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Geophysical and Engineering Geological Evaluations of Subsoil Competence: A Case Study of Alagbaka Extension Akure, Southwestern Nigeria

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Abstract:*The survey was aimed at evaluating the subsurface geotechnical competence at Alagbaka extension, Akure, south-western Nigeria. Electrical resistivity method involving Schlumberger array of Vertical Electrical Sounding (VES) technique was used in combination with the conventional engineering geological methods. Twenty-six (26) VES stations were occupied within the study site with maximum half-current electrode spread of 100 m. The engineering geological study involved twenty-six (26) soil samples (26) collected at a common depth of 2 m at the same locations with VES stations. The samples were analyzed for natural moisture content, grain size analysis, Atterberg limits, standard compaction, unconfined compressive strength and consolidation tests. The VES results delineated four geoelectric layers, which comprises of the top-soil, weathered layer, partially weathered/partially fractured basement and the fresh bedrock. At the depth slice of 2 m resistivity values across the site range from 100 - 510 Ω-m and consequently 9 out 26 locations were classified as competent area, while the remaining seventeen (17) locations are considered to be moderately competent. The bedrock resistivity range of 502 - 2317 Ω-m suggests possible presence of bedrock fractured in some VES locations. A good correlation exists between VES results and the soil profiles observed in hand dung pit and the engineering geological studies results. The particle size analysis obtained from the soil samples indicates that the area has varying amounts of fines and most of the soil samples are clayey sand, while the percentage of fines in the soils range from 26.1 to 47.4%. The plasticity index varies from 5.2 to 19.5 %. The optimum moisture content values are between 13.2 and 19.7 %, while the maximum dry density ranges between 1820 and 1995 kg/m^3. The overall results obtained revealed that the subsoil material have good engineering qualities for foundation and other construction purposes.*

Keywords: *Geophysics; electrical, geoelectric, engineering geology, subsurface competence, shear strength; foundations and subsoil competence.*

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I. Introduction

Failures of civil engineering structures throughout the Nigeria have increased in recent times. The necessity for subsoil characterization for construction purposes has therefore become very vital in order to prevent loss of valuable lives and properties that always accompany such failure. Some general reasons why engineering structures may be susceptible to collapse have been advanced, which include poor quality of building materials and old age of buildings. Less frequently mention is the subsurface conditions of the ground on which the buildings are sited. During or before foundation design, it is important to assess the overall site geology and subsoil characteristics (Delgado et al, 2000). It is very important that the competence of the subsurface soil is taken into consideration, i.e. the soil profile needs to be established and this can only be done by the combined assessment of the geology and soil test results, also the physical properties need to be takeninto consideration because the earth materials may vary spatially due to variation in subsurface lithology or distribution of constituents such as minerals and near surface structures (Delgado et al, 2000). Safe, durable and low maintenance costs structural design depend on adequate understanding of the nature of the ground on which such building is to be situated. Subsoil characterization usually provides subsurface information that assists civil engineers in the design of foundation of civil engineering structures.

The primary purpose of all site investigations is to obtain the data needed for analysis and design. The area under investigation is within Akure, South-western Nigeria. The Akure lies within Latitudes 07° 14' 12" N and 07° 14' 50" N and Longitudes 05° 13' 18" E and 05° 14' 33" E and it covers an area extent of about 9.2 km^2 (Figure. 1). Subsoil investigations involving geophysical and engineering geological methods that was carried out in the study area involved non-destructive mode of subsurface layers' determination of geophysical methods which made them suitable and cost effective, while the geotechnical investigation is essential in obtaining adequate knowledge of the engineering properties of the subsoil materials that would have direct interaction with the civil engineering structures across the area.

In the recent decades the involvement of geophysics and engineering geological methods in engineering site investigations have been very effective (Olorunfemi et al, 2005; Adepelumi et al, 2009; Akintorinwa et al, 2011; Oshinowo et al, 2011, Adeyemo and Omosuyi, 2012; Onuoha et al, 2014; Sabinus et al, 2014; Adiat et al, 2017 and Olayanju et al, 2017). This investigation will be useful in determining the nature and engineering properties of the Alagbaka extension for proper foundation design for any future structures. This study therefore employed geophysical investigation in conjunction with in-situ soil testing to provide information on the subsurface sequence, competence and structural disposition with a view to capture geo-engineering information of the subsurface that are inimical to engineering structures.

II. Geographic Location, Physiography and Drainage

Akure Metropolis lies within Latitudes 07^{o} 09' N and 07^{o} 19' N and Longitudes 05^{o} 07' E and 05^{o} 17' E (Figure 1). While the study area (Alagbaka extension) lies within Latitudes 07° 14' 12" N and 07° 14' 50" N and Longitudes 05° 13' 18" E and 05° 14' 33" E which covers an area extent of about 9.2 km^{2}. The study area is located on a gently undulating terrain with surface elevation varying from 353 - 372 m above sea level. The Nigerian basement complex lies within the remobilized zone of the West African basement. The major rock types in Akure were classified into four categories (Ademeso, 2009) namely; (a) the gneiss-migmatite-quartzite complex; (b) the schist belts which are low to medium grade supracrustal and meta-igneous rocks; (c) the Pan African granitoids (Older Granites) and other related rocks such as charnockitic rocks and syenites and (d) minor felsic and mafic intrusive. The rock intruded into the migmatite-gneiss-quartzite complex. The study area is Alagbaka extension and it lies within longitudes 5°00’E and 5°17’E and latitudes 7°10’N and 7°20’N in the Southwestern part of Nigeria (Figure 2).

