

## Research Article

# Characteristics of Tropical Residual Soils for Multipurpose Structural Applications in Edo State, Nigeria

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## Abstract

Tropical residual soils constitute the predominant natural foundation and construction materials in many tropical regions of the world, particularly in Nigeria, where they are widely utilized in road construction, building foundations, embankments, and other civil engineering works. Despite their abundance and economic advantages, the engineering performance of these soils varies considerably due to differences in parent rock composition, weathering intensity, climatic conditions, and mineralogical characteristics. Inadequate characterization and improper utilization of these soils have contributed significantly to numerous cases of structural distress, pavement deterioration, and foundation failures. This study investigates the physical, index, and mechanical properties of tropical residual soils collected from selected locations in Edo State, Nigeria, namely Auchi, Ikpeshi, and Igarra, with the objective of assessing their suitability for multipurpose structural and geotechnical applications. Comprehensive laboratory investigations were carried out, including determination of natural moisture content, particle size distribution, Atterberg limits, specific gravity, compaction characteristics, California Bearing Ratio (CBR), and direct shear strength parameters. The results revealed relatively low natural moisture contents ranging from 4.14% to 9.69%, non-plastic to slightly plastic characteristics, satisfactory specific gravity values, and moderate shear strength properties. The soils exhibited varying load-bearing capacities and compaction responses depending on their geological origin and location. Although the materials generally demonstrated acceptable engineering properties for light- to medium-duty construction applications, a noticeable reduction in strength and bearing capacity was observed under soaked conditions, indicating susceptibility to moisture-induced performance deterioration. Consequently, the study emphasizes the importance of adequate compaction, effective drainage systems, and where necessary, soil stabilization measures to enhance long-term performance. The findings provide valuable site-specific geotechnical data and practical recommendations for the sustainable utilization of tropical residual soils in foundation engineering, pavement construction, and other multipurpose infrastructure projects within tropical environments.

## Keywords

Tropical Residual Soil, Laterite, Geotechnical Properties, CBR, Multipurpose Structures, Edo State

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## 1. Introduction

Tropical residual soils are a significant geological feature found in equatorial regions, characterized by their formation through weathering of underlying bedrock. These soils are shaped by intense heat, heavy rainfall, and biological activity over extended periods. Their composition varies widely but often includes elements like aluminum and iron oxides, giving them distinct red or yellow hues [6].

Tropical residual soils are types of soil found in tropical regions, covering over 30% of the Earth's land surface [14]. They are soils formed through the weathering of rocks and are characterized by their high content of iron and aluminum oxides, which give them unique physical and mechanical properties [10]. Tropical residual soils are essential construction material in tropical regions due to their availability, cost-effectiveness, and use [2].

However, tropical residual soil poses significant challenges to construction projects due to their complex behavior under different loading conditions [14]. Their low strength, high compressibility, and high sensitivity to erosion and landslides make them prone to structural failures, which can result in significant economic losses and human casualties [13].

Furthermore, the lack of standard guidelines and recommendations for the use of tropical residual soils in construction projects exacerbates the problem [2]. Multipurpose structures such as buildings, roads, and bridges are critical infrastructure in tropical regions, and their design and construction require a thorough understanding of the soil properties and behavior [10]. The use of tropical residual soils in these structures can lead to significant cost savings and environmental benefits but also requires careful consideration of their characteristics and limitations [10]. Despite the importance of tropical residual soils in construction projects, there is a significant knowledge gap in understanding their properties and behavior [7]. Existing research has focused mainly on geotechnical properties of tropical residual soils with limited attention to their suitability for multipurpose structures to address the challenges associated with their use [3].

The research aims to investigate the physical and mechanical properties of tropical residual soils, evaluate their suitability for multipurpose structures, and develop guidelines for their use in construction projects [14]. The findings of this research will contribute to the development of sustainable and cost-effective construction practices in tropical regions, reducing the risk of structural failures and improving the overall quality of life [13].

