Geotechnical Characterization of Soils for Road Construction Along Textile Mill Road, Benin City, Nigeria

David Idiata, Ngozi Kayode-Ojo, and Solomon Okonofua

Abstract- This paper presents a geotechnical characterization of soil samples to evaluate their suitability for road construction. Laboratory tests, including specific gravity, sieve analysis, compaction, Atterberg limits, and California Bearing Ratio (CBR), were conducted to assess engineering properties. The results highlight significant variations in particle density, gradation, plasticity, and load-bearing capacity, which critically influence subgrade stability and pavement performance. The findings demonstrate that soils with higher specific gravity and well-graded particle distribution exhibit superior compaction characteristics and reduced moisture susceptibility. Lower plasticity indices correlate with enhanced stability under wet-dry cycles, minimizing long-term maintenance needs. CBR tests further reveal that soils with minimal strength loss under soaked conditions are more resilient, ensuring durability in moisture-prone environments. The study underscores the importance of selecting soils with optimal gradation, density, and plasticity to achieve cost-effective and sustainable road infrastructure. Practical implications for construction practices, including moisture control and stabilization requirements, are discussed, providing actionable insights for engineers and project planners.

***Keywords*- Geotechnical characterization, Soil properties, Road construction, California Bearing Ratio (CBR), Atterberg limits, Compaction**

I. INTRODUCTION

Geotechnical characterization of soils is an important step in the successful design and construction of road infrastructure, especially in areas with a wide range of soil types and difficult environmental conditions. This study looks at the geotechnical evaluation of soils along Textile Mill Road in Benin City, Nigeria. This road is an important transportation route that has had problems with its pavement breaking down because the soil was not properly assessed and the construction was not done right. This study is unique because it uses both traditional and geotechnical testing methods to describe the subgrade soils along this specific corridor. This gives a full picture of how the soils behave when they are under traffic and environmental loads (Amadi et al., 2022 and Ezeh et al., 2023). This study is different from others that have been done in the area because they often used broad soil classifications. This study, on the other hand, looks at the geology and climate of Benin City in a way that is specific to that area. By doing this, it fills in a major gap in localised geotechnical data, which is necessary for building roads in Nigeria's rapidly growing urban areas in a way that lasts.

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The fact that road infrastructure in Benin City keeps failing shows how important this study is. This is often blamed on using the wrong soils and not doing enough geotechnical investigations. The Textile Mill Road, like many others in the area, goes through places with very different types of soil, such as lateritic soils, clayey deposits, and sediments rich in organic matter. Each of these soils has its own unique engineering properties. To design pavements that can last through heavy traffic, seasonal rain, and temperature changes, it is important to understand these differences. This study uses a testing regime that includes specific gravity, particle size distribution, compaction characteristics, Atterberg limits, and California Bearing Ratio (CBR) to see if these soils are good for building roads. We chose these tests because they are well-known in geotechnical engineering and have been shown to be reliable for measuring the quality of subgrade (Osinubi et al., 2009; Amadi, 2014). However, it is important to explain why some advanced tests, like shear strength, compressibility, unconfined compressive strength (UCS), and tensile strength (Ts), which are often used in thorough geotechnical studies, are not included. The main reason these tests were not done is because the focus of this research is on the initial evaluation of subgrade suitability rather than detailed mechanistic modelling. Tests for shear strength and compressibility are important for designing foundations, but they are not as important for flexible pavement systems, where the main concern is the load-bearing capacity of the subgrade, which can be measured by CBR and compaction tests (AASHTO, 1993; NCHRP, 2004). The Nigerian General Specifications for Roads and Bridges (2021 revision) backs this up by saying that these standard tests should be done first on regular road projects. Also, UCS and Ts tests are more useful for cohesive soils or stabilised materials, which are not the main focus of

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this study. The chosen tests are a good balance of cost and effectiveness for reaching the study's goals without lowering the reliability of the results (Etim et al., 2023; Barksdale &Itani, 1989; Lekha et al., 2013). This is because of the limitations of field sampling and laboratory resources. The geological setting of Benin City makes the testing method used in this study even more appropriate. The Benin Formation, which is part of the Niger Delta Basin, lies beneath the region. It is made up of layers of sand, clay, and gravel that alternate (Omatsola&Adegoke, 1981, Nwankwoala& Whyte, 2023). Because these soils vary a lot from place to place, geotechnical evaluation needs to be done in a specific way. For example, the high clay content in some places makes the soils more likely to swell and shrink. This can be measured accurately using Atterberg limits and compaction tests (Ola, 1983; Gidigasu, 1976). On the other hand, the sandy and lateritic soils that are common in other areas need careful gradation analysis to make sure they drain and stay stable. By focussing on these important factors, the study gives engineers and planners useful information that can help them choose the right soil, stabilise it, and build things. This study has effects that go beyond the area around Textile Mill Road. Nigeria's roads often fail because of poor construction and not enough geotechnical research (Adeyemi et al., 2008; Oyediran&Fadamoro, 2015). This study shows how useful systematic soil characterisation can be and calls for the use of standardised geotechnical protocols in road projects all over the country. The results will also add to the growing body of knowledge about tropical soils, which are often not well covered in global geotechnical literature (Gidigasu, 1976; Osinubi et al., 2009). Combining local soil data with best practices from around the world can make Nigeria's transport infrastructure more sustainable and resilient, which will lower maintenance costs and extend the life of the infrastructure.

