

Shrink–Swell Potential of Lateritic Soils in Ibadan Metropolis

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ABSTRACT: Volumetric instability of lateritic subgrade soils can adversely affect pavement performance in tropical environments where seasonal wetting and drying are pronounced. This study evaluated the shrink–swell potential of lateritic soils across the eleven Local Government Areas (LGAs) of Ibadan Metropolis, Southwestern Nigeria, with emphasis on the role of the silty–clay/fines fraction. Thirty-three samples, representing three sampling locations per LGA, were obtained from the shallow active subgrade zone at depths of approximately Atterberg limits, Linear Shrinkage (LS) and Free Swell Index (FSI) tests. The percentage passing the 0.075 mm sieve ($P_{0.075}$) ranged from 20.8% to 39.5%, Liquid Limit from 28.1% to 48.5%, Plasticity Index from 10.6% to 23.3%, and specific gravity from 2.58 to 2.76. Linear Shrinkage ranged from 5.74% to 16.13%, while FSI ranged from 14.1% to 36.3%. Strong positive relationships were obtained between $P_{0.075}$ and FSI ($r = 0.915$), $P_{0.075}$ and LS ($r = 0.781$), and PI and FSI ($r = 0.982$). The PI–FSI regression, ($FSI = 1.68PI$) placed most samples in AASHTO A-2-6 and USCS SC, while Ido and Oluyole contained the A-7-6/SC soils with the highest fines and volumetric responses. Three broad Shrink–swell hazard zones were identified: low Shrink–swell hazard in Ona-Ara and Egbeda, moderate Shrink–swell hazard in Akinyele, Lagelu and the five urban-core LGAs, and high hazard in Ido and Oluyole. Only four of the 33 samples (12.1%) satisfied the adopted 8% Linear Shrinkage criterion. The findings support location-specific subgrade investigation, moisture control, drainage and stabilisation rather than a uniform treatment strategy across Ibadan.

KEYWORDS: Lateritic Soil, Shrink-swell potential, Plasticity index, Linear shrinkage, Soil stabilization.

1. INTRODUCTION

Lateritic soils form extensive residual soil mantles in tropical and subtropical regions and constitute important construction materials in Nigeria. In Southwestern Nigeria, lateritisation is associated with intense chemical weathering of Precambrian Basement Complex rocks, accompanied by silica leaching and accumulation of iron and aluminium sesquioxides (Gidigas, 1976; Ola, 1983). Although lateritic soils may provide satisfactory engineering performance under suitable conditions, their properties are not uniform. Variations in particle-size distribution, plasticity, degree of weathering and soil structure can result in substantial differences in moisture sensitivity and volume change. Ibadan experiences a tropical wet-and-dry climate, with seasonal changes in moisture conditions that can influence the behaviour of moisture-sensitive soil horizons. Repeated wetting and drying may cause contraction and expansion, potentially contributing to cracking, heaving, rutting and differential movement of pavements and shallow structures. The fine-grained component is particularly important because of its relatively large surface area and interaction with water. Previous studies on Nigerian lateritic soils have largely focused on strength, compaction and general engineering classification, while quantitative assessment of shrink–swell behaviour across the wider Ibadan Metropolis remains relatively limited. The present study therefore investigates the geotechnical and volumetric characteristics of lateritic soils from the eleven LGAs of Ibadan Metropolis. Particular attention is given to the

percentage passing the 0.075 mm sieve ($P_{0.075}$), adopted in this study as the fines/silty–clay fraction, and its relationships with Plasticity Index (PI), Linear Shrinkage (LS) and Free Swell Index (FSI). The study also examines the spatial distribution of shrink–swell potential and evaluates the engineering implications of the findings for road subgrade assessment and location-specific soil improvement.

2. MATERIALS AND METHODS

2.1 Study Area

The study covers Ibadan Metropolis in Oyo State, Southwestern Nigeria, approximately between latitudes 7°20'N and 7°40'N and longitudes 3°45'E and 4°05'E. The metropolis comprises five urban-core LGAs, namely Ibadan North, Ibadan North-East, Ibadan North-West, Ibadan South-East and Ibadan South-West, together with six outer LGAs: Akinyele, Lagelu, Ona-Ara, Egbeda, Oluyole and Ido. The area is underlain predominantly by Precambrian Basement Complex rocks and is characterised by variable topography, weathering profiles and drainage conditions. These factors contribute to spatial differences in the engineering properties of residual soils across the metropolis.

