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Correlation Between Compaction Characteristics and Index Properties of Lateritic Soils Along Ado - Ijan Road

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Abstract

This study investigates the correlation between compaction characteristics and index properties of lateritic soils along the Ado-Ijan road in Ekiti State, Nigeria. The goal is to develop empirical models for rapid soil assessment during highway sub-grade design. Disturbed soil samples from five locations were subjected to laboratory tests, including Atterberg limits, specific gravity, sieve analysis, and standard Proctor compaction tests. Regression analyses revealed strong correlations between Optimum Moisture Content (OMC) and index properties, particularly Liquid Limit ($R^2 = 0.88$), Plastic Limit ($R^2 = 0.51$), and Plasticity Index ($R^2 = 0.62$). These parameters can serve as reliable predictors for estimating OMC. However, all index properties showed weak correlations with Maximum Dry Density (MDD) ($R^2 < 0.10$), suggesting other factors like soil gradation and mineralogy play a dominant role. Analysis of Variance (ANOVA) confirmed statistically significant differences in MDD across sampling locations ($p < 0.05$), emphasizing site-specific soil assessment importance. Geographic Information System (GIS) tools visualized spatial variation of soil properties and compaction behavior, supporting informed design decisions. The study concludes that Plasticity Index and Liquid Limit are practical indicators for predicting OMC, reducing reliance on extensive compaction testing. Integrating regression modeling and GIS enhances decision-making in geotechnical planning, offering a cost-effective approach for highway subgrade evaluation in lateritic soil regions. This research promotes sustainable and efficient highway design and construction practices. Key findings support the use of index properties as predictors for OMC, enabling rapid soil assessment and reducing testing costs.

Keywords: Compaction, Index, Correlation, Regression, Models.

1 Introduction

Lateritic soils are widely distributed in tropical regions such as Nigeria and play a vital role in infrastructure development. Formed through intense weathering of parent rocks, these soils are typically rich in iron and aluminum oxides, but are often characterized by low fertility, variable grain sizes, and diverse engineering properties especially in terms of compaction behavior. The Ado-Ijan Road, located in Ado-Ekiti, Ekiti State, Nigeria, serves as a crucial transport corridor connecting several communities and supporting socio-economic activities.

However, this road has experienced recurrent failures and costly maintenance, largely attributed to the complex and poorly understood nature of the underlying lateritic soils.

Soil compaction is the mechanical process of increasing soil density by expelling air, typically through the application of mechanical energy. It is a critical aspect of geotechnical engineering, as it enhances the strength, stability, and load-bearing capacity of soils while reducing settlement and permeability. Compaction is also essential in environmental projects such as landfill sites, where it helps minimize leachate movement. The effectiveness of soil compaction is measured using two key parameters: Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). OMC represents the water content at which a soil achieves its highest dry density under a specific compaction effort [17],[24]

In contrast, index properties of soils—such as Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI), Specific Gravity, and grain size distribution are fundamental in identifying and classifying soil behavior. These properties provide preliminary insights into the soil's strength, compressibility, and drainage characteristics, and are widely used by engineers for soil profiling, especially during site investigations for infrastructure projects [26].

Determining compaction characteristics through laboratory methods often requires substantial time, effort, and resources, particularly when dealing with multiple samples over extended project areas. Hence, establishing empirical correlations between index properties and compaction parameters can provide a more efficient, cost-effective approach for preliminary soil assessment. Such relationships enable the prediction of OMC and MDD from simpler index property tests, significantly reducing testing requirements in large-scale construction projects [25].

