making the soil highly susceptible to settlement under structural loading.

Table 2. Compaction characteristics

| Borehole | Depth (m) | OMC (%) | MDD (g/cm ³) | Cohesion (kN/m ²) | Friction Angle (°) | Ultimate BC (kN/m ²) | Safe BC (kN/m ²) |
|----------|-----------|---------|--------------------------|-------------------------------|--------------------|----------------------------------|------------------------------|
| BH1 | 1.0 | 13.2 | 2.48 | 3.43 | 18 | 171.95 | 101.00 |
| BH1 | 2.0 | 14.0 | 1.81 | - | - | - | - |
| BH2 | 0.5 | 13.6 | 1.74 | 2.74 | 24 | 286.74 | 157.91 |
| BH2 | 1.5 | 13.8 | 1.96 | - | - | - | - |
| BH3 | 0.7 | 10.6 | 2.31 | 2.98 | 22 | 238.27 | 133.44 |
| BH3 | 1.2 | 13.6 | 1.83 | - | - | - | - |
| BH4 | 0.9 | 16.4 | 1.78 | 3.43 | 18 | 159.48 | 93.22 |
| BH4 | 1.8 | 13.8 | 1.77 | - | - | - | - |

Note: Some test results are unavailable due to practical and resource limitations during laboratory testing. In addition, certain samples were not suitable for specific tests, particularly shear strength testing, therefore only reliable and representative data are presented.

Engineering Properties

Refer to Table 2, the optimum moisture content (OMC) ranged from 10.6% to 16.4% (average ≈13.5%), while the maximum dry density (MDD) varied from 1.77 to 2.48 g/cm³ (average ≈2.10 g/cm³), indicating moderate to high compaction characteristics. These values fall within typical ranges for fine-grained soils, although the observed variation in MDD suggests heterogeneity in soil structure, which may contribute to differential settlement under loading.

Shear strength parameters indicate low cohesion values ranging from 2.74 to 3.43 kN/m² (average ≈3.05 kN/m²) and angles of internal friction between 18° and 24° (average ≈21°), which are characteristic of soft to moderately stiff clay soils. The corresponding safe bearing capacity ranges from 93.22 to 157.91 kN/m² (average ≈123.4 kN/m²), falls within the low to moderate range for shallow foundations. These results indicate limited load-bearing capacity and reduced resistance to shear failure, making the soil unsuitable for supporting structural loads without improvement.

Table 3. Consolidation parameters

| Borehole | Depth (m) | Compression Index (C_c) | Coefficient Of Consolidation, C_v ($m^2/year$) | Coefficient Of Volume Compressibility, M_v (m^2/kN) |
|----------|-----------|-----------------------------|----------------------------------------------------|-----------------------------------------------------------|
| BH1 | 1.0 | 0.22 | 0.2274 | 4×10^{-6} |
| BH2 | 0.5 | 0.24 | 0.2274 | 4×10^{-6} |
| BH3 | 0.7 | 0.22 | 0.2274 | 6×10^{-6} |
| BH4 | 0.9 | 0.22 | 0.2274 | 1×10^{-6} |

Consolidation Characteristics

Refer to Table 3, the coefficient of consolidation ($C_v \approx 0.2274 \text{ m}^2/\text{year}$) indicates a relatively slow rate of consolidation, typical of fine-grained soils with low permeability. The coefficient of volume compressibility (M_v) ranges from 0.00038 to 0.00063 m^2/kN (average $\approx 0.00051 \text{ m}^2/\text{kN}$), reflecting medium compressibility. These values are consistent with clayey soils that exhibit delayed settlement behavior under sustained loading. These conditions suggest gradual, time dependent settlement under sustained loading, increasing the risk of long term differential settlement and structural distress.

Conclusion

This study evaluated the geotechnical properties of soils responsible for ground settlement in the study area through field investigation and laboratory testing. Based on the Unified Soil Classification System (USCS), the soils were classified as inorganic clay of low to medium plasticity (CL) and inorganic silt of low plasticity (ML), while under AASHTO classification they fall within the A-7-6 group, associated with high compressibility, poor drainage, and unfavorable foundation conditions. The results indicate relatively high natural moisture content, low to intermediate plasticity, moderate compaction characteristics, and low to moderate shear strength. These properties make the soils susceptible to compression and strength reduction under loading and moisture variation. Bearing capacity analysis revealed low safe values, indicating inadequacy for shallow foundations without improvement. Consolidation parameters further suggest medium compressibility and potential for long term settlement under sustained loads. Based on these findings, proper site investigation, improved drainage systems, and suitable ground improvement techniques are recommended to minimize the risk of differential settlement and foundation failure.

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