Direct Research Journal of Engineering and Information Technology
Vol. 7(5), pp. 84-96, September 2020
ISSN 2354-4155
DOI: https://doi.org/10.26765/DRJEIT29087657011
Article Number: DRJEIT29087657011

http://directresearchpublisher.org/drjeit/

Full Length Research Paper

Behaviour and Effect of Clay Soils on Engineering Constructions in Nigeria: Implications for Geotectonism

***[1]Kankara, I. A., and [2]Yunusa, L. U.**

[1]Department of Geology, Federal University Dutsin-Ma.
[2]Department of Geology, Ahmadu Bello University Zaria.
Corresponding Author E-mail: aibrahim@fudutsinma.edu.ng

Received 3 July 2020; Accepted 26 August, 2020

ABSTRACT: Expansive soils occurring in arid and semi-arid climatic regions (with most parts of northern Nigeria inclusive) of the World cause unaccounted problems on civil engineering structures. Such soils swell when given access to water and shrink when they dry out. This present study examines the condition of brick and fire clay soils from Kankara and Dutsin-Ma in Katsina State, and Sokoto sedimentary Basin, both in Nigeria, that poses engineering problems when used in construction. The methodology adopted for the study was mainly primary and secondary sources in which clay studies were collected and investigated in the field, based on their mineralogical and physical behaviours. Other sources of data came from previous constructions that used clay soils. The findings of the study were that the clay soils have significant geotechnical and structural engineering challenges, accompanied with a lot of damages and costs lost if used. It was recommended that modern divisive means of modifying the structures of clay soils be adopted to improve their properties.

Keywords: Expansive soils, Swell-Shrink behaviour, structural damage, engineering constructions, Nigeria

INTRODUCTION

The Nigerian clay deposits have been reported to be derived from the weathering of Precambrian feldspar rich pegmatite which are controlled by fractures in the quartz-mica schists (Oyeka and Beltaro,1974; Ibrahim, 1990; Kankara, 2014) Evidences of these are indicated by the remnants of some altered muscovite plates observed in fresh clay samples.

As noted by Ibrahim (1990) and Kankara and Sada (2009), common sedimentary clays are found almost everywhere, but high grade residual clays are more restricted in distribution (Table 1). Most are of Pleistocene age, and nearly all are Post Paleaozoic, only few are Mesozoic in age. They are found particularly in areas where they overlie the crystalline basement complex where they are produced by the tropical weathering of granitic and gneissic rocks, schists and pegmatites. Their production in recent times has lead to a rapid growth in the construction and building industry in Nigeria.

Residual clay deposits are usually formed by in-situ weathering of crystalline rocks accompanied by some distinctive irregular shape, gritty texture and variable degree of ferruginization (Ibrahim, 1990; Kankara and Sada, 2009). In Nigeria, several attempts are being made to control the swell-shrink behaviour of clay soils (Figure 1). The swelling potential of the expansive soil mainly depends upon the properties of soil and environmental factors and stress conditions. Each year, expansive soils cause in damage to houses, other buildings, roads, pipelines, and other structures. This is more than twice the damage from floods, hurricanes, tornadoes, and earthquakes combined. This study presents description of expansive soil, shrink - swell behaviour and its control, factors influencing swelling and structural damage.

Expansive soils are great problems in Nigeria that poses several challenges for civil engineers. They are considered potential natural hazard, which can cause extensive damage to structures if not adequately treated. Guney *et al*. (2007) saw geological engineering problems due to expansive soils as having been reported in many countries. They cause millions of dollars due to their severe damages on structures, sometimes lost of lives and properties. These damages are most common especially in the arid and semi-arid regions.

Expansive soils contain the clay mineral montmorillonite with clay stones, shales, sedimentary and residual soils which are capable of absorbing reasonable amount of water and expand (Kankara and Sada, 2009) as shown in (Figure 2). The expansive nature of the clay is less near the ground surface where the profile is subjected to seasonal and environment changes. The more water they absorb the more their volume increases. Expansive soils also shrink when they dry out. Fissures in a soil can also develop (Chen and He, 1985) these fissures help water to penetrate to deeper layers when water is present. This produces a cycle of shrinkage and swelling that causes the soil to undergo great amount of volume changes. This movement in the soil results in structural damages especially in lightweight structures such as sidewalks, driveways, basement floors, pipelines and foundations (Lee, 2011).

As observed by Al- Homoud *et al*. (1995) expansive soils cause more damage to structures, particularly light buildings and pavements, than any other natural hazard, including earthquakes and floods. Control and mitigation of the swell-shrink behaviour of expansive soil will be investigated in this study. Control of the swell-shrink behaviour can be accomplished in several ways, for example by replace existing expansive soil with non-expansive soil, maintain constant moisture content and improve the expansive soils by stabilization.

MATERIALS AND METHODS

Geological context of Nigeria

The surface area of Nigeria is underlain by almost halves proportions by meta-sedimentary rocks and basement and younger subordinate rocks. The former are further sub-divided into three (3) main groups: The basement rocks, the Jurrassic younger granites and the volcanic rocks. The Precambrian of African consists of three major cratonic areas (Kankara, 2014). The Congo, the West African and Kalahari cratons, which have remained stable since 1,100 Ma years ago and mobile belts which surround the cratons and were transformed by the late event of Proterozoic Pan-African about 650+150 Ma years. Nigeria is found in between mobile belt that separates the West African craton and Congo craton (Black and Girod, 1972; Kankara, 2014)