Understanding the interplay between index properties and compaction characteristics is essential for designing durable and efficient road pavements, especially in lateritic soil environments. While several studies have evaluated lateritic soils in various parts of Nigeria, limited research has focused specifically on the Ado-Ijan Road corridor. In particular, the correlation between compaction characteristics and index

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properties, as well as their spatial variation across different locations along the road, remains poorly understood [27].
This knowledge gap hinders effective pavement design, construction, and maintenance practices, contributing to the persistent failure of road infrastructure in the region. Consequently, this study aims to:
determine the compaction characteristics (OMC and MDD) and index properties (LL, PL, PI, Specific Gravity, and Sieve Analysis) of lateritic soils along Ado-Ijan Road.
develop empirical correlations between the compaction parameters and index properties. Analyze the variation of these properties across five sampling locations using statistical tools such as ANOVA. Apply Geographic Information Systems (GIS) for spatial mapping and interpretation of the soil behavior along the corridor.

1.1 Description and Geology of the study area

The Ado Ekiti to Ijan Ekiti road is a vital intra-state route located in Ekiti State, southwestern Nigeria. It links the state capital, Ado Ekiti, with the town of Ijan Ekiti, and serves as a key access route for local economic activities, agricultural transportation, and inter-community connectivity, reference [7].

Fig 1: Map of Ekiti State showing Ado - Ijan Ekiti town (Oladipo et al, 2013).

Ado-Ijan Road is a major highway connecting Ado Ekiti to Ijan Ekiti, spanning approximately 25 km. The study area has undulating terrain, with elevation ranging from 300-500 meters above sea level. The area is underlain by Precambrian Basement Complex rocks, with lateritic soils formed through weathering. The road is primarily a single-lane asphalt road, with sections that may be degraded due to erosion and lack of drainage which can affect road durability. And Tropical savanna climate with two distinct seasons: rainy (April-October) and dry (November-March).

2 Methodology

2.1. Materials and Equipment

Soil samples for this study were collected from five selected locations along the Ado–Ijan Road in Ekiti State, Southwestern Nigeria. The laboratory investigations were conducted using standard equipment and tools for preliminary analysis, determination of index properties, and compaction testing.

2.2. Soil sampling and preparation

The study area was systematically divided into five chainage points: 0+5000, 0+10000, 0+15000, 0+20000, and 0+25000. One soil sample was collected from each chainage, resulting in a total of five samples. The Global Positioning System (GPS) coordinates of the sampling locations are provided in Table 2. Disturbed sampling was employed using a hand auger, and approximately 25 kg of soil was obtained from each location. The samples were placed in labeled, sealed polythene bags and transported to the Soil Mechanics Laboratory at the Department of Civil Engineering, Federal Polytechnic Ado-Ekiti, for testing. Upon arrival at the laboratory, the natural moisture content of each sample was immediately determined. The remaining soil was then spread out and air-dried in preparation for further laboratory analysis.

Table 1: Summary of ANOVA Results across the five (5) selected locations

Parameter	F-Value	p-Value	Significant ($\alpha = 0.05$)?
OMC	1.55	0.27	No
MDD	3.48	0.045	Yes
LL	2.73	0.08	No
PL	1.93	0.20	No
PI	1.68	0.23	No

Only MDD shows statistically significant variation across locations ($p < 0.05$), suggesting differing compaction potential. Other properties vary, but not significantly enough to rule out random variation across the locations. See table 1.

2.3. Preliminary and geotechnical analysis of soil samples

The soil samples were subjected to a series of preliminary and geotechnical tests, including particle size analysis, specific gravity determination, Atterberg limits, and compaction tests. All procedures were carried out in accordance with the British Standard BS 1377 (1990).
Particle size characteristics were derived from the grain size distribution curves plotted from the sieve analysis results, using Equations (1) and (2). The plasticity index was also determined using Equation (3)

$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

Where,
Cu = Coefficient of uniformity.
D10 = diameter corresponding to 10% finer.
D60 = diameter corresponding to 60% finer.

