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Evaluation of Lateritic Soil for Road Pavement: A Case Study of ATAN-OTA in OGUN State

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ABSTRACT
Understanding the engineering properties of soil is essential for ensuring the stability and safety of infrastructure projects. This research focuses on the geotechnical evaluation of soil using California Bearing Ratio (CBR), hydraulic conductivity test, compaction test, and unconfined compressive strength (UCS) to determine the soil's suitability for construction applications. The CBR test provides insights into subgrade strength, hydraulic conductivity is a measure of how easily water can pass through soil. Compaction test performed to determine the optimal moisture content at which a given soil type will become denser, and UCS tests assess load-bearing capacity without lateral confinement. Soil sample collected from Atan Ota of Ado-Odo Local Government Ogun State, Nigeria, underwent laboratory testing to establish their mechanical and physical properties. The results indicate MDD is 1800 kg/m³, indicating well-compacted soil with good strength, and OMC is 13.9%, showing optimal moisture for maximum density. The low CBR suggests the soil is weak and needs stabilization for pavement support. UCS is 137.7 kN/m², indicating moderate strength but may require improvement for heavy loads. Permeability ($k = 1.44 \times 10^{-4}$ cm/sec) is low, suggesting silty or clayey sand. This study contributes to enhanced infrastructure design by offering data-driven insights into soil behavior and suitability for sub-grading applications.

KEYWORDS
California Bearing Ratio, Hydraulic Conductivity test, Compaction test, Unconfined Compressive Strength.

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I. INTRODUCTION

The behavior of soil significantly influences the success and durability of engineering projects. It serves not only as a structural foundation but also as a construction material, with its properties directly affecting the performance of infrastructures such as roads, buildings, and embankments (Das B, 2010; Biswal D., et al 2018). Proper evaluation of soil properties is essential in geotechnical engineering to avoid structural failures, lessen maintenance costs, and ensure the durability of constructed facilities (Oluyemi-Ayibiowu B., 2019).

Among the numerous laboratory tests available, the California Bearing Ratio (CBR), Hydraulic Conductivity, Compaction/proctor, and unconfined compressive strength (UCS) tests are pivotal in assessing the mechanical and physical characteristics of soil (Goozarzi et al. 2016; Apampa A., 2019). The CBR test measures the strength and load-bearing capacity of subgrade soil, which is crucial for the stability of pavements and similar structures (ASTM International, 2017). The hydraulic conductivity test measures how easily water moves through soil pores, indicating the ease of subsurface water flow (Morris P., et al. 2022). The compaction test determines the ideal moisture content for soil and its maximum dry density, ensuring optimal compaction. (Rimbarngaye A., et al. 2022; Oluremi J., et al 2024). Additionally, the UCS test evaluates the compressive strength of cohesive soils under unconfined conditions, providing a measure of the soil's capacity to withstand axial loads (Bowles J.,, 1996). Together, these tests enable engineers to understand soil behavior and design appropriate solutions for geotechnical challenges (Little and Nair 2009).

These findings will inform construction decisions, ensuring the safety, sustainability, and cost-effectiveness of infrastructure projects in areas with similar soil conditions. This study focuses on the evaluation of soil properties through laboratory testing. The soil samples analyzed were collected from (Atan Ota of Ado-Odo Local Government Ogun State, Nigeria), and the tests conducted include the California Bearing Ratio (CBR), hydraulic conductivity test compaction test, and unconfined compressive strength (UCS). The scope is limited to providing insights into the suitability of the tested soil for subgrade and structural applications, with recommendations for construction projects in similar soil conditions. External factors such as seasonal variations, long-term soil behavior, and environmental impacts are beyond the scope of this study.

The geotechnical properties of soil are fundamental to understanding its behavior under various conditions, particularly when used in construction and engineering applications. Laboratory tests such as the California Bearing Ratio (CBR), compaction, hydraulic conductivity and unconfined compression tests are essential for assessing soil's suitability for specific projects. This chapter reviews existing studies on these methods, their significance, and their application in soil characterization and improvement (Setiawan I., et al., 2020).

The California Bearing Ratio (CBR) test is a standardized method for determining the strength and load-bearing capacity of soils and subgrade materials. Initially developed by the California Department of Transportation, the test has since become an international standard (ASTM D1883-21). The CBR value is critical in the design of pavements and subgrade layers. According to Bowles J., (1996), soils with high CBR values exhibit superior strength and are suitable for heavy-load applications. Conversely, soils with low CBR values require stabilization to meet project requirements.