In the basement rocks of Nigeria, major categories of these units known within the basement complexes of Nigeria are: migmatite-gniess, schists belts (metasediments and metavolcanics), The older granites (which are Pan-African granites) and non-affected dykes which were acidic and basic in compositions. The basement complex outcrops are distributed in three areas (Pearce, 1983; Ajibade, 1986). A triangular area in southwestern Nigeria where the rocks continue westwards into the neighboring Benin Republic, the circular to angular areas in northern Nigeria, and a rectangular area intersected by sedimentary rocks on the extreme eastern part of Nigeria with Cameroon. The basement complexes can further categorized into: A polycyclic migmatite-geniss-quartzite rocks; the Schist composed of Meta sedimentary with subordinate meta volcanic rocks, charnokitic, gabbroic, dioritic rocks and Older Granites which are the granitoids (Rahaman, 1971; Olayinka, 1992).This present research excludes other type of clay, the kaolinitic. It focuses on the collection of other two types of clays as samples; the bric k and fire clays (Table 1). Some works of engineering Schist composed of Metasedimentary with surbodinate metavolcanic rocks, charnokitic, gabbroic, dioritic rocks and Older Granites which are the granitoids (Rahaman, 1971; Olayinka, 1992).

Data collection and analysis

The research carried out by similar and present research, coupled with the samples of maps of some major structures have contributed towards modifying and completing this work. This procedure enabled the present research to make proper meaning, and besides, to proceed to knowing the technical problems in most civil engineering constructions involving clay soils. The next or fourth stage consisted of a effect of using clay in constructions on samples collected from field and in the laboratory which enabled the researcher to determine the different deformation stages in such constructions. The clay samples collected based were analyzed at Department of Geology, Usumanu Danfodio University, Sokoto, Nigeria.

Review of Related Literature

Dif and Blumel, (1991) and Day, (1994) highlighted that the mineral make-up of this type of soil is responsible for

Figure 1: Map of Nigeria showing major cities (Kankara, 2016).

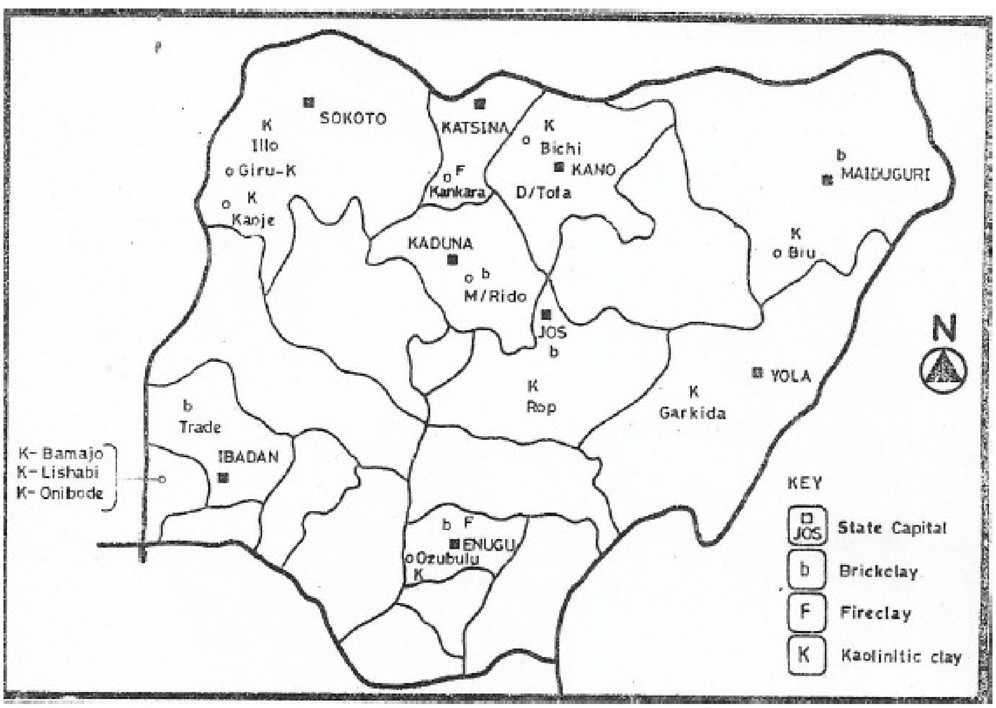

Figure 2: Map of Nigeria showing Areas of Residual Clay Deposits (Ibrahim, 1990).

the moisture retaining capabilities. All clays consist of mineral sheets packaged into layers, and can be classified as either 1:1 or 2:1. These ratios refer to the proportion of tetrahedral sheets to octahedral sheets. Octahedral sheets are sandwiched between two tetrahedral sheets in 2:1 clays, while 1:1 clays have sheets in matched pairs. Expansive clays have an expanding crystal lattice in a 2:1 ratio; however, there are 2:1 non-expansive clays (Figure 3). Soil that cracks or fractures when it dries is often a sign that it is expansive; however a lack of cracks does not necessarily indicate that the soil is not expansive. Soils containing expansive

Table 1: Summary of some residual clay deposits in Nigeria.

Deposit Location	State	Type	Reserves in Tonnes
Ukpor	Anambra	Kaolinitic	6,000,000
Uzubulu	Anambra	Kaolinitic	4,200,000
Okpekpe	Edo	Kaolinitic	6,000,000
Kankara	Katsina	Kaolinitic	3,400,000
Illo	Sokoto	Kaolinitic	Very large
Kaoje	Sokoto	Kaolinitic	Very large
Giru	Sokoto	Kaolinitic	Very large
Bamajo	Ogun	Kaolinitic	Very large
Lishabi	Ogun	Kaolinitic	Very large
Onibode	Ogun	Kaolinitic	Very large
Ropp	Plateau	Kaolinitic	Not available
Dawakin Tofa	Kano	Kaolinitic	Not available
Garkida	Adamawa	Kaolinitic	Not available
Biu	Borno	Kaolinitic	Not available
Trade	Oyo	Brickclay	1, 524,000
Enugu	Anambra	Brickclay	19,000,000
Maraba Rido	Kaduna	Brickclay	5, 524,000
Jos	Platea	Brickclay	Large
Maiduguri	Borno	Brickclay	Large
Enugu	Anambra	Fire clay	50,000,000
Dutsin-Ma	Katsina	Kaolinitic	Very large

Source: Nehikhare, 1986; Kankara, (2020).