Despite the abundance of tropical residual soils in many parts of the world, their characteristics and behavior are not well understood, resulting to difficulties designing and constructing a multipurpose structure that is not safe, durable and cost-effective. The current lack of comprehensive knowledge on the geotechnical properties of tropical residual soils, par-

ticularly their shear strength, settlement behavior and susceptibility to erosion, thus resulting construction challenges such as:

- 1) Inadequate design and construction practices;
- 2) increased risk of structural failure and collapses;
- 3) Higher construction cost due to over design.

This study investigates tropical residual soil characteristics for a multi-purpose structure. It is undertaken in a bid to addressing the challenges inherent in the use of in use tropical residual soil for multi-purpose structure.

### *Literature Review*

The increasing demand for infrastructure development in tropical regions has highlighted the need for a comprehensive understanding of the local soil condition. Tropical residual soil pose significant challenges due to their complex and variable properties. These soils are characterized by high plasticity, compressibility and susceptibility to erosion, which can lead to structural instability and failure [14].

Despite their widespread occurrence, tropical residual soils remains poorly understood and their behavior under different loading condition is not well documented. The lack of reliable data and design guidelines for these soils has resulted in costly construction delays, repairs and even catastrophic failures. Therefore it is essential to investigate the characteristics of tropical residual soils to develop appropriate design and construction strategies for multipurpose structures such as buildings, roads and bridges [1]. By examining the characteristics of tropical residual soils, this investigation seeks to provide valuable insights for engineers, researchers and policy makers, ultimately contributing to the development of safe, sustainable and resilient infrastructure in tropical regions [8].

## 2. Materials and Methods

### 2.1. Study Area

Soil samples were collected from three locations in Edo State: Auchi (Etsako West LGA), Ikpeshi, and Igarra (Akoko-Edo LGA). Akoko-Edo lies within the Basement Complex terrain dominated by granite and gneiss, while Auchi is located in a sedimentary environment influenced by sandstone and shale formations. These contrasting settings provide a basis for comparative evaluation.

### 2.2. Sample Collection

Disturbed soil samples were collected (Figure 1) at a depth of approximately 1.0 m below ground level to minimize organic influence. The samples were sealed in polythene bags, labeled, and transported to the laboratory for analysis.



Site A: Sample 1 (Red Soil)

**Figure 1.** Sample Collection (A).

Site B: Sample 2 (Yellow Soil)

**Figure 2.** Sample Collection (B).

Site C: Sample 3 (Grey Soil)

**Figure 3.** Sample Collection (C).

## 2.3. Laboratory Testing

All tests were conducted in accordance with [6]. The laboratory program included:

### *Natural moisture content.*

Moisture content is the ratio of the mass of water in a soil sample to the solid mass of particles in that material, expressed as a percentage (see Equation (1)).

$$w = \frac{(M_2 - M_3)}{(M_3 - M_1)} \times 100 \quad (1)$$

The natural moisture content of each soil sample was determined using the oven-drying method. A representative portion of the soil was weighed and then placed in an oven at 105-110 °C for 24 hours. After drying, the sample was re-weighed, and the moisture content was calculated as the ratio of weight loss to the oven-dried weight, expressed as a percentage.

**Figure 4.** Dry Moisture Content Samples.

### 1) Atterberg limits

The Atterberg limits tests were conducted to assess the consistency and plasticity characteristics of the soil. The liquid limit was determined using the Casagrande apparatus, where the number of blows required to close a standard groove in a soil paste was recorded. The plastic limit was determined by rolling soil threads until they crumbled at a diameter of 3 mm. The plasticity index was calculated as the difference between the liquid limit and plastic limit. These parameters provide insight into the soil's compressibility, workability, and susceptibility to volume changes under varying moisture conditions.