It is believed (Adekoya, 1977) that tectonic joints are quantitative and directional manifestations of operative forces that can give a clue to possible stress distribution in a deformed rock. Several works have reported on the age/origin of the charnockitic rocks of the Precambrian Basement Complex of the Southwestern and Southeastern Nigeria (Rahaman, 1976; Olarewaju, 1998; Olarewaju, 2006; Oyinloye and Obasi, 2006 and Ademeso, 2009). It has been suggested (Rahaman, 1976; Olarewaju, 1981; Olarewaju, 1988; Ekwueme and Kroner, 2006) that they are similar to the medium-coarse-grained hypersthene-granodiorite of Eastern Hebei Province, China which is the product of crystallization of anatectic magmas of the same composition. Three

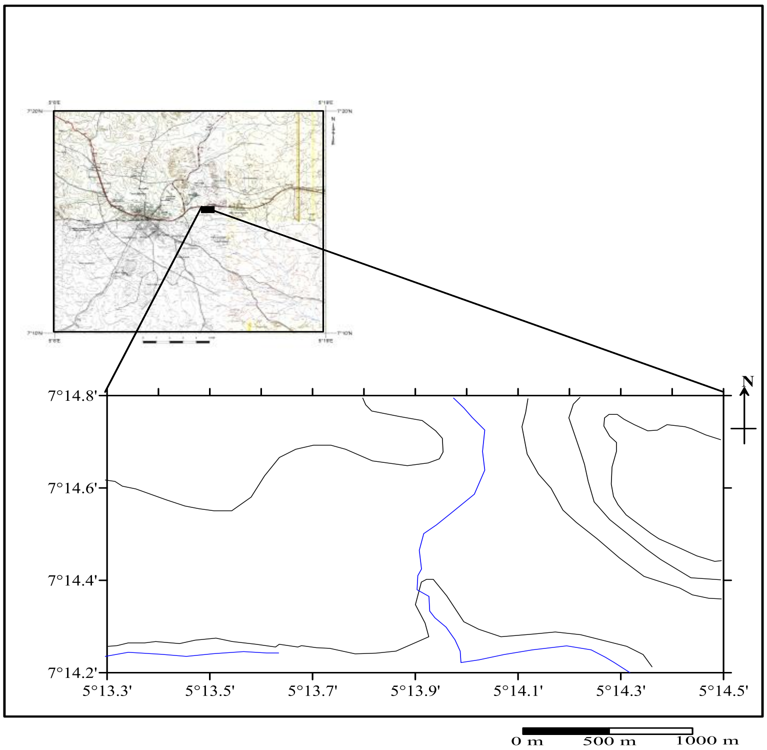


Figure 1: Base Map of Alagbaka Extension digitalized from the Topographic Map of Akure (Source: Ademeso, 2009).

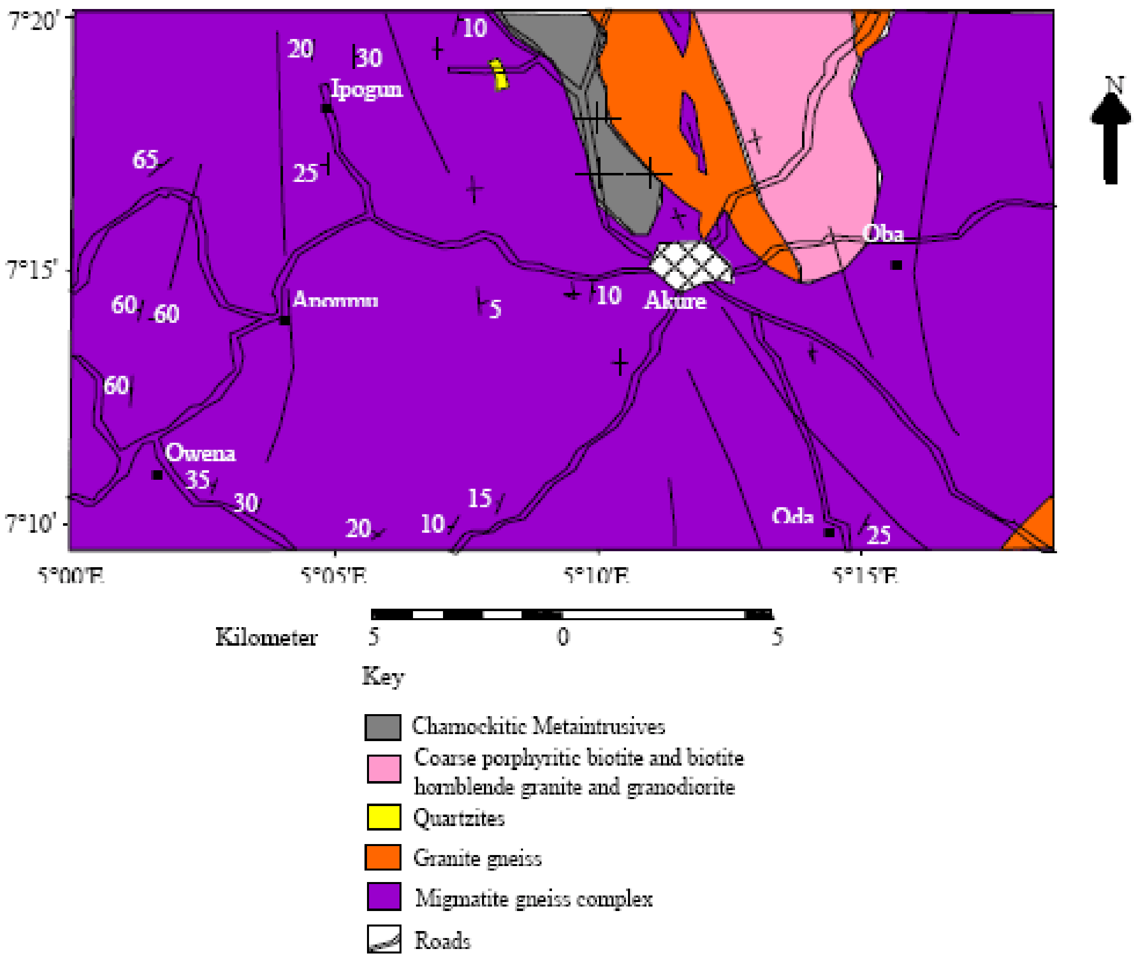


Figure 2: Geological map of Akure showing the study area (Source: Ademeso, 2009).

types of charnockitic rocks have been identified (Shitta, 2007) in Akure area on the basis of their textural characteristics; (1) coarse-grained as exemplified by the Akure body, (2) massive fine-grained which form along the margins of the granitic bodies as seen in Ijare, Uro and Edemo-Idemo and (3) the gneissic fine-grained types which were recognized within the bodies of the gneisses in Ilara and Iju. The charnockitic rocks of Akure-Ikere-Ado Ekiti have earlier been described as an association (Olarewaju, 2006). It is concluded that alteration pathways from fresh to weathered charnockitic rocks are clearly different under different climate conditions.