Figure 3: Expansive soil with cracks.

clays become very sticky when wet and usually are characterized by surface cracks or a popcorn texture when dry (Figure 4). Expansive soils take on popcorn like appearance when they dry, they look like someone spread little lumps of popcorn shaped dirt on the soil surface, it is shown in the (Figure 1). Expansive soils are often clay like, becoming very sticky when wet and hard and brittle when dry. The best way to determine if the soil at a location is expansive is to have an expansion test performed by a soil expert. Expansive soils are common in desert areas, in river bottoms or valleys formed by sediment (Bilsel, 2002). The effect of cyclic swell-shrink on the swelling behaviour of natural soil is studied by many researchers (Popesco, 1980; Chen *et al*., 1987; Subba Rao and Satyadas, 1987; Dif and Blumel, 1991; Day, 1994; Al Homoud *et al*., 1995; Bilsel, 2002; Tripathy, 2002). Some investigators studied the swelling characteristics of expansive soils after repeatedly wetting-drying cycles. Chen and He (1985), Chen *et al*. (1987), Subba Rao and Satyadas, (1987), Dif and Bluemel, (1991) concluded that when soils were subjected to full swell and allowed to shrink to their initial water content, they showed less expansion due to the fatigue of clay after Popesco, (1980), Day, (1994) and Guney *et al*. (2007) concluded that swelling potential increased with the number of cycles. Al Homoud *et al*. (1995) stated that cyclic wetting-drying resulted in particle aggregation. He supported his findings by the reduction

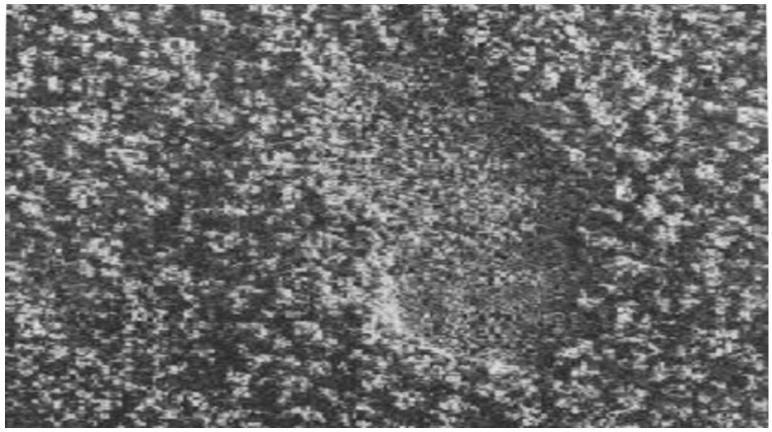

Figure 4: Expansive soil with “popcorn” texture.

in clay content and the plasticity index values of the soils after the increasing number of cycles. This inevitably causes reduction in the swelling characteristics (Tawfiq and Zalihe, 2009).

RESULTS AND DISCUSSION

The study area and synoptic geology

Kankara (2014) and Kankara and Darma (2016) stated that Nigeria is situated in the West African region and lies between longitudes 3 degrees and 14 degrees and latitudes 4 degrees and 14 degrees. It has a land mass of 923,768 sq.km. It is bordered to the north by the Republics of Niger and Tchad, to the west with the Republic of Benin, while the Republic of Cameroun shares the eastern borders right down to the shores of the Atlantic Ocean which forms the southern limits of Nigerian Territory (Figure 1). The 800km of coastline confers on the country the potentials of a maritime power. Land is in abundance in Nigeria for agricultural, industrial and commercial activities. At its widest, Nigeria measures about 1,200 km from east to west and about 1,050 km from north to south. The country’s topography ranges from lowlands along the coast and in the lower Niger Valley to high plateaus in the north and mountains along the eastern border. Much of the country is laced with productive rivers. Nigeria’s ecology varies from tropical forest in the south to dry savanna in the far north, yielding a diverse mix of plant and animal life. Inland from the southeastern coast are progressively higher regions.

The Basement rocks in Nigeria are among the three major lithological units that make up the unique geology. It forms part of the Pan-African mobile belt and lies between the West African Craton and the Congo craton and south of the Tuareg Shield which is intruded by the Mesozoic ring complexes, notably the Jurrassic Younger Granites of the Jos Plateau and is unconformably overlain by Cretaceous and Younger metasediments. The Nigerian Basement was affected by the Pan-African Orogenic event and which occupied the re-worked region that resulted from collision of plates between the West African continental margin Craton and the continental margin (Dada, 2006; Kankara, 2016). These rocks are believed to have originated as the result of former major orogenic cycles of metamorphism and remobilization that occurred around 2,700Ma; the 2,000Ma; the 1,100Ma) and 650 + 150 my.