II. Study Area

The soil samples examined in this study were obtained from Textile Mill Road in Benin City, the capital of Edo State, Nigeria. The designated sampling location is positioned in front of Christ Embassy Church, a notable landmark on this bustling thoroughfare. Benin City is located in southern Nigeria, at approximately 6.34°N latitude and 5.62°E longitude. This area belongs to Nigeria's humid tropical region, marked by pronounced wet and dry seasons (Ologunorisa and Abawua, 2005). Benin City is a historically important urban centre and the administrative capital of Edo State. The city's geographical position situates it in the rainforest zone, resulting in a comparatively high annual precipitation, averaging between 2,000 and 2,500 mm (Odemerho, 1992). Precipitation in the region is primarily concentrated from April to October, with maximum rainfall occurring between June and September. The arid season lasts from November to March, characterised by reduced humidity and the impact of harmattan winds (Nwafor, 2006). Textile Mill Road is a principal thoroughfare in Benin City, connecting industrial, residential, and commercial zones. It endures considerable vehicular congestion, encompassing trucks and heavy-duty vehicles, owing to its nearness to industrial areas and markets. The road comprises both paved and unpaved segments, rendering it vulnerable to soil erosion, sedimentation, and waterlogging, especially during the rainy season (Ogundele et al., 2011). The area's topography is primarily flat to gently undulating, characteristic of Benin City's landscape. The flat topography, combined with substantial precipitation, frequently leads to inadequate drainage, resulting in localised flooding and erosion (Adefolalu, 1991). The region's soils are predominantly lateritic, distinguished by their reddish-brown hue resulting from elevated iron oxide levels. These soils are characteristic of tropical regions and exhibit variability in engineering properties, encompassing sandy to clayey compositions (Osinubi and Nwaiwu, 2006).

Figure 1: Location of sample collection

Figure 2: Google map of Benin City

The region is situated within the Coastal Plain Sands formation, which is a component of the Niger Delta sedimentary basin. This formation primarily comprises unconsolidated sand, clay, and silts, exhibiting varying degrees of permeability (Short and Stauble, 1967). The amalgamation of sandy and clayey deposits affects the geotechnical characteristics of soils in the region, rendering them crucial for construction and infrastructure projects. The area surrounding Christ Embassy Church and Textile Mill Road comprises residential structures, small enterprises, and light industrial activities. These activities lead to anthropogenic factors such as soil compaction, contamination,

and surface runoff, which can modify the inherent properties of soil (Egbai et al., 2011).
The study area, situated along Textile Mill Road in Benin City, displays quintessential traits of a tropical urban environment. The geographic location, climate, and geological characteristics render it an optimal site for examining soil properties and their relevance to geotechnical applications.

