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INTEGRATED GEOLOGICAL AND GEOTECHNICAL PROPERTIES OF SUBSOIL FOR SHALLOW FOUNDATION DESIGN FOR M. I. WUSHISHI HOUSING ESTATE, MINNA, NIGER STATE, NORTH-CENTRAL NIGERIA

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Abstract
A study of the geological and geotechnical properties of subsoil for shallow foundation design was carried out at the M. I. Wushishi Housing Estate in Minna, Niger State, North-Central Nigeria. The main aim of the research was to ascertain the lithological and structural characteristics of the study area in order to recommend the suitable shallow foundation design for the proposed building construction. The general geological mapping of the area revealed that the area is underlain by Schist rock belonging to the Kushaka Formation. The principal joint direction in the area is NW-SE. As shown by trial pits, the area are characterized by relatively thick over burden with silty clay in some places which is traceable to the predominant rock type (schist) found in the area. Thearea is generally low-lying and accessible through Eastern Bye-pass and Maitumbi road. The soil is heterogeneous when correlated laterally from trial pits. Both disturbed and undisturbed soil samples were collected and subjected to laboratory and sieve analysis. The liquid limit ranged from 12.00-37.00 with a mean value of 23.85 while the plastic limit varied from 7.27-30.73 with an average value of 17.17.The plasticity index varies from 1.79 to 15.13 with a mean value of 6.66 while the shrinkage potential ranged from low to medium. The maximum dry density ranged between 1.66-1.95 mg/m^3 with the mean value of 1.81 mg/m^3 while the optimum moisture content ranged from 8.70-21.37 with an average value of 15.16. The natural moisture content is in the order of 11.52-29.86 % with a mean value of 21.08 %. The particle size distribution curve showed that the area is sand dominated. Based on the field and laboratory results, shallow foundation (pad/strip) can be adopted for lightly loaded structures not exceeding an allowable bearing capacity of 150KN/m^2 while deep/pile foundation are advocated for heavily loaded structures.

Keywords: *Foundation Design, Geological, Geotechnical, M. I. Wushishi Housing Estate, Minna, North-Central Nigeria*

Introduction

The purpose of undertaking a geological survey in any engineering construction is to determine the geotechnical properties and homogeneity of the earth (rock or soil) on which engineering structures are founded. All engineering structures start with the foundation, which transmits load from the structure to the ground without failure (Oke and Amadi, 2008; Amadi and Olasehinde, 2010). The primary considerations for foundation support are bearing capacity, settlement and ground movement beneath the foundation. Hence, the stability of the foundation and the superstructure supported by the foundation depends on the bearing capacity of the geologic materials underlying the site (Oyedele, 2009). The feasibility, planning, design, construction costing and safety of a building may depend critically on the geotechnical conditions of where the construction will take place (Tomlinson, 1999). In any foundation studies, large or small scale, it is desirable to investigate the detailed foundation conditions at the site (Hawkins, 1971). The application of geotechnical knowledge is needed for every structure that rests on or within the earth crust for successful installation, maintenance and performance (Amadi *et al.*, 2012). If the information obtained isnot properly applied or put into good use, failure may occur and likewise inadequate or poor performance results (Roy, 1974; Oke and Amadi, 2008). The two major foundation types are deep and shallow foundation. According to Oke *et al.*, 2009b and Amadi *et al.*, 2012, deep foundation is required for heavily loaded structure while shallow foundation is required for moderate structures in areas underlain by the basement complex.

This work was therefore aimed at determining the geology and geotechnical properties of the subsoil for Wushishi Housing Estate, Eastern bye-pass, Minna, Nigeria with the purpose of recommendingsuitable shallow foundation design for building construction and to accomplish that, physical observation, Sieve analysis, Atterberg limit tests, Compaction test, Shrinkage test and Natural moisture contents were conducted.