Geology of the residual clay deposits in Nigeria

Clay deposits in Nigeria lie in the crystalline Basement Complex. They are composed mainly of migmatites and gneiss. They are derived from alterations of Basement gneiss which form the surrounding country rocks (Kankara and Sada, 2009) (Table 1).Structural features observed in unweathered rocks associated with clays reveal the intensity of the Pan-African Orogeny, and are largely attributable to the alterations of feldspar-rich pegmatite veins in the gneiss. In areas such as the Kankara residual clay deposits, the structural features resulted in tight isoclinal folding, as observed in the basement complex with axes at about East to West, and North to South directions in the extensive mgmatite and the homogenous gneiss that accompanied the first and the second deformations (Ibrahim, 1990). During these orogenic events, two successive phases of intense Alphine-type deformations took place (McCurry, 1970; Kankara, 2014). Investigations in the environment of clay minerals gneiss show that primary silicates hydrolyzed in an environment with a high activity of H^+ have resulted in the removal of alkali and alkaline earth metals and their replacement by H^+.

Description of expansive soils

Most soils in the Front Range in Nigeria have tendency to swell. This means that the soils contain high percentage

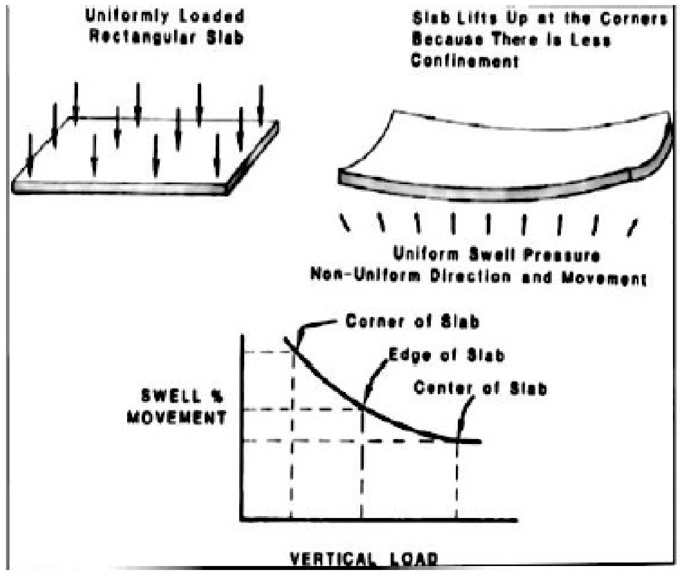

Figure 5: A rectangular slab, uniformly loaded, will tend to lift up in the corners because there is less confinement.

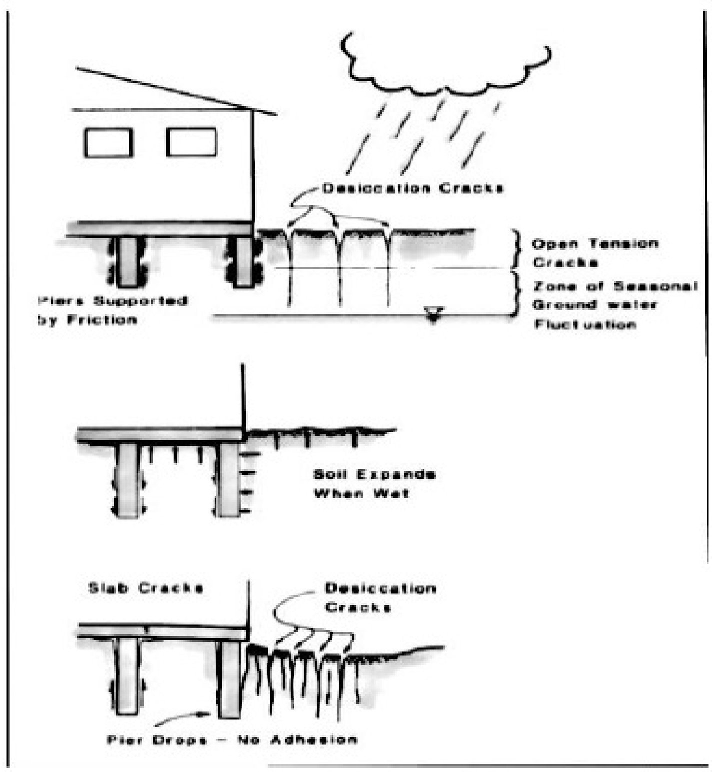

Figure 6: Damage to home supported on shallow piers. (i) At the beginning of the rainy season, the piers are still supported by friction with the soil. When it begins to rain, water enters deep into the soil through the cracks. (ii) After 5 to 10 large storms, the soil swells, lifting the house and piers. (iii) In the dry season, the groundwater table falls and the soil dries and contracts. As tension cracks grow around the pier, the skin friction is reduced and the effective stress of the soil increases (due to drying). When the building load exceeds the remaining skin friction or the effective stress of the soil increases to an all-time high, adhesion is broken by this straining, and the pier sinks.

of certain types of clays that absorb vast quantities of water. Expansive soils are also sometimes called shrink-swell soils, swelling soils, adobe, clay, or caliche soils (Lucian, 2011). This can cause the soils to expand 10% or more as moisture enters it, usually during winter snow melt and spring runoff. The soil then exerts tremendous pressure on foundations, slabs, and other structures. Now, this soil also contracts when the moisture evaporates during our hot summer months, causing extreme differences in the pressure being generated on your foundation, driveway, or patios. Expansive soils contain minerals such as smectite clays that are capable of absorbing water. When they absorb water, they increase in volume and size. The more water they absorb, the more their volume increases. Expansions of 10% or more are not uncommon. This change in volume can exert enough force on a building or other structure to cause damage. Cracked foundations, floors, and basement walls are typical types of damage done by swelling soils. Damage to the upper floors of the building can occur when motion in the structure is significant (Figure 6). Expansive soils will also shrink when they dry out. This shrinkage can remove support from buildings or other structures and result in damaging subsidence. Fissures in the soil can also develop. These fissures can facilitate the deep penetration of water when moist conditions or runoff occurs. This cycle of shrinkage and swelling places repetitive stress on structures, and damage worsens over time (Baser, 2009)

Identifying expansive soil

In Kankara (2020), it was observed that expansive soils are clay soils that are prone to large volume changes (swelling and shrinking) that are directly related to changes in water content. Soils with a high content of expansive minerals can form deep cracks in drier seasons or years; such soils are called vertisols. The minerals that determine the natural expansiveness of the soil include smectite, montmorillonite, nontronite, vermiculite, illite, bentonite and chlorite. They have the most dramatic shrink-swell capacity (Figures 3 and 4).

