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Comparative Analysis of the Geotechnical Properties of Soil for Road Subgrade in Anambra State: A Case Study of Onitsha, Nnewi, Awka, and Ihembosi.

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Abstract: Before commencing any engineering project, it is crucial to understand the geotechnical properties of the soil. The construction of buildings, roads, and bridges relies on solid and efficient design criteria, which require a thorough assessment of the soil's characteristics at the construction site. Soil investigation is essential for determining the behavior and stability of different soil types under stress, ensuring the feasibility and durability of engineering projects. To determine whether the soil from Onitsha, Nnewi, Awka, and Ihembosi in Anambra State is suitable for use as road subgrade, this study examines its geotechnical properties. Laboratory tests conducted include particle size distribution, specific gravity, Atterberg limits, shear strength, permeability, and compaction characteristics. The findings provide insights into the soil's engineering behavior, particularly regarding its load-bearing capacity and potential need for stabilization.
Keywords: Soil investigation, road sub-grade, particle size distribution, soil stabilization, and geotechnical characteristics.

I. INTRODUCTION

"The characteristics of sub-grade soil significantly impact the longevity and structural stability of road pavements. Rapid urbanization, population growth, and increased vehicle traffic in Nigeria accelerate pavement degradation, posing major challenges for urban planners. Therefore, precise geotechnical assessments and comprehensive understanding of soil properties are essential to achieving durable and effective pavement infrastructure (Ezeh et al., 2023)."

In any aspect of construction work, be it structures, road component and others, there is need to ascertain the features of soil to withstand the load for sustainability of that project. A study conducted by Anene et al 2023 recommends construction of a storey car park at Eke Nibo to eradicate the traffic congestion. Anene et al 2023 also in a study conducted at Onitsha-Owerri road also recommends construction of standard checkpoints, weighing gauge for vehicles. Before one can go into these designs, soil features must be known for adequate and efficient construction.

"Road infrastructure in many developing countries, including Nigeria, often deteriorates rapidly due to inadequate consideration of site-specific subgrade conditions during the design and construction phases. This oversight contributes significantly to premature pavement failure. Consequently, proper site-specific geotechnical evaluations are essential to enhance pavement durability and minimize frequent distress and associated maintenance costs (Ugwu et al., 2021)."

"The characteristics of subgrade soils, including particle size distribution, plasticity (Atterberg limits), moisture-density relationship, compaction characteristics, and California Bearing Ratio (CBR), significantly influence pavement performance. Soils with low bearing capacity, high plasticity, or high moisture sensitivity can cause pavement failures, resulting in increased maintenance requirements, traffic accidents, and disruptions to economic activities (Okafor & Okeke, 2022)."

"Rapid urbanization and industrialization in Anambra State have led to increased vehicular traffic, thereby placing additional pressure on existing road infrastructure. Due to diverse geographical and geological conditions, sub-grade soil properties vary considerably across urban and semi-urban areas such as Onitsha, Awka, Nnewi, and Ihembosi. Each locality possesses distinct soil characteristics that differently affect pavement durability and stability. Thus, comparative analyses of these soils are essential to inform effective pavement engineering tailored specifically to the unique conditions of each site (Ugwu et al., 2021; Agu & Okafor, 2022)."

Previous studies conducted in Anambra State and other regions in Nigeria have highlighted notable variations in subgrade soil properties, even within relatively short geographic distances. Agu and Okafor (2022) emphasized the necessity of localized assessments, revealing significant differences in soil behavior that substantially influence pavement resilience across the state. Additionally, Obi et al. (2023) indicated that integrating comprehensive soil characterization with modern pavement design significantly enhances pavement durability and reduces lifecycle maintenance costs, especially in rapidly developing urban areas.

"In response to these challenges and identified research gaps, this study aims to conduct a comprehensive comparative analysis of subgrade soil characteristics from selected locations in Anambra State: Onitsha, Nnewi, Awka, and Ihembosi. The investigation systematically evaluates critical geotechnical parameters such as grain size distribution, plasticity index, compaction characteristics, moisture-density relationships, and California Bearing Ratio (CBR). The findings will inform optimized pavement designs, enhance construction methods, and support robust maintenance strategies, ultimately promoting sustainable road infrastructure management within the region."

II. LITERATURE REVIEW

According to Venkatramaiah (2006), soil is an unconsolidated inorganic material and a fundamental component of geotechnical engineering. It is formed through the breakdown of rocks near the earth's surface due to physical, chemical, and biological weathering processes. The engineering properties of soil significantly influence infrastructure durability; therefore, for effective structural design, it is essential to assess key parameters such as bearing capacity, moisture-density relationship, compaction characteristics, plasticity index, and particle size distribution (Federal Republic of Nigeria Highway Manual, 1992).

