

Effect of Exploration Depth on Microstructural Behavior of Subsurface Soft Clayey Soil for Foundation Construction Purposes

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ABSTRACT

The geomorphological, microstructural pattern and mineralogical configuration of subsurface soils explored from 1-meter, 3-meter and 7-meter depths have been studied for the purpose of foundation materials suitability. Soils samples are hauled from borrow sites to where they are utilized as foundation materials. In very most cases, this exploration is done at varying depths and soil being an erratic geomaterial change in its important engineering characteristics with depth. This laboratory examination was necessary to establish the microstructural behaviour and pattern of soils when they are explored from different depths. The samples collected from different depths showed to be A-3 soils according to AASHTO classification method and poorly graded according to the USCS. Also varying depth of the soil sample was characterized by a proportional increase in moisture content; this as well applies to the 'liquid limit, plastic limit and plasticity index values respectively with an exception in the shrinkage limit, which reduces with increase in depth of soil sample. This can be attributed to the erratic behavior of soil, which makes it change behavior from location to location and from depth to depth, clayey contents changes with depth likewise its desiccation properties. The geomorphology and microstructure of the soils show weaker configuration with increased depth of exploration to 7 meters. This shows that for any foundation purposes, soils at both 3 meter and 7-meter depths require treatment to be suitable for construction purposes. Geo-constructions like compacted earth liner systems, mechanically stabilized earths or backfills, pavement subgrade systems can be constructed with the studied soils but care must be taken to modify the soils to meet the basic design considerations.

Keywords: Microstructural behavior; subsurface exploration; soft clay soil; foundation construction; scanning electron microscopy; x-ray diffractometer

INTRODUCTION

The utilization of soils as pavement compacted subgrade has been a construction standard for years and the properties of the excavated soil determines the reactive behavior of the compacted soil when in use (AASHTO 1993; AASHTO T 190-09 2014; AASHTO T 307 2014; ASTM C618 1978). The reactive behavior of construction soils utilized as sub-structural and super-structural materials, within the double diffused layers (DDL) are becoming prominent in soils mechanics and geotechnical engineering (Bui Van and Onyelowe, 2018). This behavior takes place at the microstructural level of these geo-materials when they come

in contact with treated soils and determines the materials suitability for use in construction (Bui Van and Onyelowe 2018; BS1377-2, 3 1990; BS1924 1990; K. C. Onyelowe et al. 2019a; 2019b). More important is the consideration of these materials in the construction of hydraulically bound facilities like road pavements, airfield pavements, parking lots, landscapes, etc. where structures are constantly exposed to the rise and fall of water levels, which eventually induces linear and volumetric shrinkage (Manuel et al. 1995; M. H. Abdelaziz et al. 2019; Nigeria General Specification (NGS 1997; Onyelowe et al. 2019; 2018; Onyelowe and Maduabuchi 2017). This effect exposes foundation structures to swelling and shrinkage cycles (Bui Van and Onyelowe,

2018; K. C. Onyelowe et al. 2019a). More so, the effect of moisture on the reactive phase during soil stabilization exercise is of great concern to the geotechnical engineering designers and constructors because of the standard decisions that would be made to ensure the operational and service life of the stabilized soil (Onyelowe et al. 2020; Onyelowe 2017). The designs of earth structures require knowledge of the behavior and stress-related deformability of soils that will support the structure and the geological conditions of the soil under consideration (Onyelowe et al. 2017). The Geotechnical properties of a soil such as grain size distribution, plasticity, compressibility, shear strength, permeability, soil compaction, California bearing ratio, shear strength and so on, are used in predicting the behavior of soil when subject to loads (Rowe et al. 2017; Smith and Callahan, 1987). These properties can be assessed by proper laboratory or in situ tests. The choice of soils more especially unstable soils as foundation materials is the result of most structural failures we experience across the world in recent years.