Study Area Location

The investigated area is located along eastern bye- pass, Minna and it lies between Latitude 9° 36.95'N and 9° 38.25'N and Longitude 6° 34.63'E and 6° 35.80'E of Minna Sheet 164 NE. It is a low-lying terrain from 268m in the west to 250m in the east (above sea level) and easily accessible through eastern bye- pass, Minna (Figure 4)

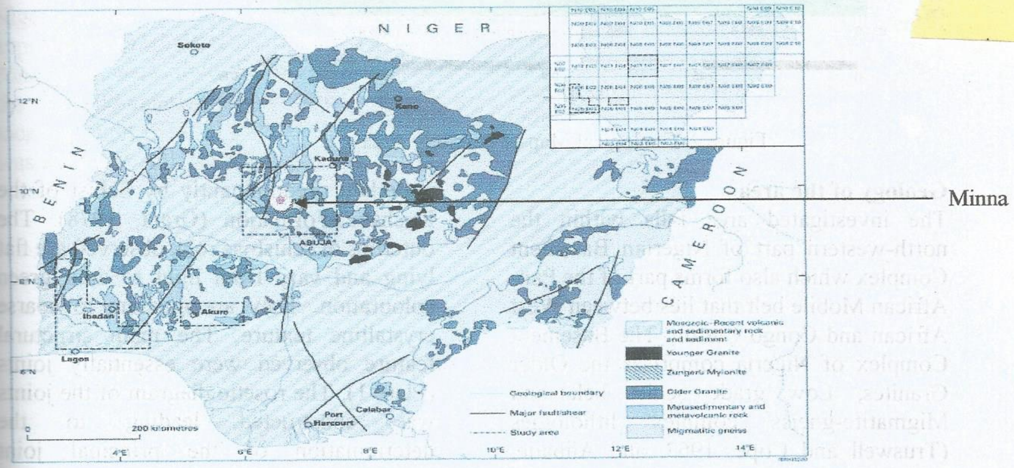


Figure 1: Simplified Geological map of Nigeria showing the location of the study area, NGSA, 1976.

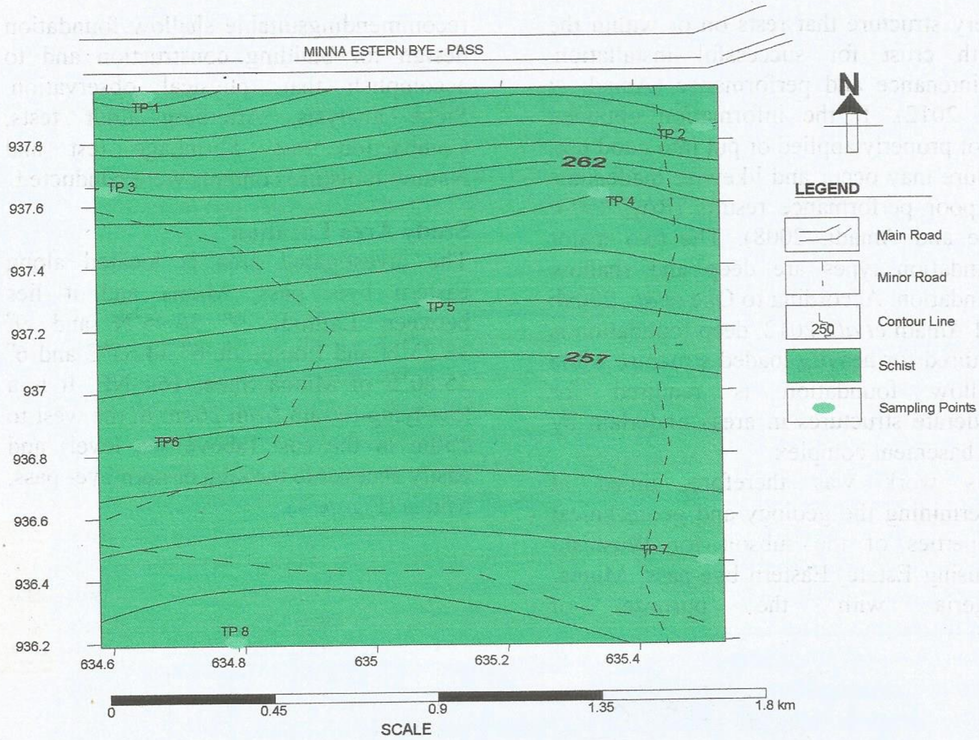
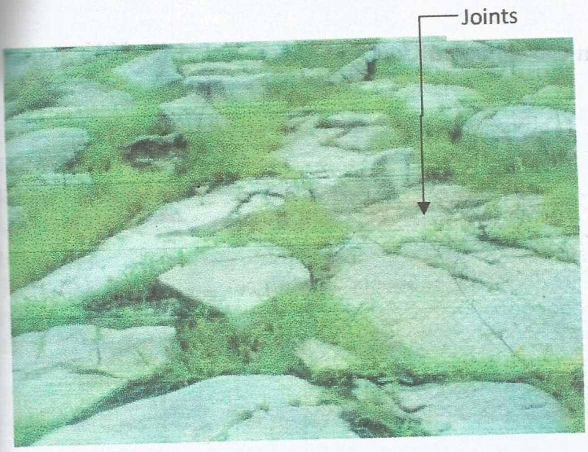