III. Literature Review

The analysed studies reveal a consistent interconnection among these parameters and their combined influence on the durability and performance of roads. The amalgamation of testing outcomes, bolstered by statistical and modelling methodologies, provides a robust framework for forecasting soil behaviour and guiding design decisions. Given the escalating demand for robust infrastructure due to climate variability and heightened traffic loads, extensive geotechnical testing is not merely advantageous—it is essential. The design and construction of sustainable and resilient road infrastructure rely heavily on precise geotechnical characterisation of subgrade soils. Inadequately defined or inappropriate subgrade conditions frequently lead to pavement failures, irregular settlements, and expensive maintenance. Thus, geotechnical soil tests—including specific gravity, gradation, Atterberg limits, compaction, and California Bearing Ratio (CBR)—are crucial for assessing the engineering characteristics of soils and forecasting their performance under load and environmental conditions. Specific gravity (SG) is a fundamental property that indicates the density of soil solids in relation to water. Determining void ratio, porosity, and degree of saturation is essential, as these factors affect load-bearing performance. Anyaegbunam et al. (2021) assert that specific gravity aids in determining soil mineralogy and assessing compaction parameters. Soils exhibiting elevated specific gravity are generally abundant in heavy minerals, resulting in enhanced stability under traffic loads. A study by Bello et al. (2019) indicated that lateritic soils with specific gravity (SG) ranging from 2.60 to 2.75 exhibited superior performance as subgrades compared to those with lower SG values, attributable to their denser composition. Oke et al. (2018) illustrated that specific gravity can distinguish between organic and inorganic soils, a differentiation essential for road construction. Organic soils typically exhibit specific gravity values below 2.50, signifying inadequate compaction potential and diminished strength. The specific gravity (SG) significantly affects the California Bearing Ratio (CBR) and compressibility properties, with elevated SG typically resulting in enhanced mechanical performance (Edeh&Igwe, 2020). Gradation or sieve analysis ascertains the distribution of gravel, sand, silt, and clay particles within the soil, which profoundly influences strength, permeability, and stability. Well-graded soils facilitate superior interlocking and diminish voids, thereby improving compaction and decreasing permeability. Osinubi and Nwaiwu (2017) assert that well-graded granular soils are optimal for base and subbase courses, providing enhanced shear strength and superior drainage. Ajayi et al. (2022) highlighted that inadequately graded or uniformly graded soils frequently experience differential settlements and moisture susceptibility. The research contrasted two subgrade soils with varying gradation curves, revealing that the well-graded sample exhibited a 25% superior California Bearing Ratio (CBR) and a greater maximum dry density (MDD). Adebisi and Akinyele (2020) demonstrated that gradation influences the optimum moisture content (OMC) during compaction. Coarse-grained soils, characterised by a diverse particle size distribution, typically necessitate less water and attain superior compaction compared to fine-grained soils. Gradation is also associated with the Atterberg limits and compaction characteristics. Nwachukwu et al. (2019) demonstrate that clayey soils characterised by a substantial fine fraction and inadequate gradation exhibit elevated plasticity indices and necessitate chemical stabilisation for enhanced performance. The Atterberg limits are essential for the classification of fine-grained soils and the evaluation of their plasticity, workability, and moisture sensitivity. The liquid limit (LL), plastic limit (PL), and plasticity index (PI) denote soil behaviour under different moisture conditions. Soils exhibiting elevated liquid limit (LL) and plasticity index (PI) are expansive and pose challenges for road construction due to their swelling and shrinkage characteristics. Akinwumi et al. (2021) assessed the Atterberg limits of lateritic and clayey soils from southwestern Nigeria, concluding that soils with plasticity index values exceeding 20% exhibited inadequate performance as subgrades without stabilisation. Conversely, soils with a Plasticity Index below 10% exhibited negligible volume alteration and were appropriate for light to medium traffic roadways. Yahaya et al. (2018) observed that the Atterberg limits facilitate the prediction of compaction behaviour and California Bearing Ratio (CBR). Soils exhibiting reduced Liquid Limit (LL) and Plasticity Index (PI) generally demonstrate superior compaction and enhanced bearing capacity. Musa et al. (2022) identified a significant inverse correlation between Plasticity Index (PI) and California Bearing Ratio (CBR); highly plastic soils demonstrated CBR values as low as 4%, whereas soils with low plasticity achieved values exceeding 20%, suggesting their appropriateness for subgrade and subbase applications. Moreover, Atterberg limits facilitate soil classification within the AASHTO and Unified Soil Classification Systems (USCS), informing decisions regarding necessary treatments or replacements prior to road construction (Ola, 2017). Compaction is the mechanical densification of soil to augment its strength, diminish settlement, and enhance resistance to deformation. The standard Proctor and modified Proctor tests provide parameters including Maximum Dry Density (MDD) and Optimum Moisture Content (OMC), which inform field compaction activities. Research conducted by Ogundipe et al. (2019) demonstrates that well-compacted soils facilitate superior load distribution and extend pavement longevity. It was determined that MDD values ranging from 1.70 to 2.10 g/cm³ offered sufficient subgrade support in tropical lateritic soils. OMC, conversely, fluctuates according to soil type. Fine-grained soils generally demonstrate elevated optimum moisture content, rendering them more susceptible to construction scheduling, particularly during periods of precipitation. Ibrahim et al. (2020) noted that soil type and