### 2) Sieve Analysis

Sieve analysis is a laboratory test used to determine the particle size distribution of a soil sample. It involves passing the soil through a series of sieves with progressively smaller openings to separate the particles into different size fractions [15]. The soil was first oven-dried to remove moisture, then placed on a nest of standard sieves and mechanically shaken. The mass of soil retained on each sieve was recorded, and the percentage distribution of different particle sizes was calculated.



**Figure 5.** Sieving of Soil Samples being Sieved.

### 3) Specific gravity

The specific gravity test is a laboratory experiment used to determine the specific gravity (relative density) of soils. Specific gravity is a dimensionless quantity that represents the ratio of the density of a material to the density of water.

The specific gravity of the soil solids was determined using a pycnometer. A known mass of oven-dried soil was added to the pycnometer containing distilled water. The volume of water displaced by the soil was measured, and the specific gravity was calculated as the ratio of the mass of the soil solids to the mass of an equal volume of water. Specific gravity is an important parameter used in calculating void ratios, porosity, and compaction characteristics of soils.



**Figure 6.** Sample in the Density Bottle (Pycnometer) with stopper.

### 4) Compaction Test

The compaction test is a laboratory procedure used to determine the relationship between the moisture content and the dry density of soil when subjected to a specified compactive effort. In the compaction test, a known weight of soil is mixed with varying amounts of water and compacted in layers inside a mould using a standard rammer. After compaction, the bulk density of each specimen is determined, and the corresponding moisture content is measured. From these results, a graph of dry density against moisture content is plotted to obtain the Maximum Dry Density (MDD) and the Optimum Moisture Content (OMC). The OMC and MDD values provide essential data on the load-bearing capacity, stability, and overall suitability of these soils for multipurpose structures such as foundations, roads, and embankments [12, 11].



**Figure 7.** Mixing of Sample in a Tray.

### 5) California Bearing Ratio (CBR)

The California Bearing Ratio (CBR) test is a penetration test developed by the California Division of Highways to evaluate the strength of soils and aggregate materials used in pavements and foundations. The CBR test was carried out to evaluate the strength and load-bearing capacity of the soil, particularly for pavement and subgrade applications. Soil samples were compacted at their optimum moisture content into a standard mould. Both soaked and unsoaked tests were performed, where a standard plunger was allowed to penetrate the soil at a constant rate, and the corresponding load was measured. The CBR value was then expressed as a percentage of the standard load. This test provides essential data for pavement design and determines the suitability of the soil for supporting multipurpose structures.

### 6) Direct shear test

The direct shear test is a laboratory test used to determine

the shear strength of a soil sample. It involves applying a constant vertical load and measuring the shear stress required to cause failure along a predetermined failure plane [11, 15].

A re-molded soil sample was placed in a shear box and subjected to vertical normal stress. Horizontal force was applied until the sample failed along a predetermined plane. The shear stress at failure was recorded and used to compute the shear strength parameters. This test is critical for understanding slope stability, foundation design, and the general behavior of soils under lateral loading.

### 3. Results and Discussion

#### 3.1. Natural Moisture Content

The soils exhibited low natural moisture contents ranging from 4.14% to 9.69%, consistent with sandy to silty residual soils. These values indicate low susceptibility to volumetric changes, which is advantageous for foundation and pavement applications. The values obtained are presented in the Table below:

*Table 1. Average Value of Natural Moisture Content.*

Test Name	Red Soil	Yellow Soil	Grey Soil
Moisture Content (%)	9.69	4.14	4.14

The values obtained for the three soils (4.14-9.69%) therefore fall within the expected range for sandy or silty soils, confirming their non-plastic, coarse-grained nature as was already shown by the Atterberg limits and compaction test results. The red soil, with the highest natural moisture content of 9.69%, may indicate slightly higher fines or organic matter compared to the others, while the yellow soil, with the lowest value of 4.14%, appears to be the driest and coarser of the three.