Figure 2: Geological Map of the study Area

Geology of the area

The investigated area falls within the north-western part of Nigerian Basement Complex which also forms part of the Pan-African Mobile belt that lies between West African and Congo Craton. The Basement Complex of Nigeria comprises the Older Granites, Low grade schist belt and Migmatite-gneiss complex lithologies (Truswell and Cope, 1963, and Ajibade, 1976). The geological mapping reveals the lithology of the area (Figure 2) to be underlain predominantly by Schist of the Kushaka Formation (Grant, 1978). The outcrops of schistose rock observed are flat lying and vary from light to dark green colouration. They are medium to coarse crystalline texture. The main structural feature observed were essentially joints (Plate 1). The rosette diagram of the joints was constructed leading to the determination of the principal joint direction as NW – SE (Figure 3).



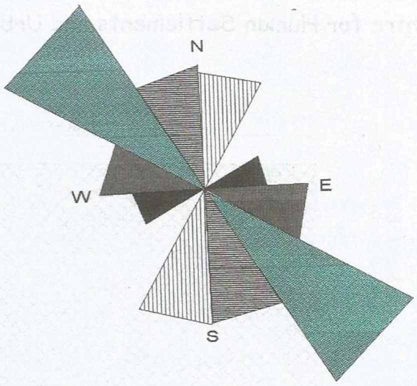


Plate 1: An outcrop with joints (Omanayin, 2008) Figure 3: Rosette diagram (Omanayin, 2008)

Methodology

Geological mapping was carried out on a scale of 1: 17;500 which was enlarged from the map of Minna Sheet 164 N.E with a scale of 1:100,000 produced by the Federal Geological Survey Agency, Nigeria, 1976. The total area covered was approximately 4km^2. The subsoil conditions were investigated establishing the site boundaries, dimension and by locating eight (8) trial pits (Figure 4). This was achieved with the aid of Garmin eTrex Legend GPS (Global Positioning System). The GPS locates unmanned satellite to measure the earth's georeference data. The Length and Breadth of the site area, Longitude, Latitude and Elevation of the boundary pillars and trial pits location were measured with the aid of the GPS. At each trial pit location, a peg was driven to mark the spot to be excavated. The excavation of the trial pits were undertaken with the aid of shovel and digger.