Recent studies have explored methods to improve CBR values, such as soil stabilization using cement, lime, or industrial by-products. For example, Olaniyan O., et al. (2020) demonstrated that the addition of lime significantly increased the CBR value of lateritic soils, making them more suitable for road construction. Similarly, the use of fly ash has shown promising results in enhancing the strength characteristics of subgrades [Singh B., & Yadav R., 2018].

The compaction test, also known as the Proctor test, is conducted to determine whether a specific type of soil is suitable for use as a fill material in road construction and other engineering projects by measuring its Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) (Chen R., et al., 2019; Rahman I., et al., 2021). Properly controlling soil compaction enhances its strength and stability while minimizing deformation, ensuring the safety and reliability of geotechnical structures. Therefore, regulating soil compaction effectively is essential in engineering construction (Gang W., et al., 2020; Miao M., et al., 2021).

Hydraulic conductivity is a crucial property that determines a material's ability to allow water to pass through, playing a key role in soil classification, water management, plant selection, and erosion control (Musa J., and Gupa Y., 2019). It reflects how effectively soil and sediments transmit water through their pore spaces (Xue P., et al., 2021). Specifically, soils with higher permeability exhibit greater hydraulic conductivity, while lower permeability results in reduced conductivity (Kozlowski T., et al., 2019). Hydraulic conductivity can be estimated through grain size analysis or measured using in situ and laboratory experimental methods (Mengting W., et al., 2021).

Hydraulic conductivity, represented by K, is defined as the rate at which soil transmits a unit volume of water under a hydraulic gradient of one. As a result, its dimensional unit is length per time, similar to flow velocity (Mishra P., and Scheuermann A., 2020).

The unconfined compression (UC) test is a critical method for evaluating the compressive strength of cohesive soils. This test provides insights into the soil's ability to withstand axial loading without lateral confinement. According to Head & Epps (2014), the UC test is widely used due to its simplicity and effectiveness in determining undrained shear strength.

Several studies have focused on correlating UC test results with other geotechnical properties. For example, Lambe & Whitman (1979) established relationships between unconfined compressive strength and soil consistency, highlighting the test's utility in identifying soil types and their engineering behavior. Additionally, Al-Rawas A., et al. (2005) emphasized the role of the UC test in evaluating the effects of chemical stabilization on cohesive soils. Their findings revealed significant improvements in strength and durability when stabilizers like cement or lime were incorporated.

Soil stabilization is a critical aspect of geotechnical engineering, aiming to enhance the mechanical characteristics of soils. Common stabilization methods include the use of chemical additives, mechanical compaction, and geosynthetics. According to Tingle & Santoni (2003), lime stabilization is particularly effective for enhancing the strength and workability of clayey soils. Recent advancements in soil stabilization have explored the use of non-traditional additives such as polymers and industrial by-products. For instance, Chen R., et al. (2021) investigated the use of bio-enzymes in improving the engineering properties of sandy soils. Their results indicated increased compressive strength and reduced permeability, demonstrating the potential of eco-friendly stabilizers (Victors O., *et al* 2022).

II. METHODOLOGY

2.1 Compaction Test/Proctor Test

For the compaction test, 2.5kg of the air dried sample was passed through a 4.75mm sieve with all lumps pulverized and poured into a tray. Little amount of water was then added to the soil in the tray and manually mixed thoroughly to ensure a uniform distribution of water. Afterward, the mixed soil was divided into three part, and mass of empty mold with the base plate (M_1) was weighed and oiled. The mold was filled with first part of the wet soil sample from the tray and compacted with 25 uniformly distributed blows on the surface, using the standard rammer of mass 2.5kg, at a fall height of 30cm. The surface of the compacted soil was scraped with a spatula to ensure a well fitted bond with the next layer. The collar was fitted on the mold and the soil for the second layer was put inside the mold and compacted as explained above, similarly for the third layer.

The collar was removed, and the excess soil projecting above the top of the mold was trimmed off with the aid of a straight edge. The mass of the mold, base plate and compacted soil (M_2) was weighed. The soil was removed and put back in the tray. Whilst removing the dirt from the mold, representative samples were taken for moisture content determination. Knowing the mass of the compacted soil (M_2 -M_1), the bulk density was calculated. After determining the moisture content, the dry density was computed. The soil in the tray was again pulverized and water content was increased by a suitable amount 4% for the second tests. The steps were repeated to get five sets of water content, and dry density values giving a drop in the mass of compacted soil during the test. The dry density was plotted against moisture content to obtain the compaction curve.

