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# Variability Analysis of the Behaviors of a Lateritic Soil Profile as a Structural Material

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## HIGHLIGHTS

- Specific gravity variation of soil samples proved their were inorganic nature, hence suitable for construction works.
- The soil samples have high plasticity, good shear strength, and bearing ability.
- The lateritic soil samples are suitable for subgrade, subbase, and base materials.

## ARTICLE INFO

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## ABSTRACT

The desideratum of determining the behavior of the underlying soil on which the foundations will be laid is indisputable. This study evaluates the strength characteristics of lateritic soil material at a new construction site opposite College of Engineering and Engineering Technology (CEET), Michael Okpara University of Agriculture, Umudike (MOUAU). A trail pit was dug taking disturbed soil samples at a depth of 1m, 2m, and 3m for experimental analysis. Laboratory tests on specific gravity, grain size distribution, moisture content, atterberg limits, and triaxial tests were carried out on each sample by the procedure highlighted in BS1377 1990. Inspecting visually, the soil profile was observed to consist of three layers; light reddish, reddish, and whitish at the top, middle, and bottom respectively. The natural water content of the soil samples varied as 9.06+0.00 %, 7.98+0.00 %, and 9.32+0.03 %, while the specific gravity obtained from the test results was 2. 630+0.00 %, 2.634+0.00 % and 2.647+0.00 % at depths 1m, 2m, and 3m respectively. Using the unified soil classification system (USCS), the top, middle and bottom layers were classified as cloud sand (SC). The soil samples have a liquid limit (LL) of 24.5%, 28.8%, 31.0%; plastic limit (PL) of 19.4%, 17.2%, 18.5%; and plasticity index (PI) of 5.1%, 11.6%, and 12.5% at depths 1m, 2m, and 3m respectively. It was observed that the soil index properties vary and are enhanced as the depth of the excavation increases. Furthermore, the value of the cohesion property of the soil is 74.62 kN/m$^2$, 29.70 KN/m$^2$, and 24.65 KN/m$^2$ for samples at 2m, 3m, and 3m depth respectively. The greatest and least cohesion value was noted to be 74.62 kN/m2 and 24.65 kN/m$^2$ for samples at 2m and 3m depth respectively; the maximum and minimum angles of internal friction were 25.52o and 13.67o at depths 1m and 2m respectively. The outcome of this paper showed that the analyzed soil samples are suitable for civil engineering works.

## 1. Introduction

Soils are geological materials formed by weathering, erosion, and sedimentation processes [1], upon which engineering structures are founded and are commonly used as construction materials [2]. The performance of soils is largely influenced by their nature and properties. These properties determine the suitability of their role as a foundation or construction material [3].

Soils are categorized as organic, transported and residual soils based on their method of formation. Residual soils consist of lateritic and top soil, which are formed in situ through chemical weathering under high temperatures and humidity [4]. In most tropical places, lateritic soils serve as fill-material for different construction activities.

Attributes of soil that assist in the recognition and categorization of soils are regarded as soil index properties. These attributes include the natural moisture content, swell potential of soils, particle size distribution range, Atterberg limits, the activity of soils, liquidity index, compression index, and specific gravity test [5]. They are widely used by engineers to distinguish several kinds of soils within a class [6]. These properties describe the soil conditions, and soil type, and nurture a relationship to structural properties.



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In the construction industry, investigation of the soil's index properties is part of the prerequisite for its application [7]. Most investors often neglect thorough examination of these properties and this results in structural failure as well as the loss of lives and properties [8].

There exists colossal variability in the chemical, biological, and physical behavior of various types of soils in a region [9] and the subject of soil variability has gained much research interest [10]. Potential soil users benefit from the information derived from the variation of soil properties as optimum productivity is enhanced [11]. To overcome the failure of engineering structures, an investigation of soil index properties is needed. The impulse of this study is the absence of documented research on the physical features and the bearing strength of the soil in the study area. This study is focused on evaluating the index parameters of lateritic soil found at a construction-site opposite CEET, MOUAU. This study is aimed at:

1) Investigating the index and shear strength properties of the soil at varying depths.
2) ascertaining the suitability of this soil as an infrastructural foundation material.
3) determining the safest depth to place the structural foundations in the area.