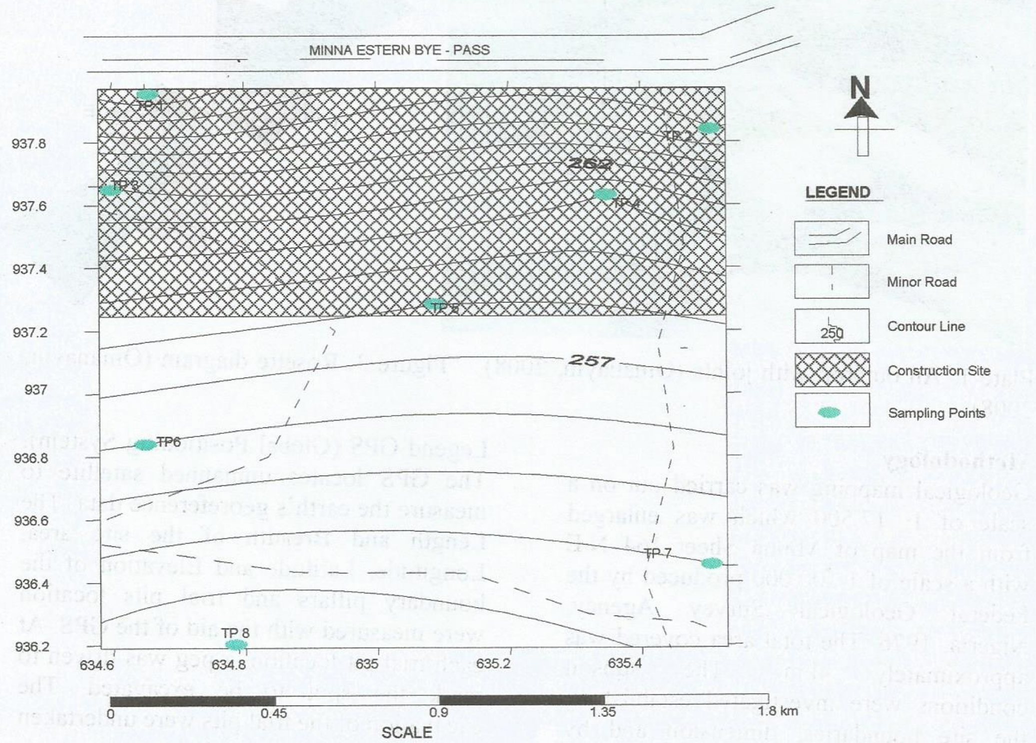


Figure 4: Map of the study location showing the sampling points

The Eight (8) trial pits located were excavated from the ground level to a range of between 0.0 – 1.5 meters according to British Standard Code of practices for site investigation 5930, 1981. From field descriptions, trial pits 2 and 4, 5 and 7, 6 and 8 shows similar characteristics (texture and colour) based on these, only samples from trial pits 1, 3, 4, 7 and 8 were selected for laboratory analysis in Civil Engineering Laboratory, Federal University of Technology Minna, for relevant geotechnical parameters; according to British Standard Methods of test for soil for Civil Engineering purpose (British Standard Institution, BS 1377: Part 1- 9, 1990).

Sieve analysis was conducted in order to obtain the particle size distribution of the soil samples with a set of sieve sizes (5.00, 3.35, 2.00, 1.18, 0.856, 0.600, 0.425, 0.300, 0.150, 0.075, and 0.063) mm and mechanical sieve shaker. Liquid limit test was performed with cone penetrometer. Plastic limit test was executed by kneading and rolling soil samples between fingers and thumb into about 6mm diameter thread. Each thread was further rolled between fingertips on a clean flat glass plate with sufficient pressure to reduce the diameter into 3mm. At exactly 3mm, the soil paste starts to crumble and cannot roll further, the process was repeated until both longitudinal and transverse crack appear at a rolled diameter of 3m, immediately, the moisture content of the crack thread was determined. Compaction test was determined by filling the mould with moisture soil sample in three layers, each layer was given 25 blows from the rammer, distributing the blows uniformly over the surface of the soil. It was weighted to determine the bulk density. Moisture contents of soil samples were determined and the dry density was calculated. Shrinkage test was also done by filling the mould with soil pastes prepared; taking note of the initial dimension of the sample, then oven dried for 24 hours and the final dimension was taken. The values obtained were substituted into the equation; Shrinkage limit = [1 – {final length / initial length}] x 100 to get their respective shrinkage results.

Results and Discussion

Field Observation

A representative soil profile of the trial pits (Figure 5) revealed that the soils are homogeneous when correlated laterally and heterogeneous when vertically related in each of the trial pit. It is generally made up of light clay - dark red lateritic - brownish lateritic soil. Summary of the trial pit locations are contained in Table 1.

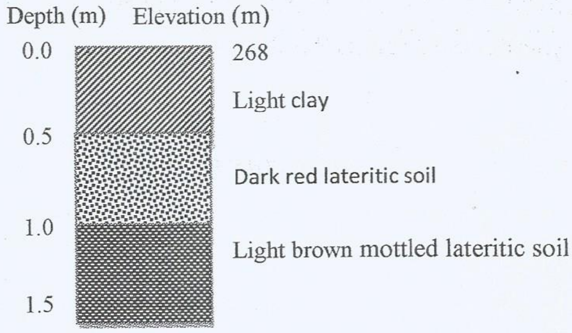


Figure 5:Soil profile of trial pit 1

Table 1: Summary of the Trial Pits Locations

Location	Trial Pits	Longitude (E)	Latitude (N)	Elevation (m)
1	TP-1	$9^0 37.970^1$	$6^0 34.653^1$	268
2	TP-2	$9^0 37.840^1$	$6^0 35.510^1$	265
3	TP-3	$9^0 37.668^1$	$6^0 34.582^1$	262
4	TP-4	$9^0 37.628^1$	$6^0 35.348^1$	260
5	TP-5	$9^0 37.277^1$	$6^0 35.093^1$	258
6	TP-6	$9^0 36.692^1$	$6^0 34.789^1$	252
7	TP-7	$9^0 36.448^1$	$6^0 35.528^1$	254
8	TP-8	$9^0 36.835^1$	$6^0 34.648^1$	256

