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Effects of Cyclic Wetting and Drying on Geotechnical Properties of Lateritic Soil in Ado Ekiti, Nigeria

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ABSTRACT

The objective of this research was to examine the impact of periodic wetting and drying on the geotechnical characteristics of lateritic soil in Ado Ekiti, Nigeria. For thirty days, a cyclic wetting and drying procedure was applied to thirty soil samples that were gathered from various locations in Ado Ekiti. Prior to and following the cyclic process, the geotechnical properties, including specific gravity, moisture content, liquid limit, plastic limit, and shrinkage limit, were ascertained. According to the findings, the lateritic soil's geotechnical characteristics were significantly influenced by the cyclic process. From an average of 2.55 to 2.41, the specific gravity fell, and from 16.5% to 23.3%, the moisture content increased. Furthermore, rising from an average of 38.6%, 23.2%, and 15.8% to 44.7%, 28.5%, and 18.5%, respectively, were the liquid limit, plastic limit, and shrinkage limit. This indicates that the lateritic soil was softer as a result of the cyclic process, which increased its susceptibility to deformation. These findings underscore the need for appropriate soil stabilisation techniques in areas prone to cyclic wetting and drying, and they have significant implications for the Ado Ekiti construction industry.

Key words: Wetting and drying, Shrinkage, Plastic limit, Deformation, Liquid limit, Lateritic soil, Ado-Ekiti

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1. INTRODUCTION

Lateritic soils are rich in iron and aluminum, highly weathered, and frequently rusty-red (high iron oxide content). They are primarily formed in hot, humid tropical and subtropical rock regions [1]. One of the most significant soils, it is frequently utilised for building a variety of engineering structures, such as dams and roadways. Lateritic soils are particularly prone to collapsing when wet, according to [1] and [3], who also observed that variations in moisture content cause shifts in the volume of laterites that have been compacted, which can lead to structural collapse, compression, and crumbling on roads. Additionally, lateritic soils have been observed to cause structural failures in highway pavements and embankments, particularly during rainy seasons [4]. Lateritic soils are a significant type of residual soil in Nigeria that can be found in plains and level areas of South-West Nigeria [5]. They are frequently used in road construction projects, particularly as fill material and flexible pavement foundations. Their ease of manipulation on the road surface and naturally stable grading with an appropriate proportion to act as binders are the main reasons for their use as sub-base and base construction materials [6]. Geotechnical parameters like specific gravity, shear strength, swelling potential, Atterberg limits, bearing capacity, and petrographic properties are influenced by the mineralogical composition of lateritic soil [7]. In addition, lateritic soils are employed in the construction of earthen roads (rural roads), dams, and breakwaters. In order to identify quarries where raw materials corresponding to the precise road construction can be borrowed, the contractor companies must conduct preliminary work such as surveys and basic geotechnical analyses (grain size analysis and Atterberg limits) on these soils prior to establishing the road infrastructure [8].

On roads, failure starts with the base materials. This can happen when the subbase materials are of poor quality and quantity, or when the base material deteriorates as a result of environmental variations, lowering the initial quality of those materials. When the pavement loses its ability to facilitate the smooth flow of vehicles carrying goods and services, road failure occurs. When evaluating and looking into road failure, it is crucial to give careful consideration to the structure and foundation of the road pavement. In any country that aspires to develop, the relationship between highway pavements and their foundation soils cannot be overstated [9]. Highway premature failure occurs within the highway pavement structure, the road foundation, or both [10]. Lateritic samples from various burrow pits in Ekiti State and its surroundings were used in this investigation. [11] discussed a variety of road failure scenarios, from potholes and cracks to road cuts that cause the pavement material to differentially heave and cause regular bumps on the highway. Our goal in conducting this study is to find out how the geotechnical characteristics of lateritic soil which is frequently utilised as a primary fill material in construction projects are affected by cyclic wetting and drying that occurs concurrently with weather fluctuation in most tropical regions.