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gradation substantially affect compaction behaviour. Coarse-grained soils attain elevated Maximum Dry Density (MDD) at reduced Optimum Moisture Content (OMC), whereas fine-grained and organic soils necessitate increased moisture yet frequently do not achieve optimal MDD levels. This underscores the necessity of pre-construction soil analysis to customise compaction specifications effectively. Afolayan et al. (2022) investigated the impact of different compactive efforts on clayey soils and discovered that heightened compactive energy increased the maximum dry density (MDD) by as much as 15%, specifically for soils with low plasticity index (PI) values. For highly plastic soils, the enhancement was minimal, indicating that compaction alone may be inadequate without stabilisation. The California Bearing Ratio is a penetration test that assesses the strength and stiffness of soil and subgrade materials under simulated loading conditions. It continues to be one of the most essential factors in pavement design, especially for flexible pavements. CBR values directly indicate the soil's appropriateness for use as subgrade, subbase, or base material. Olowofela and Okogbue (2017) demonstrated that lateritic soils with CBR values exceeding 15% are typically appropriate as subgrade materials, whereas those below 5% necessitate stabilisation or replacement. Ogbonna et al. (2021) performed comprehensive CBR testing on expansive clay soils and discovered that CBR values significantly decreased with elevated moisture content, emphasising the necessity of effective drainage and moisture management in pavement construction. The research highlighted the relationship between Atterberg limits and CBR values, indicating that soils with higher plasticity indices consistently exhibited lower CBR values. Research conducted by Okunlola and Ibrahim (2019) evaluated the California Bearing Ratio (CBR) of different tropical soils, demonstrating that sandy soils attained CBR values exceeding 30% in their natural condition, whereas clayey soils necessitated cement or lime stabilisation to surpass the minimum design threshold of 10–15%. Furthermore, CBR testing under saturated conditions replicates worst-case scenarios, and this methodology is crucial in regions susceptible to water infiltration. Contemporary methods of geotechnical characterisation prioritise integrated testing, wherein the outcomes of one test influence the anticipations or modifications required for subsequent tests. Arowojolu and Adedokun (2020) proposed a classification model utilising Atterberg limits and gradation to predict CBR values. This model enhances efficiency in initial investigations and diminishes testing expenses. Ezeokonkwo et al. (2020) developed a regression model correlating MDD, OMC, PI, and specific gravity with CBR values, illustrating that a comprehensive approach provides more dependable subgrade classification than individual testing. Mugabe and Muriithi (2021) evaluated road failure in low-volume roads in East Africa and attributed the cause to insufficient geotechnical testing during the design phase. Soils exhibiting high plasticity and inadequate drainage were utilised without appropriate compaction or stabilisation, resulting in pavement failure during seasonal precipitation. The research emphasised the importance of employing Atterberg limits, compaction, and CBR data to tailor designs to regional soil characteristics. In Nigeria, Fatoba and Alabi (2018) examined over 30 unsuccessful road projects and determined that inadequate analysis of CBR and Atterberg limits contributed to over 50% of design failures. They promoted compulsory geotechnical testing, especially in clay-dominant areas with significant precipitation. Innovative technologies in geotechnical characterisation encompass expedited field testing techniques and artificial intelligence for forecasting test outcomes. Akinlolu et al. (2023) elucidate that machine learning models can forecast CBR values utilising data from Atterberg limits, gradation, and compaction. These tools offer efficiency, particularly in extensive projects where time and resources are constrained. The geotechnical characterisation through specific gravity, gradation, Atterberg limits, compaction, and CBR tests constitutes the foundation of effective road construction methodologies. These tests yield critical insights into soil behaviour in response to loading, variations in moisture, and compaction efforts. Specific gravity aids in determining soil mineralogy and density; gradation affects stability and drainage; Atterberg limits evaluate plasticity and potential volume change; compaction establishes the optimal moisture and density for performance; and CBR measures strength and stiffness for pavement design.

IV. Research Methodology

This study employed a systematic, multi-stage research methodology to evaluate the geotechnical properties of soils along Textile Mill Road in Benin City, Nigeria. The approach combined field investigations with comprehensive laboratory testing, following international standards while adapting to local conditions. The methodology was designed to provide reliable data for road construction while addressing the unique challenges posed by tropical residual soils in the region. The research focused on a strategic location along Textile Mill Road, selected based on preliminary visual surveys and historical records of pavement distress. Sampling followed the Nigerian General Specifications for Roads and Bridges (2021) guidelines, with disturbed and undisturbed samples collected from 0.5-1.5m depths at each location. A modified Shelby tube sampler was used to obtain undisturbed samples for compaction and CBR tests, while disturbed samples were collected for classification and index property tests. The sampling strategy accounted for seasonal variations by conducting collections during both wet and dry seasons, as recommended by Amadi et al. (2022) for tropical soil studies.

The laboratory investigation comprised a suite of tests selected to evaluate fundamental engineering properties relevant to road construction. Particle size distribution analysis was performed using both wet sieving (for particles >75μm) and hydrometer methods (for fines), following ASTM D6913 and D7928 standards. Atterberg limits were determined according to ASTM D4318, with particular attention to the plasticity characteristics that influence soil behaviour under moisture variations. Compaction characteristics were evaluated using the standard Proctor test (ASTM D698), crucial for understanding the moisture-density relationship of the soils. The CBR tests were conducted following ASTM D1883, with both soaked and unsoaked conditions evaluated to simulate worst-case and typical field scenarios. This dual approach, as advocated by Sani et al. (2023), provides more realistic performance predictions for

Benin City's tropical climate. The soaking period of 96 hours accounted for potential prolonged water exposure during heavy rains.

V. Results And Discussion

The results and discussion with respect to the geotechnical tests are presented below: The specific gravity test results (Table 1) for samples C1 and C2 reveal distinct differences in their soil particle densities. Sample C1 has an average specific gravity of 2.39, while C2 exhibits a higher value of 2.60. This suggests that C2 contains denser mineral particles, possibly due to a higher concentration of heavy minerals like iron oxides or quartz. The consistency in C2's measurements (2.61 and 2.60) indicates precise lab work, whereas C1's slight variation (2.37 and 2.40) may reflect minor heterogeneity in the sample. These values are critical for understanding soil behaviour, as higher specific gravity often correlates with better load-bearing capacity and lower porosity. The results align with typical ranges for sandy or clayey soils, with C2's higher density hinting at superior engineering properties for construction applications.