Sieve size	Weight of Sieve with Sand (grams)	Weight of Sieve empty (grams)	Weight of Sand (grams)	Cumulative Weight (grams)	Weight Percent	Cumulative Weight Percent	Percent Passing
5.00 mm	479.80	477.20	2.60	2.60	1.60	1.60	98.40
3.35 mm	468.90	467.30	1.60	4.20	0.98	2.58	97.42

2.00 mm	419.90	417.00	2.90	7.10	1.78	4.36	95.64
1.18 mm	395.10	387.40	7.70	14.80	4.74	9.10	90.90
850 µm	365.20	355.60	9.60	24.24	5.91	15.01	84.99
600 µm	481.60	466.90	14.70	39.10	9.05	24.06	75.94
425 µm	453.40	434.50	18.90	58.00	11.63	35.66	64.31
300 µm	340.00	313.30	26.70	84.70	16.43	52.12	47.88
150 µm	476.50	416.80	59.70	144.40	36.74	88.86	11.14
75 µm	415.80	403.30	12.50	156.90	7.69	96.55	3.45
Pan	276.20	270.60	5.60	162.50	3.45	100.00	-

Table 2: A Typical Sieve Analysis Result

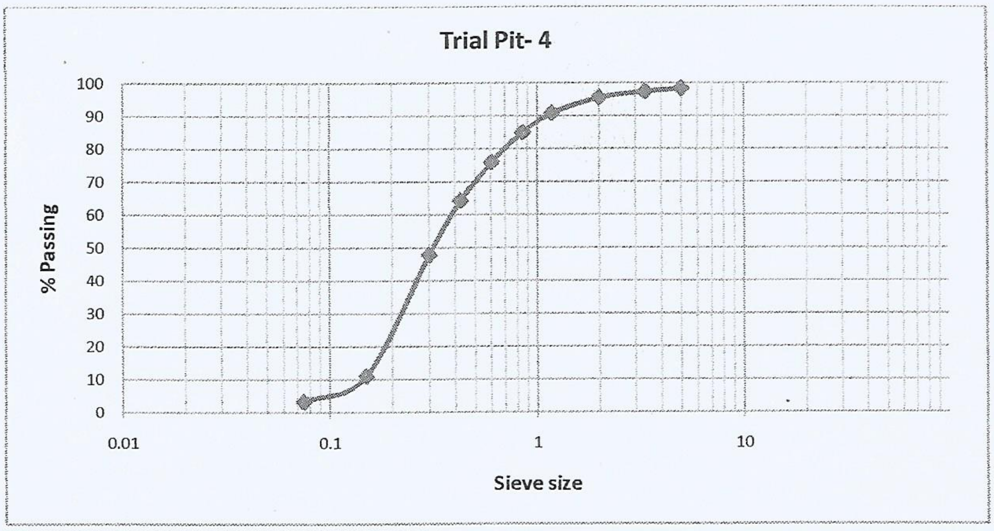


Figure 6:A representative soil particle distribution curve from the study area

Sieve Analysis

Table 2 shows a typical sieve analysis. The soils can generally be described to have a negligible clay particle size. The dominated particle sizes are that of sand and followed by gravel as shown in the gradation curve (Figure 6). A silty sand soil is good site to put a foundation because settlement will only occur while the construction of building is on or immediately after the end of the construction, but settlement long after the construction while on clayey soil will experience both short time (immediate) and long time (secondary) settlement. From the general result, it reveals that trial pit 4 and 7 are well graded areas while trial pit 1, 3 and 8 are not well graded. The well graded area shows a good distribution of different soil sizes thus behave as drained material, therefore, permeability is improved and the incidence of water logging is limited. They are better foundation materials.

Table 3: Summary of Atterberg limit result showing plasticity

Trial pits	Depth (m)	Liquid limit	Plastic limit	Plasticity index	Shrinkage potential	Plasticity chart
Tp - 1	1.5	29.00	24.46	4.54	low	ML
Tp - 3	1.5	18.84	13.18	5.62	Low	ML
Tp - 4	1.5	37.00	30.73	6.30	Low	CL
Tp - 7	1.5	22.40	7.27	15.13	Low	MI
Tp - 8	1.5	12.00	10.21	1.73	Low	CL