2. MATERIALS AND METHODS

2.1 Study area

The study area, Ado-Ekiti, is situated at latitude 7.6124° N and longitude 5.2371° E in the humid tropical region of southwest Nigeria. As depicted in Fig. 1, the road network links and serves a number of other areas both inside and outside of Ado-Ekiti. The region is distinguished by seasons that alternate between rainy and dry. According to [8], the dry season lasts from October to March, while the wet season starts in April and ends in October. The air temperature is 25.10 °C, and the average annual rainfall is approximately 1334 mm. The natural moisture content, specific gravity, consistency limits, linear shrinkage, grain size distribution, compaction, California bearing ratio (CBR), compressive strength, and shear strength of the samples were tested in the laboratory, as shown in Figure 2. The British Standard Methods of Testing for Soils for Civil Engineering Purposes [12] were followed in the conduct of the laboratory tests shown in Figure 2. The standards were selected because road construction frequently uses them.

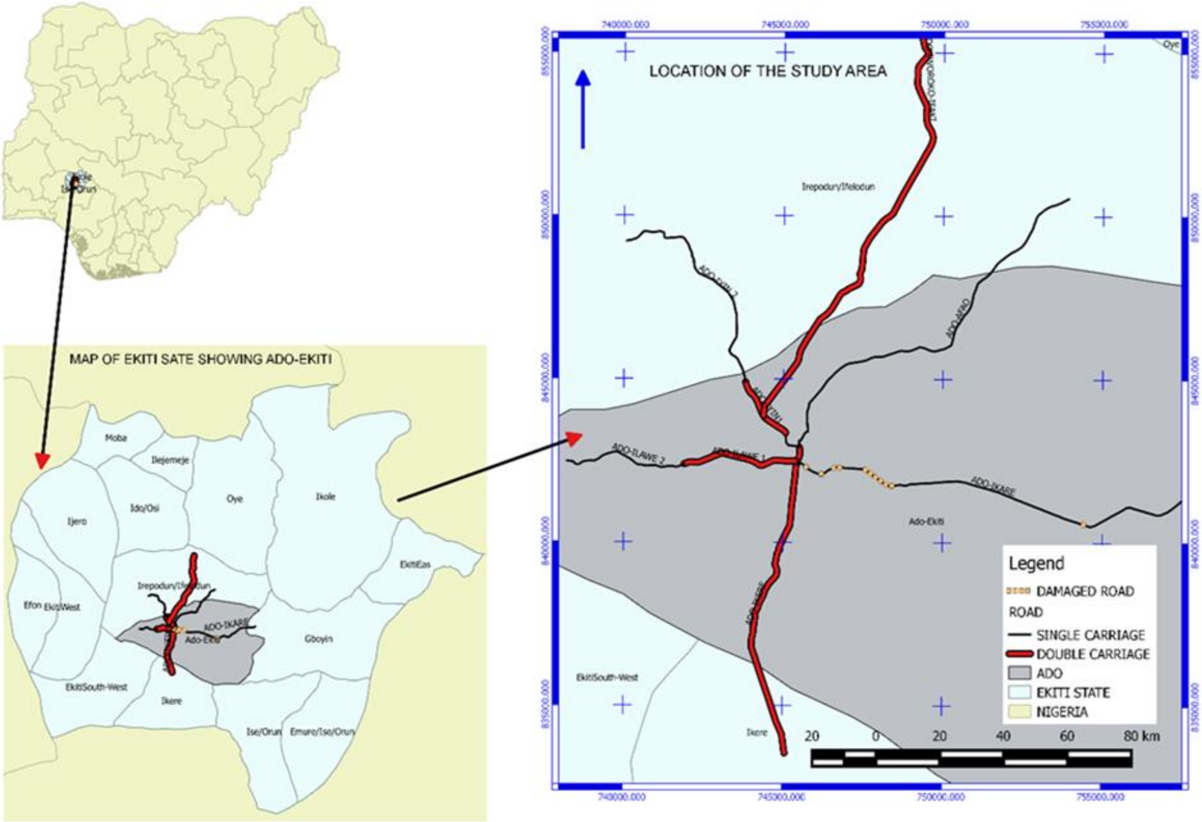

Figure 1: Location map of the study area showing the failed and stable sections of the road