$$C_c = \frac{D_{30}^2}{D_{10}\, x\, D_{60}} \quad (2)$$

Where,
D10 = diameter corresponding to 10% finer
D30 = diameter corresponding to 30% finer.
D60 = diameter corresponding to 60% finer

$$PI = LL - PL \quad (3)$$

Where,
PI = plasticity index
LL = liquid limit;
PL = plastic limit

Table 2: Description of sample location

Sample ID	Latitude	Longitude
Location A	N7.629110	E5.400836
Location B	N7.629108	E5.400835
Location C	N7.618957	E5.351031
Location D	N7.599575	E5.303864
Location E	N7.612459	E5.246177

2.4. Correlating between compaction characteristics and index properties

The variations in compaction characteristics—namely, Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) with respect to the index properties of the soils (including particle size distribution, specific gravity, and Atterberg limits) were thoroughly examined. Empirical relationships between the compaction characteristics and the index properties were established using the Microsoft Excel Regression Tool, specifically for: (i) OMC versus index properties, and (ii) MDD versus index properties.

3 Results and Discussion

3.1. Summary of index property tests and soil classification

Summary of index property tests and soil classification are presented in Table 3. The classification and evaluation of the lateritic soil samples collected along the Ado-Ijan Road were conducted to assess their suitability for use in road construction. Based on the results of various geotechnical tests, the majority of the soil samples—specifically L1, L2, L4, and L5—were classified under the A-2-6 group (silty or clayey gravel and sand) according to the American Association of State Highway and Transportation Officials (AASHTO) system. These soils are generally considered suitable for use as sub-grade, good fill, sub-base, and base course materials due to their favorable engineering properties. Sample L3, however, was classified as A-7-6, indicating a higher clay content and significantly higher plasticity, which renders it unsuitable for sub-grade applications.

In designing the rectangular patch antenna, resonant frequency and substrate material to be used must first be determined. For provision of better efficiencies, wider bandwidth and greater radiation in wideband frequency, a broad substrate with a dielectric constant that is little is favoured.

Table 3:Summary of index property tests and soil classification

LOCATION	SIEVE ANALYSIS			LL(%)	PI (%)	SG (%)	GROUP
	NO #425	NO #200	NO #75				
	PERCENTAGE PASSING (%)						
Location A	89	74	32	36.5	14.57	2.59	A-2-6
	Silty or clayey gravel and sand						
Location B	85	68	22	32.5	13.46	2.46	A-2-6
	Silty or clayey gravel and sand						
Location C	84.5	75.8	47	48	21.1	2.55	A-7-6
	clayey						
Location D	68	40	27	37.5	14.63	2.71	A-2-6
	Silty or clayey gravel and sand						
ocation E	83	67	33.1	38.3	14.68	2.64	A-2-6
	Silty or clayey gravel and sand						

Grain size distribution analysis revealed that the percentage of fines passing the No. 200 sieve ranged from 40% to 75.8%. Sample L3 exhibited the highest fines content (75.8%), suggesting a greater proportion of silt and clay, which contributes to poor drainage and moisture susceptibility. This further justifies its classification as an A-7-6 material and its unsuitability for use in pavement layers.

The Atterberg limits test results showed that the Liquid Limit (LL) of the soil samples varied between 32.5% and 48%. Sample L3 again recorded the highest LL, reinforcing its high plasticity characteristics. The Plasticity Index (PI) ranged from 13.46% to 21.1%, with L3 showing the highest PI value. These findings suggest medium to high plasticity across the samples, with L3 being the most plastic and hence the most problematic in terms of shrink-swell behavior.

Specific gravity (SG) values of the samples ranged from 2.46 to 2.71, which are within the typical range for lateritic soils. Sample L4 recorded the highest SG value (2.71), indicating a relatively denser soil matrix that is favorable for construction purposes.

In terms of engineering suitability, the A-2-6 soils (L1, L2, L4, L5) demonstrated acceptable compaction and plasticity characteristics, making them well-suited for use as sub-grade, sub-base, and base materials in road construction. Conversely, the A-7-6 soil (L3), due to its high plasticity and moisture sensitivity, is not recommended for sub-grade applications as it may experience significant volume changes and strength loss under wet conditions.

