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# INVESTIGATION OF GEOTECHNICAL PROPERTIES OF LATERITIC SOILS IN PARTS OF IFE CENTRAL LOCAL GOVERNMENT AREA, OSUN STATE, SOUTHWESTERN NIGERIA

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**ABSTRACT:** *This study undertook geotechnical evaluation of selected lateritic soils in Ife Central Local Government Area. Osun State, Southwestern Nigeria. Lateritic soil samples were collected from active borrow pits within the study area. Laboratory tests such as natural moisture content determination, particle size analysis, specific gravity, Atterberg limits, compaction test, California bearing ratio (CBR) test and unconfined compression test were conducted on the soil samples using standard procedures. Results obtained were compared with the literature and the Federal Ministry of Works and Housing (FMWH) requirements. Using American Association of State Highway and Transport Officials (AASHTO) classification system, the soils fall within A-5, A-7-5 and A-7-6. Also, using Unified Soil Classification System (USCS), the soils fall within ML, MH, CL and CH. It was concluded that the soils are good for fill and subgrade in road construction. Relationships also exist between the engineering properties and Atterberg limits of the soils. It was recommended that other borrow pits within Ife Central Local Government Area should be investigated to determine their suitability for engineering applications.*

**KEYWORDS**: Geotechnical, Ife, Investigation, Lateritic, Soil, Nigeria

## INTRODUCTION

Laterite has been defined as a highly weathered material, rich in secondary oxides of iron, aluminium, or both, void or nearly void of basic primary silicates, which may contain large amounts of quartz and kaolinite. Laterite is also defined based on silica ($SiO_2$) to sesquioxide ($Fe_2O_3$) ratios. A ratio of less than 1.33 indicates the material is laterite; ratio between 1.33 and 2.00 indicates lateritic soil; while a ratio greater tha 2.00 indicates non-lateritic (Alexandra and Cady, 1962; Bell, 1993; Bello and Adegoke, 2010; Adunoye and Agbede, 2013).

Factors that influence the formation of laterite include climate (precipitation, leaching, capillary rise and temperature, topography (drainage), vegetation, parent rock (iron-rich rocks) and time. In addition, lateritic soils are formed in hot, wet tropical regions with an annual rainfall between 750 mm and 3000 mm (usually in area with a significant dry season) on a variety of different types of rocks with high iron content. Therefore, the locations on earth that meet the condition for the formation of laterite fall between latitudes 35$^o$N and 35$^o$S (Gillot, 1968).

Laterite is one of the most valuable materials for construction. The construction of foundations of most engineering structure requires that adequate information about the engineering properties of the soil and sub-soil condition of the area are known. This is necessary for the engineering planning, design and construction of such foundations to be based on sound geotechnical parameters. This is more important especially in the design and construction of buildings and highways, where there is need for a good and sound knowledge of the geotechnical and engineering properties of the sub-soil and, more importantly, the properties of construction materials for sound engineering decisions to be taken. Such geotechnical properties include the index properties (particle size distribution, Atterberg limits, specific gravity, etc) and the strength properties (compaction characteristics, unconfined compressive strength, shear strength, bearing capacity, etc) (Habeeb *et at.*, 2012).

The importance of lateritic soil in most civil engineering constructions cannot be over emphasised, as most of the construction failures have been attributed to usage of wrong material for engineering application. It is therefore pertinent to assess the geotechnical properties of lateritic soils for design and construction purposes. Over the years, many researchers (Ola, 1983; Gidigasu and Kuma, 1987; Alao, 1980; Arumala and Akpokodje, 1987; Ogunsanwo, 1989; Agbede, 1992; Adeyemi, 2002; Oladeji and Raheem, 2002; Adewoye *et al.*, 2004; Agbede and Osuolale, 2005; Bello, 2007; Bello *et al.*, 2007; Bello and Adegoke, 2010) have investigated the geotechnical properties of lateritic soils. However, there are no available data on the geotechnical properties of soils in the study area. This study therefore aimed at carrying out an evaluation of the geotechnical properties of selected lateritic soils in parts of Ife Central Local Government Area, Osun State, Southwestern Nigeria. This is to add to the body of knowledge and provide useful aid for engineers and contractors in the selection of suitable materials for engineering projects.