The geological mapping and other related studies of the area around the Akure Metropolis have been carried out by several workers (Rahaman, 1976; Olarewaju, 1981, Olarewaju, 1988, Owoyemi, 1996; Aluko, 2008 and Ademeso, 2009). The study area which is within Akure Metropolis is underlain by four of the six lithological units of the Basement Complex of Southwestern Nigeria (Rahaman, 1976; Olarewaju, 1988; Adekoya et al, 2003 and Aluko, 2008). They are the Migmatite-Gneiss-Quartzite Complex, Older Granites, Charnockitic and Dolerite dykes (Figure 2). The basement rocks exhibit varieties of structures such as foliation, schistocity, folds, faults, joints and fractures. Generally, the structural trends in the study area are NNW-SSE and NNE-SSW. The geology of Alagbaka extension consists mainly of migmatite-gneiss, quartzite and porphyritic granite. The rocks occur largely as low lying outcrops although a pocket of high vision outcrops around the study area.

The topsoil in the study area is characterized by organic materials. The subsoil (regolith) which is a product of the in-situ weathering of the underlying crystalline rocks is composed of loose reddish-brown, medium to coarse grained mineral materials with some clayey component. The soil consists of essentially lateritic material (Figure 3).

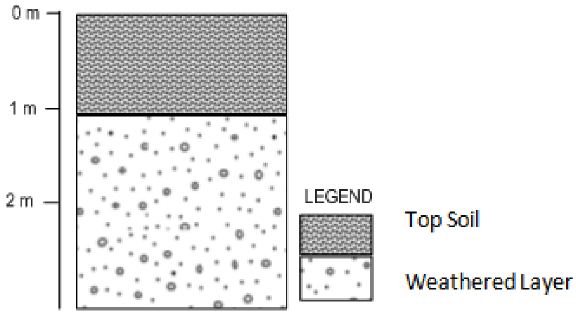


Figure 3: Soil profile of the study area

III Materials and Method Used

3.1 Geophysical survey

Twenty-six (26) Vertical Electrical Soundings (VES) were conducted across the study area (Figure 1) using Schlumberger array with electrode separations (AB/2) varying from 1 to 100 m. The sounding stations were all geo-referenced using GARMIN 12 channel personal navigator (GPS) unit and the coordinates were measured in Universal Traverse Mercator (UTM). The VES survey measurements were carried out parallel along the traverse lines. The apparent resistivity measurements from all the VES points were presented as a plot of apparent resistivities against half current electrode spacing (AB/2) on bi-logarithmic graph sheets. The curves were qualitatively interpreted to determine the layer number and curve types. The quantitative interpretations of the curves weredone using partial curve matching method (Zohdy, 1965; Keller and Frischnecht, 1966 and Koefoed, 1979). The results of the curve matching (layer resistivities and thicknesses) were fed into the computer as a starting model in an iterative forward modeling technique using RESIST version 1.0 (Vander Velpen, 1989). The resultant VES results (layer resistivities and thicknesses) were presented as iterated curves, table, geoelectric sections and map. The resistivity values were used to classify the subsurface into different competence zones based on the classifications in Table 1 below (Olorunfemi, et al, 2005 and Olorunfemi et al, 2006).

Table 1: Rating Adopted for Geophysical Parameter (After: Olorunfemi et al, 2005 and Olorunfemi et al, 2006)

	Index Range	Class Classification	Index Rating
Resistivity of Weathered Layer	< 100	Incompetent	0.25
	100-350	Moderately Competent	0.50
	> 350	Highly Competent	0.75
Resistivity of Bedrock	< 600	Incompetent	0.25
	600-750	Moderately Competent	0.50
	> 750	Highly Competent	0.75

3.2 Engineering Geology Tests

Soil samples were collected from twenty-six (26) geo-referenced locations from the study area. The samples were analysed for natural moisture content, specific gravity, grain size analysis, hydrometer analysis, Atterberg limits, Standard compaction, consolidation test and Unconfined Compressive Strength. The plasticity index can be used as an index of subsoil competence evaluation as shown in Table 2 (Adeyemi and Oyediran, 2004).

This study integrated the geoelectric and geotechnical parameters in evaluating geotechnical competence of the subsurface in the study area. Subsurface layer resistivity at the depth slice of 2 m was correlated with the engineering properties of subsurface soil at the same depth of 2 m. The Unified Soil Classification System (USCS) was adopted for soil classification. The base map and geologic map of the study area were pre-processed for geometric correction, haze reduction and re-sampling (Figure 4). The sampling points and the VES points were super-imposed on the geological map of the area (Figure 5).

Table 2: Rating Adopted for Engineering Geological Parameter [After: Adeyemi and Oyediran, 2004]

	Index Range	Class Classification	Index Rating
Consolidation	> 0.15	Low Competence	0.25
	0.15-0.075	Moderate Competence	0.50
	< 0.075	High Competence	0.75

Atterberg Limits (Plasticity Index)	> 20	Low Competence	0.25
	10-20	Moderate Competence	0.50
	< 10	High Competence	0.75
Unconfined Compressive Strength	< 38	Low Competence	0.25
	38-71	Moderate Competence	0.50
	> 71	High Competence	0.75