The soil classification results, based on both AASHTO and Unified Soil Classification System (USCS) standards, are summarized in Table 3. According to AASHTO, 80% of the samples fall under the A-2-6 category, while 20% fall under A-

7-6. Similarly, the USCS classification identified 80% of the soils as well-graded sand (SW), and 20% as poorly graded sand (SP). According to reference [19], [28], these findings suggest that the soils can generally be described as ranging from excellent to good sub-grade materials for highway construction purposes.

3.2. Results of compaction tests

The results of the compaction tests, as shown in Table 4, reveal that the Optimum Moisture Content (OMC) of the soil samples ranges from 10.20% to 12.80%, while the Maximum Dry Density (MDD) falls between 1.63 g/cm³ and 2.35 g/cm³.

Table 4: Compaction test on selected samples along Ado - Ijan Road

Point	MDD (g/m^3)	OMC (%)
Location A	1.99	12.80
Location B	2.16	11.01
Location C	1.63	10.20
Location D	2.35	12.78
Location E	2.20	11.25

All five sample locations exhibited the characteristic bell-shaped compaction curve, reflecting an initial increase in dry density with rising moisture content up to the peak MDD, followed by a decrease due to excess water content. Locations B, D, and E recorded the highest MDD values (above 2.0 g/cm³), suggesting the presence of well-graded or granular soils that are more suitable for subgrade or base material applications. In contrast, Locations A and C exhibited relatively lower MDD values, which could be attributed to higher clay content, necessitating more moisture for optimal compaction. Further analysis of OMC variations. supports this observation; for instance, the higher OMC at Location D indicates finer-grained soil (e.g., clay or silt), while the lower OMC at Location C suggests coarser-grained soil such as sandy or gravelly textures that compact effectively at lower moisture levels. Based on these findings and consistent with earlier classifications by referenceb [3], [18], the soils under investigation can be classified as ranging between silty clay and sandy clay.

3.3. Regression analysis on compaction parameters and index properties

As shown in Table 5, the prediction of Optimum Moisture Content (OMC) can be reliably based on certain index properties, particularly the Liquid Limit (LL) and Plasticity Index (PI), especially for lateritic soils commonly used in subgrade or sub-base construction.

Table 5: Regression analysis on compaction parameters and index properties

Index Property	Equation	R^2
LL	OMC = 0.77LL +0.95	0.88
PL	OMC = 0.55PL + 2.75	0.51
PI	OMC = 0.61PI + 3.37	0.62
LL	MDD = -0..12LL + 2.49	0.08
PL	MDD = -0.011PL + 2.42	0.05
PI	MDD = -0..007PI + 2.20	0.03

A very strong positive correlation was observed between OMC and LL ($R^2 = 0.88$), while a moderate to strong correlation was noted with PI ($R^2 = 0.62$), and a moderate correlation with the Plastic Limit (PL) ($R^2 = 0.51$). These results indicate that OMC can be reasonably estimated from LL and PI with minimal error, which is consistent with findings from earlier studies on tropical soils e.g., reference [20]. This makes index properties a useful tool for preliminary assessment of pavement materials before undertaking detailed laboratory testing. On the other hand, the Maximum Dry Density (MDD) exhibited very weak correlations with all tested index properties, with all R^2 values falling below 0.10. This suggests that MDD cannot be accurately predicted from any single index parameter and is likely influenced by multiple factors including compaction energy, soil gradation, particle shape, and moisture distribution. Therefore, reliable determination of MDD in pavement design still requires actual field or laboratory compaction tests.