2.2 Sampling

Three representative sampling locations were investigated in each of the eleven LGAs, giving a total of 33 soil samples. Samples were collected from approximately 0.5–1.5 m below

natural ground level, corresponding to the shallow active zone considered relevant to pavement and shallow foundation performance. The samples were properly identified, packaged and transported to the laboratory for testing. Laboratory procedures followed the relevant provisions of BS 1377 (British Standards Institution, 1990), supplemented where applicable by standard geotechnical testing practice.

2.3 Laboratory Testing

The laboratory investigation comprised natural moisture content, particle-size distribution, specific gravity, Atterberg limits, Linear Shrinkage and Free Swell Index tests. Particle-size distribution was used to determine the percentage passing the 0.075 mm sieve ($P_{0.075}$). In this study, $P_{0.075}$ was adopted as the fines/silty-clay fraction for the statistical assessment. The Free Swell Index was determined by placing 200 mL of oven-dried soil in a graduated vessel, adding distilled water and allowing the sample to reach equilibrium for 24 hours. Linear Shrinkage was determined from the reduction in length of the soil bar after drying.

2.4 Soil Classification

The investigated soils were classified using the AASHTO and Unified Soil Classification System (USCS) methods. The classifications were subsequently related to the measured index and volumetric properties to assess their potential engineering behaviour.

2.5 Statistical Analysis

Descriptive statistics were used to summarise the measured properties. Pearson product-moment correlation was employed to evaluate the relationships among $P_{0.075}$, PI, specific gravity, LS and FSI. Simple and multiple ordinary least-squares regression models were developed to estimate LS and FSI from PI and $P_{0.075}$. Model performance was evaluated using the coefficient of determination (R^2), adjusted R^2 , significance tests, root mean square error (RMSE) and mean absolute error (MAE). The regression relationship was expressed generally from Eq 1:

$$Y = a + bX \quad \text{Eq (1)}$$

where Y is the dependent variable, X is the predictor variable, a is the intercept, and b is the regression coefficient. The combined results of the index properties, shrink–swell parameters and classification were used to identify broad volumetric hazard zones within the study area.

3. RESULTS AND DISCUSSION

3.1 Geotechnical Characteristics

The investigated lateritic soils exhibited appreciable spatial variability across Ibadan Metropolis. The percentage passing the 0.075 mm sieve ranged from 20.8% to 39.5%, indicating considerable variation in the amount of fine material. Liquid Limit ranged from 28.1% to 48.5%, Plasticity Index from 10.6% to 23.3%, and specific gravity from 2.58 to 2.76. The lower plasticity values occurred mainly in Ona-Ara and Egbeda, whereas the highest values were observed in Ido and Oluyole. This spatial variation indicates that the lateritic soils within the

metropolis should not be treated as a homogeneous material for geotechnical assessment, as shown in Table 1.

Table 1. Range of principal geotechnical and volumetric properties (N = 33).

Parameter	Minimum	Maximum	Engineering significance
$P_{0.075}$ (%)	20.8	39.5	Fine fraction and moisture sensitivity
Liquid Limit (%)	28.1	48.5	Consistency and moisture sensitivity
Plasticity Index (%)	10.6	23.3	Plasticity and volume-change indicator
Specific Gravity	2.58	2.76	Soil-solid/weathering indicator
Linear Shrinkage (%)	5.74	16.13	Shrinkage potential
Free Swell Index (%)	14.1	36.3	Relative swelling response

3.2 Shrink–Swell Behaviour

Linear Shrinkage values ranged from 5.74% to 16.13%, demonstrating substantial differences in contraction potential among the sampled soils. Free Swell Index values ranged from 14.1% to 36.3%. The highest FSI values were recorded in Ido and Oluyole, whereas Ona-Ara and Egbeda generally recorded the lowest values. The results indicate that soils containing higher proportions of fines and exhibiting greater plasticity tend to experience greater moisture-induced volume change. This behaviour is consistent with the greater water sensitivity generally associated with fine-grained soil fractions. The relationship between PI and FSI was particularly strong, with a Pearson correlation coefficient of $r = 0.982$. This indicates a close association between the plasticity characteristics of the investigated soils and their swelling response. $P_{0.075}$ also correlated strongly with FSI ($r = 0.915$) and LS ($r = 0.781$). These relationships demonstrate the importance of the fines/silty-clay fraction as a screening parameter, although its influence should be interpreted together with plasticity characteristics.