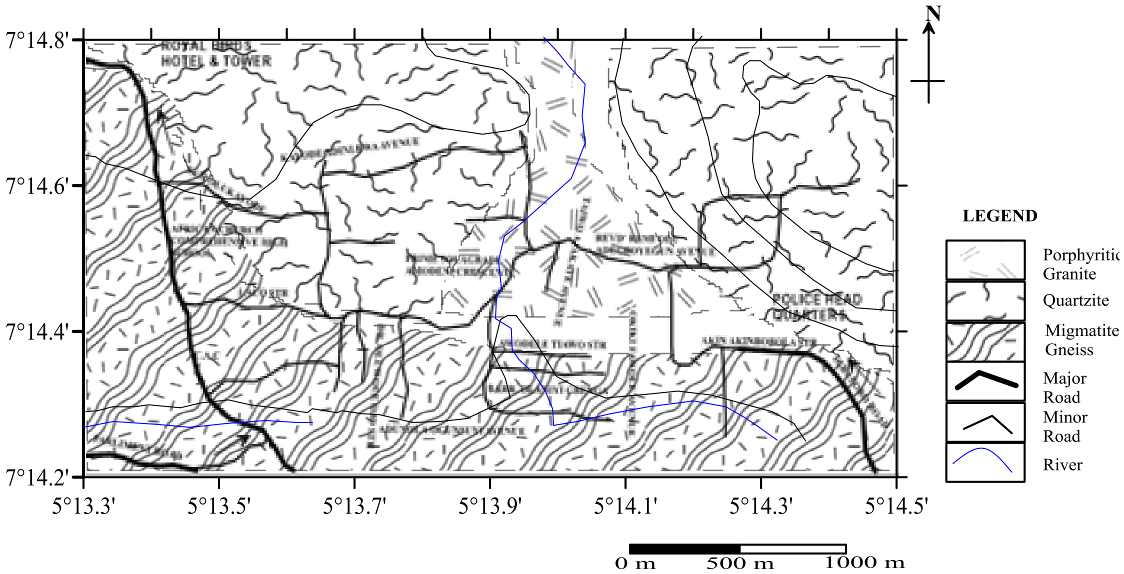


Figure 4: Geological Map of the Study Area

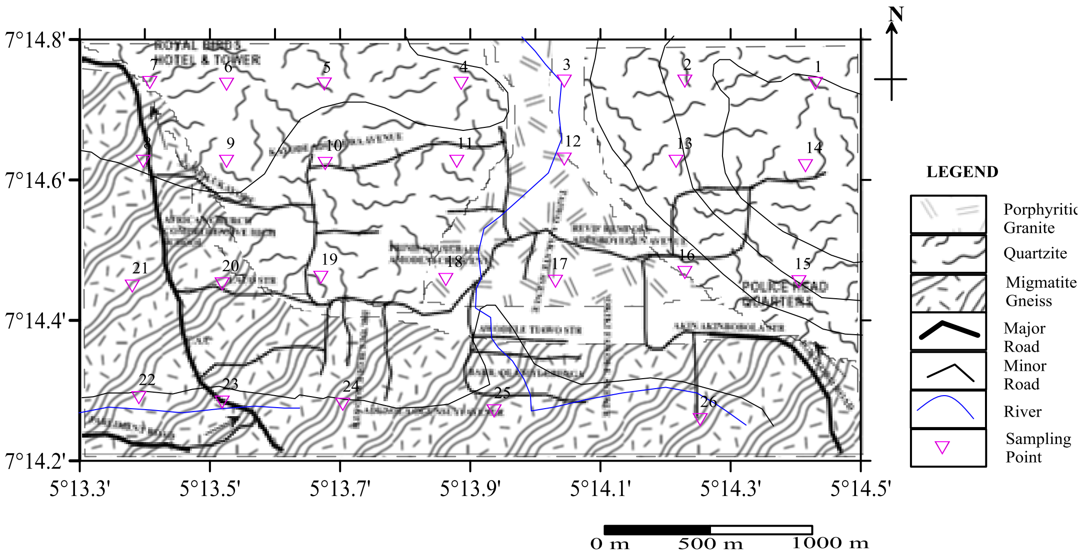


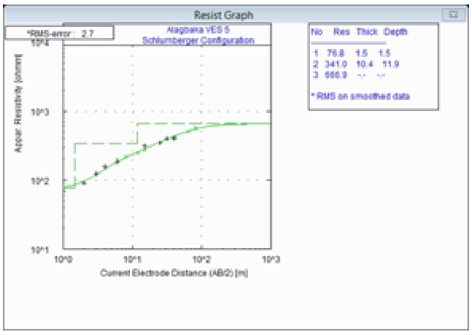
Figure 5: Geological Map of the study area showing the soil sampling points

IV Results and Discussion

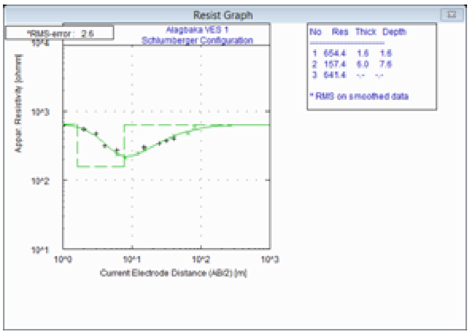
4.1 Geo-electrical Sounding Results

Four characteristics curve types were obtained from the study area; A, H, HA and KH (Figure 6, Table 3). Four (4) geo-electric layers (Table 3, Figure 6) were delineated across the study area which may or may not correspond with geologic layers. The geoelectric layers are the top soil, weathered layer, partially weathered/partially fractured basement and the fresh bedrock. The topsoil resistivity range from 77 to 654 Ωm while the layer thickness varies from 1.1 to 3.9 m, the weathered layer resistivity varies from 101 to 626 Ωm and the layer thickness varies from 3.8 to 11.4 m, the weathered/partially fractured has resistivity range of 154 to 2317Ωm and layer thickness of 4.6 to 22.5 m and the fresh bedrock has resistivity values ranging from 629 to 1261 Ωm and thickness values varying from 5.6 to 50 m. At the depth slice of 2 m resistivity values range from

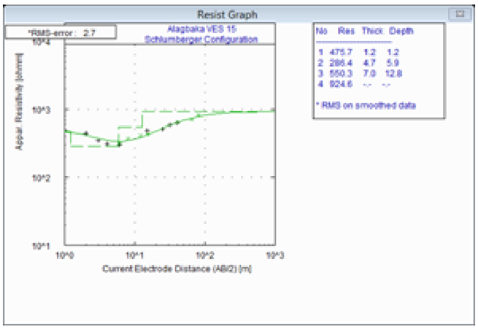
100 to 510 Ωm and based on the rating resistivity parameter rating in table 2 (Olorunfemi et al, 2004) nine (9) out 26 locations were classified as competent while the remaining seventeen (17) locations are classified as moderately competent (Figure 7). The bedrock resistivity value of 502Ωm suggests possible presence of bedrock fractured at location 23 and the location is considered to be of incompetent bedrock layer, while fifteen (15) VES locations make up the competent zone and moderately competent zone consist of eleven locations.