## 2. Review of Previous Works

Sule et al. [7], assessed the index properties of subsoils along Jos-makurdi-road in north-central Nigeria. The disturbed-sampling approach was employed for the collection of soil samples from a trial pit dug beneath four varying bridges at 1m depth each. Their study showed that the index properties of each soil sample varied with location respectively.

The Geotechnical attributes of residual-clay soils from two test pits 30m apart were determined by Oyediran and Durojaiye [12]. The soils were observed to be inorganic, well-graded medium to high-plasticity. When subjected to statistical analysis, an insignificant difference was seen between the soils.

Mohammed et al., [4] investigated the index characteristics of a residual soil profile at Bosso campus of the Federal University of Technology, Minna. The authors used disturbed soil specimens taken from a trial pit depth of 0.5m, 1m, 1.5m, 2m, 2.5m, and 3 m respectively. For each soil sample, the authors carried out natural water content tests, specific gravity, Atterberg limit test, sieve analysis, standard-proctor-compaction test, and hydrometer test. Their study showed that the soil's index properties varied with depth.

Amadi et al., [13] analyzed the Geotechnical attitude of lateritic soils to ascertain their suitability as a base or sub-base material for road construction in Minna and environs, North-Central Nigeria. The authors excavated five trial pits from the existing ground level to a maximum of 4.5m. The examined soil samples were found to be easily compatible with good drainage, incompressible, and classified as sandy clay.

Onyeka and Osegbowa [14] examined the suitability of three laterite soils as a road construction material and for improved stabilization. Samples were taken from Muko, Jikwoyi and Apiwe borrow pits in Abuja, the Federal capital territory of Nigeria. Comparing the experimental outcome of Jikwoyi and Apiwe with Muko laterite soil material, it was confirmed that Muko soil satisfied the specification and is considered the most suitable for a sub-base course during road construction. Their study accentuated that soils can be stabilized using lime and ordinary Portland cement.

Onyeka [15] studied the stabilization and consolidation-settlement of soil structure interaction to verify the influence of soil stabilization of selected laterite employing bitumen, lime, and cement. The compaction test, Atterberg limit test, and California-Bearing-Ratio (CBR) test were conducted by applying mechanical, chemical, cement, and bio-enzymatic stabilization method. The study showed that cement stabilization is the best option that can be effectively implemented in the research area.

The varied character of geologic materials is of great concern to engineers and researchers. Previous studies divulged that soils of the same locus, condition, and topology exhibit varying Geotechnical behaviors. To circumvent the failure or collapse of buildings and other massive engineering structures, it is crucial to examine and understand the variations in the index characteristics of lateritic soils with respect to depth. The uniqueness of this work is factored in its sample collection technique, depth, and location. Basically, this study investigates the index features of lateritic soil at varying depths of a new construction site opposite CEET, MOUAU to determine the variability behavior of the soil as a structural material. Making appropriate decisions on construction sites is oftentimes challenging due to the absence of thorough soil data. This work will aid quick decision-making as regards design and construction activities in the study area.

## 3. Methodology

The subsoil status was investigated by excavating three trial pits from the existing ground level to a maximum of 3.0m. Disturbed soil samples were collected from the trial pits and analyzed in a civil engineering laboratory, MOUAU for relevant Geotechnical analysis. The laboratory analysis was done in accordance with [16].

### 3.1 Moisture Content

Moisture content is expressed as the ratio of the weight of the water in a soil specimen to the dry weight of the specimen [17]. The mineralogy and formation environment affect the moisture content of lateritic soil [13]. This test was performed in line with the stipulation of [16].

### 3.2 Specific Gravity

This test was conducted in the laboratory in accordance with the specification in [16], using three density bottles. Three values of specific gravity were obtained using each of the density bottles, and the specific gravity of the natural soil was then determined as the average of the three values.

### 3.3 Sieve Analysis

Using BS sieve sizes of 25.40mm, 19.05mm, 12.70mm, 9.52mm, 4.75mm, 2.36mm, 1.18mm, 600µm, 300µm, 150µm, and a pan, the test was done in the laboratory in accordance to the specification of [16]. The weight of the materials retained on each sieve size was then recorded and applied in the computations for plotting the grain-size distribution curve.

### 3.4 Atterberg Limit

The liquid and plastic limit of the soil is determined for proper soil classification, identification, and strong correlations. The water content at which the soil transforms from a semisolid to a plastic state is regarded as the plastic limit (PL) whereas the water content at which soil changes from plastic to a liquid state is called the liquid limit (LL). These parameters are also known as Atterberg limits. This test was done according to the stipulation of [16].