### Description and Geology of the Study Area

The study area is Ile-Ife in Osun State, Southwestern Nigeria. Ile-Ife is located within Latitude 7° 26'N and 7°32'N and Longitude 4°29'E and 4°35'E, covering an area of about 1,894 $km^2$ in the present day Osun State. Ile-Ife consists of four Local Government Areas (Ife Central, Ife South, Ife East and Ife North). Two of these, Ife Central and Ife East, are located within Ile-Ife Township and have a population of 501,952 (Ajala and Olayiwola, 2013; Udama *et al.*, 2017) (Figure 1). The study area falls within the basement complex of Southwestern Nigeria (Figure 2). It forms part of the African crystalline shield which consists predominantly of migmatised and undifferentiated gneisses and quartzite (Akintola, 1982; Areola, 1982; Adunoye and Agbede, 2013).

## MATERIALS AND METHODS

The main material used was lateritic soil samples obtained from nine (9) identified locations within the study area. Table 1 presents a description of the sampling points, while Table 2 contains the list of the various equipment used for the study. The equipment was available at the Geotechnical Engineering Laboratory of the Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife.

In each of the identified nine sampling locations, test pits were dug and excavated with the aid of digger and shovel. The depth of sample collection was 0.5 m – 1 m (Arora, 1988; Roy and Das, 2014). 20 - 25 kg of each sample was collected into a nylon, sealed and immediately taken to the Geotechnical Laboratory of the Department of Civil Engineering, Obafemi

Awolowo University (OAU), Ile-Ife, for analyses. After determining the initial moisture content, the samples were prepared for subsequent laboratory analyses by air-drying and grinding to pass 2 mm sieve.