The availability and engineering significance of laterite soils, which are commonly used in road pavement construction, have led to extensive research in Nigeria. Studies by Ayetey and Freping (1996), Adeyemi and Wahab (2008), and Ogunanwo (1990) confirm that well-characterized laterite soil provides reliable strength and stability for pavement applications. However, due to rapid urbanization and increasing vehicular loads, particularly in regions like Anambra State, localized soil investigations are essential to ensure optimal pavement resilience (Ugwu et al., 2021; Agu & Okafor, 2022). Furthermore, the integration of comprehensive soil characterization with modern pavement design enhances durability and reduces maintenance costs (Obi et al., 2023). Additionally, variations in clay and silt content in lateritic soil significantly affect its bearing capacity and compaction properties, highlighting the importance of proper material selection in road construction (Ezeokonkwo et al., 2020).

Soil remains one of the most fundamental constituents in concrete production, and its quality must be carefully evaluated prior to use. According to Mmonwuba et al. (2025), incorporating blends of Portland Cement (PC) and Rice Husk Ash (RHA) enhances the strength of concrete produced with sand sourced from contaminated areas. This underscores the crucial role of supplementary additives in improving soil-based aggregates for sustainable and environmentally friendly concrete applications.

The mechanical performance and durability of concrete are significantly influenced by aggregate selection. Ogunjiofor et al. (2023) investigated the compressive strength of concrete using fine aggregates sourced from Onitsha, Uli, and Njaba. Their findings revealed that all samples exceeded 20 N/mm^2 in compressive strength, with Uli-sourced aggregates achieving the highest strength of 33.2 N/mm^2 at 28 days. These results underscore the critical role of aggregate sourcing in optimizing concrete properties and ensuring structural integrity.

Similarly, Okonkwo and Alhassan (2019) examined the impact of aggregate gradation on concrete performance, concluding that well-graded fine aggregates enhance workability and compressive strength by improving particle packing density. Additionally, Afolayan et al. (2021) demonstrated that incorporating alternative fine aggregates, such as crushed stone dust, enhances mechanical properties and durability, offering a sustainable solution to aggregate shortages.

Fiber reinforcement has gained significant attention in recent years as an innovative approach to enhancing the mechanical properties of concrete. A study by Ogunjiofor et al. (2024) on coconut fiber-reinforced concrete demonstrated a substantial improvement in tensile strength while maintaining adequate compressive strength. Their findings indicate that as fiber content increased, tensile strength significantly improved, whereas workability decreased, highlighting the potential of coconut fiber as a sustainable reinforcement material for eco-friendly concrete applications. Similarly, Aliyu et al. (2023) explored the potential of sugarcane bagasse ash as a partial cement replacement and found that it enhances durability while reducing environmental impact. This aligns with the findings of Ogunjiofor et al. (2025), whose study on oil palm fiber-reinforced concrete demonstrated that fiber incorporation improves tensile strength while maintaining compressive strength and workability. Their research identified oil palm fiber as a viable sustainable material for concrete reinforcement, with 0.5% fiber content providing the optimal balance between early-age tensile strength enhancement and improved post-cracking resistance.

In the production of sustainable concrete, the use of supplementary cementitious materials (SCMs) has gained greater prominence compared to fiber reinforcement. Mohammed et al. (2023) investigated the effects of fly ash and metakaolin on concrete properties, revealing that properly dosed SCMs enhance long-term strength development, reduce permeability, and improve overall durability. Similarly, Afolayan et al. (2021) demonstrated that incorporating alternative fine aggregates, such as crushed stone dust, enhances mechanical properties and durability, offering a sustainable solution to aggregate shortages.

Furthermore, advancements in nanomaterials have significantly transformed concrete technology. Hassan et al. (2024) investigated the effects of nano-silica on cementitious composites and found that it enhanced early-age strength, reduced water absorption, and improved resistance to sulfate attack. This study highlights the growing potential of nanotechnology in optimizing concrete performance for long-term structural applications.

III. MATERIALS AND METHODOLOGY

A. Materials

1) Laterite Soil

Samples were collected from borrow pits in Onitsha, Nnewi, Awka, and Ihembosi for laboratory testing and engineering analysis.