### 3.5 Triaxial Test

This test is performed in order to obtain the shear strength parameters (cohesion and friction angle) and the stiffness of the soil. Pore water pressure and stress-strain behavior of the soil are also determined. This test is performed to fulfill the requirements of [18]

## 4. Results and Discussion

The result of experimental analyses of specific gravity, grain size distribution, moisture content, atterberg limits, and triaxial tests conducted for three disturbed samples in accordance with the procedure highlighted in [16] is summarized in Table 1. The grain-size distribution curve was presented in Figure 1 while Figure 2, 3, and 4 contains the result of the Triaxial shear test of the soil sample at 1m, 2m, and 3m depths respectively. Statistical analysis of the result was performed to summarize the results obtained.

In the visual inspection of soil property, the soil profile was observed to consist of three layers; light reddish, reddish, and whitish at the top, middle, and bottom respectively. The reddish color of soil samples at 1m, 2m, and 3m depth showed that the soil material is laterite.

**Table 1:** Summary of laboratory tests

| Sample Depth | Natural Moisture | Specific Gravity | Atterberg Limit | | | Triaxial Test | | | | Sieve Analysis | | USCS Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | LL | PL | PI | C | ø | Cc | Cu | % Passing 4.75mm | % Passing 75µm | |
| m | % | | % | % | % | kN/m$^2$ | o | | | % | % | |
| 1 | 9.06 | 2.630 | 24.5 | 19.4 | 5.1 | 29.70 | 25.52 | 65.46 | 181.82 | 100.00 | 19.85 | SC |
| 2 | 7.98 | 2.634 | 28.8 | 17.2 | 11.6 | 74.62 | 13.67 | 25.31 | 125.0 | 100.00 | 24.45 | SC |
| 3 | 9.32 | 2.647 | 31.0 | 18.5 | 12.5 | 24.65 | 19.15 | 11.14 | 90.91 | 100.00 | 23.26 | SC |

The natural water content of the soil samples varied as 9.06$\pm$0.00 %, 7.98$\pm$0.00%, and 9.32$\pm$0.03%, while the specific gravity obtained from the test results was 2. 630$\pm$0.00 %, 2.634$\pm$0.00 % and 2.647$\pm$0.00 % at depths 1m, 2m, and 3m respectively. Using the unified soil classification system (USCS), the top, middle and bottom layers were classified as cloud sand (SC). The results of the moisture content Table 1, showed that all the soil samples have values at the lower range of approximately as 9.06 %, 7.98%, and 9.32% despite their significant difference based on statistical analysis. Since the moisture content is lesser than the liquid limit, the soil is considered to be inelastic and brittle. Meanwhile, the lower range value indicated moisture content could infer that the soil samples may not hold water strongly and this could be attributed to the sandy-clay nature of the soil.

The result of the specific gravity of soil which indicates how saturated the soil, Prakash and Jain, [19] is with water is usually between 2.65-2.80 with finer soils having higher values than coarser ones. Table 1 shows that the specific gravity of the soil at 1m depth is 2.630 which increased slightly to 2.634 as the depth increased to 2m, but significant variation ($p<0.05$) is observed at the depth of 3m, the value of the specific gravity increased to 2.647. The types of soil samples based on specific gravity according to Bowles [20] are considered as organic soil and thus, justified soil grading before construction works.

Table 1 also shows the results of the liquid limit (LL %), plastic limit (PL %), and plasticity index (PI %) evaluated on all the trial pits. The soil samples have a liquid limit (LL) of 24.5%, 28.8%, 31.0%; plastic limit (PL) of 19.4%, 17.2%, 18.5%; and plasticity index (PI) of 5.1%, 11.6%, and 12.5% at depths 1m, 2m, and 3m respectively. This LL shows that the soil has negligibly little shear strength. Statistically, there was a significant ($p<0.05$) difference between them. The sample at 3 m depth showed the highest PI, followed by the sample at 2 m, then the sample at 1m depth. Based on the Federal Ministry of Works (FMWH) [21] recommended liquid limit is not greater than 80% for sub-grade and not greater than 35% for sub-base and base courses. According to the specification of the FMWH, the lateritic soil samples are suitable for subgrade, subbase, and base materials as the percentage by weight finer than the No. 200 BS test sieve is less than 35%. It was observed that the soil index properties vary and are enhanced as the depth of the excavation increases. Also, a plasticity index not greater than 55% for sub-grade and not greater than 12% for both sub-base and base is equally recommended.