#### 3.2. Atterberg Limits

The Atterberg Limit Test was conducted to determine the consistency limits of the soil. The parameters obtained include the Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI), which describe the soil's plasticity and workability. The values obtained are presented in the Table below:

*Table 2. Atterberg Limit Casagrade Method.*

Test Name	Red Soil	Yellow Soil	Grey Soil
Liquid Limit & PI (%)	16.25. & 16.25	11.50. & 11.50	13.25. & 13.25

With LL values below 20%, the soils are classified by [4] as non-plastic silts or sands. They have low cohesion, low compressibility, and minimal volume change, making them stable under moisture variation but weak in strength and prone to erosion. To improve their performance, stabilization, good compaction, and proper drainage are recommended. Overall, the soils show limited natural strength and very low shrinkage

potential, consistent with their non-clayey nature.

#### 3.3. Sieve Analysis Test

This test classifies the soil into different fractions (gravel, sand, silt, and clay) and helps assess grading characteristics. The values obtained are presented in the Table below:

*Table 3. Weight of Retained Soil in each Sieve.*

Sieve size	Red Soil	Grey Soil	Yellow Soil
4.75	21.15	50.15	24.95
3.35	19.40	82.23	35.94
2.36	31.62	71.62	32.63
1.25	73.01	89.60	45.59

Sieve size	Red Soil	Grey Soil	Yellow Soil
0.6	460.46	246.28	293.49
0.25	355.22	392.74	541.75
0.18	20.73	37.52	11.32
0.125	9.95	17.74	8.43
Sieve Collector	8.10	11.94	4.97

According to [4] test procedure, the particle size distribution of the tropical residual soils was determined, and based on the USCS classification system, all three soils fall within the silty sand -sand silt mixtures category. This shows that the soils are predominantly sandy with a notable amount of silt and very little or no clay fraction.

### 3.4. Specific Gravity

The Specific Gravity Test Was Carried Out to Determine the Ratio of the Weight of Soil Solids to the Weight of an Equal Volume of Water. The Parameter Is Important for Identifying Soil Type, Computing Void Ratio and Degree of Saturation. The Results Obtained Are Presented in the Table below:

*Table 4. Specific Gravity Summary & Discussion.*

Samples	Laboratory Tests	Experimental Values	BS 1377 Specification
1	Specific gravity	2.36	2.60. to 2.80
2	Specific gravity	2.55	2.60. to 2.80
3	Specific gravity	2.51	2.60. to 2.80

The specific gravity values obtained for the tropical residual soils were 2.36 for the Red soil, 2.55 for the Grey soil, and 2.51 for the Yellow soil. According to [6], the specific gravity of most mineral soils falls within the range of 2.60 to 2.80, with an average of about 2.65. From this comparison, it is clear that the values of the three soils fall below the standard range.

### 3.5. Compaction Characteristics

This process reduces settlement, decreases permeability, and enhances shear strength. The test results are important for determining the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD), which guide field compaction for stability and strength. The results obtained from compacting the samples are tabulated in Table 5:

*Table 5. Compaction Summary and Discussion.*

Samples	Laboratory Tests	Experimental Values	BS 1377 Specification
1	OMC and MDD	7.32% and 2.02g/cm	5 to 15% and 1.6g/cm to 2.20g/cm
2	OMC and MDD	8.33% and 2.26g/cm	5 to 15% and 1.6g/cm to 2.20g/cm
3	OMC and MDD	5.99% and 2.26%	5 to 15% and 1.6g/cm to 2.20g/cm

These results show that the soils have low OMC and relatively high MDD values, which are desirable for construction purposes. Low OMC means less water is needed to achieve compaction, making them cost-effective in the field, while high MDD indicates good strength and load-bearing capacity. These soils can therefore be considered suitable for use in road subgrades, embankments, and other geotechnical works, though the slightly lower density of the red soil may require additional

compactive effort compared to the grey and yellow soils.