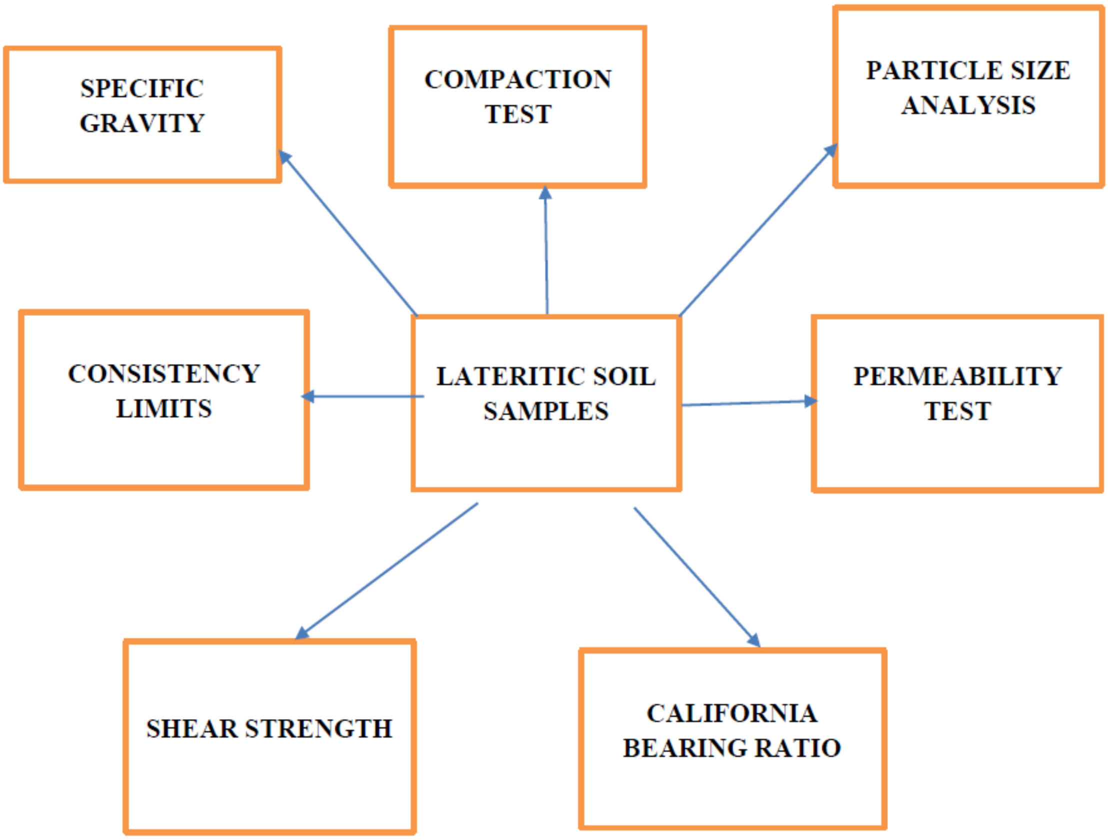

Figure 2: Experimental steps

2.2 Determination of specific gravity

The ratio of the density or specific weight of the soil particles to the density or unit weight of water is known as the particle density of soils, or specific gravity (Gs) [4]. Using the gas jar method, the specific gravity of lateritic soils that went through a 20-mm sieve was ascertained in compliance with BS 1377-2 [15]. Equation (1) was used to determine the specific gravity of the lateritic soil samples taken from the road pavement's failed and control sections.

$$G_s = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)} \quad (1)$$

Where, m_1 is the mass of the gas jar and the glass plate, m_2 is the mass of the gas jar, plate and dry soil, m_3 is the mass of the gas jar, plate, soil and water while m_4 is the mass of the gas jar, plate and water.