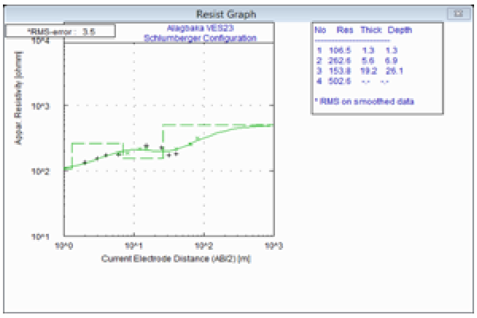


(a) Typical A curve type



(b) Typical H curve type





(c) Typical HA curve type

(d) Typical KH curve type

Figure 6$_{(a-d)}$: Typical sounding curves in the study area

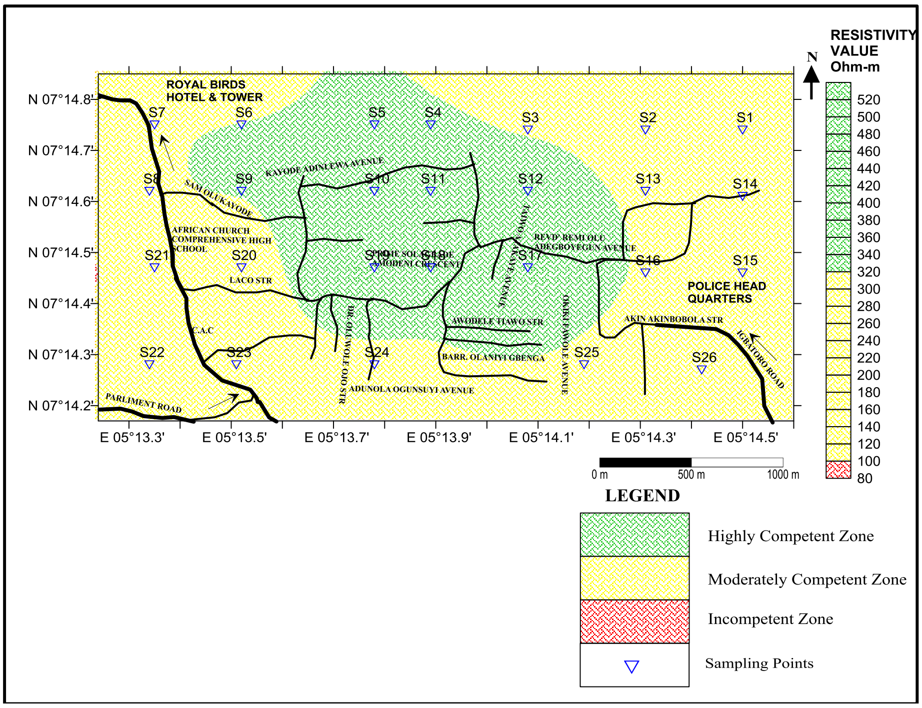


Figure 7: Competency Map Generated from Resistivity Values of the Study Area

Table 3: Vertical Electric Sounding Results

VES NO	Layer Resistivity (Ωm) $\rho_1/\rho_2/\rho_3$……h_n	Layer Thickness (m) $h_1/h_2/h_3$……h_n	No of Layer	Curve Type
1	654/ 157/ 641	1.6/ 6.0	3	H
2	602/ 197/ 549/ 779	1.5/ 8.5/ 14.9	4	HA
3	528/ 194/ 533/ 798	1.6/ 9.7/ 17.2	4	HA
4	130/ 309/ 716	2.2/ 6.2	3	A
5	77/ 341/ 667	1.5/ 10.4	3	A
6	401/ 208/ 694	1.1/ 6.3	3	H
7	433/ 117/ 532/ 727	1.3/ 7.1/ 14.8	4	HA
8	582/ 105/ 419/ 1261	2.3/ 8.3/ 9.5	4	HA
9	83/ 378/1150	1.7/ 10.0	3	A
10	89/ 323/ 2317	1.7/ 10.0	3	A
11	396/ 538/ 954	2.9/ 4.8	3	A
12	131/ 374/ 604	1.4/ 7.1	3	A
13	503/ 212/ 616/ 887	1.2/ 4.5/ 4.6	4	HA
14	569/ 173/ 918/ 1177	1.2/ 6.0/ 10.8	4	HA
15	476/ 286/ 550/ 925	1.2/ 4.7/ 7.0	4	HA
16	482/ 269/ 879	1.2/ 6.5	3	H
17	172/ 511/ 756	1.4/ 11.4	3	A
18	645/ 378/ 952	1.3/ 4.3	3	H
19	510/ 626/ 1027	3.9/ 3.8	3	A
20	651/103/ 506/ 1150	1.6/ 7.6/12.7	4	HA
21	435/ 101/ 652/ 800	1.5/ 6.6/ 22.2	4	HA
22	532/ 128/ 462/ 689	1.6/ 8.1/ 15.0	4	HA
23	107/ 263/ 154/ 503	1.3/ 5.6/ 19.2	4	KH
24	486/115/ 523/ 629	1.2/ 9.1/ 22.5	4	HA
25	468/132/ 468/ 747	1.6/ 8.4/ 14.6	4	HA
26	401/ 101/ 485/ 711	1.2/ 6.7/ 14.5	4	HA

4.2 Engineering Geotechnical Investigation

The grain size distribution characteristic and consistency limits results enhanced the characterization and classification of soil. The moisture content obtained for the soil samples range from 6.1 to 18.5 % (Table 4). The plastic limit values range from 17.6 to 29.5 %, while the plasticity index range from 5.2 to 19.5 % (Table 5 and Figure 8), these values are characteristics of soils obtained within the Basement Complex environment and can be used have varying amounts of fines, though most of the soil samples are clayey sand and the percentage of as foundation materials. The tested soil samples fine in the soils range from 26.1 to 47.4% (Table 6). These show that the soils are generally matured residual materials with sufficient binders for the coarse constituents to

Table 4: Moisture Content Results

Sample Number	Test 1 (%)	Test 2 (%)	Average (%)
1	15.0	15.5	15.3
2	18.6	18.2	18.4
3	9.2	8.8	9.0
4	6.4	6.4	6.4
5	8.4	8.2	8.3
6	8.4	8.7	8.6
7	12.8	13.2	13.0
8	9.1	9.5	9.3
9	8.7	8.9	8.8
10	9.5	9.9	9.7
11	8.2	8.2	8.2
12	7.9	7.8	7.8
13	9.7	9.5	9.6
14	10.6	10.4	10.5
15	12.0	13.5	12.8
16	13.4	13.2	13.3
17	23.0	14	18.5
18	10.0	10.3	10.2
19	9.7	10.1	9.9
20	13.7	14.1	13.9
21	11.3	11.7	11.5
22	12.3	12.7	12.5
23	15.2	15.9	15.6
24	16.2	16.3	16.3
25	13.8	13.4	13.6