3.3 Correlation and Regression Analysis

Five regression models were developed to examine the relationships between the principal index and volumetric properties. The most useful single-variable model for FSI was: $FSI (\%) = 1.638PI -$

2.583. The model produced $R^2 = 0.964$ and adjusted $R^2 = 0.963$, indicating that PI accounted for 96.4% of the observed

variation in FSI within the investigated dataset. The corresponding model based on $P_{0.075}$ was:

$$FSI (\%) = 0.986P_{0.075} - 6.412$$

with $R^2 = 0.837$. Thus, $P_{0.075}$ alone explained 83.7% of the observed variation in FSI. For Linear Shrinkage, the regression models were:

$$LS (\%) = 0.442PI +$$

$$2.781 \text{ with } R^2 = 0.584, \text{ and:}$$

$$LS (\%) = 0.284P_{0.075} + 1.258$$

with $R^2 = 0.610$. A multiple regression model for FSI was also developed:

$$FSI (\%) = 1.412PI +$$

$$0.185P_{0.075} - 3.104.$$

The model produced $RMSE = 0.98\%$ and $MAE = 0.76\%$, representing the lowest prediction errors among the reported FSI models. The principal PI-based relationships were statistically significant at the 5% level ($p < 0.0001$). For the multiple FSI model, PI remained statistically significant ($p < 0.0001$), while the additional contribution of $P_{0.075}$ was marginal at the 5% significance level ($p = 0.0508$). Residual diagnostics for the principal PI–FSI model indicated no significant departure from normality based on the Shapiro–Wilk test ($p = 0.582$), while the Breusch–Pagan test indicated no significant evidence of heteroscedasticity ($p = 0.285$). These results suggest that PI is the strongest single predictor of FSI within the range represented by the sampled soils. However, $P_{0.075}$ remains a useful supporting indicator because of its strong relationship with both PI and the measured volumetric parameters, as shown in Table 2.

Table 2. Selected Pearson correlation coefficients for the 33 investigated soils.

Variable pair	Pearson r	Interpretation
$P_{0.075} - PI$	0.942	Very strong positive
$P_{0.075} - FSI$	0.915	Strong positive
$P_{0.075} - LS$	0.781	Strong positive
$PI - FSI$	0.982	Very strong positive
$PI - LS$	0.764	Strong positive
$G_s - FSI$	-0.871	Strong negative

3.4 Soil Classification

Under the AASHTO classification system, the samples were mainly classified as A-2-4, A-2-6 and A-7-6, while the USCS classifications were predominantly SC and SW-SC. The A-2-4/SW-SC soils occurred mainly in Egbeda and Ona-Ara and were associated with lower fines and plasticity values. The largest classification group comprised A-2-6/SC soils, representing 21 of the 33 samples (63.6%). Six samples (18.2%) from Ido and Oluyole were classified as A-7-6/SC and had $P_{0.075}$ values of 36.1–39.5%, Liquid Limits of 45.8–48.5% and Plasticity Indices of 21.9–23.3%. The occurrence of A-7-6/SC

soils in Ido and Oluyole corresponds with the higher shrink–swell responses observed in these areas and reinforces the need for detailed site-specific assessment before the use of such soils in pavement construction.

3.5 Volumetric Shrink–Swell Hazard

Zoning: The combined fines content, plasticity and shrink–swell results were used to identify three broad shrink–swell hazard zones across the study area, as shown in Table 3. The spatial distribution indicates that shrink–swell behaviour is not uniform across Ibadan Metropolis. Ona-Ara and Egbeda generally exhibited lower volumetric responses, while Ido and Oluyole recorded the highest values. The moderate shrink–swell zone covers areas where the soils exhibit intermediate behaviour and where construction control and site-specific assessment are particularly important.

Table 3. Broad shrink–swell hazard zoning derived from the study results

Hazard zone	LGA	Typical FSI (%)	Typical LS (%)	Engineering implication
Zone I – Low	Ona-Ara, Egbeda	14.1 – 17.2	5.74 – 15.32	Generally favourable natural subgrade where other requirements are satisfied
Zone II – Moderate	Akinyele, Lagelu and five urban-core LGAs	21.2 – 26.9	7.38 – 11.48	Moisture control, drainage and stabilisation where required
Zone III – High	Ido, Oluyole	33.0 – 36.3	8.20 – 16.13	Detailed investigation and treatment or replacement where necessary