The plasticity index (PI) of the soil at 1m depth is 5.1%, which is an indication of low plastic soil, while PI at depths 2m and 3m are 11.6% and 12.5% respectively, which implies that the soil is medium-plastic. These results are in agreement with the work of Sule et al. [7] and Eze et al., [8].

Furthermore, the determination of the shear strength of the soil samples was performed by an un-consolidated un-drained triaxial test. Figures 2, 3, and 4 present the plots of the shear stress and the principal stress. After the failure envelope is drawn, the cohesion (C) and internal friction angle (Ø) is obtained. Based on the results, there was a significant difference in the values of the samples used at various depths for cohesion (C) and internal friction angle (Ø) respectively. The un-drained cohesion of the sample at 2 m depth indicated the highest value of 74.62 $kN/m^2$ followed by the sample at 1 m depth with a C value of 29.70 $kN/m^2$, then 24.65 $kN/m^2$ for a sample at 3m depth. The greatest and least cohesion value was noted to be 74.62 $kN/m^2$ and 24.65 $kN/m^2$ for samples at 2m and 3m depth respectively. This indicated higher stability of the sample at 3 m depth under stress, followed by the sample at 1m depth while the sample at 2 m depth showed the highest failure. The internal friction angle (Ø) was found to be 25.52°, 13.67°, and 19.15° at 1m, 2m, and 3m depths respectively. Thus, the maximum and minimum angles of internal friction were 25.52$^o$ and 13.67$^o$ at depths 1m and 2m respectively.

This implies that the soil samples have high plasticity, low shear strength, and bearing ability. According to Obrzud and Truty [22], the specific value of internal friction angle (Ø) for sandy-clay soil is 31, and based on the results, the values are lower than the specific value indicating that the soil samples are very loose according to Meyerhoff [23]. More, so, this result showed that the soil samples have high plasticity, low shear strength, and bearing ability. The result of the analysis showed that the investigated soil samples are very loose and well-graded based on triaxial test and sieve analysis and will make a better sub-grade material for civil engineering construction if stabilized or consolidated.