26	6.2	6.0	6.1
Mean	11.5	11.3	11.4

Table 5: Consistency Limit Results

Sample Number	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Linear Shrinkage	Unified Soil Classification System (USCS) Group Symbol
1	32.1	20.8	11.3	5.3	CI
2	35.6	24.4	11.2	5.2	CI
3	25.2	17.6	7.6	4.2	CL
4	27.9	22.7	5.2	3.9	CL
5	30.0	23.2	6.8	2.9	CL
6	28.7	22.0	6.7	3.6	CL
7	35.2	24.9	10.3	5.1	CI
8	47.6	29.5	18.1	7.5	CI
9	28.9	23.9	7.0	3.1	CL
10	29.5	23.1	6.4	3.1	CL
11	31.2	23.7	8.5	4.6	CL
12	25.1	17.8	7.3	4.1	CL
13	37.2	26.1	11.1	5.2	CI
14	26.2	18.3	7.9	4.3	CL
15	29.3	21.2	8.1	4.5	CL
16	31.8	23.1	8.7	4.6	CL
17	48.6	29.1	19.5	7.7	CI
18	30.7	23.6	7.1	3.5	CL
19	29.7	21.5	8.2	4.5	CL
20	48.1	29.0	19.1	7.7	CI
21	48.1	28.9	19.2	7.7	CI
22	38.6	26.9	11.7	5.4	CI
23	47.1	29.0	18.1	7.5	CI
24	46.6	29.1	17.3	7.5	CI
25	36.6	24.0	12.6	5.3	CI
26	28.3	20.3	8.0	4.5	CL

attain high shear strength. The tested soils are generally well-graded (Figure 9) and subject to the prevailing moisture content they can serve as good foundation materials. The specific gravity value is a very useful index in the identification and evaluation of laterite aggregates for construction purposes. An increase in specific gravity has been found to be associated with a decrease in voids ratio (Adeyemi and Oyediran, 2004). The specific gravity values of the tested soils range from 2.65 and 2.80 g/cm$^{3.}$

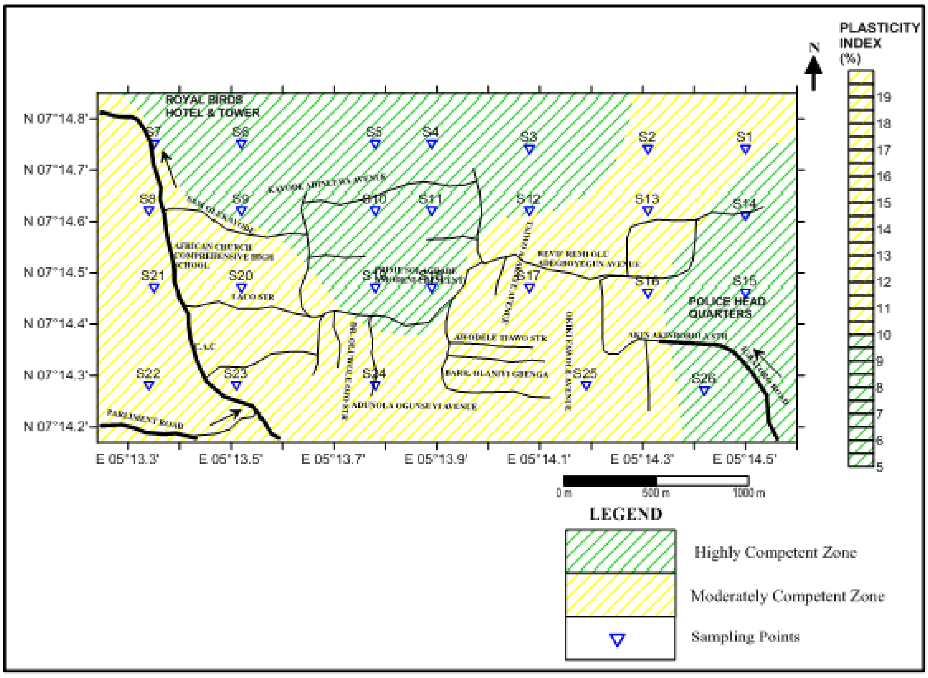


Figure 8: Competency map generated from Plasticity Index

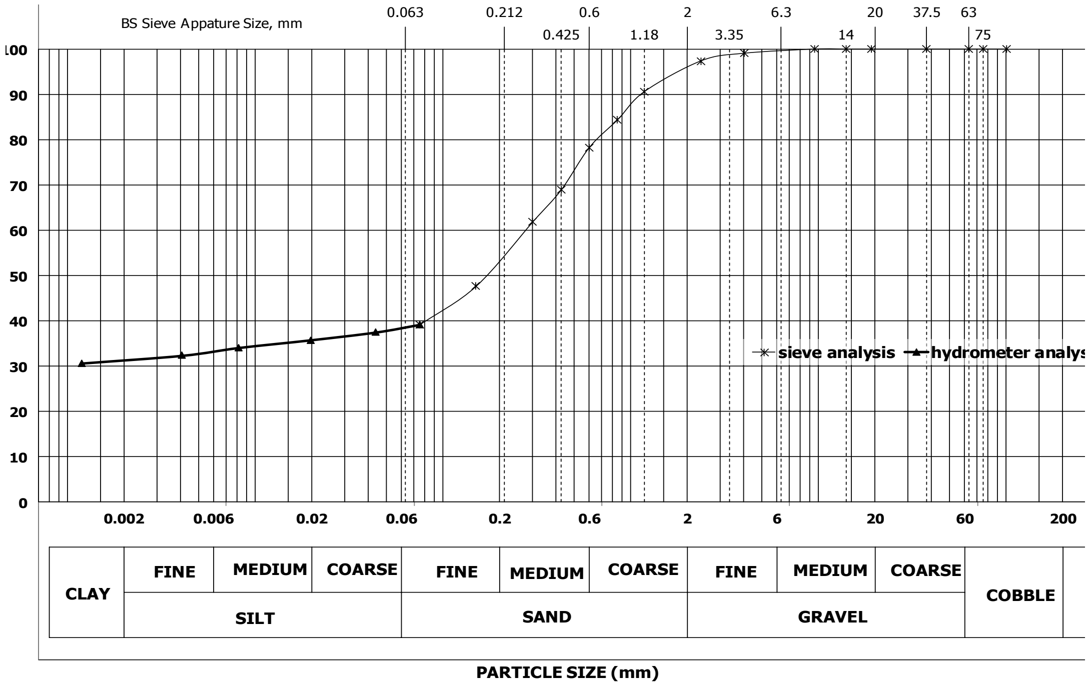


Figure 9: Grain Size Distribution (well-graded)