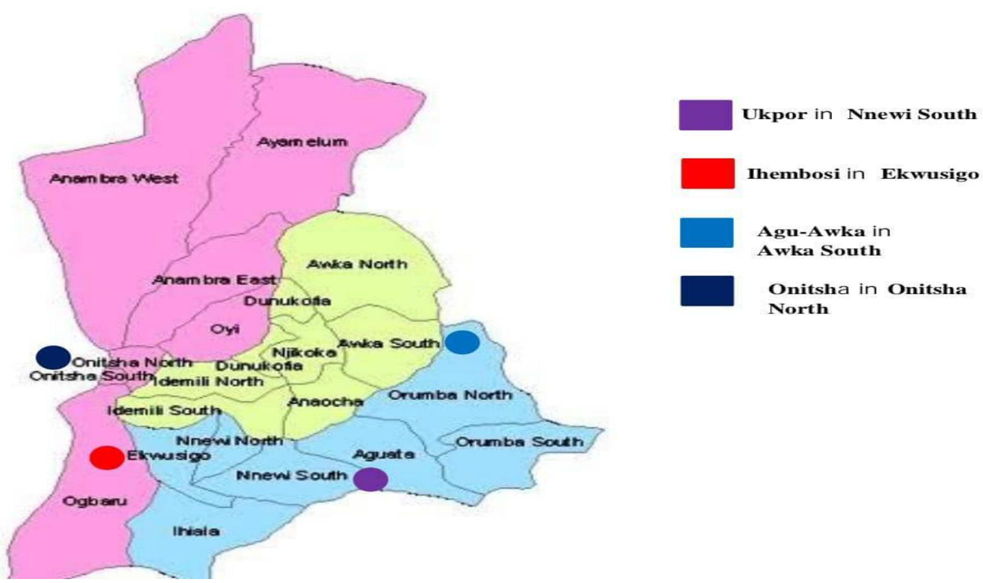

Figure 3.1: Map of Anambra State showing the Study Locations(Onitsha, Agu-Awka, Ukpor and Ihembosi)

The map shows the spatial distribution of the study locations within Anambra State, representing commercial, administrative, industrial and semi-urban areas.

2) Portable Water

Water was used for sample preparation in laboratory testing and analysis.

B. Methodology

1) Moisture Content Determination:

This experiment aims to determine the moisture content of a soil sample by measuring the ratio of water mass to dry soil mass, a critical factor influencing soil behavior in geotechnical engineering.

The materials used include four labeled containers (A, B, C and D), an electric balance, an oven set at 110°C, desiccators, and a lateritic soil sample.

For the procedure, the containers were labeled and weighed (W_1), filled with soil and reweighed (W_2), then oven-dried at 110°C for 24 hours. After cooling in desiccators, their final weights (W_3) were recorded.

2) Particle Size Distribution and Classification:

The particle size distribution analysis was conducted in accordance with BS 1377 Part 2 (1990) using mechanical sieve analysis to classify soil samples based on grain size. The weight of soil retained on each sieve was used to determine the percentage finer by weight, enabling the construction of a grading curve for soil characterization.

This test establishes the percentage of different grain sizes within a soil sample, which is essential for soil classification and geotechnical applications. Grain size distribution affects compaction, permeability, and shear strength, influencing the soil's suitability for construction.

A 600 g soil sample was washed through sieve No. 200 (0.075 mm) to remove fines, dried in an oven, and sieved using a mechanical shaker for 10 minutes. The percentage passing each sieve was calculated and plotted on a semi-logarithmic graph to determine the coefficient of uniformity (Cu) and coefficient of curvature (Cc), which were used to classify the soil according to the MIT and Indian Standard (IS) classification systems.

3) Specific Gravity:

The specific gravity (G) of soil solids, defined as the ratio of the unit weight of soil solids to that of water at a given temperature, was determined using a pycnometer, a precision balance (sensitive to 1 g), a glass rod, and an oven. The procedure involved weighing the empty pycnometer (W_1), adding 200 g of oven-dried soil, and recording the combined weight (W_2). Water was then added, thoroughly mixed, and the pycnometer was filled to the top before measuring the new weight (W_3). After emptying and cleaning, the pycnometer was refilled with distilled water and weighed again (W_4). The test was conducted two to three times, and the average specific gravity was calculated, providing critical data for soil classification and geotechnical analysis.

4) Atterberg/Consistency Limit Test:

The Atterberg Limit Test determines the moisture content at which soil transitions between consistency states, assessing plasticity through parameters such as the liquid limit, plastic limit, and plasticity index.

The liquid limit is the moisture content at which soil flows under standard blows. The test was conducted using the Casagrande apparatus, grooving tool, precision balance (0.01 g accuracy), oven, moisture cans, glass plate (500 mm × 500 mm), and distilled water. For the procedure, 500 g of soil (passing sieve No. 40 - 0.425 mm) was mixed with distilled water to form a uniform paste. A portion was placed in the Casagrande cup, leveled to 1 cm depth, and a V-shaped groove was made using a standard grooving tool. The Casagrande apparatus was operated at 2 revolutions per second, and the number of blows required to close the groove was recorded. The test was repeated with incremental water additions to achieve blow counts between 10 and 49. Moisture samples were oven-dried, cooled in a desiccator, and reweighed. The results were plotted on a semi-logarithmic graph, with the liquid limit determined at 25 blows, aiding in soil classification and geotechnical analysis.