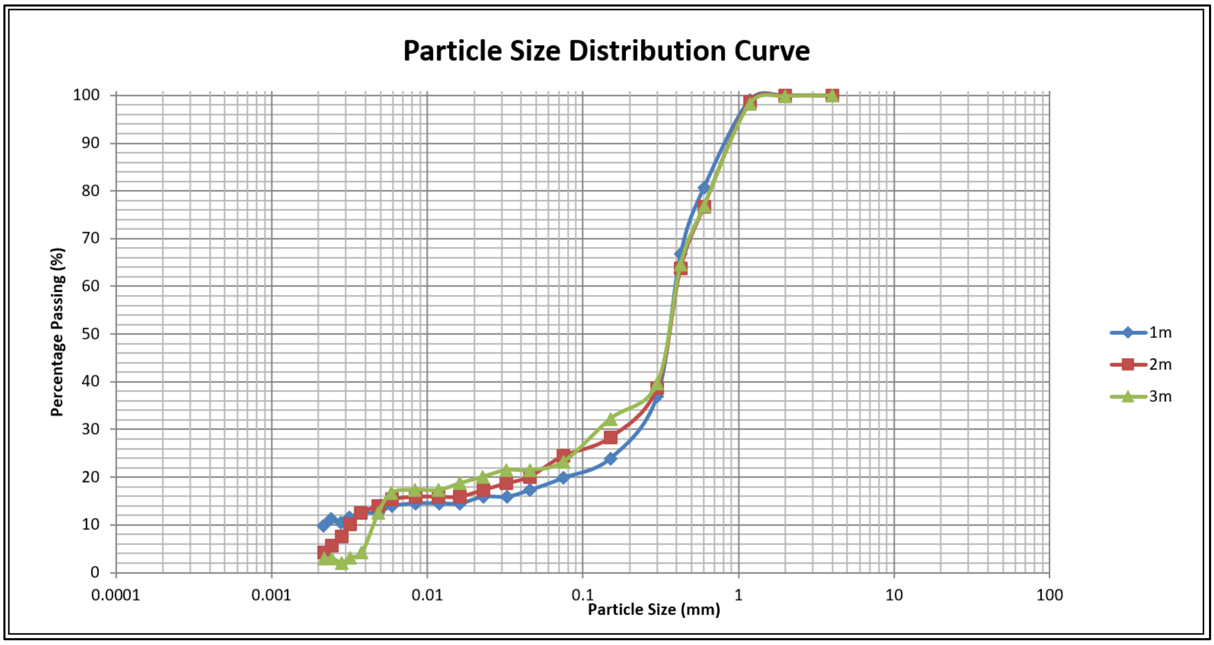


**Figure 1:** Gradation Curve of the soil samples

## UNCONSOLIDATED UNDRAINED TRIAXIAL TEST

| | |
|---|---|
| BOREHOLE | 1 |
| DEPTH OF SAMPLE | 1M |

| Minor Principal Stress | Deviator Stress | Major Principal Stress |
|---|---|---|
| δ3 | δ1- δ3 | δ1 |
| (kN/m2) | ( kN/m2) | (kN/m2) |
| 55 | 177.87 | 232.87 |
| 105 | 252.20 | 357.20 |
| 155 | 328.78 | 483.78 |

| RESULT | | | | |
|---|---|---|---|---|
| Undrained Cohesion Cu | Angle of Int Friction ø | Moisture Cont. | Bulk Unit Weight | Dry Unit Weight |
| (kN/m2 | ($^{o}$) | (%) | (kN/m3) | (kN/m3) |
| 29.70 | 25.52 | 9.1 | 19.74 | 18.10 |

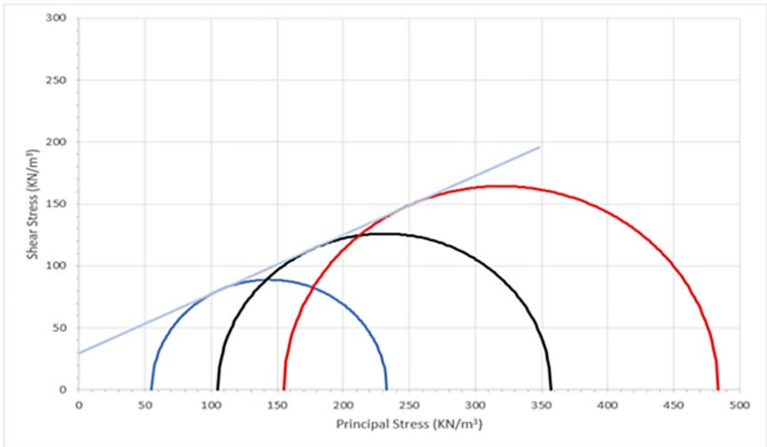


**Figure 2:** Triaxial test of the soil sample at 1m depth

## UNCONSOLIDATED UNDRAINED TRIAXIAL TEST

| | |
|---|---|
| BOREHOLE | 1 |
| DEPTH OF SAMPLE | 2M |

| Minor Principal Stress | Deviator Stress | Major Principal Stress |
|---|---|---|
| δ3 | δ1- δ3 | δ1 |
| (kN/m2) | (kN/m2) | (kN/m2) |
| 55 | 223.43 | 278.43 |
| 105 | 255.91 | 360.91 |
| 155 | 285.67 | 440.67 |

| RESULT | | | | |
|---|---|---|---|---|
| Undrained Cohesion Cu | Angle of Int Friction ø | Moisture Cont. | Bulk Unit Weight | Dry Unit Weight |
| (kN/m2) | ($^{o}$) | (%) | (kN/m3) | (kN/m3) |
| 74.62 | 13.67 | 8.0 | 22.06 | 20.43 |