Furthermore, the insufficient knowledge of the microstructural and geomorphological behavior of such foundation materials contribute hugely to the hazards we face in the infrastructural development and construction industry (K. C. Onyelowe et al. 2019a; 2019b). This area is always being neglected while more attention is placed on the major behavioral patterns. It is important to note that the hydration reaction, calcination, carbonation, pozzolanic reaction, and possible flocculation are all microstructural reactions that give rise to strength gain and densification of soils in a stabilization experiment (Smith and Callahan, 1987; Y. Xua et al. 2019). Lateritic soils are explored from pits at different depths and considerations in most cases are not given to the changes in the microstructural behavior of the soils as they are explored and hauled for use as foundation materials (Bui Van and Onyelowe 2018). In recent times,

the construction of containment liners used as underlain in landfills has been on the rise to protect the environment from the hazardous effect of leachate (K. C. Onyelowe et al. 2019a; 2019b). The generation of solid waste the world over is on the increase and the tendency to dispose same on landfills increases also (Bui Van and Onyelowe 2018). The decomposition of the disposed solid waste materials releases hazardous materials which pass into the soil and the environment through leachate action (Bui Van and Onyelowe 2018). To forestall this leachate action which passes into the soil and the environment through the action permeability is achieved by using geomaterials that eventually reduce the permeability coefficient of landfill liners (Onyelowe et al. 2020). To achieve an ecofriendly construction in this wise, containment liners are currently being constructed with clay materials treated with supplementary cementing materials (SCM) (ASTM C618, 1978). It is quite important and technically expedient that the structures of clayey or lateritic soils are evaluated to determine the microstructural or geomorphological pattern and mineralogical composition (Onyelowe et al. 2019; Onyelowe et al. 2018).

In this work, soils are excavated from different depths to examine the geomorphological behavior and mineralogical arrangement of the soils at different soil depths collected at 1m, 3m and 7m employing the scanning electron microscope and x-ray diffractometer. This gives future research pointer and presents the required geotechnical exercises towards achieving suitable construction with the knowledge of the microstructure and mineral composition, which contribute to the double diffused layer reaction between clay, water and perhaps reactive agents from cementitious or non-cementitious admixtures in a soil treatment protocol. The primary aim of this work is to evaluate the effect of depth of exploration on the microstructural, geomorphological and mineralogical behavior of soft soils utilized as foundation materials.



FIGURE 1. Geographical location of test samples

MATERIALS AND METHODS

SITE LOCATION, BORING AND SAMPLES PREPARATION

The study area as shown in Figure 1 is located at Okigwe within the Abia state axis of the Enugu –Port Harcourt express way. The samples for the work were collected in solid form which comprises of soft clay soil, which was collected at a depth of 1 meter, 3 meters and 7 meters respectively, the sample can be said to be Reddish brown, red and red in color respectively and has a soft texture when held and felt in the hand. The soils samples were properly spread in an oven tray and allowed to dry overnight in an oven maintained at 105-110°C, sieve characterization of the samples was carried out with a well-arranged BS sieve test apparatus.

The sample was classified respectively according to AASHTO soil classification system as A-3 for sample 1, A-3 for sample 2 and A-3 for sample 3 based on its liquid limit, plasticity index and percentage passing No 200(75µm) B.S sieve and a as a poorly graded gravel respectively for the three samples according to the unified soil classification system. The apparatus used for the sieve analysis comprises of a British standard test sieve, an appropriate receiver, a weighing balance and accurate to 0.01g, sample divider, a thermostatically controlled drying oven capable of maintaining a temperature of 105°C to 110 °C, sieve brushes, metal trays, scoop and a mechanical sieve shaker. Atterberg limit test was conducted on the samples according to BS1377-2, 3, (1990) with the following apparatus; Flat glass plate about 12mm in diameter, spatula, Casagrande Liquid Limit device, grooving tool, drying oven and weighing balance accurate to 0.01g. The Atterberg limit test procedure was repeated for at least two additional trials with an objective of obtaining a sample with successive lower numbers of drops to close the groove. The Moisture Content test was carried out according to standard conditions (BS1377-2, 3, 1990) with the following apparatus; Balance accurate to 0.01g, sample container (watch glass returns), oven (24 hours at 105°C + 5°C) and desiccators.