2.3 Determination of particle size distribution

A list of values or a mathematical function that specifies the relative amount, usually expressed in mass, of particles present according to size is known as the particle-size distribution (PSD) of a powder, granular material, or particles dispersed in fluid [14]. To break down soil particles into the PSD, also known as a grain size distribution, a significant amount of energy is typically needed [15]. Equations 2-4 were used to calculate the percentage of various grain sizes present in the soil during the test, which was carried out in accordance with the [12] standard [5].

$$\text{Weight passing} = [\text{ Total weight (g)} - \text{Weight retained (g)}] \quad (2)$$

$$\%\ \text{retained} = \frac{\text{Weight retained (g)}}{\text{Total weight (g)}} * 100\% \quad (3)$$

$$\%\ \text{passing} = 100 - \%\ \text{retained} \quad (4)$$

2.4 Determination of atterberg limit

The technique is predicated on measuring the water content at discrete points where the consistency of the soil varies. These transitions, also known as Atterberg limits, are described as shrinkage limits, plastic limits, and liquid limits. Equation 9 was used to calculate the obtained soil's linear shrinkage limit.

$$\mathrm{LS}\ (\%) = \left[1 - \frac{\mathrm{L_D}}{\mathrm{L_O}}\right] * 100 \tag{5}$$

where L_O is the specimen's initial length (mm) and LD is the length of the oven-dried specimen (mm). Equation 7 was used to determine each obtained sample's plastic limit.

$$\mathrm{LL^n} = \mathrm{W^n} * \left\langle\frac{\mathrm{N}}{25}\right\rangle^{0.121} \tag{6}$$

Where, LL^n is the one point limit for given trial, %; N is the number of blows causing closure of the groove for given trials; W^n is the water content for given trial, %. The plasticity index (PI) is a measure of the plasticity of a soil. The plasticity index is the size of the range of water contents where the soil exhibits plastic properties. The plasticity index (PI) is the difference between the liquid limit and the plastic limit and was computed using equation 7.

$$\mathrm{PI} = \mathrm{LL} - \mathrm{PL} \tag{7}$$

Where, LL is the liquid limit and PL is plastic limit.

2.5 Compaction test

The process of compaction involves applying mechanical energy to increase the degree of packing of soil particles [4]. A laboratory test called the Proctor compaction test was used to determine through experimentation the ideal moisture content at which a particular type of soil can reach its maximum dry density. When air is released while maintaining a constant moisture content, the tightly packed soil particles enhance the soil's strength, density, and bearing capacity. The compaction test was conducted in compliance with [6] and BS 1377-4 (1990), and the dry density was ascertained in conjunction with the bulk density. The material class and minimum field density suggested by the general specifications for road and bridge works [4] were taken into consideration when selecting these compaction tests. The test was conducted to find lateritic soil's maximum dry density (MDD) and ideal moisture content during wetting and drying cycles. Equation 8 was used to calculate the initial amount of water to be added.

$$\mathrm{W_{add}} = \frac{(\mathrm{S_m})8}{100} \tag{8}$$

Where, W_{add} is the water to add (ml); and S_m is the soil mass (g) [5]. The dry density was used to compute using equation 9.

$$\rho_d = \frac{\rho}{1+w} \tag{9}$$

Where, w is the moisture content in percent divided by 100; and ρ is the wet density in grams per cm^3 or kilogram per m^3.

2.5.1 California bearing ratio test

The resistance of a material to a plunger's penetration under controlled density and moisture conditions is measured by the California Bearing Ratio (CBR). The BS 1377-4(1990) standard was used to conduct this test. Prior to penetration, the collected samples were allowed to drain for 20 minutes after being vigorously compacted in a CBR mould and soaked for five days in a water tank. Equation 10 was used to calculate CBR based on the corrected load values.

$$\mathrm{CBR} = \frac{\mathrm{P_T} * \mathrm{C_F}}{\mathrm{P_s}} * 100 \tag{10}$$

P_T = Corrected unit test load corresponding to the chosen penetration from load penetration curve P_S = Total standard load for the same depth of penetration.

2.6 Wetting and drying cycles

After being compacted and soaked in water for a while, the laterite samples were oven dried at different temperatures in a series of wettings. Figure 3 illustrates how the oven drying times and temperatures were considered as variables. To ensure that every sample underwent cycles of wetting and drying, the wetting and oven-drying procedures were repeated. The compacted laterite underwent a geotechnical property test after each wetting and drying process. The collected data was examined to ascertain how wetting and drying affected the geotechnical characteristics of laterite with regard to road failure in the research region.

2.7 Data analysis

To evaluate potential differences during the different cycles of wetting and drying of the soil sample, statistical metrics like analysis of variance (ANOVA) were utilised. Between every treatment and the control, the least significant difference (LSD) was compared. To conduct additional statistical analyses, R-Studio for Statistical Computing was used.