2.2 California Bearing Ratio (CBR)

A portion of air dried soil sample retained on B.S sieve 4.75mm was pulverized. 6kg of the pulverized sample was weighed and thoroughly mixed with water percent obtained from compaction test which is the OMC value. The mixed sample was put in the CBR mold in five (5) layers, with each layer compacted with 56 blows using the standard rammer of 4.5kg. The collar was removed and the surface of the mold was trimmed with the aid of a straight edge, and the compacted soil and mold was weighed and placed under the CBR machine. The gauges (proving ring gauge and plunger penetration gauge) were calibrated to zero. As soon as the plunger made contact with the soil, both gauges activated simultaneously. Readings were then recorded from the proving ring gauge at penetration depths of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, and 7.5 mm.

2.3 Unconfined Compression Test (UCS)

About 250g of air dried laterite soil sample on B.S sieve 4.75mm was weighed and remodeled to undisturbed sample by adding the OMC obtained from the proctor test result to the weighed sample, mixed thoroughly and put in a cylindrical core, and then position the specimen centrally in the compression machine. Applied compressive load, observed and record the axial strain and load reading at deformation reading of 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.2, 2.4, 2.6, 2.8, and 3.0 failure.

2.4 Hydraulic Conductivity Test

For the hydraulic conductivity test, a portion of air dried soil sample was poured and compacted in a permeameter and saturated with water. A standpipe was then filled with water to an initial level (h_0), and connected to the soil in the mold and allowed the water to flow through it. By the time water flow through the soil, it means it has gotten to permeability state. The time for water level to drop from h_0 to h_f was then recorded and the permeability was calculated.

III. RESULTS AND DISCUSSION

Table 1: Proctor/Compaction test on Lateritic Soil

Moisture content %	Dry density kg/m3
9.4	1525
11.7	1691
13.9	1800
16	1523
18.5	1378

3.1 Compaction Test/Proctor Test

A compaction/proctor test is conducted to define the maximum dry density (MDD) and optimum moisture content (OMC) of soil. Five different trials were done to obtain moisture content and dry density values as shown in table 1 below, in which the dry density was plotted against the moisture content as shown in figure 1. The result of the MDD is 1800 kg/m³ while the OMC is 13.9% which is the moisture content at which the soil achieves maximum density. It helps determine the best field compaction conditions.