The Compaction Test (Standard Proctor Test) was carried out on the studied samples according to standard conditions (BS1377-2, 3, 1990) with the following apparatus; a cylindrical mold with an internal diameter of 105mm and an internal effective height of 115.5mm, metal rammer with 50mm diameter face, weight of 2.5kg sliding freely in a tube which controls the height of drop to 300mm, jacking apparatus for extracting the compacted materials from the mold, 20mm British Standard sieves, balance readable to 5g, watertight container, drying oven capable of maintaining a temperature of 105°C to 110°C and a pallet knife.

Finally, Specific Gravity Test was carried out according to BS1377-2, 3, (1990) with the following apparatus; Pycnometer, balance, volume pump, funnel and spoon.

SCANNING ELECTRON MICROSCOPY (SEM)

This is the procedure that scanned the soil samples with an electron beam to produce a magnified image for analysis. This was applied on the samples at 1meter depth, 3 meters depth and 7 meters depth respectively with Scanning Electron Microscopy Experimental Set-up; Phenom ProX, by phenom world Eindhoven, the Netherlands presented in Figure 2.

X-RAY DIFFRACTION (XRD)

Fig. 3 shows the x-ray diffractometer set up. The set up was applied for the identification and characterization of compounds based on their diffraction pattern. This was done by obtaining dual wave/particle nature of X-rays to obtain information about the structure of crystalline materials.

RESULTS AND DISCUSSION

From the analytical studies, it can be seen as shown in Table 1 that the soil at different depths has different properties. Also increase in depth of the soil sample was characterized by a proportional increase in moisture content; this as well applies to the liquid limit, plastic limit and plasticity index values respectively with an exception in the shrinkage limit which reduces with increase in depth of soil sample this can be attributed to the erratic behavior of soil which makes it change its behavior from location to location and from depth to depth, clayey contents changes with depth likewise its desiccation properties. Figure 4 shows the particle size distribution curve of the soil sample at different depths respectively.

The soil samples were classified as an A-3 soil according to AASHTO (AASHTO, 1993; AASHTO T 190-09, 2014; AASHTO T 307, 2014) with a color of reddish brown, red and red respectively for 1m depth soil sample. 3m soil sample and 7m soil sample respectively. The spectra conditions of the soil samples were shown in Figure 5, 6 and 7 respectively with respect to the depths.

MICROSTRUCTURE BY SCANNING ELECTRON MICROSCOPY OF THE SUBSURFACE SOILS

Figures 8, 9 and 10 show the geomorphology and microstructural analysis of the subsoil from the electron microscopy conducted showing the soil samples contained different elements at varying concentrations as the depth vary respectively. It was noticed that the different soil samples contained more Silicon and aluminum respectively more than any other element present in them. Figure 8 shows a closer geomorphological compactness and with arrays of stony arrangement than it is in Figure 9 and 10. This shows that the soil sample from 1-meter depth stands a chance to resist construction pressures than samples from 3- and 7-meter depth. They also exhibit high aluminosilicate structures therefore pozzolanic.



FIGURE 2. Scanning Electron Microscopy Experimental Set-up; Phenom ProX, by phenom world Eindhoven, the Netherlands



FIGURE 3: X-Ray Diffractometer Experimental Set-up

TABLE 1. Preliminary property of studied subsurface soils

Property description of soils and units	Values / Descriptions		
	1m Depth Soil	3m Depth Soil	7m Depth Soil
% Passing Sieve, No 200	14	17	23
NMC (%)	10	14	18
LL (%)	27	45	52
PL (%)	21	25	28
PI (%)	6	20	24
SL (%)	15	8	5
FSI (%)	56	72	155
G_s	2.61	2.73	2.73
AASHTO Classification	A-3	A-3	A-3
USCS	GP	GP	GP
MDD (g/cm ³)	2.45	2.21	2.01
OMC (%)	10.2	12.0	13.3
Color	Reddish Brown	Reddish	Reddish