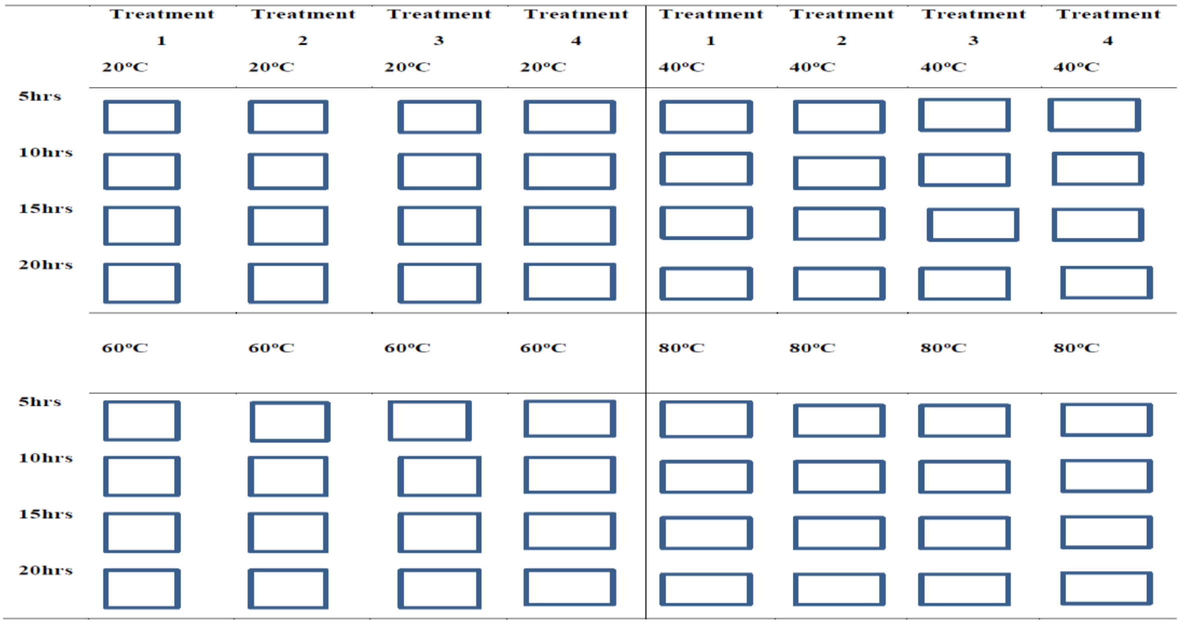

Figure 3: Experimental layout

3. RESULTS AND DISCUSSION

3.1 Impact of cycles of wetting and drying

Figure 4a shows the changes in suction as a function of water content (w). Estimates for the initial and first drying cycles' water content were 15%, and the cohesion and frictional angle were 26 °C and 77 kpa, respectively. At 180 degrees Celsius, the water content (w) decreased during the first drying cycle, resulting in a -0.30 loss of soil. The soil loss for the FRDs at 180°C decreased further by -0.4, but the loss at the second (SDs) and third (TDs) dry cycles remain constant. During the wetting process, when the temperature was raised from 20 to 80 degrees Celsius, the general behaviour of the lateric soil showed signs of swelling to some extent. Figure 3a shows that the maximum swelling was 0.33 at both FDs and SDs, and the lowest swelling was 0.30 at the TDs and 0.24 at the FRDs drying cycles. As shown in Figure 3a, the lowest soil loss of -1.8 was recorded at the first drying cycle (FDs) and the highest soil loss of -3.6 was recorded at the fourth drying cycle (FRDs) at the maximum heating temperature of 480 °C. With increasing wetting-drying cycles, the absolute swelling ratio rises while the relative swelling rates fall. For both natural and modified soil samples, both of these parameters reach their ultimate equilibrium during the last cycle. The result is in line with studies by [16] and [17], which demonstrated that the void ratio falls at maximum density and vice versa. Vacuum volume and void ratio are highly correlated; that is, when the water content is increased to the optimal level, the void volume decreases, resulting in the minimum void ratio.