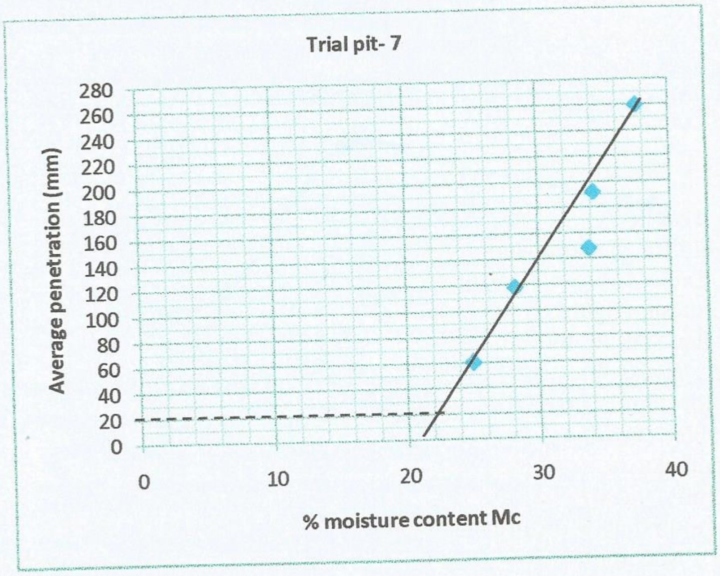


Figure 7: A typical Liquid Limit plot of Trial pit -7

Atterberg Limits

Results of the Atterberg limit are summarized in Table 3 while the Liquid Limit graph of Trial pit 7, is in Figure 7. The Liquid Limit, Plastic Limit and Plasticity Index have the mean values of 23.85%, 17.17% and 6.70% respectively. The liquid limit ranges from 12.0% - 29.0%, plastic limit ranges from 7.27% - 30.73% while plasticity index ranges from 1.73% - 15.13%.

From the result obtained, it is observed that soil samples were of low plasticity. The plot of plasticity index (PI) against liquid limits (LL) in figure 8 shows that most of the soil samples fall below A-Line; indicating silty soil which is a suitable site for foundation as supported by the discussion from sieve analysis result.

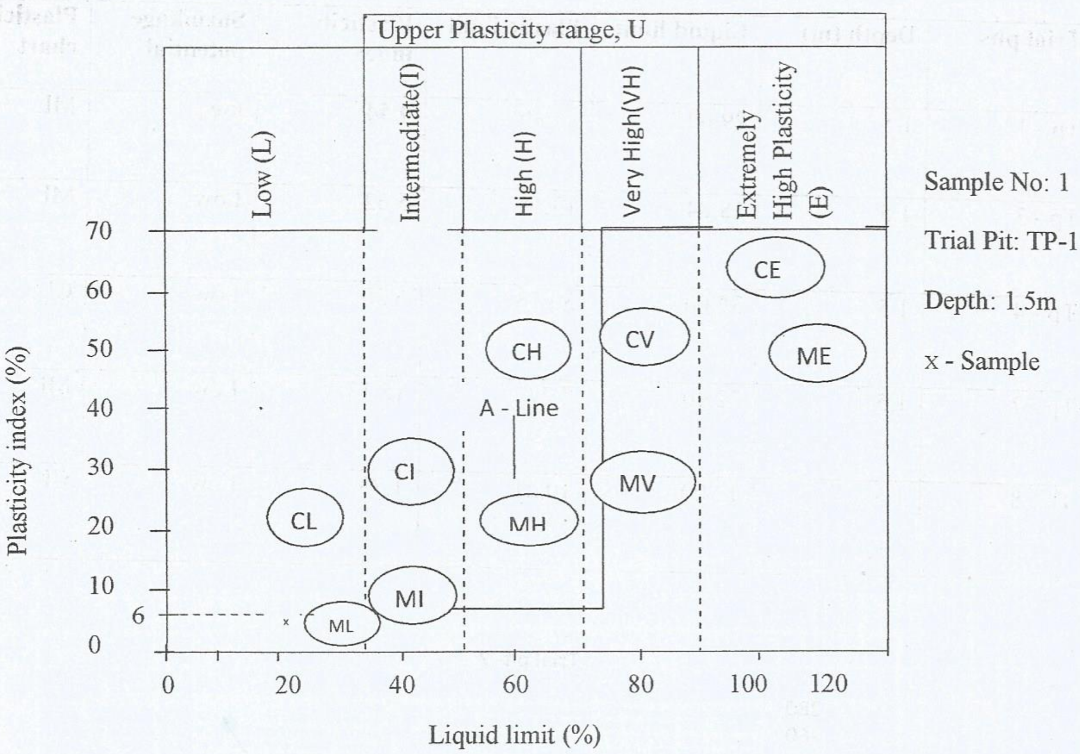


Figure 8:Plot of Plasticity Index (PI) against Liquid Limit (LL)