Table 6: Grain Size and Hydrometer Analyses

Sample Number	% Clay	% Silt	% Sand	% Gravel	Soil Group
1	22.8	9.5	64.6	5.1	Clayey Sand
2	31.0	8.1	58.3	2.6	Clayey Sand
3	20.9	5.8	58.8	14.5	Clayey Sand
4	24.9	7.6	56.7	10.8	Laterite
5	24.0	9.1	56.1	10.7	Laterite
6	22.0	10.3	58.0	9.7	Laterite
7	27.6	7.4	47.9	3.3	Clayey Sand
8	38.7	8.7	51.0	1.7	Clayey Sand
9	21.7	10.4	58.6	9.3	Laterite
10	23.4	9.6	60.4	6.7	Laterite
11	23.9	8.5	58.5	9.2	Laterite
12	18.3	7.7	59.5	14.5	Clayey Sand
13	27.4	11.8	49.9	10.9	Clayey Sand
14	19.9	7.9	60.8	11.4	Clayey Sand
15	20.6	8.0	57.2	10.6	Clayey Sand
16	25.5	8.1	52.5	9.2	Clayey Sand
17	20.6	8.0	57.2	3.9	Clayey Sand
18	24.5	9.2	56.6	9.8	Laterite
19	22.4	7.9	60.8	8.9	Laterite
20	38.5	7.0	51.3	3.2	Clayey Sand
21	39.6	7.0	51.3	2.0	Clayey Sand
22	30.1	9.0	57.0	3.4	Clayey Sand
23	36.2	11.2	50.1	3.9	Clayey Sand
24	35.6	11.4	51.0	4.1	Clayey Sand
25	28.8	9.8	46.7	5.6	Clayey Sand
26	27.4	11.8	49.9	10.9	Clayey Sand

The moisture-density relationship (compaction characteristics) of the soils (Table 7) shows that the maximum dry densities of the studied samples are relatively moderate (Figure 10). A comparison of the values with compaction characteristics shows that the soils fall within fair to good class (Adeyemi and Oyediran, 2004). The optimum moisture content ranges between 13.2 and 19.7 % while the maximum dry density ranges between 1820 and 1995 kg/m^3 (Table 7). The best soils are those with maximum dry density at low optimum moisture content.

The coefficients of compressibility (M_v) for the consolidation at various overburden pressures range from 0.18349 to 0.44142 MPa^{-1} and coefficients of consolidation (C_v) at various overburden pressures also vary from 0.01060 to 0.01546 m^2/yr (Table 8 and Figure 11). The shear strength values for the soil analysis ranges from 74.1 to 103.8 KPa and the unconfined compressive strength values varies from 148.3 to 207.6 KPa (Table 9 and Figure 12). The overall results obtained revealed that the tested soil samples have high soil bearing capacity, the subsoil material have good engineering qualities for foundation and other construction purposes.

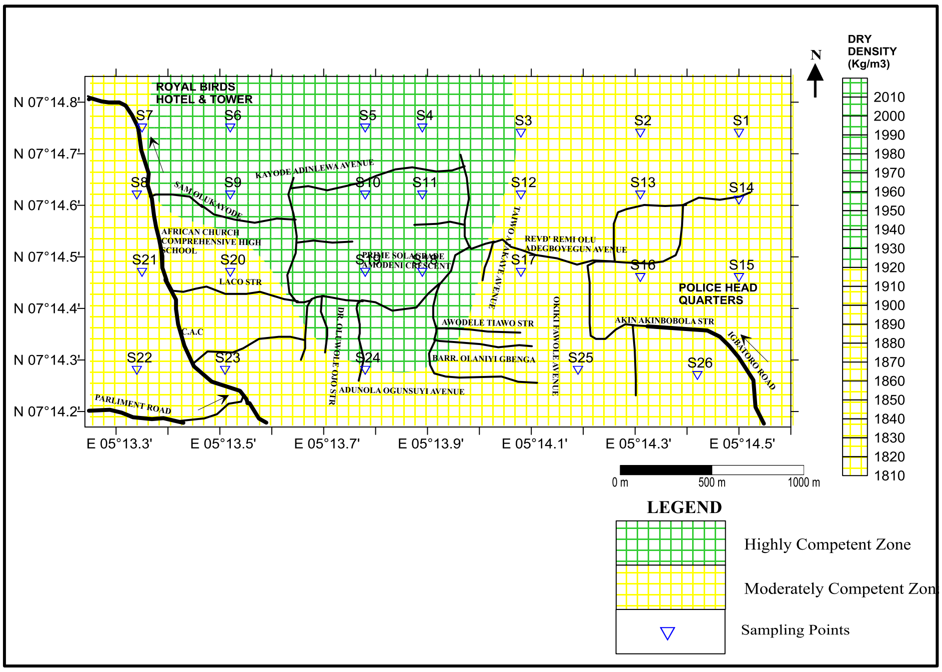


Figure 10: Competency Map Generated from Dry Density Values of the Study Area

Table 7: Compaction Characteristics of the Soil Samples

Sample Number	Average Specific Gravity	Average Specific Gravity	Maximum Dry Density (Kg/m^3)	Optimum Moisture Content (%)
1	2.66	2.66	1857	13.2
2	2.65	2.65	1868	19.2
3	2.66	2.66	1899	18.2
4	2.80	2.80	1989	15.3
5	2.75	2.75	1986	15.4
6	2.80	2.80	1998	15.0
7	2.65	2.65	1820	14.0
8	2.65	2.65	1853	19.7
9	2.75	2.75	1995	15.1
10	2.80	2.80	1977	15.7
11	2.75	2.75	1971	15.9
12	2.65	2.65	1909	17.9
13	2.65	2.65	1905	18.0
14	2.65	2.65	1856	19.6
15	2.65	2.65	1915	17.7
16	2.66	2.66	1896	18.3
17	2.65	2.65	1859	19.5
18	2.78	2.78	1974	15.8
19	2.75	2.75	1967	16.0
20	2.65	2.65	1840	20.1

21	2.65	2.65	1918	17.6
22	2.66	2.66	1905	18.0
23	2.66	2.66	1902	18.1
24	2.66	2.66	1893	18.4
25	2.65	2.65	1881	18.8
26	2.66	2.66	1865	19.3