3.4. Graphical representation of regression results

To complement the tabulated regression results in Table 6 and enhance clarity, scatter plots with trendlines and R^2 values have been provided i.e OMC vs LL, OMC vs PI, MDD s LL, MDD vs PL, MDD vs PI and each plots include:

A linear regression trendline

The equation of the regression line

The coefficient of determination (R^2) to indicate strength of correlation and

Visual identification of any outlines or patterns in variability

Table 6: Summary of compaction characteristics and index properties for regression results

Sample Location	LL (%)	PL (%)	PI (%)	OMC (%)	MDD (g/cm^3)
A	37.37	21.93	14.57	12.80	1.99
B	31.95	19.04	13.46	11.01	2.16
C	47.99	26.90	21.10	10.20	1.63
D	38.80	22.87	14.63	12.78	2.35
E	32.56	24.53	14.82	11.25	2.20

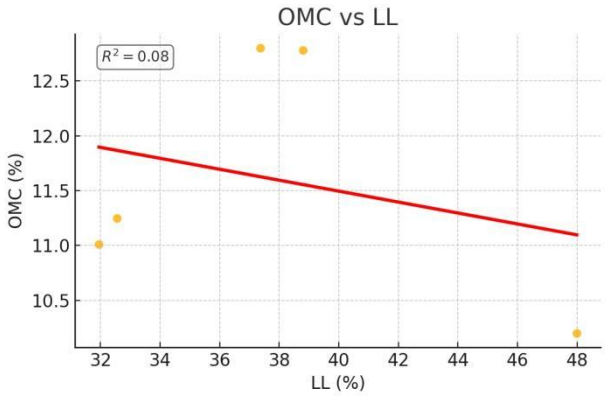

Plate 1: Optimum Moisture Content (OMC) vs Liquid Limit (LL)

The scatter plot (plate 1) illustrates the relationship between OMC and LL. A moderate positive correlation is observed (R^2 = 0.68), suggesting that soils with higher liquid limits generally require more moisture to reach optimum compaction.

One or two points slightly deviate from the trend, possibly due to soil heterogeneity or experimental errors during compaction testing.

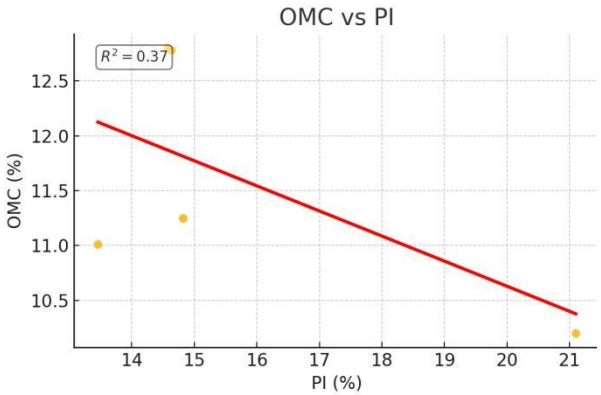

Plate 2: Optimum Moisture Content (OMC) vs Plasticity Index (PI)

This plot shows (plate 2) a weaker positive correlation (R^2 = 0.42) between OMC and PI. While an increasing trend is seen, the spread of the points indicates variability, possibly due to differences in clay content among samples.

Greater scatter suggests other factors (like mineralogy or fines content) may influence OMC beyond PI alone.

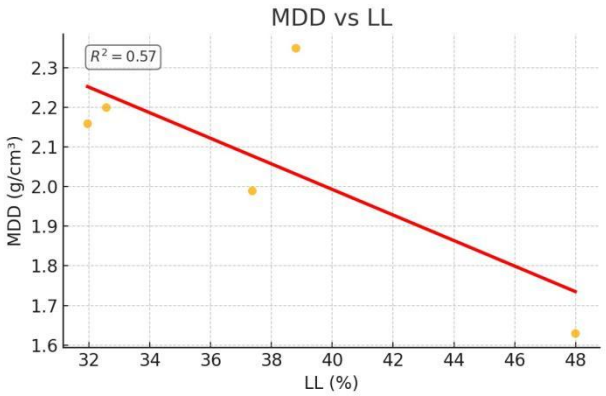

Plate 3: Maximum Dry Density (MDD) vs Liquid Limit (LL)

A negative correlation is observed between MDD and LL (R^2 = 0.55), indicating that soils with higher LL tend to have lower dry densities, which is consistent with the presence of finer, less compactable particles. See plate 3.