Compaction Test

Summary Table for the compaction test is illustrated in Table 4. From Trial pit -7 as shown in the graph (figure 9) as a typical behavior of the soil in the studied area indicated that, in response to load bearing is adequate for lightly loaded structures with allowable bearing pressure of 120KN/m^2 but not suitable for heavily loaded structure. In general, the mean values for Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) are 15.16% and 1.81% respectively. The OMC ranges from 8.70% - 21.37% while MDD ranges from 1.66mg/m^3 – 1.95mg/m^3. Samples from trial pit 1 have the lowest value with 1.66 MDD while samples from trial pits 3, 4 and 7 possess MDD value which indicates low shear strength at high moisture content and it is therefore suitable for both foundation and fills materials. The range of OMC values indicates silt deposit with a mixture of clay, which is negligible.

Table 4: Summary of Compaction test results

Trial pits	Depth	OMC % MDD mg/m³	1	2	3	4	5	MDD mg/m³	OMC
Tp - 1	1.5	OMC %	11.25	15.50	17.25	20.15	25.35	1.66	18.50
		MDD mg/m³	1.44	1.47	1.65	1.63	1.54		
Tp - 3	1.5	OMC %	9.04	12.77	15.23	18.22	23.58	1.84	15.65
		MDD mg/m³	1.45	1.50	1.83	1.77	1.68		
Tp- 4	1.5	OMC %	13.07	1.68	21.37	22.10	28.12	1.70	21.37
		MDD mg/m³	1.42	1.45	1.70	1.68	1.58		
Tp -7	1.5	OMC %	5.83	7.65	11.00	14.12	19.83	1.92	11.57
		MDD mg/m³	1.52	1.57	1.91	1.86	1.77		
Tp -8	1.5	OMC %	6.70	8.33	11.57	14.05	17.49	1.95	8.70
		MDD mg/m³	1.61	1.94	1.91	1.87	1.81		

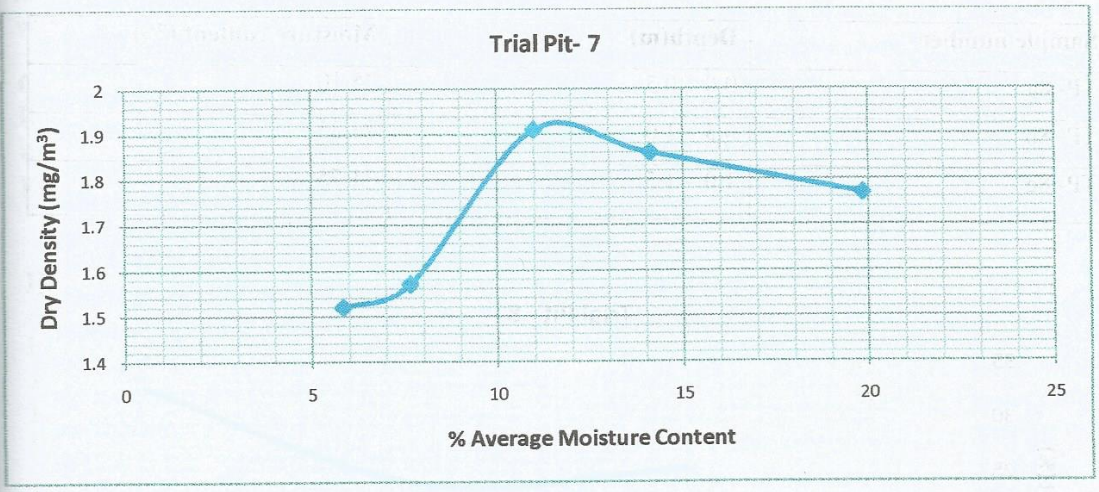


Figure 9: Compaction graph of trial pit- 7

Table 5: Summary of shrinkage limit results

Sample number	Trial pits	Linear shrinkage (%)
1	Tp – 1	11
2	Tp – 3	10
3	Tp – 4	14
4	Tp – 7	12
5	Tp - 8	13

Shrinkage Test

The shrinkage is as a result of certain clay, which absorbed water during wet season when there is a rise in ground water level. During dry season when the ground water level might have decreased, the clay will shrink; such rapid fluctuations will lead to differential settlement of foundation which will manifest as cracks in walls of buildings. Generally, the shrinkage value ranges from 11.0% - 14.0% and the mean value is 12%. From the result obtained from the studied area, it has generally low shrinkage potential and is therefore considered as cohesive soil hence, there will be little or no differential settlement which makes the site suitable for building construction. It is as illustrated in Table 5.