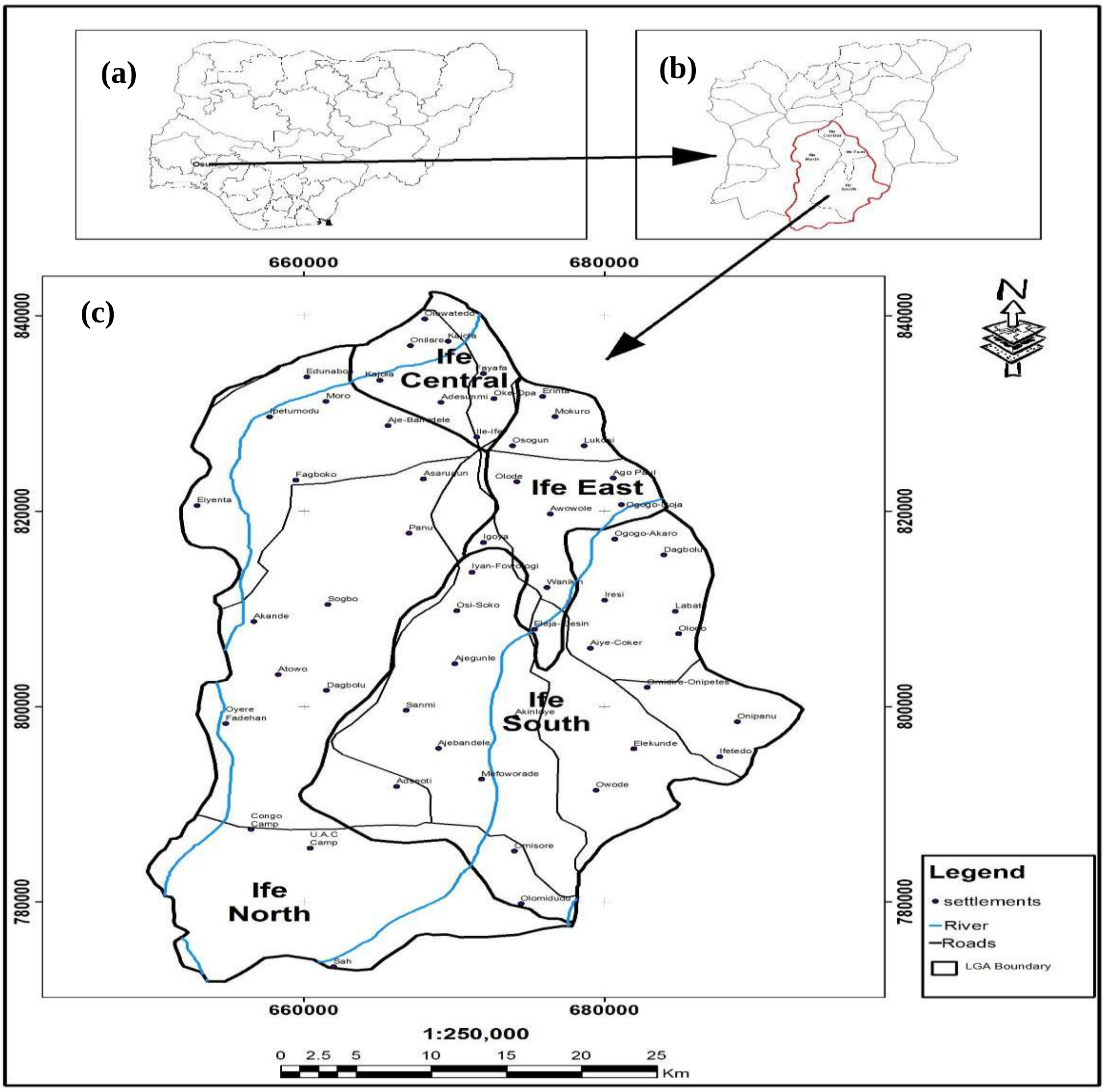


**Figure 1: Map of the Study Area: (a) Map of Nigeria showing Osun State; (b) Map of Osun State showing Ile-Ife; (c) Map of Ile-Ife (Adapted from Udama *et al.*, 2017)**