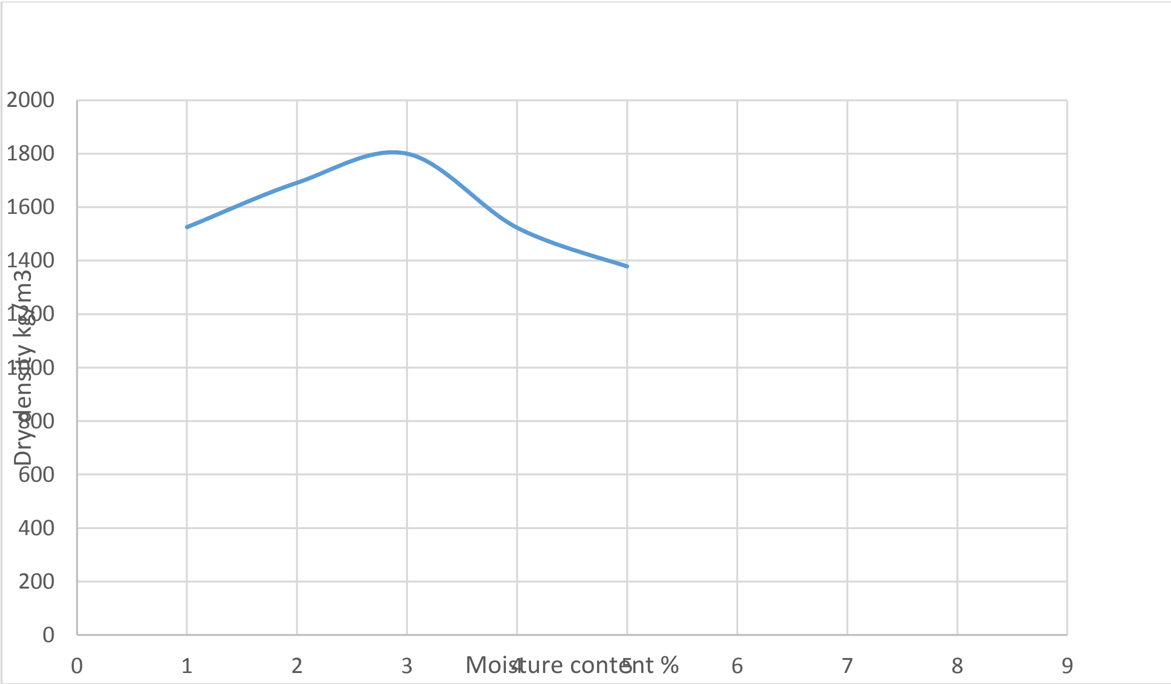

Figure 1: Density Moisture Relationship

MDD =1800 kg/m3
OMC =13.9 %

4.2 California Bearing Ratio (CBR)

The penetration readings at 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, and 7.5 as shown in table 2 were recorded, in which the load reading was plotted against the penetration reading as shown in figure 2. The test load at 2.5mm and 5.0mm was then calculated.

According to CBR test standards (ASTM D1883, AASHTO T193), the CBR value is determined by selecting the higher of the two penetration measurements, either 2.5 mm or 5.0 mm. Since the result of the CBR gotten at 2.5mm and 5mm penetration are 2.4% and 2.3% consecutively, this means the CBR is 2.4%.

Table 2: Carlifornia Bearing Ratio (CBR) for Soaked Sample

PENETRATION READING (mm)	LOAD READING (kg)
0	0
0.5	6
1.0	13
1.5	20
2.0	27
2.5	33
3.0	38
3.5	41
4.0	44
4.5	46
5.0	48
5.5	50
6.0	52
6.5	54
7.0	56
7.5	57