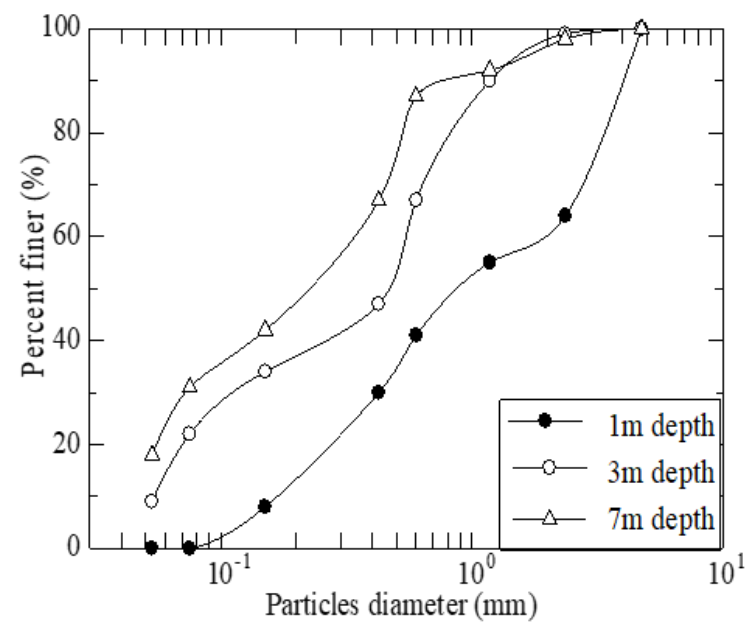


FIGURE 4. Particle size distribution curves for test soils

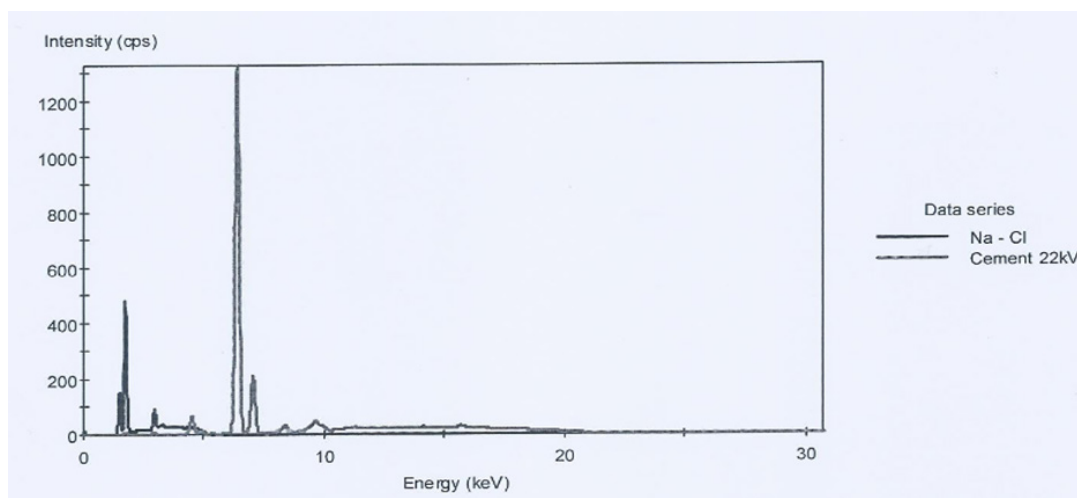


FIGURE 5. Spectral conditions of subsurface Soil at 1-meter depth