5) Plastic Limit and Plasticity Index:

The plastic limit is the moisture content at which soil can be rolled into 3 mm threads without breaking, indicating its plasticity and clay content.

The test was conducted using a glass plate, spatula, distilled water, and moisture content cans. Soil paste at varying moisture contents was rolled into 3 mm threads on a glass plate until they began to break. The threads were then placed in moisture cans, weighed, oven-dried for 24 hours, cooled in a desiccator, and reweighed to determine the plastic limit (PL). The plasticity index (PI) represents the range of moisture content in which soil remains plastic and is calculated as the difference between the liquid limit (LL) and plastic limit (PL). Soils with higher PI values exhibit greater plasticity and higher clay content, while those with lower PI values tend to be more silty, aiding in soil classification and geotechnical analysis.

6) Standard Proctor Compaction Test:

The Standard Proctor Compaction Test, conducted per BS 1377 Part 4 (1990), determines the moisture-density relationship of soil and the maximum dry density (MDD) under specified compaction energy. A 3000 g soil sample was mixed with 4% water, compacted in three layers, with 27 blows per layer, and weighed. The process was repeated with incremental water additions (4%, 8%, 12%, 16%, and 20%) until dry density decreased. Moisture content samples were oven-dried for 24 hours, cooled in a desiccator, and reweighed. The results determined the optimum moisture content (OMC) and MDD, essential for soil compaction in geotechnical engineering.

7) California Bearing Ratio (CBR) Test

The California Bearing Ratio (CBR) test, developed by the California State Highway Department, evaluates the strength of sub-grade soil and pavement materials for flexible pavement design. A 50 mm diameter plunger penetrates a remolded or undisturbed soil sample at 1.25 mm per minute, measuring loads at 2.5 mm and 5.0 mm penetration, with the CBR value expressed as a percentage of the standard load value for compacted crushed stone aggregates.

The test was conducted using a cylindrical metal mold, precision balances, an oven, a steel straightedge, and IS sieves. Soil was compacted in three layers, each 5 kg, with 56 blows per layer, achieving 95%-100% compaction density. The unsoaked test was performed immediately, while the soaked test involved submerging the specimen for up to four days before testing. The CBR value was determined by applying a 10 lb surcharge load, recording penetration load values, and plotting penetration (mm) vs. load (kg) for pavement design and geotechnical analysis.

IV. RESULTS AND DISCUSSION

The following tests were conducted on the specified soil samples.

A. Moisture Content

Moisture content, expressed as the ratio of water weight to dry soil weight, was determined using the direct measurement method, with results presented in Table 1.

Table 1: Moisture content result

Sample Location	Moisture Content (%)
A (Onitsha)	23.13
B (Nnewi)	19.72
C (Awka)	13.14
D (Ihembosi)	39.64

B. Particle Size Distribution

The particle size analysis was conducted to determine the proportions of gravel, sand, and silt in the soil samples, as well as the coefficient of uniformity (Cu) and Coefficient of Curvature(Cc), which are essential for soil classification and suitability assessment. The result is presented in table 2

Table 2: Particle Size Distribution and Soil Classification Parameters

Location	Gravel	Sand	Silt	Cu	Cc
A (Onitsha)	0.00	43.18	56.82	2.00	0.58
B (Nnewi)	0.08	70.60	29.40	6.00	0.17
C (Awka)	0.20	61.04	38.96	2.80	0.38
D (Ihembosi)	0.00	73.54	26.46	2.88	0.35

C. Specific Gravity

The specific gravity of soil, the ratio of soil weight to an equal volume of water, determines its unit weight. As shown in Table 3, the values for Onitsha, Nnewi, Awka, and Ihembosi were 2.40, 2.35, 2.48, and 2.41, respectively. While slightly below the typical lateritic soil range (2.6–2.8), the results confirm lateritic soil characteristics.

Table 3: Specific Gravity Results

Sample	Specific Gravity
A (Onitsha)	2.40
B (Nnewi)	2.35
C (Awka)	2.48
D (Ihembosi)	2.41

D. Atterberg Limit

The liquid limit (LL) marks the transition to a liquid state, while the plastic limit (PL) is the moisture content at which soil cracks when rolled into 3 mm threads. The plasticity index (PI), calculated as LL - PL, indicates the soil's plastic range. Results are shown in Table 4.