Swell - Shrink Behaviour

The swell - shrink potential of expansive soils is determined by its initial water content; void ratio; internal structure and vertical stresses, as well as the type and amount of clay minerals in the soil. Swelling pressures can cause heaving, or lifting, of structures whilst shrinkage can cause differential settlement. Failure results when the volume changes are unevenly distributed beneath the foundation, as noted by Lee, (2011). Generally, the larger the amount of these minerals presents in the soil, the greater the expansive potential. However, these expansive effects may become ‘diluted’ by the presence of other non-swelling minerals such as quartz and carbonate (Kankara and Sada, 2009). Excluding deep underground excavations (e.g. tunnels), shrinkage and swelling effects are restricted to the near surface zone; significant activity usually occurs to about 3m depth, but this can vary depending on climatic conditions. Fine-grained clay-rich soils can absorb large quantities of water after rainfall, becoming sticky and heavy. Conversely, they can also become very hard when dry, resulting in shrinking and cracking on the ground. This hardening and softening is known as ‘shrink-swell’ behaviour. When supporting structures, the effects of significant changes in water content on soils with a high shrink–swell potential can be severe. Swelling and shrinkage are not fully reversible processes (Figures 5 and 6). The process of shrinkage causes cracks, which on re-wetting, do not close-up perfectly and hence cause the soil to bulk-out slightly, and also allow enhanced access to water for the swelling process. In geological time scales shrinkage cracks may become in-filled with sediment, thus imparting heterogeneity to the soil. When material falls into cracks the soil is unable to move back, thus resulting in enhanced swelling pressures (Jefferson, 2011).

Geological and geochemical factors influencing swelling

The swell potential of an expansive soil may be affected by either the soil properties influencing the nature of the internal force field, the environmental factors those may change the internal force system or the state of stress present on the soil (Figure 7).
Some physical factors such as initial water content, initial density, amount and type of compaction also influence the swell potential and swell parameters of soils (Baser, 2009).
These factors are summarized below:

Soil properties influencing swell potential

Clay mineralogy

Clay minerals commonly form as breakdown products of feldspars and other silicate minerals. They are phyllosilicates with a layered crystal structure similar to that of micas and compositionally they are aluminosilicates. The crystal layers are made up of silica with aluminium and magnesium ions, with oxygen atoms linking the sheets (Figure 7). Two patterns of layer-ing occur, one with two layers, the *kandite group*, and the other with three layers, the *smectite group*. Of the many different clay minerals that occur in sedimentary rocks the