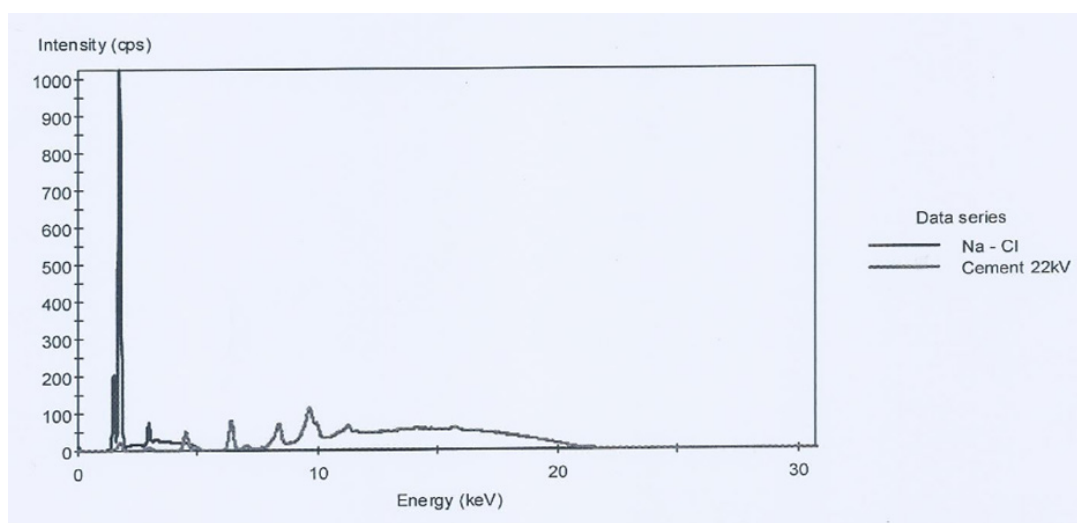


FIGURE 6. Spectral conditions of subsurface Soil at 3-meter depth

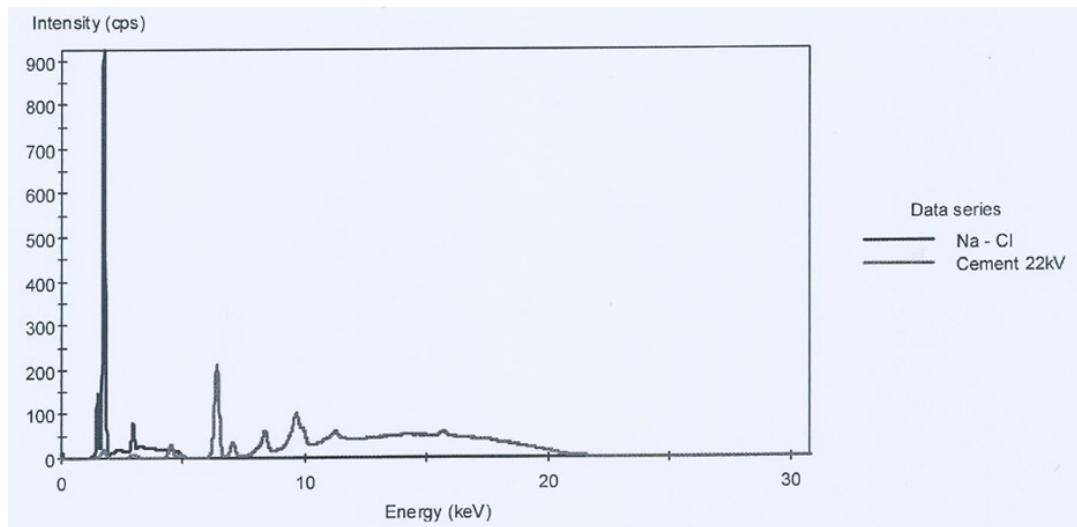
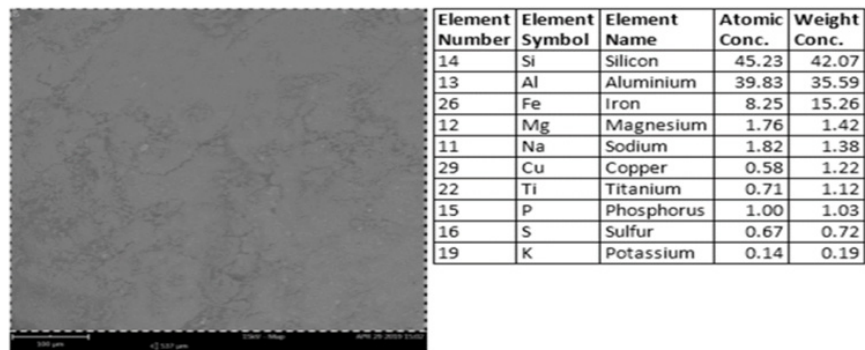
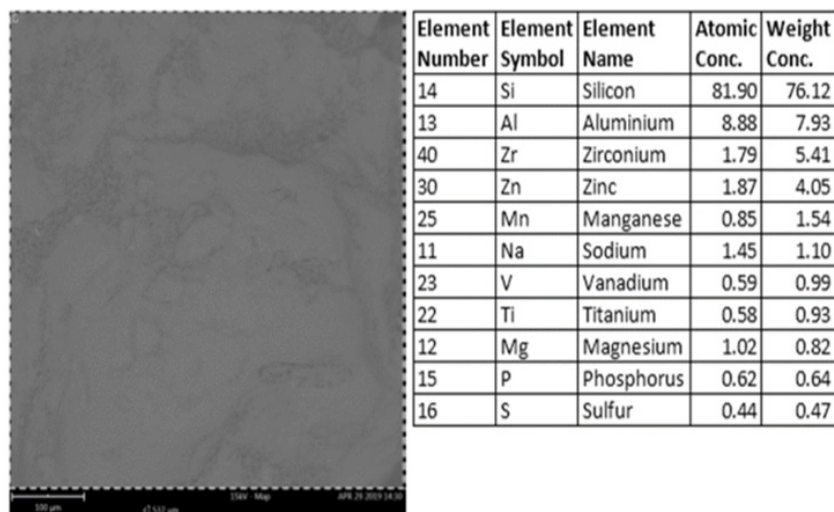