Table 4: Atterberg Limit Results

Sample	LL (%)	PL (%)	PI (%)
A (Onitsha)	41.00	11.38	29.62
B (Nnewi)	42.10	7.15	34.95
C (Awka)	42.10	7.15	34.95
D (Ihembosi)	31.00	24.02	6.98

E. Compaction Test

Compaction of samples A, B, C, and D was conducted across moisture content (MC) ranges of 7.44%–20.74% (Onitsha), 3.33%–17.60% (Nnewi), 5.58%–21.81% (Awka), and 4.29%–20.70% (Ihembosi). The optimum moisture content (OMC) and maximum dry density (MDD) values, as shown in Table 5, indicate low water absorption and loosely bound lateritic soils. Since Zame et al. (2017) recommends a minimum MDD of 1.69 Mg/m³ for base course materials, stabilization may be required.

Table 5: Compaction Test Results

Sample	MDD (kN/m^3)	OMC (%)
A (Onitsha)	18.61	7.33
B (Nnewi)	19.70	7.23
C (Awka)	18.60	12.32
D (Ihembosi)	18.41	11.76

F. California Bearing Ratio (CBR) Test

The CBR test measures the force and penetration of a cylindrical plunger to estimate the bearing capacity of sub-grade and sub-base soils. The soaked and unsoaked CBR values for Samples A and C are shown in Table 6.

Table 6: CBR Results for Samples A and C

Sample	Soaked CBR (%)	Unsoaked CBR (%)
A (Onitsha)		
Top	2.50	5.00
Bottom	1.95	3.67
C (Awka)		
Top	17.90	18.79
Bottom	14.97	15.76

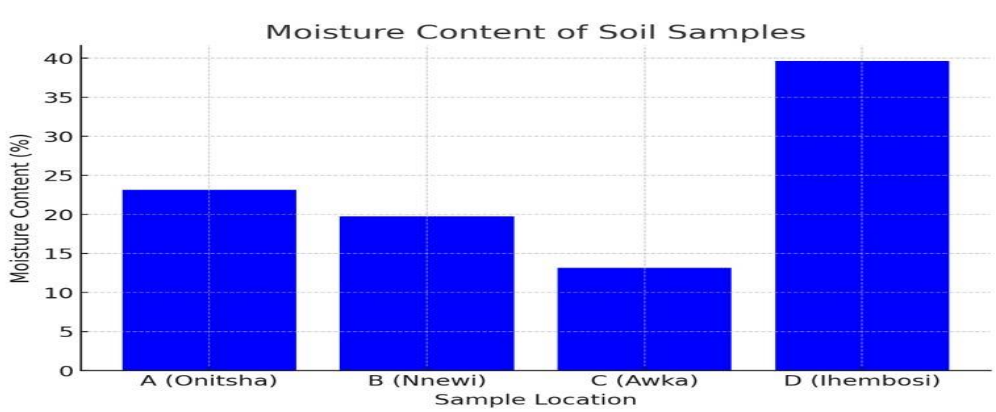

Fig. 1: Moisture content bar chart

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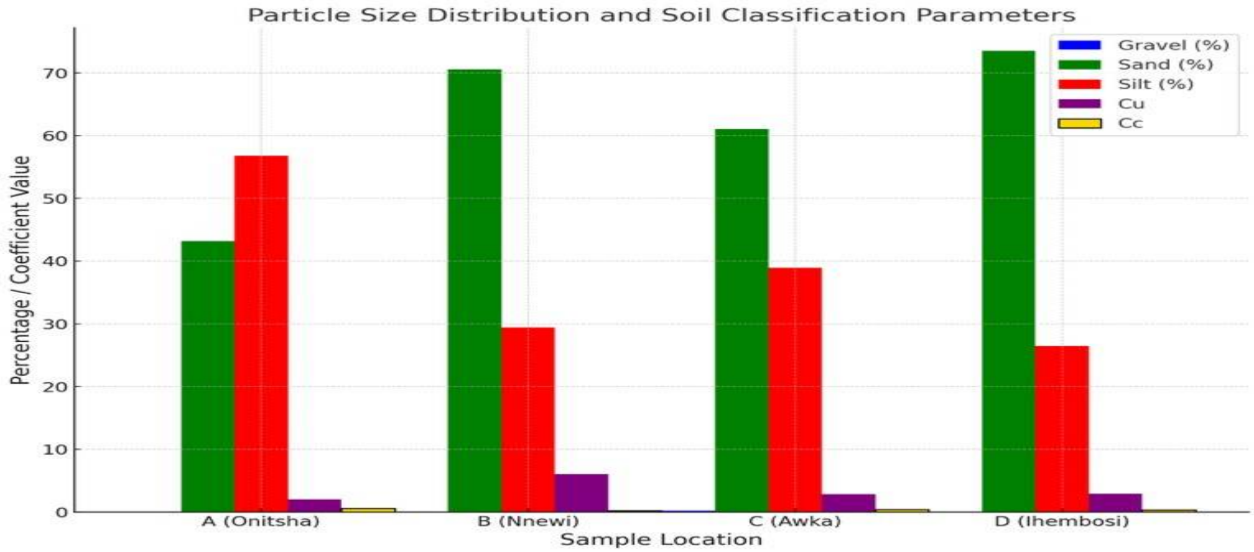