Detailed investigation and treatment or replacement where necessary 3.6 Compliance with Road Material Requirements Comparison with the adopted Federal Ministry of Works and Housing requirements showed that 27 of the 33 samples (81.8%) complied with the $P_{0.075}$ limit of 35%, while 19 samples (57.6%) complied with the Liquid Limit limit of 35%. Only six samples (18.2%) satisfied the PI limit of 12%, and four samples (12.1%) satisfied the Linear Shrinkage limit of 8%. The six samples exceeding the $P_{0.075}$ limit were located in Ido and Oluyole. The relatively low compliance with the PI and LS

criteria indicates that classification as lateritic soil alone is insufficient for assessing its suitability as untreated subgrade or subbase material. The spatial pattern has direct implications for pavement design and construction. Soils from relatively low-hazard areas may be considered for use as natural subgrade where compaction, drainage and other project requirements are satisfied. Moderate-hazard areas require closer control of moisture and site-specific evaluation. In Ido and Oluyole, where high fines content, plasticity, shrinkage and swelling were observed, stabilisation or replacement of unsuitable material should be considered following detailed investigation and laboratory mix-design studies.

4. ENGINEERING IMPLICATIONS

The results demonstrate that shrink–swell potential varies spatially across Ibadan Metropolis and should therefore be considered during preliminary geotechnical investigations for road projects. The strong correlations of $P_{0.075}$ with PI, FSI and LS indicate that the fines fraction is an important screening variable. However, PI provided the strongest single-variable estimate of FSI within the present dataset. Consequently, assessment of moisture-sensitive lateritic subgrades should combine particle-size distribution, Atterberg limits, LS and FSI rather than rely on a single index property. Drainage is particularly important for moisture-sensitive subgrades because uncontrolled infiltration and prolonged saturation can intensify swelling, while drying can increase shrinkage. Construction control should therefore include adequate surface and subsurface drainage, appropriate moisture conditioning and effective field density control. Where the required material limits are not achieved, stabilisation should be selected through laboratory mix-design studies rather than by applying a uniform stabiliser percentage across the metropolis. Cement, lime and selected agro-industrial ash materials may be considered for further investigation, with treatment levels determined according to the severity and characteristics of the local soil.

5. CONCLUSION

This study evaluated the shrink–swell characteristics of lateritic soils from 33 locations covering the eleven LGAs of Ibadan Metropolis. The soils exhibited substantial spatial variation in fines content, plasticity and volumetric behaviour. $P_{0.075}$ ranged from 20.8% to 39.5%, PI from 10.6% to 23.3%, LS from 5.74% to 16.13%, and FSI from 14.1% to 36.3%. The statistical results confirmed strong relationships between the fines fraction and volumetric response, particularly the $P_{0.075}$ –FSI relationship ($r = 0.915$) and the $P_{0.075}$ –LS relationship ($r = 0.781$). The strongest relationship was obtained between PI and FSI ($r = 0.982$), with the PI-based regression explaining 96.4% of the variation in FSI. PI is therefore a useful first-approximation predictor of swelling response within the range of soils investigated, while the silty-clay/fines fraction remains an important indicator of spatial variability and moisture sensitivity. The engineering assessment identified Ona-Ara and Egbeda as relatively low-hazard areas, Akinyele, Lagelu and the five urban-core LGAs

as moderate-hazard areas, and Ido and Oluyole as high-hazard areas. Only 12.1% of the samples satisfied the adopted 8% Linear Shrinkage criterion. The findings support site-specific investigation, appropriate drainage and moisture control, with stabilisation or replacement considered where the soil does not satisfy project requirements.

6. RECOMMENDATIONS

1. Detailed Geotechnical Investigations Should Be Undertaken Before Pavement Construction, Particularly Where High Fines Content, Plasticity, Shrinkage Or Swelling Is Indicated.
2. Ido And Oluyole Should Receive Particular Attention During Pavement Investigation And Construction Because Of Their Comparatively High Fines Content, PI, LS And FSI Values.
3. Laboratory Mix-Design Studies Should Be Conducted To Determine The Appropriate Type And Dosage Of Stabilising Material For Each Site. Uniform Stabilisation Percentages Should Not Be Assumed For The Entire Metropolis.
4. Adequate Surface And Subsurface Drainage Should Be Provided On Moisture-Sensitive Subgrades To Minimise Prolonged Saturation And Seasonal Moisture Fluctuations.
5. Compaction Should Be Controlled Using Laboratory-Determined Moisture–Density Relationships, Supported By Field Density Testing During Construction.
6. The Regression Equations Developed In This Study Should Be Regarded As Site-Specific Screening Tools For The Sampled Lateritic Soils And Should Be Validated Using Additional Data Before Wider Application.

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