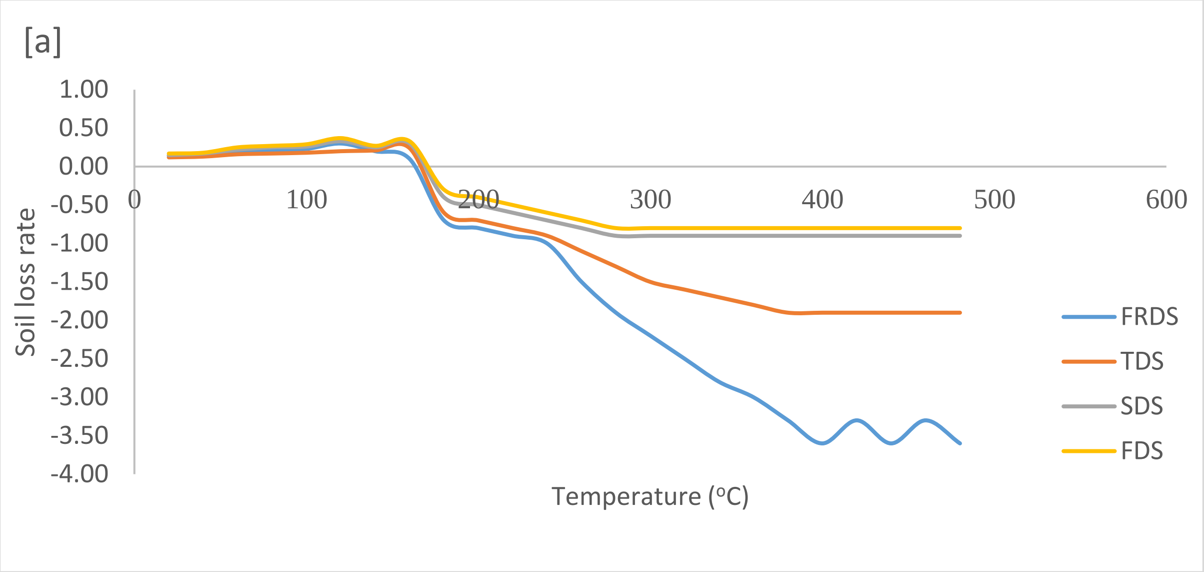

Figure 4a: Effect of temperature on soil loss rate

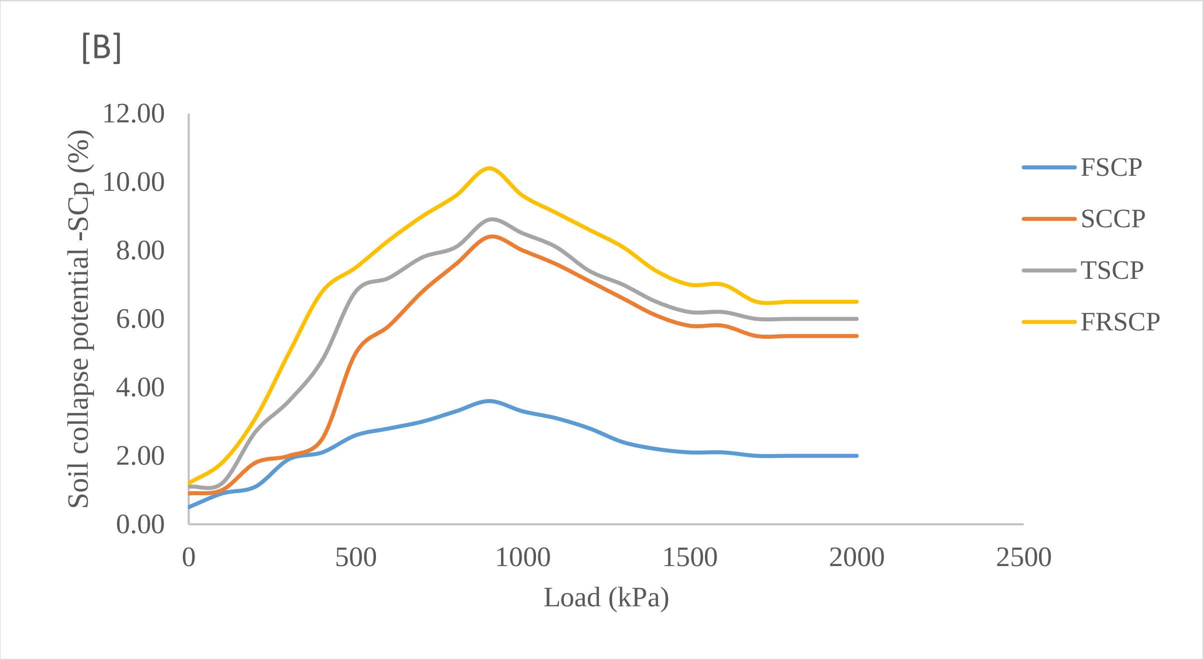

Figure 4b: Effects of applied stress on the soil collapse potential

The effects of drying-wetting cycles on the collapse potential (Cp) of lateric soil set at an initial water content (w) of 15% are shown in Figure 4b. The outcome showed how Cp changed at different drying and wetting cycles depending on the applied load. For example, at a stress of 900 Kpa, the Cp obtained at the first (FSCp), second (SCCP), third (TSCP), and fourth (FRSCP) collapse potentials was 3.6%, 8.4%, and 10.4%. Suction, on the other hand, clarifies the effect of the increase in Cp with decreasing water content; that is, as the water content drops, the suction rises, increasing capillary pressure and the lateric soil's resistance. This result is consistent with research by [18] and [19], which showed that the collapse potential increases with decreasing dry density, decreasing moisture content, and increasing vertical pressure. When wet, collapsible lateric soil exhibits significant settling without increasing the vertical soil's height, despite its ability to tolerate high applied vertical pressure and minimal compression. The behaviour of the soil structure during collapse is influenced by both stability and deformation phenomena combined. The macro-mechanical approach, which includes wetting, loading, creep, excess pore water pressure, and radial softening, and the micro-mechanical approach, which includes grain crushing, de-bounding, softening, hardening, and fabric transition, are the two levels at which the failure mechanisms of collapsible soils can be