Table 6: Summary of Natural moisture content results

S/No	Sample	Moisture content (%)
1	Tp – 1	20.07
2	Tp – 3	11.52
3	Tp – 4	17.23
4	Tp – 7	29.86
5	TP – 8	26.73

Table 7: Natural Moisture Content for Trial pit 8

Sample number	Depth(m)	Moisture content (%)
TP- 8a	0.0 – 0.5	25.10
TP- 8b	0.5 – 1.0	23.35
TP- 8c	1.0 – 1.5	31.75

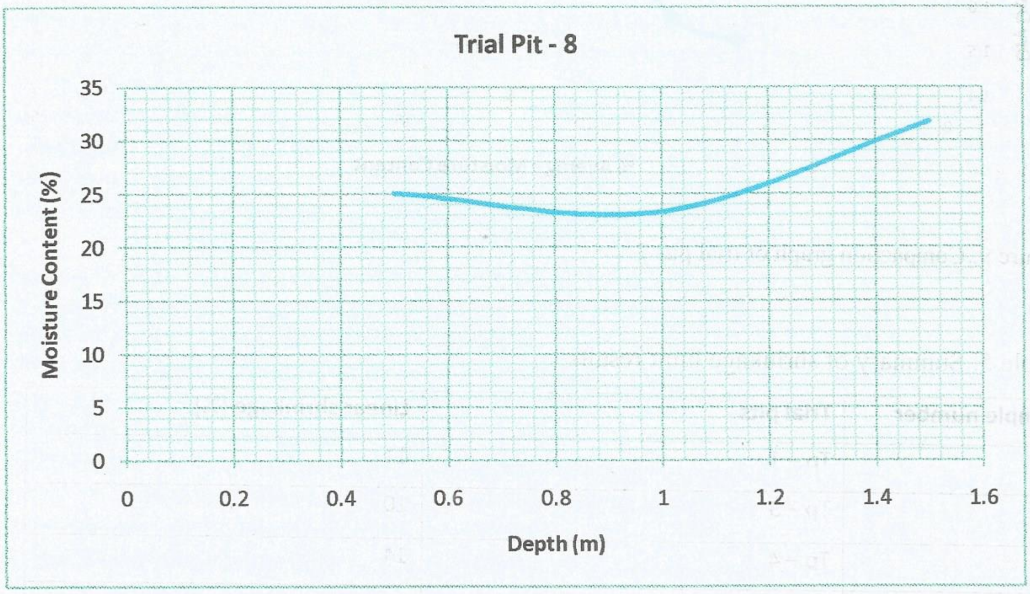


Figure 10: Natural Moisture Content graph of Trial pit-8

Natural Moisture Content

A Typical Natural Moisture Content result of Trial pit- 8 as shown in table 6 and plotted in figure 10 indicated that between the depth of 0.0 – 0.5m, the soil required addition of water during foundation construction than at the depth of between 1.0 – 1.5m which also tally with general elevation of the study area; 268m in west to 250m in the east. Summary of the Natural Moisture Content result as shown in (Table 7) are in the range of 11.52% - 29.86% with average mean value of 21.10%. Trial pits 1, 3 and 4 also required the addition of water while samples with higher moisture content like trial pit 7 do not require much addition of water during construction. The higher the natural moisture content of a soil, the closer it is to the groundwater table. Generally, the soil is classified as good to average good which is suitable for engineering purposes.

Conclusion and Recommendation

It should be noted however that, the importance of detailed knowledge of geology and soil behavior of an area to be constructed upon can never be over emphasized, as every engineering structure is as good as its foundation, and rocks are weathered into soil. The soils at the investigated area are cohesive and generally have low to moderate bearing capacities. They also have average plasticity which is good for foundation support for medium sized structures. As a result, foundation not exceeding 1m in diameter (pad and strip), an allowable bearing pressure of $150KN/m^2$ should be utilized in foundation with total settlement not exceeding 25mm and thus, negligible differential settlement. Construction along the principal joint direction of NW-SE in the area should be avoided in order to prevent cracks on the wall which may later lead to partial or total collapse in future. It is therefore, recommended that geophysical methods of investigation should essentially be made to complement the traditional engineering methods of foundation investigation.

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