### 3.6. California Bearing Ratio

The California Bearing Ratio (CBR) test was carried out to evaluate the strength of the soil and its suitability for use in pavements and subgrade construction. The values obtained are presented in the Table below:

*Table 6. CBR Summary and Discussion.*

Samples	Laboratory Tests	Experimental Values	BS 1377 Specification
1	CBR	28	20-50
2	CBR	22	20-50
3	CBR	16	20-50

In general, the California Bearing Ratio (CBR) is a key test in highway and geotechnical engineering because it provides a direct measure of the strength of soils for use in pavement design. Higher CBR values indicate stronger soils that can withstand heavier traffic loads and require thinner pavement layers, while lower CBR values signify weaker soils that will need thicker pavement sections or stabilisation measures [9]. In this study, the soils tested produced moderate to high CBR values, confirming that tropical residual soils, despite their non-plastic nature, can still serve as useful subgrade materials.

The variations in the results between the red, grey, and yellow soils further demonstrate how soil composition and degree of weathering influence bearing capacity.

### 3.7. Shear Strength Parameters

The direct shear test was conducted to obtain the shear strength parameters of the soil, namely cohesion ( $c$ ), and the angle of internal friction ( $\theta$ ). The values obtained are presented in the Table below:

*Table 7. Shear Strength Summary and Discussion.*

Samples	Laboratory Test	Experimental Values ( $c$ , $\theta$ , $q$ )	BS 1377 Specification (Allowable Bearing Pressure)
1	Shear Strength	2, 39, 85. KN/m <sup>2</sup>	50-200KN/m <sup>2</sup>
2	Shear Strength	2, 37, 69.82 KN/m <sup>2</sup>	50-200KN/m <sup>2</sup>
3	Shear Strength	2, 36, 62.22 KN/m <sup>2</sup>	50-200KN/m <sup>2</sup>

The shear strength parameters of the tropical residual soils were used to determine their bearing capacities. After applying a factor of safety of 3, the allowable bearing capacities were obtained as 85.03 kN/m<sup>2</sup> for the red soil, 69.82 kN/m<sup>2</sup> for the grey soil, and 62.22 kN/m<sup>2</sup> for the yellow soil. These values fall within the lower range of allowable bearing pressures specified for sandy and silty soils according to [4], which typically gives values between 50-200 kN/m<sup>2</sup> for such soil types.

In summary, the bearing capacity results confirm that tropical residual soils can serve as foundation materials, but their suitability depends on the degree of weathering and soil texture. The red soil is the most reliable, the grey soil moderately

suitable, and the yellow soil the least favorable without treatment. Proper compaction, control of groundwater, or stabilization may be required in practice to enhance performance, especially for the weaker soils [5].

## 4. Conclusion

- (i) The results showed that the red, grey, and yellow soils are non-plastic with low natural moisture contents and moderate specific gravity values, indicating low clay content, minimal volume change with moisture variation, and good compaction potential.

- (ii) Compaction test results indicated that the soils attained high maximum dry densities at low optimum moisture contents, demonstrating favourable compaction characteristics for construction purposes.
- (iii) Based on sieve analysis, the soils were classified as silty sands (SM). The red and grey soils exhibited higher CBR values and bearing capacities, making them suitable for road subgrades, embankments, and shallow foundations, while the yellow soil showed comparatively lower strength and may require improvement before use.
- (iv) Despite the generally satisfactory engineering performance, the silty sand nature of the soils makes them susceptible to erosion and strength reduction under saturated conditions. Therefore, adequate drainage provision and appropriate soil stabilization measures are recommended for improved performance in construction applications.

## Abbreviations

SM	Silty Sands
CBR	California Bearing Ratio
OMC	Optimum Moisture Content
MDD	Maximum Dry Density

## Author Contributions

**Ibrahim Abdulrazaq Olayinka:** Supervision  
**Eberiga Oremeyi Mercy:** Data curation, Methodology  
**Uchola Victor Onuche:** Funding acquisition  
**John Wasiu:** Validation  
**Obebe Monisola Dorcas:** Visualization

## Conflicts of Interest

The author(s) declare that there is no conflict of interest.

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