analysed and described. Soil collapse can be classified into two types: total collapse, which leads to the complete failure of the system, and local collapse, which is confined to the regions with weak soil structure. Without a thorough reconstruction of its structure, a total collapse cannot be balanced.

3.2 Free swelling rate

The results for each drying and wetting cycle of the lateric soil are shown in Figure 5a, along with the swelling reduction (SR) and free swelling (FS). In cycles two and three, the FS of the D-W cycle dropped from 40.2% in cycle one to 35.2% and 30.1%, respectively. On the other hand, as Figure 5a shows, a free swelling of 34.3% was obtained at the fourth drying and wetting cycle, and 27.4%, 28.3%, 23.4%, and 20.3% were obtained from cycles 5 to 8. The estimated coefficient of determination (R^2) value of 0.889 indicates that the free swelling values for subsequent drying and wetting cycles have decreased even more. As a result, cycle 8 produced the biggest reduction in free soil swelling, of -50.0%, as shown in Figure 5b. The results align with those of multiple studies. According to [20], when full shrinking is used, the progressive decrease in free swelling behaviour in relation to the adopted shrinking is the opposite. The results of [12] demonstrated varying degrees of increases and decreases in the free swelling, which differed from the findings of the current studies. Particularly when it comes to permeability, elasticity modulus, and compressive strength, soil density and plasticity have a major impact on mechanical behaviour. During the W-D process, shrinkage causes soil density to rise with decreasing water content and vice versa [21].