Fig. 2: Particle Size Distribution and Soil Classification Parameters

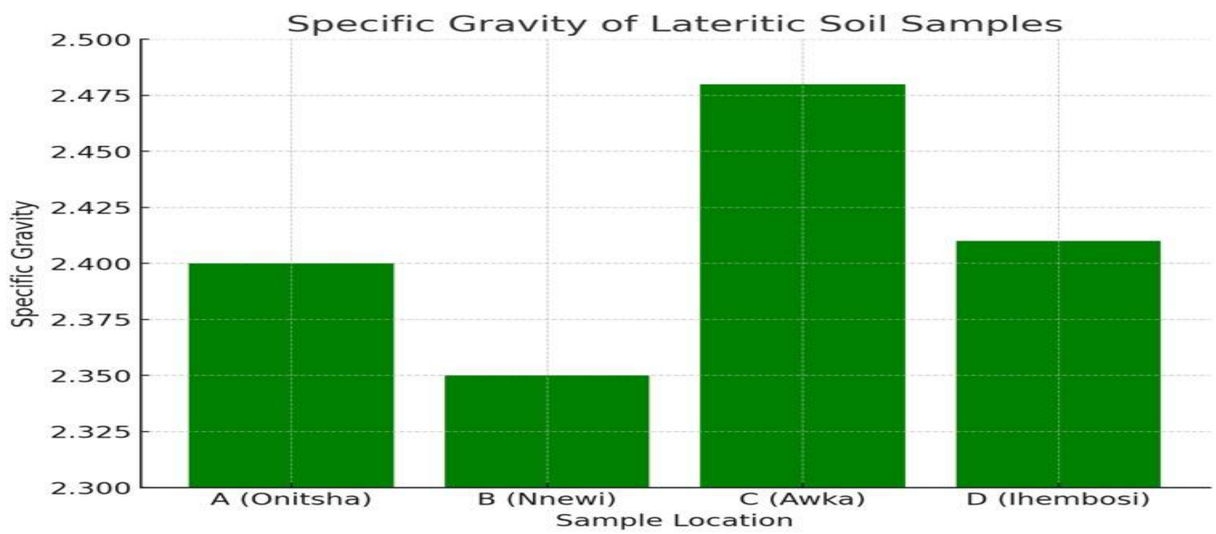

Fig. 3: Specific Gravity of Lateritic Soil Samples

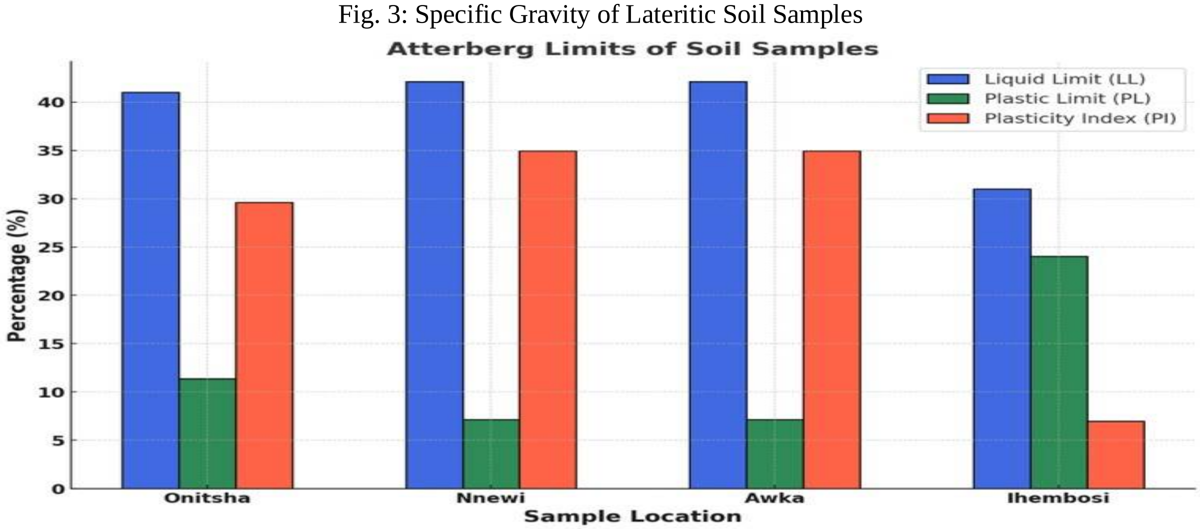

Fig. 4: Atterberg Limits of Soil Samples (Liquid Limit, Plastic Limit, and Plasticity Index)