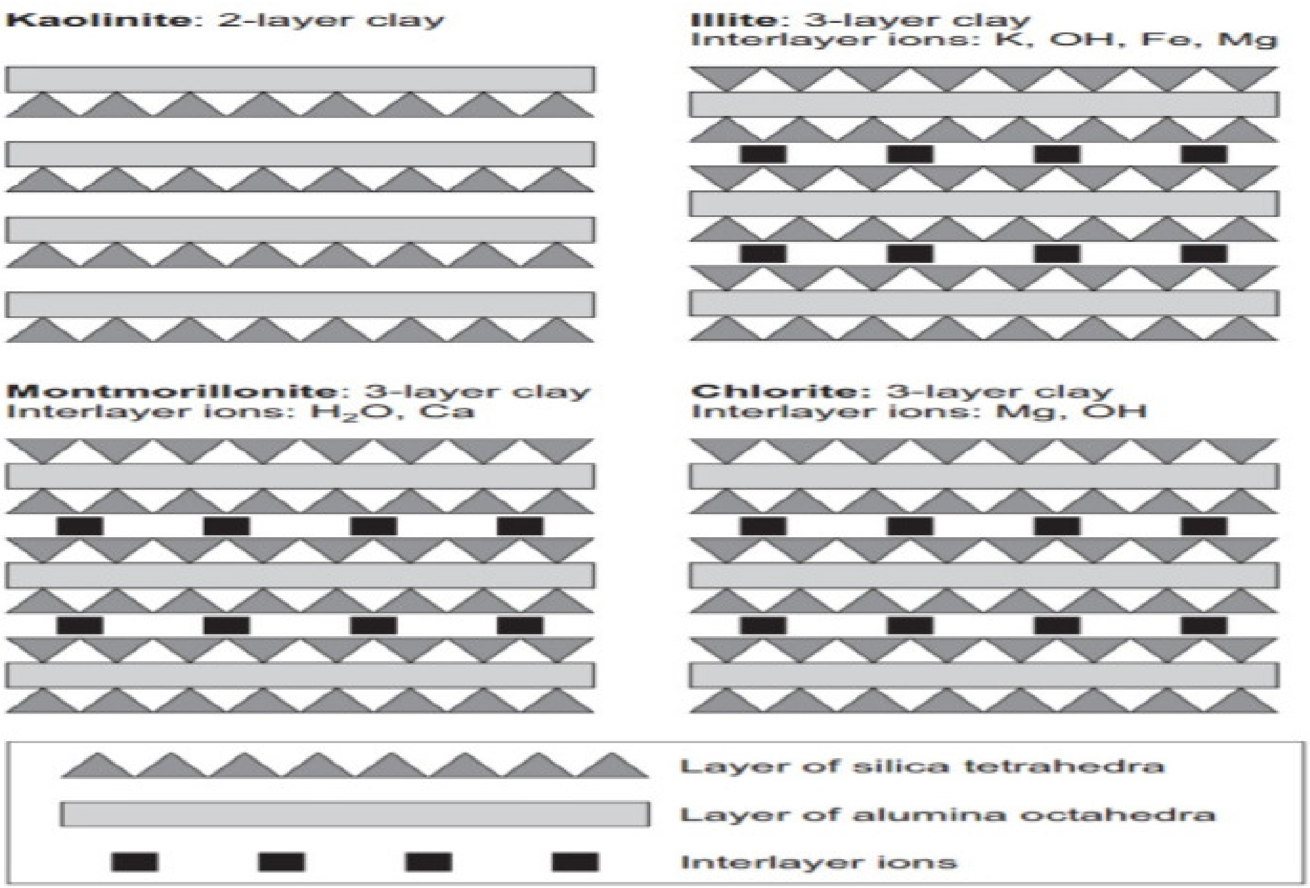

Figure 7: The crystal lattice structure of some of the more common clay minerals.

four most common are considered here (Figure 7). *Kaolinite* is the commonest member of the kandite group and is generally formed in soil profiles in warm, humid environments where acidic waters intensely leach bedrock lithologies such as granite. Clay minerals of the smectite group include the expandable or *swelling clays* such as *montmorillonite*, which can absorb water within their structure. Montmorillonite is a product of more moderate temperature conditions in soils with neutral to alkaline pH. It also forms under alkaline conditions in arid climates.

Another three-layer clay mineral is *illite*, which is related to the mica group and is the most common clay mineral in sediments, forming in soils in temperate areas where leaching is limited. *Chlorite* is a three-layer clay mineral that forms most commonly in soils with moderate leaching under fairly acidic groundwater conditions and in soils in arid climates. Montmorillonite, illite and chlorite all form as a weathering product of volcanic rocks, particularly volcanic glass. Clay minerals which typically cause soil volume changes are montmorillonites, vermiculates, and some mixed layer minerals. illlites and kaolinites are frequently in expansive, but can cause volume changes when study sizes are extremely fine.

Soil water chemistry

Swelling is repressed by increased cation concentration and increased cation valence. For example, Mg2+ cations in the soil water would result in less swelling than Na+ cations (Kankara, 2014).

Soil Suction

Soil suction is an independent effective stress variable, represented by the negative pore pressure in unsaturated soils. Soil suction is related to saturation, gravity, pore size and shape, surface tension, and electrical and chemical characteristics of the soil study and water.

Plasticity

In general, soils that exhibit plastic behaviour over wide ranges of moisture content and that have high liquid limits have greater potential for swelling and shrinkage. Plasticity is an indicator of swell potential. Soils, particularly clays, display a significant amount of inelasticity under load. The causes of plasticity in soils can be quite complex and are strongly dependent on the microstructure, chemical composition, and water content. Plastic behaviour in soils is caused primarily by the rearrangement of clusters of adjacent grains (Kankara and Sada, 2009).

Soil structure and fabric

Flocculated clays tend to be more expansive than dispersed clays. Cemented study reduce swell. Fabric and structure are altered by compaction at high water content or remolding. Kneading compaction has been shown to create dispersed structures with lower swell potential than soils statically compacted at lower water contents.

Dry density

Higher densities usually indicate closer study spacing, which may mean greater repulsive forces between study and larger swelling potential.

Environmental factors affecting swell potential

Initial moisture content

A desiccated expansive soil will have high affinity for water, or higher suction than the same soil at higher water content, lower suction. Conversely, a wet soil profile will lose water more readily on exposure to drying influences, and shrink more than a relatively dry initial profile. The initial soil suction must be considered in conjunction with the expected range of final suction conditions.

Moisture variations

Changes in moisture in the active zone near the upper part of the profile primarily define heave, it is in those layers that the widest variation in moisture and volume change will occur

Climate

Amount and variation of precipitation and evapotranspiration greatly influence the moisture availability and depth of seasonal moisture fluctuation. Greatest seasonal heave occurs in semiarid climates that have short wet periods.

Groundwater

Shallow water tables provide source of moisture and fluctuating water tables contribute to moisture.

Drainage

Surface drainage features, such as ponding around a poorly graded house foundation, provide sources of water at the surface; leaky plumbing can give the soil access to water at greater depth.

Vegetation

Trees, shrubs, and grasses deplete moisture from the soil through transpiration, and cause the soil to be differentially wetted in areas of varying vegetation.

Permeability

Soils with higher permeability, particularly due to fissures and cracks in the field soil mass, allow faster migration of water and promote faster rates of swell.

Temperature

Increasing temperatures cause moisture to diffuse to cooler areas beneath pavements and buildings.

Stress conditions affecting swell potential

Stress history

An over consolidated soil is more expansive than the same soil at the same void ratio, but normally consolidated. Swell pressures can increase on aging of compacted clays, but amount of swell under light loading has been shown to be unaffected by aging. Repeated wetting and drying tend to reduce swell in laboratory samples, but after a certain number of wetting-drying cycles, swell is unaffected.

In situ Conditions

The initial stress state in a soil must be estimated in order to evaluate the probable consequences of loading the soil mass and/or altering the moisture environment therein. The initial effective stresses can be roughly determined through sampling and testing in a laboratory, or by making in-situ measurements and observations.