FIGURE 7. Spectral conditions of subsurface Soil at 7-meter depth



FOV: 537 μm , Mode: 15kV - Map, Detector: BSD Full, Time: APR 29 2019 15:02

FIGURE 8. Geomorphological structure and mineralogical composition of the soil at 1-meter depth



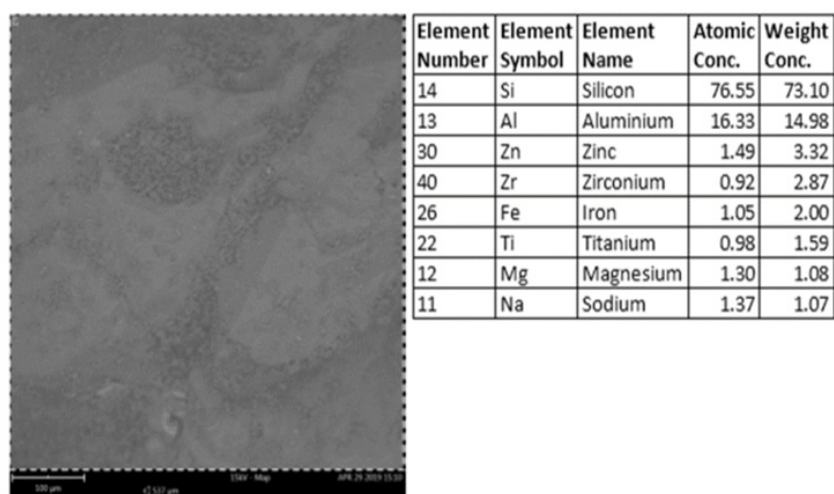
FOV: 537 μm , Mode: 15kV - Map, Detector: BSD Full, Time: APR 29 2019 14:30

FIGURE 9. Geomorphological structure and mineralogical composition of the soil at 3-meter depth

MINERALOGICAL AND OXIDE COMPOSITION CONCENTRATION BY
X-RAY DIFFRACTION OF THE SUBSURFACE SOILS

Figures 11, 12 and 13 present the mineralogical structure and oxide concentration of the studied samples. At 1m depth, the soil sample has three minerals present from the x-ray diffraction test conducted which are quartz, kaolinite and hematite. The quartz has the highest concentration of 44, which shows a high concentration

of silicate oxide. At 3m depth, the soil sample has two minerals present, which are, quartz and kaolinite. The quartz has the highest concentration of 72, which shows a high concentration of silicate oxide. At 7m depth, the soil sample has three minerals present, which are, quartz, kaolinite and rutile. The quartz has the highest concentration of 35, which shows a high concentration of silicate oxide.