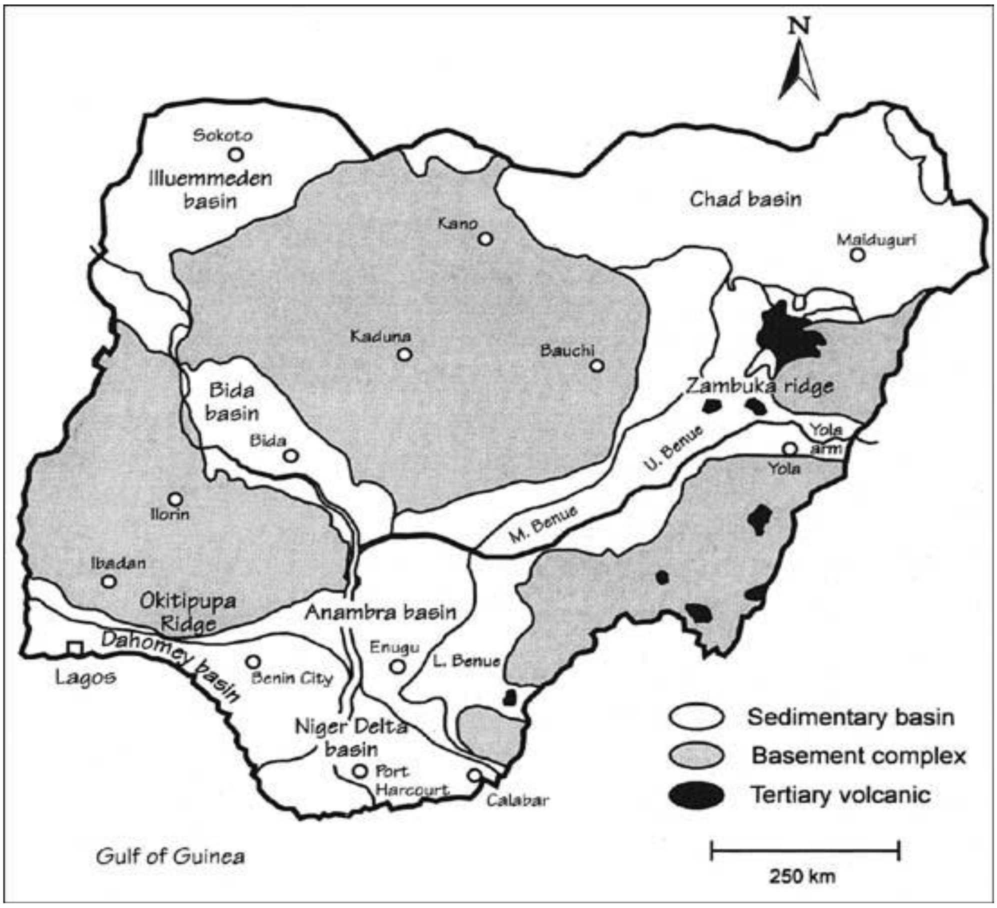


**Figure 2: Map of the Major Geological Formations of Nigeria (Anukam, 1997)**

Index property tests (specific gravity, particle size analysis and Atterberg limits – liquid limit, plastic limit and shrinkage limit) and engineering tests (compaction, unconfined compressive strength (UCS) and California bearing ration (CBR)) were conducted on the samples. The tests were carried out in accordance with British standard code of practice (BS 1377:1990), Methods of test for soils for civil engineering purposes.

**Table 1: Description of Sample Locations**

| Sample ID | Longitude (E) | Latitude (N) |
|---|---|---|
| S1 | $4^0$32’49.07” | $7^0$27’59.67” |
| S2 | $4^0$34’34.94” | $7^0$28’50.23” |
| S3 | $4^0$36’55.42” | $7^0$25’56.48” |
| S4 | $4^0$27’57.61” | $7^0$30’02.88” |
| S5 | $4^0$28’19.18” | $7^0$29’54.02” |
| S6 | $4^0$52’45.35” | $7^0$49’38.80” |
| S7 | $4^0$51’28.63” | $7^0$51’92.53” |
| S8 | $4^0$51’28.71” | $7^0$51’92.53” |
| S9 | $4^0$48’22.62” | $7^0$49’40.76” |

**Table 2: List of Equipment**

| Equipment | Purpose |
|---|---|
| Set of Sieves (4.5mm to 0.06mm) | Particle size analysis (coarse grain) |
| Sieve Shaker | Shaking of soil sieves |
| Hydrometer Bulb | Particle size analysis (fine grain) |
| Specific Gravity Bottle | Specific gravity determination |
| Atterberg Apparatus | Plastic and liquid limits determination |
| Electric Oven (Temp 105°C to 110°C) | Drying of moist soil sample |
| Weighing balance | Weighing of soil |
| Measuring Cans | Measurement |
| Compaction Moulds and Rammers | Compaction test |
| CBR machine | Determination of CBR |

## RESULTS AND DISCUSSION

### Preliminary and index properties of soil samples

The results of preliminary and index property tests are shown in Table 3.

### Natural moisture content

The natural moisture content of any soil varies from season to season, being highest during rainy season and lowest during dry season. According to Emesiobi (2000), natural moisture content in soil may range from below 5% to 50% in gravel and sand. The natural moisture content of the lateritic soil samples ranges from 17 % to 25 %. The values are fairly high considering the time of test, indicating the soil potential for water retention. This is a property of fine grains (Osuji and Akinwamide, 2018).