Table 1. Specific Gravity Test

S/N	POINTS	SPECIFIC GRAVITY
1	C1	2.39
2	C2	2.60

The sieve analysis highlights the gradation differences between C1 and C2(Figures 3 and 4). C1 shows 93.1% passing the 1.18mm sieve, compared to 87.25% for C2, indicating C1 is finer. However, C2 has a higher percentage (55.35%) passing the 0.425mm sieve versus C1 (51.75%), suggesting a more uniform particle distribution.

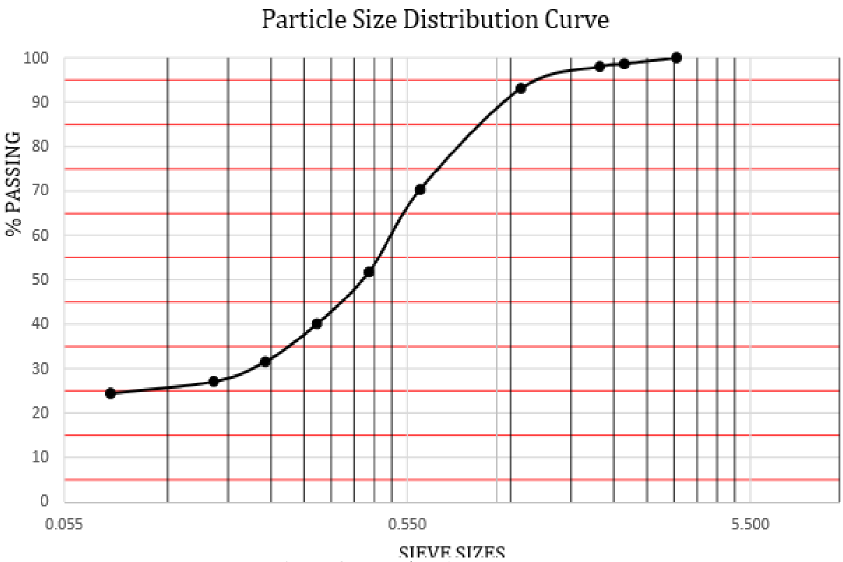

Figure 3: Sample C1 PSD curve

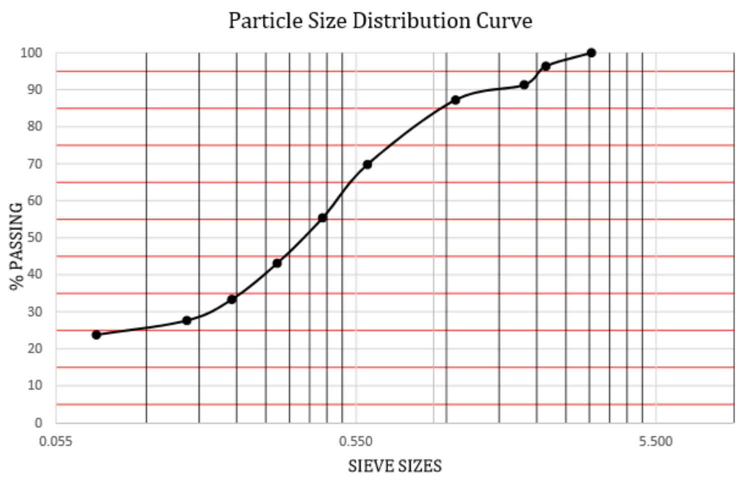

Figure 4: Sample C2 PSD curve

Both samples classify as A-2 soils per AASHTO, with C1 as A-2-6 (higher plasticity) and C2 as A-2-4 (lower plasticity). The finer fraction (<0.075mm) is similar (~24%), but C2's coarser mid-range particles may enhance drainage and reduce compaction effort. These results are vital for determining suitability in subgrade or embankment construction, where gradation affects stability and permeability. The compaction tests show C1 (Figure 5) achieves a higher maximum dry density (MDD) of 2.03 g/cm³ at 11.3% optimum moisture content (OMC), while C2 (Figure 6) reaches 1.99 g/cm³ at 11.2% OMC. The marginal difference in OMC suggests similar water requirements for compaction, but C1's higher MDD implies better particle packing, likely due to its finer texture. Both curves peak sharply, indicating well-graded soils. The lower MDD of C2 may reflect its coarser composition, which could reduce shear strength but improve drainage. These findings guide field compaction practices, emphasizing the need for moisture control to achieve optimal density for load-bearing layers.