FOV: 537 μm , Mode: 15kV - Map, Detector: BSD Full, Time: APR 29 2019 15:10

FIGURE 10. Geomorphological structure and mineralogical composition of the soil at 7-meter depth

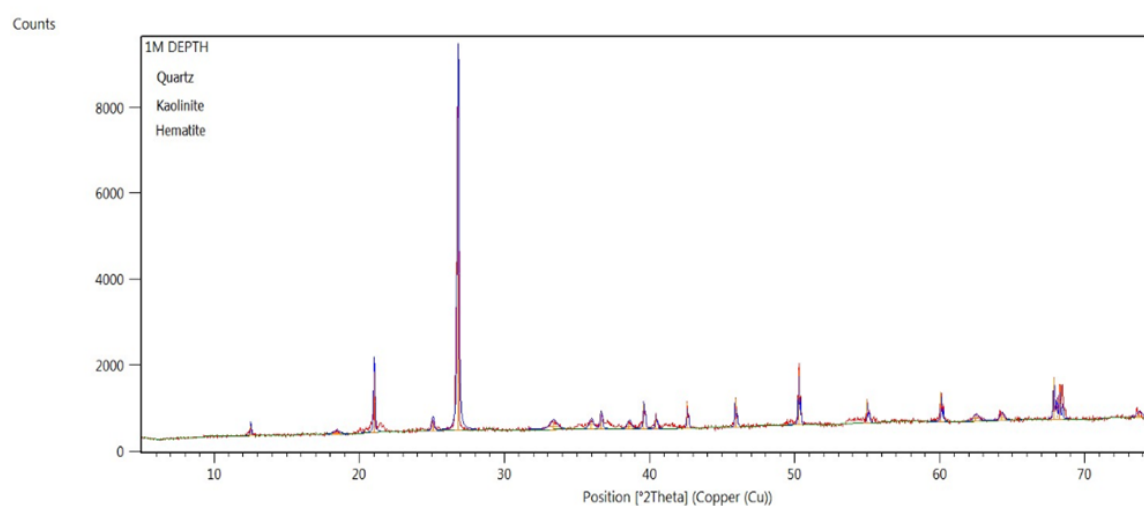


FIGURE 11. Mineralogical and Oxide Composition Concentration of the Subsurface Soils at 1-meter depth