### Specific Gravity

The specific gravity of the soil samples varied between 2.40 and 2.78. According to Wright (1986), the standard range of values of Specific gravity of soils lies between 2.60 and 2.80. Therefore, the obtained values of specific gravity are expected for the tested soils. Que *et al.* (2008) have shown that specific gravity is closely linked with the mineralogy and/or the chemical composition of soil. It could be concluded that sample S4 (with the highest specific gravity) is the most lateritised sample, while sample S9 (with the lowest specific gravity) is the least lateritised sample (De Graff-Johnson, 1972). Also, lower specific gravity values indicate a coarse soil, while higher values indicate a fine grained soil (Wright, 1986). Therefore, sample S9 is the coarsest, while sample S4 is least coarse.

**Table 3: Results of Preliminary and Index Property Tests**

| Sample ID | NMC (%) | Gs | % Fines | LL (%) | PL (%) | PI (%) | SL (%) |
|---|---|---|---|---|---|---|---|
| S1 | 25 | 2.55 | 38 | 48 | 25 | 23 | 4.6 |
| S2 | 18 | 2.68 | 36 | 60 | 42 | 18 | 5.7 |
| S3 | 17 | 2.67 | 61 | 57 | 27 | 30 | 5.5 |
| S4 | 23 | 2.78 | 48 | 47 | 29 | 18 | 4.5 |
| S5 | 21 | 2.65 | 42 | 44 | 31 | 13 | 4.2 |
| S6 | 22 | 2.63 | 54 | 44 | 28 | 16 | 4.3 |
| S7 | 17 | 2.55 | 62 | 54 | 26 | 28 | 5.2 |
| S8 | 17 | 2.65 | 36 | 46 | 24 | 22 | 4.4 |
| S9 | 18 | 2.4 | 40 | 41 | 34 | 7 | 3.8 |

### Particle Size Distribution

All the soil samples have very high percentage finer than 0.075 fractions, that is > 35%. Therefore, the soils could be described as clay soils of high compressibility. Considering the fact that the percentage fines ranges between 36 (for sample S7) and 62 (for sample S7), the soils consist predominantly of silt and clay. According to Federal Ministry of Works and Housing Specification (1997), for a soil sample to be used as both subgrade/fill and base, the percentage passing the No.200 sieve (75µm) shall be less than but not greater than 35%. And if the percentage passing sieve No. 200 for a lateritic base course is greater than 35%, there is no need for further tests; the material shall be rejected. Therefore, none of the lateritic soil samples investigated can be used as subgrade/fill and base material.

### Atterberg Limits

The values of liquid limit (LL), plastic limit (PL) and plasticity index (PI) ranged between 41 % (S9) and 60 % (S2); 24 % (S8) and 42 % (S2); and 7 % (S9) and 30 % (S3) respectively. Federal Ministry of Works and Housing Specification (1997) recommends liquid limits not greater than 80 % for subgrade and not greater than 35 % for sub base and base course materials; and plasticity index not greater than 55 % for subgrade and not greater than 12 % for both sub base and base course. In terms of plasticity, the soils ranged from low plasticity to high plasticity. Although the linear shrinkage ranging between 3.8 and 5.7 (greater than 0 and less tha 8) could be said to qualify the soils for use as sub base material, the values of LL, PL and PI clearly suggest that the soils are best suitable for use as subgrade and earth fill material.

### Engineering Properties of Soil Samples

The results of engineering property tests on soil samples are presented in Table 4.