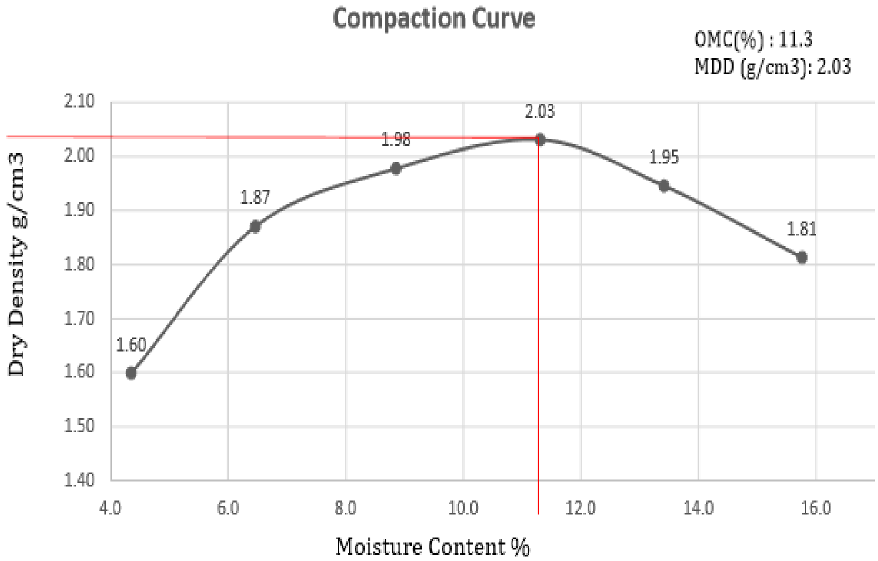

Figure 5: Compaction curve for sample C1

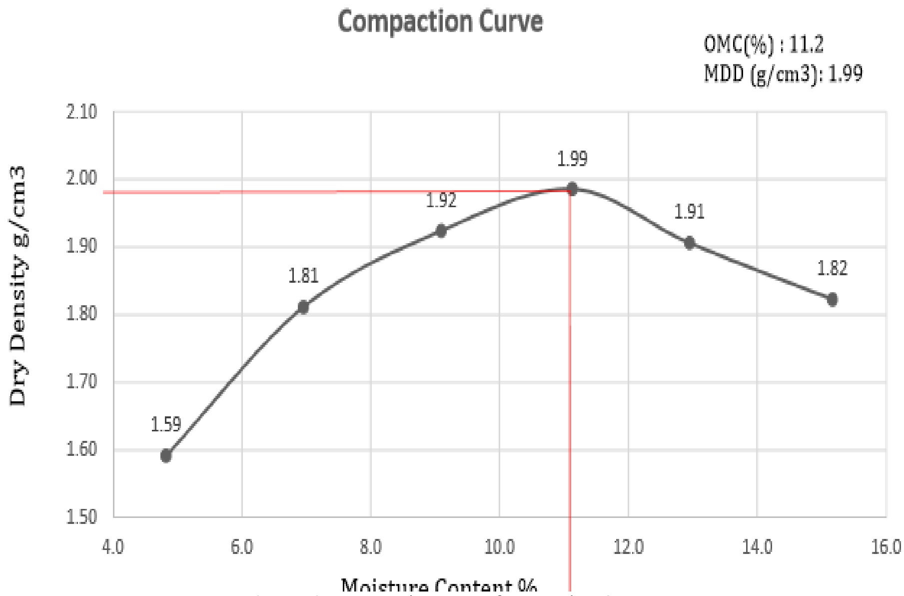

Figure 6: Compaction curve for sample C2

Sample C1 (Figure 7) exhibits higher plasticity (LL=29%, PI=14) than C2 (Figure 8) (LL=22.1%, PI=10), classifying C1 as more clayey and C2 as siltier. The lower plasticity of C2 suggests reduced shrink- swell potential, making it more stable under moisture variations. Both samples have low liquid limits (<30%), typical of subgrade materials, but C1's higher PI indicates greater cohesion, which may enhance strength but increase susceptibility to cracking. These results are crucial for predicting soil behaviour under wet conditions and selecting stabilization methods for road construction.