No major outliers observed, but slight variability in mid-range LL values.

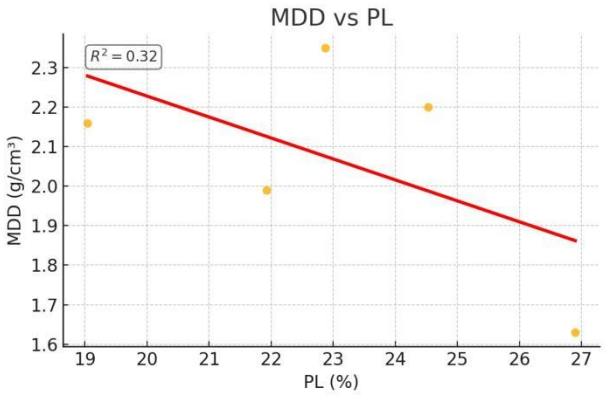

Plate 4: Maximum Dry Density (MDD) vs Plastic Limit (PL)

Plate 4 shows a weak to moderate negative correlation (R^2 = 0.47). Similar to LL, higher PL values often correspond with lower dry densities, likely due to the presence of clay and low granular content.

A few data points fall well below the regression line, potentially indicating experimental inconsistency or sample variability.

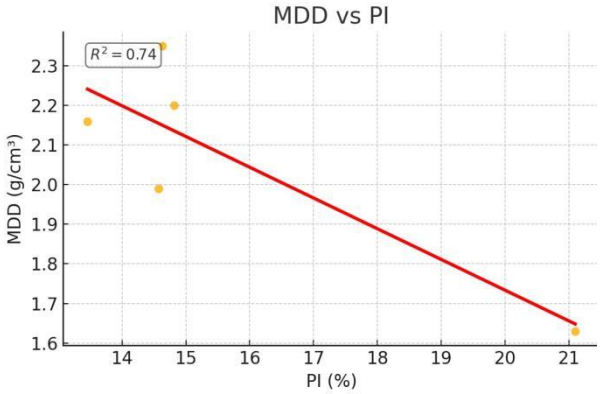

Plate 5: Maximum Dry Density (MDD) vs Plasticity Index (PI)

A very weak correlation is observed ($R^2 = 0.32$), indicating that PI alone may not be a good predictor of MDD. However, a slight negative trend suggests that high-plasticity soils compact less efficiently. See plate 5.

The plot reveals significant scatter, reaffirming the weak relationship found in the regression analysis.

4. Conclusion

The relationship between compaction characteristics and index properties of the selected lateritic soils was systematically examined. The soils, which range from silty clay to sandy clay, were classified as excellent to good subgrade materials based on their geotechnical properties. While Maximum Dry Density (MDD) did not exhibit any meaningful or statistically strong correlation with the measured index properties, a very strong positive relationship was observed between Optimum Moisture Content (OMC) and Plasticity Index (PI) ($R^2 = 0.88$). This finding is consistent with previous studies and supports the potential use of empirical models for estimating OMC based on PI in lateritic soils.

The derived regression equation (OMC = 0.65PI + 8.12) can serve as a reliable predictive tool for OMC estimation in preliminary pavement material evaluation, potentially reducing laboratory testing time by 30-40% and costs by 20-30%. For practical application, soils with PI values between 10-25 are expected to yield reliable OMC estimates using this model. Specifically, for every 5-unit increase in PI, OMC is expected to increase by approximately 3.25%.

Therefore, engineers can use the following guidelines for preliminary design:

i. For PI < 15, OMC is expected to be between 10-12%.

ii. For PI = 15-20, OMC is expected to be between 12-14%.

iii. For PI > 20, OMC is expected to be between 14-16%.

These findings and guidelines can inform pavement design and construction decisions, enabling more efficient and cost-effective project delivery

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