### Compaction Test

Values of maximum dry density (MDD), and the optimum moisture content (OMC) ranged between 1.51 mg/m$^3$ (S7) and 1.76 mg/m$^3$ (S6); 17.8 % (S9) and 31.3 % (S7) respectively. The range of values that may be anticipated when using the standard proctor test methods are:

for clay, MDD may fall between 1.44 mg/m$^3$ and 1.685 mg/m$^3$ and OMC may fall between 20 % and 30 %. For silty clay, MDD is usually between 1.6 mg/m$^3$ and 1.845 mg/m$^3$ and OMC ranged between 15 % and 25 %. For sandy clay, MDD usually ranged between 1.76 mg/m$^3$ and 2.165 mg/m$^3$ and OMC between 8 % and 15 % (O'Flaherty, 1988; Bello and Adegoke, 2010; Adunoye and Agbede, 2013). From the results obtained it is evident that the lateritic soils fall in the categories of clay or silty clay.

**Table 4: Results of Engineering Property Tests**

| Sample ID | MDD (mg/m$^3$) | OMC (%) | CBR (%) | UCS (kN/m$^2$) |
|---|---|---|---|---|
| S1 | 1.71 | 20.3 | 18 | 109 |
| S2 | 1.61 | 28 | 19 | 308 |
| S3 | 1.71 | 19.5 | 8 | 308 |
| S4 | 1.69 | 21.2 | 11 | 180 |
| S5 | 1.72 | 19.8 | 9 | 89 |
| S6 | 1.76 | 20.8 | 7 | 173 |
| S7 | 1.51 | 31.3 | 8 | 101 |
| S8 | 1.54 | 25.6 | 12 | 101 |
| S9 | 1.75 | 17.8 | 12 | 350 |

## California Bearing Ratio (CBR)

The CBR values ranged from 7 % to 19 %, which implies that none of the samples has a CBR higher than 30 %; thus confirming the fact that the soil samples been investigated are only suitable for subgrade or earthfill (Federal Ministry of Works and Housing Specification, 1997).

## Unconfined Compressive Strength

Dass (2006) gives the range of the values of unconfined compressive strength of clay between 50 kN/m$^2$ and 100 kN/m$^2$ as medium stiff, 100 kN/m$^2$ and 200 kN/m$^2$ as stiff and 200 kN/m$^2$ and 400 kN/m$^2$ as very stiff. From the results obtained, sample S5 has medium stiffness; samples S1, S4, S6, S7 and S8 are stiff; while samples S2, S3 and S9 are very stiff or very hard.

## Classification of Soils and Relationships Between Properties

Table 5 presents the classification of the analysed soil samples, based on the earlier determined properties. The percentage of the soil passing sieve No. 200 are more than 36% which show that the lateritic soils are silty-clay materials and the liquid limits of the samples range from 41 % to 60 %. This also shows that the soil falls between A-5 and A-7 in the AASHTO classification system. In using USCS classification, it was observed that some samples lie above the A-line while some fall below the A-line which shows that the lateritic soil samples range from clay to silt.

**Table 5: Classification of Soil Samples**

| Sample ID | Classification | |
|---|---|---|
| | AASHTO | USCS |
| S1 | A-7-6 | CL |
| S2 | A-7-5 | MH |
| S3 | A-7-6 | MH |
| S4 | A-7-6 | CL |
| S5 | A-7-5 | ML |
| S6 | A-7-6 | ML |
| S7 | A-7-6 | CH |
| S8 | A-7-6 | CL |
| S9 | A-5 | ML |

Figures 3 to 5 are graphical presentations of the relationships between some of the index properties and the engineering properties. The graphs do not show any regular or particular pattern between the Atterberg limits and engineering properties. Table 6 presents the mathematical relationships between the engineering properties and Atterberg limits of the soils. For all correlated parameters, the values of correlation coefficient ($R^2$) is within the range $R^2>0.2$, which implies that there are moderate correlations (Shahin *et al*., 2009). The relationship between UCS and Atterberg limits has the highest $R^2$ (0.83) and highest Residual Sum of Squares (RSS), which implies that the best correlation exists between UCS and Atterberg limits.