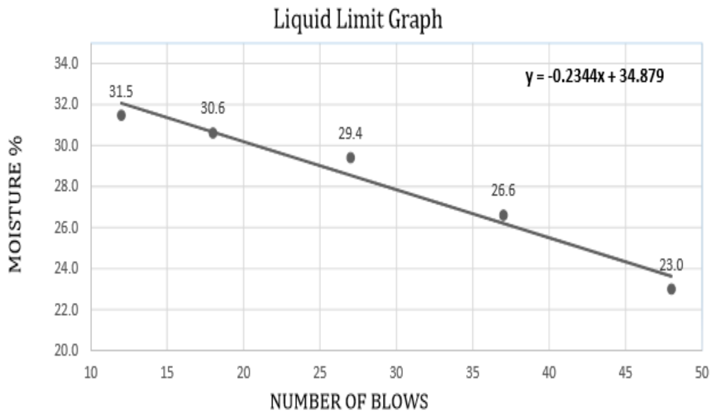

Figure 7: Liquid limit graph for sample C1

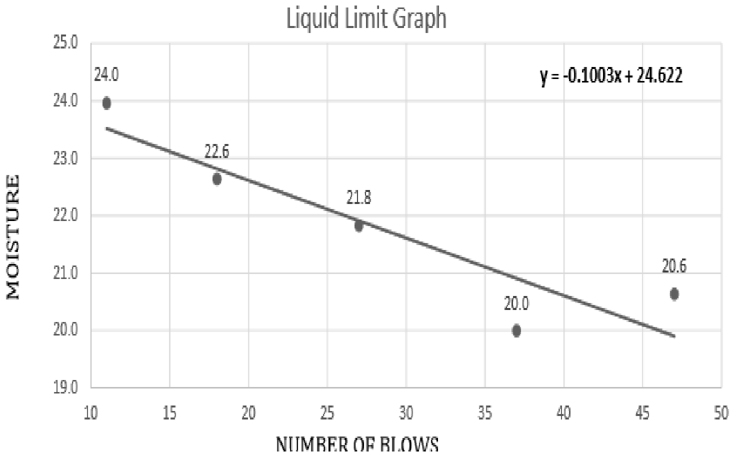

Figure 8: Liquid limit graph for sample C2

The California Bearing Ratio (CBR) tests reveal C2 outperforms C1 in both unsoaked and soaked conditions. For instance, C2's unsoakedCBR at 5.0mm penetration is 16.36% (bottom layer) versus C1's 15.03%. Notably, C2's soaked CBR (15.58%) shows minimal reduction from unsoaked values, indicating superior water resistance, while C1's soaked CBR drops significantly (13.62% to 7.55% for 2.5mm penetration). This underscores C2's better suitability for water-prone areas. The top layer results follow similar trends, reinforcing C2's reliability for pavement subgrades under varying moisture conditions.

Table 2: CBR Values Summary

Sample	Condition	CBR (2.5mm)	CBR (5.0mm)
C1	Unsoaked	11.09	15.03
C1	Soaked	7.55	13.62
C2	Unsoaked	12.39	16.36
C2	Soaked	12.39	15.58

Discussion

The laboratory test results for soil samples C1 and C2 provide critical insights into their suitability for road construction. These tests—specific gravity, sieve analysis, compaction, Atterberg limits, and California Bearing Ratio (CBR)—collectively define the geotechnical properties that influence subgrade stability, compaction efficiency, drainage, and long-term durability. The findings suggest that while both soils fall within acceptable ranges for road construction, C2 exhibits superior engineering properties, particularly in load-bearing capacity and moisture resistance. The specific gravity values for C1 (2.39) and C2 (2.60) indicate differences in mineral composition. A higher specific gravity, as seen in C2, typically suggests the presence of denser minerals such as quartz or iron oxides, which contribute to better shear strength and reduced void ratios. This property is crucial for road subgrades, as denser soils resist deformation under traffic loads more effectively. The consistency in C2's measurements (2.61 and 2.60) also implies sample homogeneity, whereas C1's slight variation (2.37 to 2.40) may indicate minor inconsistencies in particle distribution. For road construction, C2's higher density implies better compaction potential and reduced settlement risks. The sieve analysis classifies C1 as A-2-6 and C2 as A-2-4 under the AASHTO system. C1 has a higher percentage passing the 1.18mm sieve (93.1% vs. 87.25%), indicating a finer texture, while C2 shows better uniformity in mid-range particles (55.35% passing 0.425mm vs. 51.75% for C1). The near-identical fines content (~24% passing 0.075mm) suggests similar susceptibility to moisture, but C2's coarser fraction enhances drainage, reducing the risk of water retention and subsequent weakening. For road construction, C2's gradation is more favourable because it balances fines (for cohesion) and coarser particles (for permeability). Excessive fines, as in C1, can lead to poor drainage and higher plasticity, increasing the risk of swelling and shrinkage. The A-2 classification confirms both soils as suitable subgrade materials, but C2's A-2-4 designation (lower plasticity) makes it preferable for areas with fluctuating moisture conditions. The compaction tests reveal that C1 achieves a higher maximum dry density (MDD = 2.03 g/cm³) at an optimum moisture content (OMC = 11.3%), while C2 reaches a slightly lower MDD (1.99 g/cm³) at nearly the same OMC (11.2%). The marginal difference in OMC suggests similar water requirements for compaction, but C1's higher MDD indicates better particle packing due to its finer texture. However, C2's compaction curve shows a broader plateau near the peak, meaning it is less sensitive to minor variations in moisture. This is advantageous in field conditions where exact moisture control is challenging. C1's steeper curve implies stricter moisture control is needed to avoid under- or over-compaction. In practice, C2's behaviour reduces the risk of weak spots in the road base, making it more forgiving during construction. The Atterberg limits highlight key differences in soil behaviour under moisture changes. **C1** has a higher liquid limit (LL = 29%) and plasticity index (PI = 14) compared to C2 (LL = 22.1%, PI = 10), classifying C1 as more clayey and C2 as siltier with lower plasticity. High-plasticity soils like C1 are prone to significant volume changes—swelling when wet and shrinking when dry—which can lead to cracking and uneven settlement in pavements. C2's lower PI suggests greater stability under moisture variations, reducing maintenance needs. For road construction, C2's lower plasticity makes it a more reliable subgrade material, especially in regions with seasonal rainfall. The CBR test is a critical indicator of a soil's strength under traffic loads. C2 outperforms C1 in both soaked and unsoaked conditions. In the unsoaked state, C2's CBR (16.36% at 5.0mm penetration) is higher than C1's (15.03%), indicating better resistance to deformation. More importantly, C2's soaked CBR (15.58%) shows minimal reduction from its unsoaked value, whereas C1's soaked CBR drops sharply (13.62% to 7.55% at 2.5mm penetration). This resilience to water is crucial for road longevity, as subgrades often experience moisture infiltration. C2's superior soaked CBR implies it will maintain structural integrity even in wet conditions, reducing the risk of potholes and rutting. C1's significant strength loss when saturated suggests it may require stabilization (e.g., lime or cement treatment) if used in high-moisture environments.