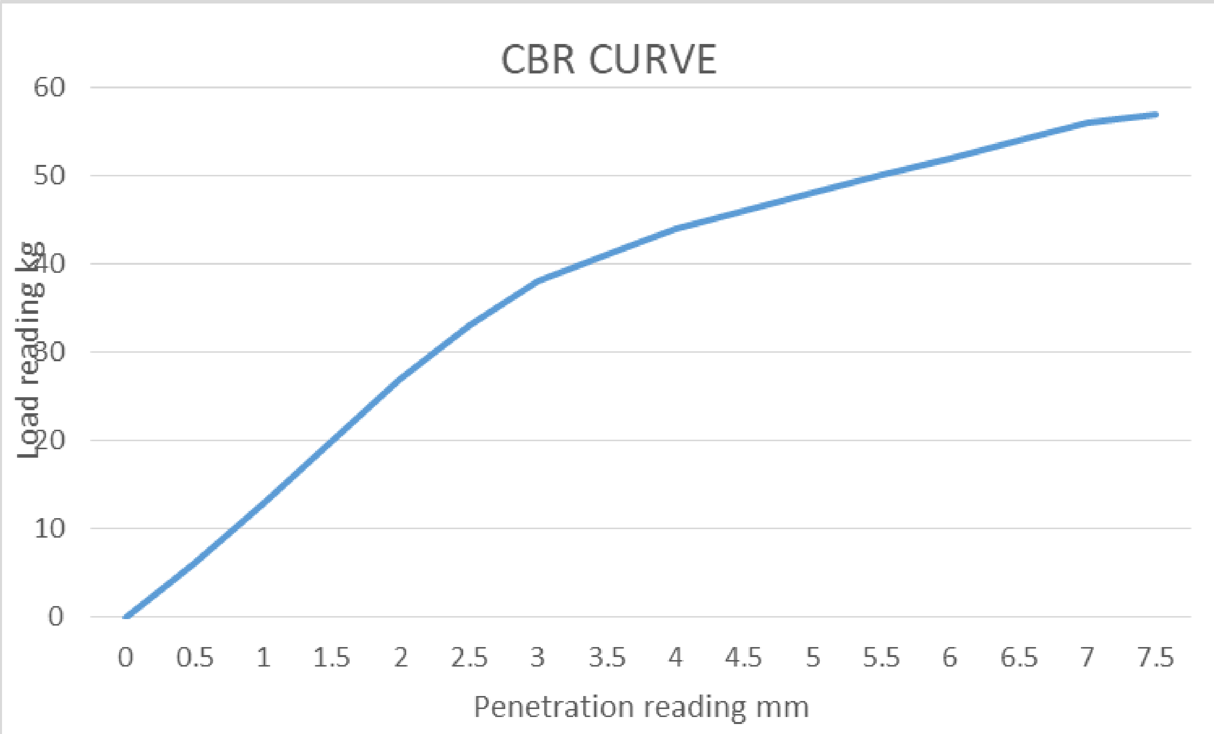

Figure 2: California Bearing Ratio Curve

$$2.5 = \frac{\text{Test Load}}{\text{Stress}} \text{X } 100$$

$$33 \text{ x} \frac{100}{1370} = \quad 2.4\%$$

$$5.0 = \frac{\text{Test Load}}{\text{Stress}} \text{X } 100$$

$$48 \text{ x} \frac{100}{2055} = \quad 2.3\%$$

CBR VALUE =2.4 %

4.3 Unconfined Compression Test (UCS)

UCS test measures the compressive strength of a soil sample without lateral confinement. It is commonly used for cohesive soils like clay and lateritic soils. As shown in table 3 below, the load readings were recorded at each deformation readings, then the strain, with corrected areas and strain were calculated. The UCS result gotten is 137.7kN/m².

Table 3: Unconfined Compressive Strength Test (UCS)

CBR	
2.5 mm	2.4%
5.0 mm	2.3%

Corrected Area (Ac) $= \frac{A0}{1-E}$

Deformation Reading	Load Reading Kg	Strain E = Al / Lo	Initial Area A_0 m^2	Corrected Area (Ac) m^2	Stress KN/m^2
0	0	0	0	0	0
0.2	6	0.00260	0.001134	0.001137	52.8

0.4	7	0.00526	0.001134	0.001141	61.3
0.6	9	0.00789	0.001134	0.001143	78.7
0.8	10	0.0105	0.001134	0.001146	87.3
1.0	12	0.0131	0.001134	0.001150	104.3
1.2	13	0.0157	0.001134	0.001152	112.8
1.4	14	0.0184	0.001134	0.001154	121.3
1.6	15	0.0210	0.001134	0.001158	129.5
1.8	16	0.0236	0.001134	0.001162	137.7
2.0	15	0.0263	0.001134	0.001164	128.9
2.2	14	0.0289	0.001134	0.001168	119.9
2.4	13	0.0315	0.001134	0.001171	111.0
2.6	12	0.0342	0.001134	0.001177	102.0
2.8	12	0.0368	0.001134	0.001183	101.4
3.0	11	0.0394	0.001134	0.001187	92.7

UCS = $\frac{0.16}{0.001162}$ = **137.7 KN/m²**

4.4 Hydraulic Conductivity Test

Hydraulic conductivity (k) represents the ability of soil to allow water to pass through its pores. It depends on soil type, particle size, and structure. A higher k-value indicate the soil is highly permeable (e.g., sand, gravel). A lower k-value indicate the soil is less permeable (e.g., clay, silt).
From table 4, the k value gotten is 1.44×10^{-4} cm/sec which falls in a low permeability range.

Table 4: Hydraulic Conductivity

	A	B
Initial Head (mm)	90	95
Final Head (mm)	78	85
Time (sec)	120	100
K (cm/sec)	1.48×10^{-4}	1.4×10^{-4}

$$K = \frac{2.3\, al}{At} \log \frac{ho}{hf}$$

Where;

a = 0.78
A = 78.55
l = 12.5
ho = Initial head
hf = Final head

$$K = \frac{1.48 \times 10-4 + 1.4 \times 10-4}{2} = \quad \mathbf{1.44 \times 10^{-4}\ cm/sec}$$

IV. CONCLUSION

The test results indicate that the soil is moderately compactable, with an MDD of 1800 kg/m³ and an OMC of 13.9%, suggesting optimal moisture conditions for achieving maximum density. However, the low CBR value of 2.4% shows that the soil has poor load-bearing capacity and is unsuitable for supporting pavement without stabilization. The UCS of 137.7 kN/m² suggests moderate strength (stiff clay) but may require improvement for heavy loads. The low hydraulic conductivity ($k = 1.44\times10^{-4}$ cm/sec) indicates that the soil has low permeability, likely classifying it as silty or clayey sand. Stabilization methods such as lime, cement, or bitumen treatment may be needed to enhance its engineering properties.

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