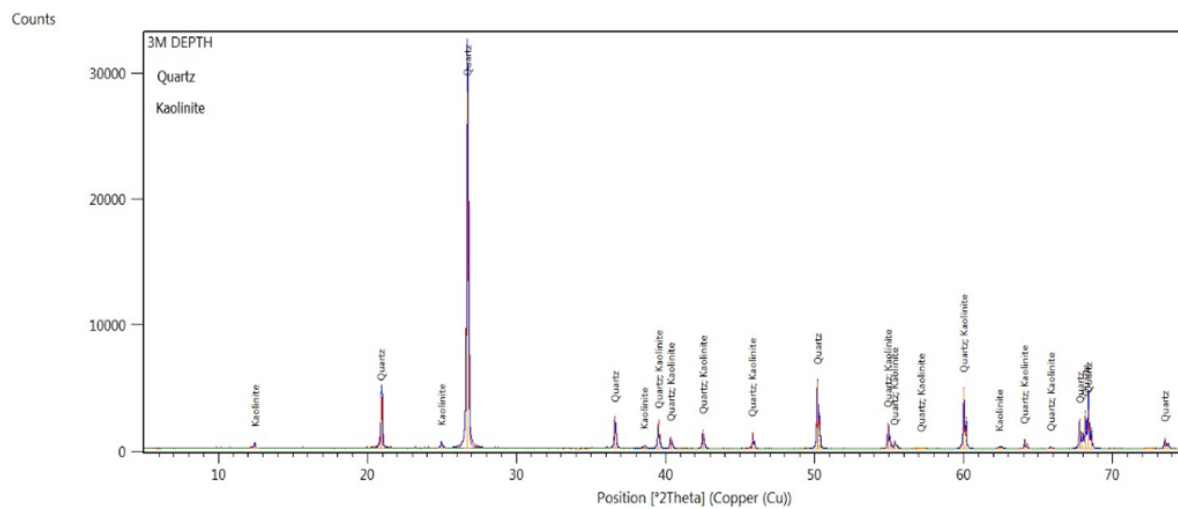


FIGURE 12. Mineralogical and Oxide Composition Concentration of the Subsurface Soils at 3-meter depth

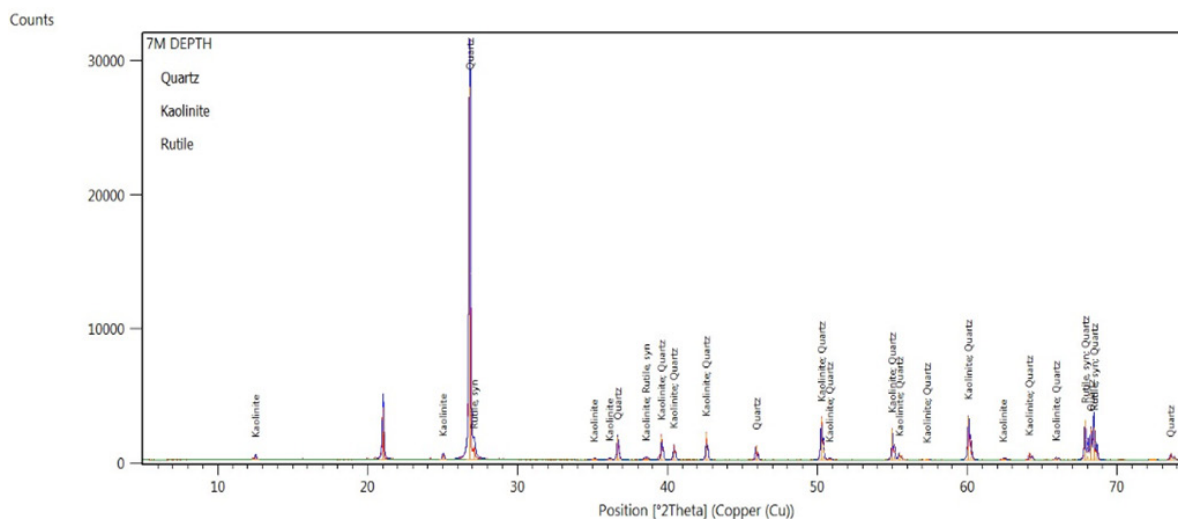


FIGURE 13. Mineralogical and Oxide Composition Concentration of the Subsurface Soils at 7-meter depth

CONCLUSION

From all the tests conducted on the various soil samples, it shows that the soil samples at 3m depth and 7m depth are not suitable for civil engineering works because they are silt sand.

Silt is a fine aggregate having size in between clay and sand, because of its size; it exhibits very complex behavior and requires stabilization in accordance with British Standard International, BSI (BS 1924, 1990), before they can meet the minimum requirements to be used as foundation materials. Moreover, on the strength perspective there will be a decrease in the strength of the concrete, and it hinders the bonding

of rebar with concrete, thus decreasing the bonding test.

1m depth soil sample is most suitable for foundation construction purposes due to the presence of stone fragments, gravel and sand which enhances bonding of concrete.

It is recommended that for foundations beyond 1m within the research locality a proper soil stabilization

technique should be employed that will suit the required foundation.

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DECLARATION OF COMPETING INTEREST

None.

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