Loading

Magnitude of surcharge load determines the amount of volume change that will occur for a given moisture content and density. An externally applied load acts to balance inter-particle repulsive forces and reduces swell.

Soil profile

The thickness and location of potentially expansive layers in the profile considerably influence potential movements.

Figure 8: Structural damage to house caused by ‘end lift’ (Lee, 2011).

Figure 9: Major cracks in exterior walls at doors and windows (Gunev et al, 2007).

Greatest movement will occur in profiles that have expansive clays extending from the surface to depths below the active zone. Less movement will occur if expansive soil is overlain by non-expansive material or overlies bedrock at shallow depth.

Effects of expansive soils on structures

All structures experience various levels of damages during their lifetime. For structures to be economical especially those made of concrete, a certain degree of cracking is inevitable. The damages are due to design faults or no design at all, cheap construction materials, poor workmanship or calamities, poor drainage characteristics, climatic condition and intricate behaviour of expansive soils (Figure 8). The most obvious identification of drainage to buildings are doors and windows that get jammed, uneven floors, and cracked foundations, floors, masonry walls and ceilings. Moreover, different crack patterns mean causes for different foundation materials. In most cases cracks due to shrinkage and expansive clay (Figure 9) usually run from corner towards adjacent opening and are uniform in width or v-shaped, wider at the top than the foundation wall. This pattern of cracks happens when the moisture movement is from the perimeter to the center of the house (Lucian, 2011). Swelling pressures can cause heaving, or lifting, of structures whilst shrinkage can cause differential settlement. Failure results when the

Figure 10: Residential driveway damaged by expansive soil (Al-Homoud *et al*., 1995).

Figure 11: Cracks in exterior walls, as a result of upward soil expansion (Popescu, 1980).

volume changes are unevenly distributed beneath the foundation. For example, water content changes in the soil around the edge of a building can cause swelling pressure beneath the perimeter of the building, while the water content of the soil beneath the center remains constant. This results in a failure known as end lift. The opposite of this is center lift, where swelling is focused beneath the center of the structure or where shrinkage takes place under the edges (Lee, 2011). Often, damage from expansive soils can be seen within the first few months or years after a home is constructed (Figures 10 and 11). As water from irrigation or rainfall migrates underneath the homes foundation, the soil around the edge of the foundation expands, pushing up on the edges of the foundation. This condition, called edge-lift, can cause cracking in the drywall and in the foundation itself. Over a period of years, as the moisture further migrates underneath the center of the slab, center-lift can occur, causing additional damage to the home.

Controlling the swell-shrink behaviour

Expansive soils owe their characteristics to the presence of swelling clay minerals. As they get wet, the clay minerals absorb water molecules and expand; conversely, as they dry they shrink, leaving large voids in the soil. Swelling clays can control the behaviour of virtually any type of soil if the percentage of clay is more than about 5% by weight. Soils with smectite clay minerals, such as montmorillonite, exhibit the most profound swelling properties. However, the shrink-swell behaviour can be controlled through the replacement of existing expansive soil with non-expansive soils, maintaining constant moisture content and improving the expansive soils by stabilization.

Replacement of existing expansive soil with non-expansive soil

The process involves replacing the original top expansive soil with compacted non-expansive backfill to a depth below which the seasonal moisture content will tend to remain constant. The idea behind is to capitalize on constant specific volume maintained by non-expensive soil when the water contents change. However, soil replacement is economical for reasonable thickness of the expansive soil. Thus, if the expansive stratum extends to a depth too great to remove economically, then other treatments should be sought.

Maintaining constant moisture content

Increased moisture content

The main source of soil moisture changes in the soils is rainfall. Other sources include poor drainage system and poor roof drainage, plumbing leakage and wet spots around the foundation, overwatering and trees. The following recommendations are put forward against each source.

Rainfall

The way out is to properly grade the soil around the building with a reasonable slop enough to carry all water well away from the foundation and beyond the backfill area. Gutters with downspouts should be provided to discharge rainwater into area drains with catch basins that divert rainfall away from the house to hard surfaces (Kankara, 2014).

Poor drainage

Pave around the foundation with concrete or non-erodible surfaces. The overall grading must provide for positive drainage away from the foundation direct to the concrete channel drains. The channel drains should again discharge water away from the foundation.

Over-watering

Plant flowers and shrubs away from the foundation that no watering takes place around the foundation.

Trees

Always plant trees a distance greater than their mature height away from the foundation. For existing trees, cut and cap their roots so that they do not trespass to the foundation.

Decreased moisture content

During hot days soil moisture content decreases considerably resulting into soil dehydration hence its shrinkage under the foundation. The best way is to assist the ‘mother nature’ by watering the soils surrounding the foundation as need arises. However, this recommendation is hypothetical in third world countries where water scarcity is the order of the day.

Improving the expansive soils by stabilization

Soil stabilization can improve the properties of expansive soils considerably. Possible materials for the stabilization could include lime, pozzolana, lime-pozzolana mixture, cement, resins or fly ash. The choice of a material or a combination of materials depends on the size and importance of the building (risk/damage acceptable) and economic consideration of the client. However, the need to strike a proper balance between quality and cost should not be overlooked (Lucian, 2011).

Conclusion

Expansive soil deposits in Nigeria occur in the arid and semi-arid areas, and are problematic to engineering structures because of their tendency to swell during wet season and shrink during dry seasons. They are soils are soils that experience significant volume change associated with changes in water contents. The Swelling potential of the expansive soil mainly depends upon the properties of soil and environmental factors. Expansive soils present significant geotechnical and structural engineering challenges with costs associated with expansive behaviour estimated to run into several billion annually.