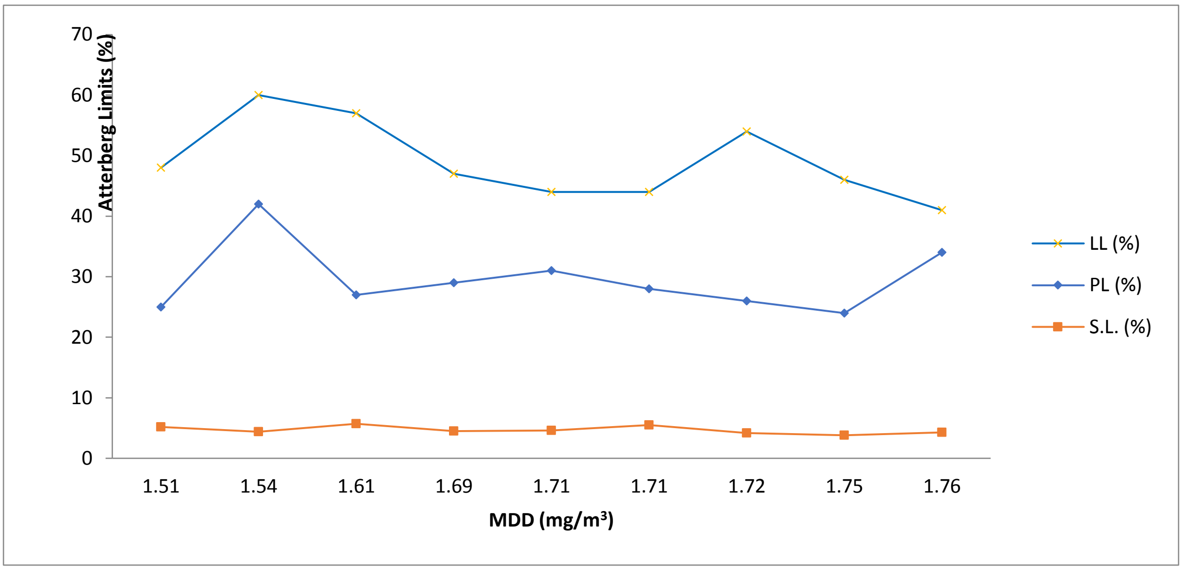


**Figure 3: Atterberg Limits vs MDD**

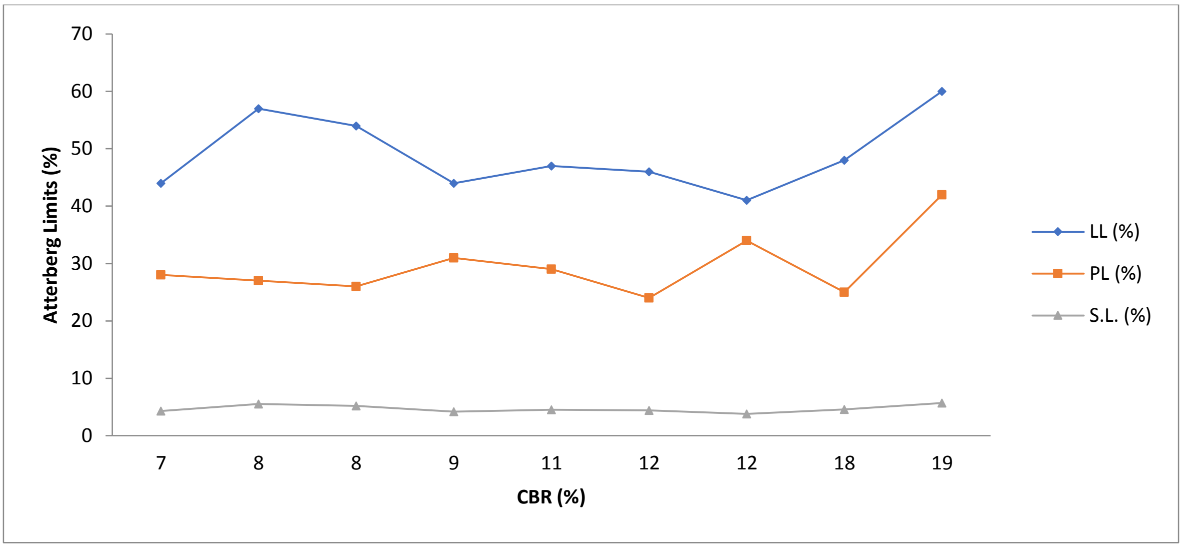


**Figure 4: Atterberg limits vs CBR**

## CONCLUSION

Geotechnical evaluation of selected soils in Ife Central Local Government was carried out. The soils were found suitable for earth fill and subgrade in road construction. Relationships also exist between the engineering properties and Atterberg limits of the soils. The results were valid for tested samples, sampling locations and within the described procedures. Other borrow pits within Ife Central Local Government Area should be investigated to determine their suitability for engineering applications.