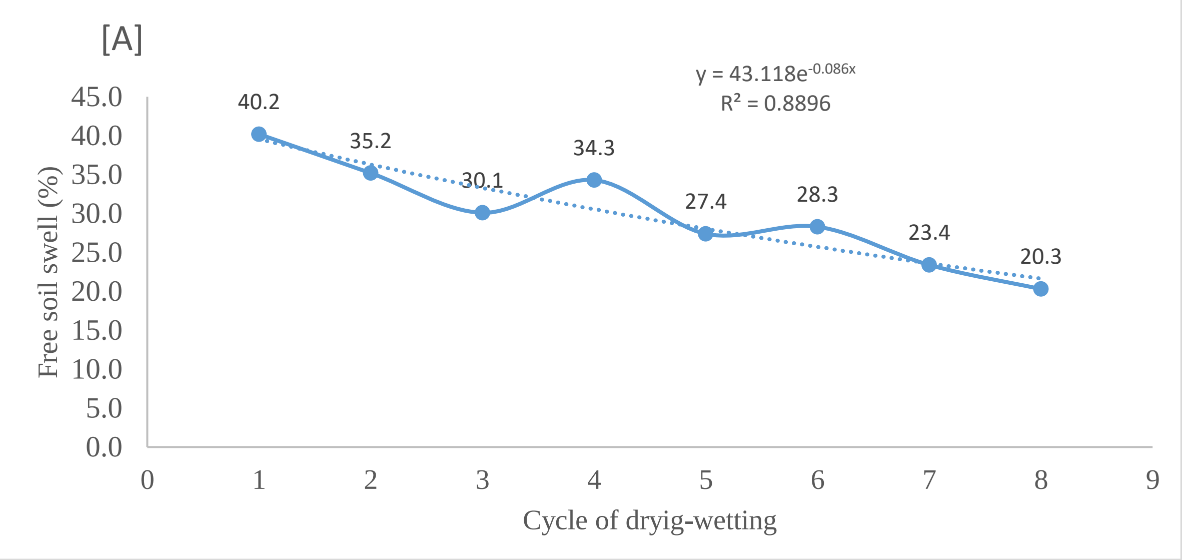

Figure 5a: Free swell increase

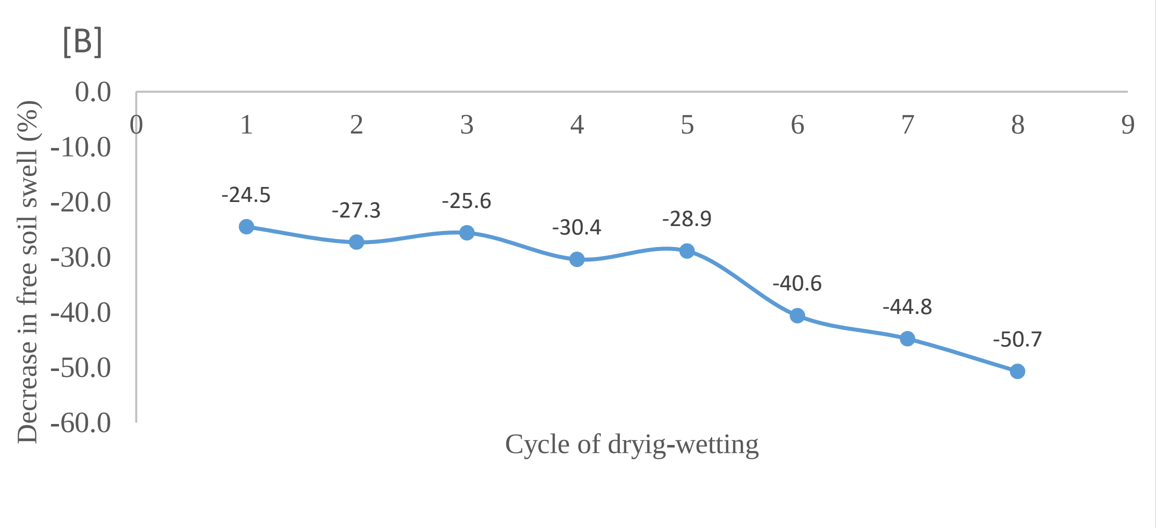

Figure 5b: Free swell decrease

4. CONCLUSION

Based on the findings of the analysis, unconfined compression tests were carried out on a compacted expansive soil mixture of lateritic soil under drying-wetting cycle repetition. The results showed that the D-W cycle repetition had a significant impact on the soil's suction, compressive strength, and soil volume change. Increased cycles result in a decrease in the void ratio and an increase in the saturation level. Soil suction also tends to decrease at the same void ratio, as does soil compressive strength at the same water content. Consequently, the research findings offer a valuable database of geotechnical properties for lateritic soil in Ado-Ekiti, Nigeria.

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