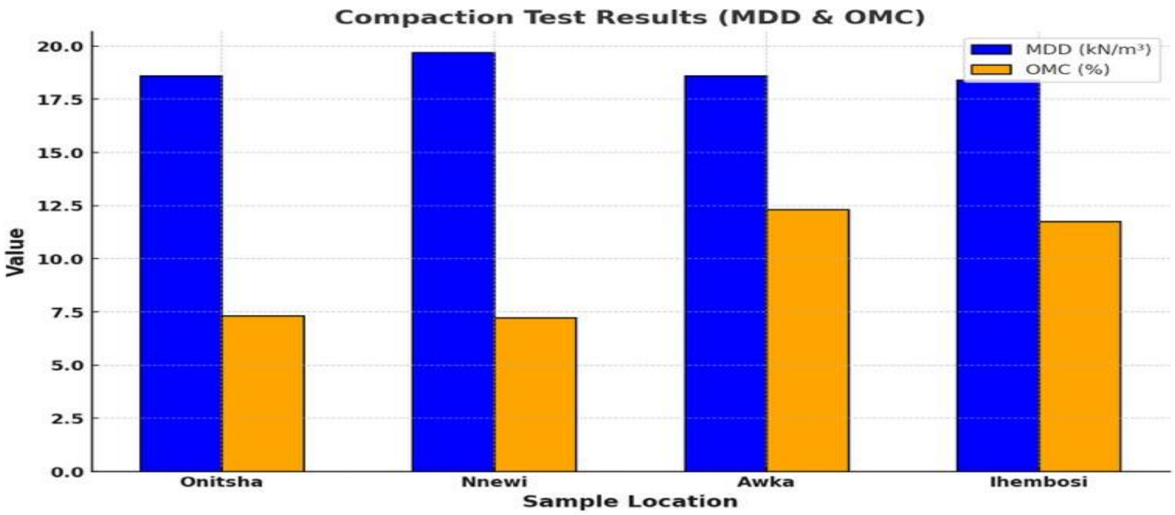

Fig 5: compaction Test Results

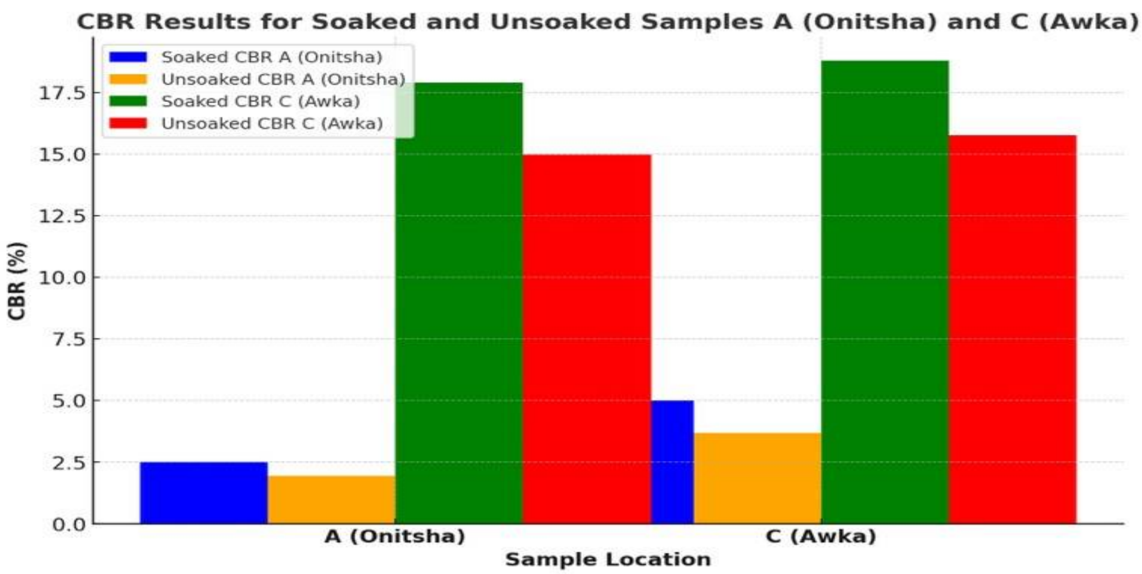

Fig 6: Fig. 5: CBR Results for Soaked and Unsoaked Samples A (Onitsha) and C (Awka).