Recommendations

Many adoptive measures can be employed to bring the problems of engineering issues to a halt, such as the soil stabilization as seen earlier, which can improve the properties of expansive soils considerably. Possible materials for the stabilization could include lime, pozzolana, lime-pozzolana mixture, cement, resins or fly ash.

REFERENCES

Ajibade AC (1986). Field Relation In the Basement of the Kusherki Minna Area. A study *Presented At The Geological Survey Departmetal Seminar, Kaduna.*

Al-Homoud AS, Basma AA, Malkavi AIH, Al-Bashabshah MA (1995). Cyclic swelling behaviour of clays. Journal of Geotechnical Engineering, 121:562-565.

Baser O (2009). Stabilization of Expansive Soils Using Waste Marble, a

Thesis Submitted to the Graduate School of Natural and Applied Sciences of Middle East Technical University.
Bilsel H (2002). Climatic effects on the engineering and the physico-chemical properties of calcareous swelling clays of Cyprus. Ph.D. Thesis, Eastern Mediterranean University, Famagusta- Turkish Republic of Northern Cyprus.
Black R, Girod M (1972). Late Paleozoic to recent Igneous activities in West Africa and its relationship to Basement structures. In: Clifford TW, Gass IG (eds) African magmatism and Tectonics. *Oliver and Boyd, Edinburgh*. 185 – 210.
Chen XO, Lu ZW, He XF (1985). Moisture movement and deformation of expansive soils. 14th International Conference on Soil Mechanics and Foundation Engineering, San Francisco, California, 4: 2389-2392.
Chen FH, Ma GS (1987). Swelling and shrinkage behaviour of expansive clays. 6th International Conference on Expansive soils. New Delhi, 127-129.
Day RW (1994). Swell–shrink behaviour of expansive compacted clay. Journal of Geotechnical Engineering, ASCE, 120(3): 618-623.
Dif AF, Blumel WF (1991). Expansive soils with cyclic drying and wetting. ASTM, Geotechnical Testing Journal, 14(1): 96-102.
Guney Y, Sarı D, Cetin M, Tuncan M (2007). Impact of cyclic wetting-drying on swelling behaviour of lime-stabilized soil. Building and Environment, 42(2): 681-68.
Ibrahim A (1990). Geochemistry of Area around Kankara Kaolinitic Clay Deposits. An unpublished MSc Thesis submitted to Department of Geology, Ahmadu Bello University Zaria, Nigeria.
Kankara IA, Sada I (2009). Environmental *Investigations of Kankara Kaolinitic Clay Deposits*. A study presented at the Second CHEMSEARCH Conference, 29th Nov.-1st Dec. 2010, Royal Tropicana Hotel, Kano.
Kankara IA (2014). Geology and Geochemical Characterization of Rocks in Funtua Northeast, Sheet 78, Scale of 1:50,000, Northwestern Nigeria. An Unpublished PhD Thesis submitted to Department of Geology, Federal University of Technology, Minna-Nigeria.
Kankara IA, Darma MR (2016). *A Review of Gold Metallorgeny in Nigeria.* A study presented at the 3rd International Conference on Chemical, Agricultural and Biological Sciences (CABS-16) Dubai, September, 12-14, 2016.
Kankara IA (2020). Geology and Mineral Resources of Katsina State, Nigeria: An Investor Guide. Printed by Darma Prints, Katsina, and published by Katsina Rennaissance Center. Pp. 63-106.
Lee DJ (2011). British Geological Survey & Ian Jefferson, School of Civil Engineering, University of Birmingham, Institution of Civil Engineers Manuals series, Chapter C5 – Expansive Soils.
Lucian C (2011). Geotechnical Aspects of Buildings on Expansive Soils in Kibaha, Tanzania: Preliminary Study, Licentiate Thesis, Department of Civil and Architectural Engineering Royal Institute of Technology Stockholm, Sweden.
McCurry P (1970). The Geology of Degree Sheet 21 (Zaria). An unpublished MSc Thesis, Department of Geology, Ahmadu Bello University, Zaria, Nigeria.
Nehikhare JI (1986). Nigeria's Mineral Resources at the turn of the Century. XIInd NMGS Conference, Port Harcourt. Pp. 12-13.
Olayinka AI (1992). Geophysical Sitting of Boreholes in Crystalline Basement Areas of Africa. *Journal of African Science*14:197-207.
Oyeka AN, Beltaro F (1974). Report on Kaolin Clay Deposits Near Kankara, Katsina State. Geological Survey of Nigeria. An unpublished Report No. 1529.
Pearce JA (1983). The Role of Sub-continental Lithosphere in magma genesis at Active continental margins, In: Hawkesworth CJ, Norry MJ, (edu) *Continental Basalts and Mantle Xenoliths* Shiva, Nantwich Pp. 230-249.
Popescu M (1980). Behaviour of expansive soils with crumb structures. In Proceedings of the 4th International Conference on Expansive Soils. Denver, Co., Pp. 158-171.
Rahaman MA (1971). Classification of Rocks in the Nigerian Precambrian Basement Complex, *(Abs) at 5th Annual Conf. of Nigerian Mining, Geol. and Metall. Soc., Kaduna.*
Subba Rao, KS, Satyadas GC (1987). Swelling potential with cycles of swelling and partial shrinkage. 6th International Conference on Expansive soils. New Delhi, Pp. 137-142.
Tawfiq S, Zalihe N (2009). Swell-shrink behaviour of expansive clays, Eastern Mediterranean University, Department of Civil Engineering, Gazimagusa, North Cyprus.
Tripathy S, Rao KS, Fredlund DG (2002). Water content-void ratio swell-shrink paths of compacted expansive soils. Canadian Geotechnical Journal, 39: 938-959.