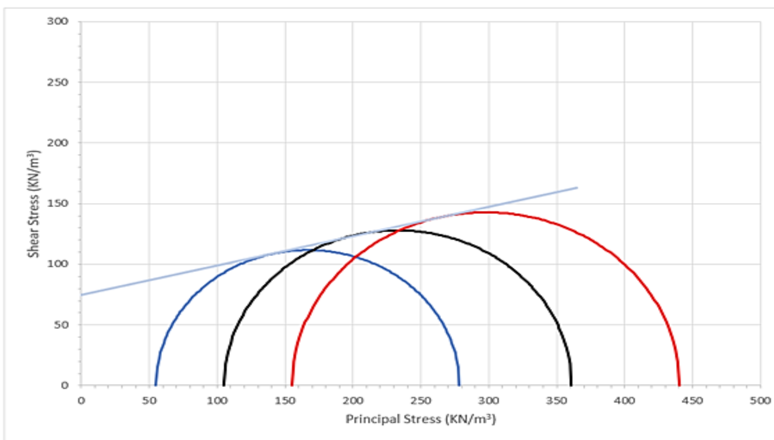


**Figure 3:** Triaxial test of the soil sample at 2m depth

## UNCONSOLIDATED UNDRAINED TRIAXIAL TEST

| | |
|---|---|
| BOREHOLE | 1 |
| DEPTH OF SAMPLE | 3M |

| Minor Principal Stress | Deviator Stress | Major Principal Stress |
|---|---|---|
| δ3 | δ1- δ3 | δ1 |
| (kN/m2) | (kN/m2) | (kN/m2) |
| 55 | 122.94 | 177.94 |
| 105 | 172.03 | 277.03 |
| 155 | 220.66 | 375.66 |

| RESULT | | | | |
|---|---|---|---|---|
| Undrained Cohesion Cu | Angle of Int Friction ø | Moisture Cont. | Bulk Unit Weight | Dry Unit Weight |
| (kN/m2) | (°) | (%) | (kN/m3) | (kN/m3) |
| 24.65 | 19.15 | 8.0 | 22.06 | 20.43 |

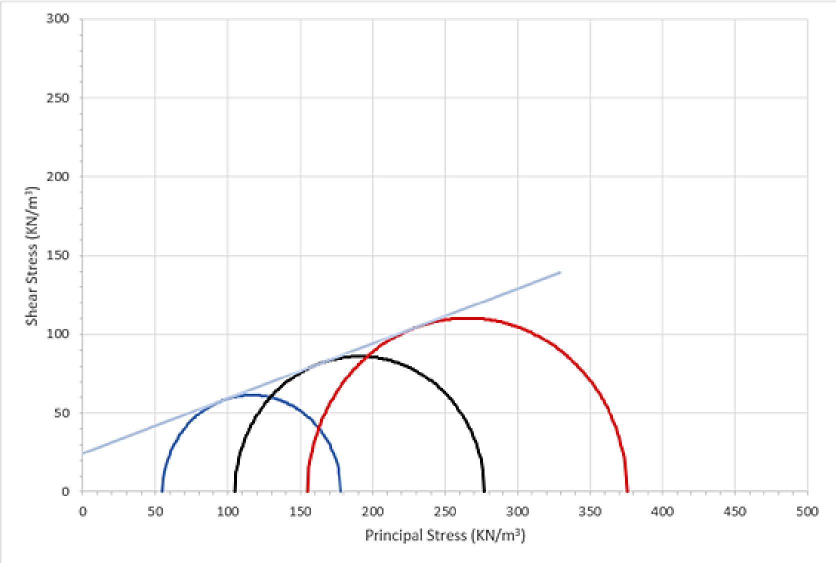


**Figure 4:** Triaxial test of the soil sample at 3m depth

## 5. Conclusion

The research work concludes that:

- The soil is considered to be inelastic and brittle since the moisture content is lesser than the liquid limit.
- The variation of the specific gravity of the soil samples proved that they were inorganic soil, hence suitable for construction works.
- The plasticity index (PI) of the soil at 1m depth was 5.1%, which is an indication of low plastic soil, while PI at depths 2m and 3m were 11.6% and 12.5% respectively, which implies that the soil is medium-plastic.
- The internal friction angle (Ø) was found to be 25.52°, 13.67°, and 19.15° at 1m, 2m, and 3m depths respectively. The greatest and least angles of internal friction were 25.52° and 13.67° at depths 1m and 2m respectively. Hence, the soil samples have high plasticity, good shear strength, and bearing ability.
- The lateritic soil samples are suitable for subgrade, subbase, and base materials according to the specification of FMWH.

### Author contributions

All authors contributed equally to this work.

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### Data availability statement

Not applicable.

### Conflicts of interest

The authors of the current work do not have conflict of interest.

### References

**[1]** Raj, P. P. Soil mechanics and foundation engineering, Dorling Kindersley (India) Pvt. Ltd., New Delhi, 2012.

**[2]** Bowles, J. E. Engineering properties of soils and their measurements, Fourth edition, McGraw Hill Education (India) Private Limited, New Delhi, 2012.