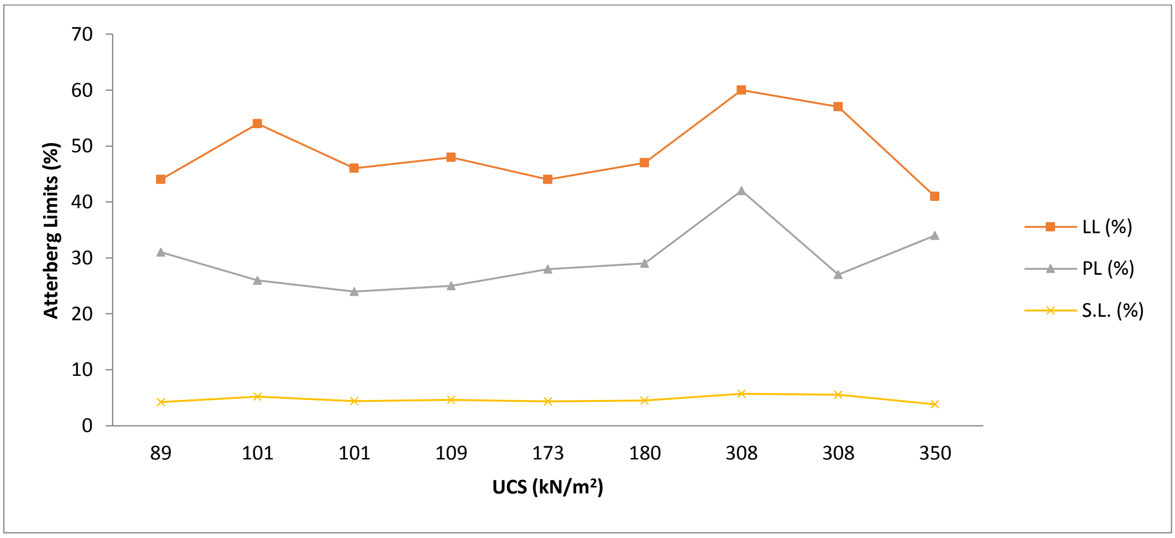


**Figure 5: Atterberg Limits vs UCS**

**Table 6: Mathematical Relationships Between Engineering Properties and Atterberg Limits**

| Equation No | Equation | $R^2$ | RSS |
|---|---|---|---|
| 1 | $MDD = -5.82 \cdot 10^{-3} PI^2 + 7.51 \cdot 10^{-2} PI.SL + 8.30 \cdot 10^{-2} SL^2 - 1.28 \cdot 10^{-1} PI - 2.28SL + 8.40$ | 0.62 | 0.025 |
| 2 | $CBR = 2.41 \cdot 10^{-1} PI^2 - 3.63PI.SL + 3.85SL^2 + 7.56PI + 34.02SL - 141.62$ | 0.71 | 43.88 |
| 3 | $UCS = -3.32PI^2 + 38.47PI.SL + 408.07SL^2 - 42.96PI - 4693.70SL + 11705.84$ | 0.83 | 14349.45 |

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