V. CONCLUSION AND RECOMMENDATIONS

The geotechnical assessment of lateritic soils from Anambra State showed that while some samples met the required AASHTO and Federal Ministry of Works and Housing standards, others did not. Sample C (Awka) is suitable as subgrade material in road construction, while Samples A (Onitsha), B (Nnewi), and D (Ihembosi) require the addition of admixtures to enhance their engineering properties. It is recommended that Sample C be used directly as subgrade material, and that Samples A, B, and D be considered with admixtures for improved performance. Further geotechnical investigations on lateritic soils from various locations and depths in Anambra State are suggested to better guide future road construction project in the region.

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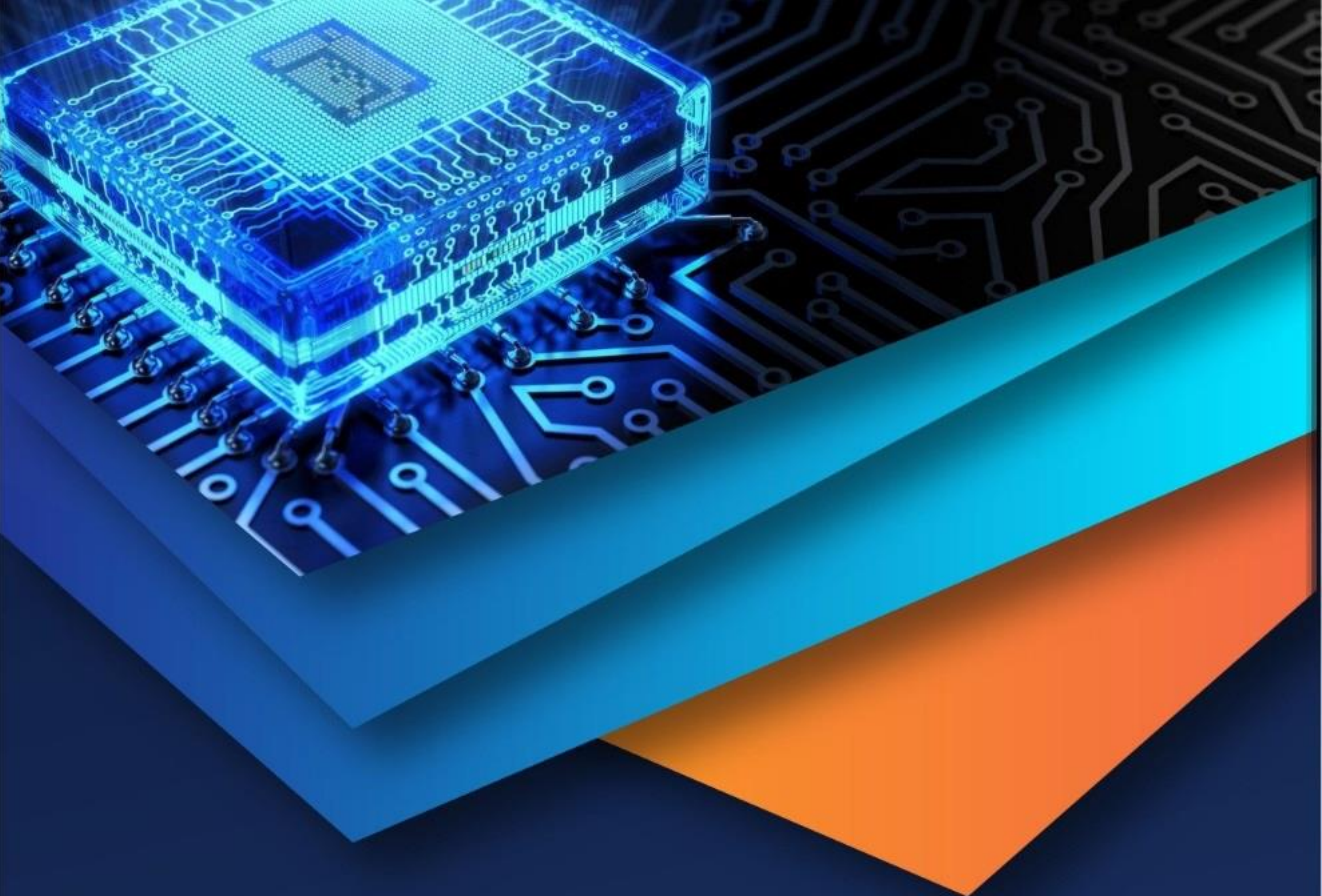

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