**[3]** O. Ademila, Application of geophysical survey for subsurface investigation of an erected multistory building in southwestern Nigeria, Int. Basic Appl. Res. J., 2 (2016) 1-12.

**[4]** K. A. Mohammed, G. L.Yisa, E. Sule, H. L. Makwin, Investigation of index properties of a residual soil profile, IOSR J . Civ. Mech. Eng., 11 (2014) 1-4.

**[5]** P. L. Dharamapriya, H.A.H. Jayasena, Prior assessment of variability in the geotechnical properties of soils for efficient infrastructure management, Research Square, 1 (2021) 1-26. https://doi.org/10.21203/rs.3.rs-1032504/v1

**[6]** A. Laskar, S. K. Pal, Geotechnical characteristics of two different soils and their mixture and relationships between parameters, Electron. J. Geotech. Eng., 17 (2012) 2821-2832.

**[7]** E. Sule, E. H. Maude, A. Y. Adamu, B. Y. Mailafiya, Investigation of index properties of soils along jos-makurdi road in North-Central Nigeria, Saudi J. Civ. Eng., 5 (2021) 87-90.

**[8]** E. O. Eze, O. S. Osuji, J. T. Akinwamide, Characterisation of index properties of lateritic soils in Ado Ekiti South-Western, Nigeria, Int. J. Sci. Res., 6 (2017) 308-312.

**[9]** B. N. Ndukwu, E. U. Onweremadu, U. N. Nkwopara, C. M. Ahukaemere, E. E. Ihem, L. C. Agim, Variability of selected soil properties of a river slope in Amaigbo, South-Eastern Nigeria, Futo J. Sci., 1 (2015) 8–16.

**[10]** R.M. Lark , H. C. Wheeler, Understanding and using yield maps and analytical tool for their interpretation, Outlook on Agriculture, 29 (2000) 39-45. https://doi.org/10.5367/000000000101293031

**[11]** U. N. Nkwopara, Variability in selected soil properties of soils of dissimilar parent materials in the humid tropics, Int. J. Environ. Agric. Biotech., 3 (2018) 1467-1472. http://dx.doi.org/10.22161/ijeab/3.4.44

**[12]** I. A. Oyediran, H. F. Durojaiye, Variability in the Geotechnical properties of some residual clay soils from South-Western Nigeria, Int. J. Sci. Eng. Res., 2 (2011) 235-240.

**[13]** A. N. Amadi, W. G. Akande, I. A. Okunlola, M. O. Jimoh, D. G. Francis, Assessment of the geotechnical properties of lateritic soils in Minna, North-Central, Nigeria for road design and construction, American J. Min. Metall., 3 (2015) 15-20.

**[14]** F. C. Onyeka, D. Osegbowa, Soil structural analysis of laterite properties used as a road construction material, Abuja as a case study, Int. Res. J. Innov. Eng. Technol., 4 (2020) 35-42. https://doi.org/10.47001/IRJIET/2020.411005

**[15]** F. C. Onyeka, Structural analysis of stabilization and consolidation settlement of selected laterite soil using cement lime and bitumen, Int. J. Trend Sci. Res. Dev., 4 (2019)13-20.

**[16]** British Standard Institute, Methods of Testing Soils for Civil Engineering Purposes, BS1377, part 2, 1990.

**[17]** Vankatramaiah, Geotechnical engineering, third edition. New Age International Publishers, New Delhi, 2007.

**[18]** BS EN ISO 17892-8:2018, Investigation and Testing. Laboratory testing of soil unconsolidated undrained triaxial test.

**[19]** S. Prakash and P. K. Jain, Engineering soil testing. Nem Chand & Bros, Roorkee India, 2002.

**[20]** J. E. Bowles, Engineering properties of soils and their measurements, Fourth edition, McGraw Hill Education (India) Private Limited, New Delhi, 2012.

**[21]** Federal Ministry of Works and Housing (FMWH), General specification for roads and bridges, volume II, Federal Highway Department, Lagos, Nigeria, 317, 1997.

**[22]** R. Obrzud and A. Truty, The Hardening soil model. a practical guide book. Z Soil PC 100701 report, 2012.

**[23]** G. Meyerhof, Penetration tests and bearing capacity of cohesionless soils, J. Soil Mech. Found. Div., ASCE 82, SM1 (1956).