VI. Conclusion

The comprehensive geotechnical evaluation of soil samples C1 and C2 provides critical insights into their suitability for road construction, highlighting key differences in their engineering properties and long-term performance. The laboratory tests—specific gravity, sieve analysis, compaction characteristics, Atterberg limits, and California Bearing Ratio (CBR)—collectively paint a clear picture of how these soils will behave under the stresses imposed by traffic loads, environmental conditions, and moisture fluctuations. The findings underscore the importance of selecting the right soil type to ensure structural integrity, minimize maintenance costs, and enhance the durability of road infrastructure. C2 emerges as the superior material for road construction due to its favourable geotechnical properties. Its higher specific gravity (2.60) suggests a denser mineral composition, which translates to better load-bearing capacity and reduced susceptibility to settlement. The sieve analysis further supports this advantage, revealing a well-graded particle distribution that balances cohesion and permeability. With 55.35% of particles passing the 0.425mm sieve and only 23.8% fines, C2 offers optimal drainage characteristics, reducing the risk of water retention that could weaken the subgrade over time. This is particularly crucial in regions prone to heavy rainfall or seasonal moisture variations, where poor drainage can lead to premature pavement failure. The compaction test results reinforce C2's practicality in field applications. While it achieves a slightly lower maximum dry density (1.99 g/cm³) compared to C1 (2.03 g/cm³), its broader compaction curve indicates greater flexibility in moisture control during construction. This is a significant advantage in real-world scenarios, where maintaining exact moisture levels can be challenging. C1's steeper curve, on the other hand, demands stricter quality control, increasing the risk of under- or over-compaction if conditions deviate even slightly from the optimum. The reduced sensitivity of C2 to moisture variations makes it a more forgiving and cost-effective choice for large-scale projects. The Atterberg limits further differentiate the two soils, with C2's lower plasticity index (PI = 10) indicating reduced susceptibility to volume changes under wet and dry cycles. In contrast, C1's higher PI (14) suggests a greater tendency for swelling and shrinkage, which can lead to cracking and uneven settlement in pavement layers. For engineers, this means that while C1 may provide adequate short-term performance, C2 offers long-term stability with fewer maintenance demands. This distinction is particularly important in climates with significant seasonal weather changes, where expansive soils can cause recurrent damage to road surfaces. The CBR test results deliver perhaps the most compelling evidence of C2's superiority. Its higher unsoakedCBR (16.36%) compared to C1 (15.03%) confirms better resistance to deformation under load. More critically, C2's soaked CBR (15.58%) shows minimal reduction from its unsoaked value, demonstrating remarkable resilience to water infiltration. C1, however, suffers a drastic drop in strength when saturated (from 13.62% to 7.55%), highlighting its vulnerability to moisture. This stark contrast underscores the risks of using C1 in areas with high groundwater levels or poor drainage, where prolonged exposure to water could compromise the entire pavement structure. From a practical standpoint, the choice between these soils hinges on both engineering and economic considerations. C2's inherent strengths—superior drainage, lower plasticity, and consistent load-bearing capacity—make it the preferred material for subgrade and base layers, particularly in high-traffic or moisture-prone areas. Its use would likely reduce the need for costly stabilization techniques and extend the service life of the road. C1, while usable, would require additional measures such as chemical stabilization or improved drainage systems to mitigate its limitations. These interventions add to construction costs and complexity, making C2 a more sustainable option in the long run. In conclusion, the geotechnical characterization of C1 and C2 reaffirms a fundamental principle in road construction: the importance of selecting materials that align with both environmental conditions and performance requirements. C2's balanced properties—gradation, density, plasticity, and moisture resistance—make it an ideal choice for durable, low-maintenance roads. By contrast, C1's higher plasticity and moisture sensitivity necessitate careful engineering interventions to ensure comparable performance. These findings not only guide material selection for this specific project but also emphasize the value of thorough soil testing in achieving cost-effective and resilient infrastructure. Ultimately, investing in the right soil at the construction phase pays dividends in reduced maintenance and enhanced road longevity, benefiting both builders and end-users alike.

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