Table 8: Consolidation Test Result

Sample Number	Coefficient of Compressibility (A_v)	Coefficient of Vol. Compressibility (M_v)	Compression Index (C_c)	Swelling Index (C_s)	Coefficient of Consolidation (C_v)(m^2/min)
1	0.33648	0.24911	0.0456	0.01919	0.02684
2	0.51812	0.32256	0.0699	0.03159	0.02413
3	0.29904	0.18978	0.0409	0.01543	0.02919
4	0.37069	0.25124	0.0503	0.02119	0.02676
5	0.36620	0.24804	0.0497	0.02086	0.02688
6	0.36468	0.24911	0.0495	0.02080	0.02684
7	0.38034	0.27808	0.0515	0.02238	0.02575
8	0.69695	0.43127	0.0936	0.04484	0.02051
9	0.36234	0.24697	0.0492	0.02061	0.02692
10	0.38016	0.25552	0.0515	0.02184	0.02660
11	0.37180	0.24911	0.0504	0.02120	0.02684
12	0.28722	0.18349	0.0393	0.01460	0.02944
13	0.49869	0.31929	0.0673	0.03034	0.02425
14	0.32693	0.20135	0.0446	0.01730	0.02872
15	0.32454	0.20874	0.0442	0.01742	0.02842
16	0.41274	0.26195	0.0559	0.02389	0.02635
17	0.70993	0.44142	0.0953	0.04584	0.02019
18	0.39359	0.26410	0.0533	0.02283	0.02627
19	0.34087	0.22780	0.0463	0.01889	0.02767
20	0.69511	0.42676	0.0934	0.04465	0.02065
21	0.65582	0.42564	0.0881	0.04211	0.02068
22	0.50331	0.32256	0.0679	0.03069	0.02413
23	0.64421	0.41329	0.0866	0.04117	0.02108
24	0.64364	0.40992	0.0865	0.04108	0.02119
25	0.50448	0.31711	0.0681	0.03064	0.02433
26	0.52418	0.32365	0.0707	0.03198	0.02410

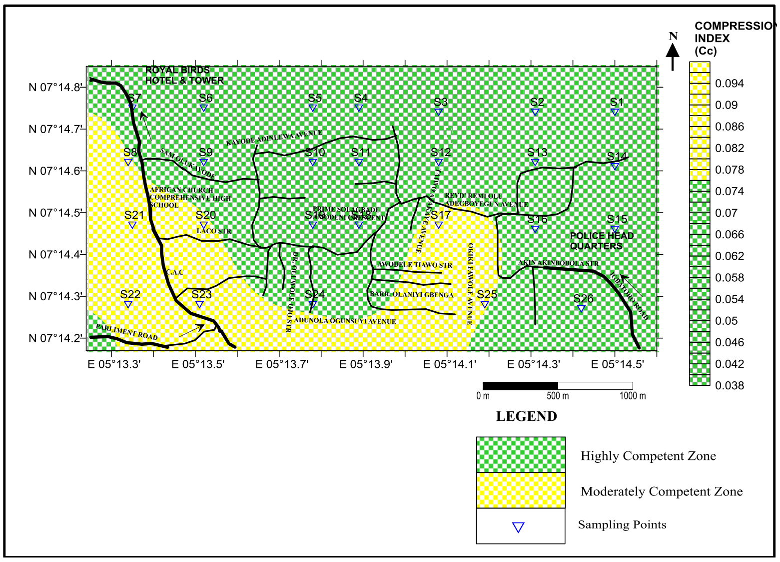


Figure 11: Competency map generated from Compression Index Values

Table 9: Unconfined Comprehensive Strength Result

Sample Number	Unconfined Compressive Strength (kPa)	Shear Strength (kPa)
1	169.8	84.9
2	174.1	87.0
3	161.3	80.7
4	165.6	82.8
5	186.4	93.2
6	207.1	103.6
7	190.8	95.4
8	160.6	80.3
9	199.1	99.6
10	203.3	101.7
11	207.6	103.8
12	199.1	99.6
13	186.4	93.2
14	178.3	89.2
15	174.1	87.0
16	169.8	84.9
17	152.8	76.4
18	198.7	99.3
19	202.9	101.4
20	160.6	80.3
21	156.4	78.2
22	156.7	78.4
23	148.3	74.1
24	161.0	80.5
25	165.2	82.6
26	165.2	82.6

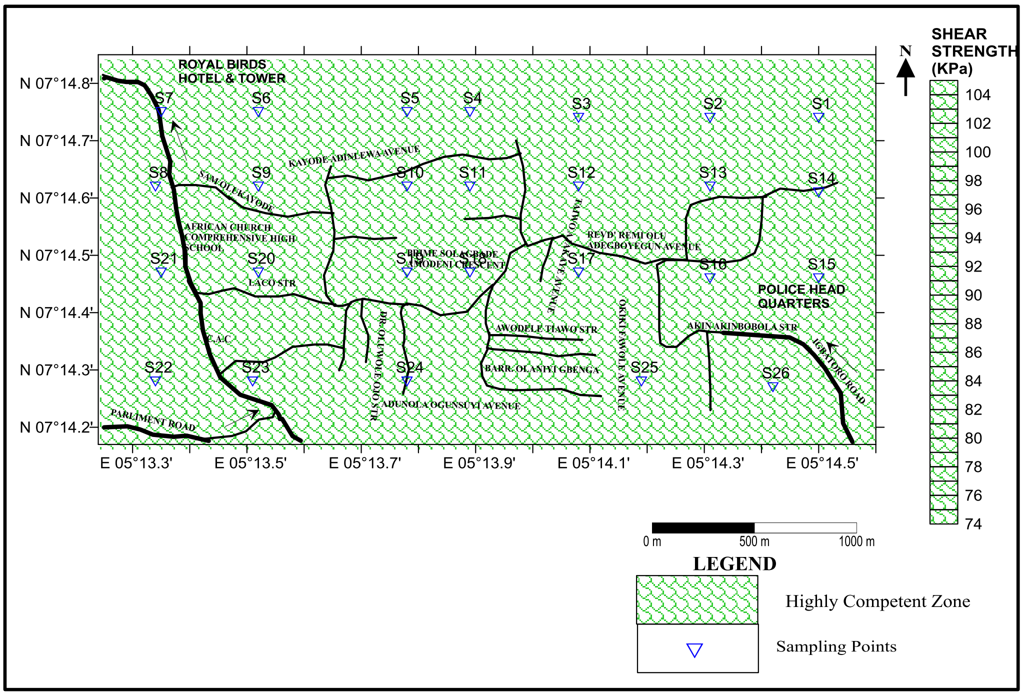


Figure 12: Competency map generated from shear strength values of the study area

V Conclusion and Recommendation

An integrated geophysical and geotechnical investigation was carried out at Alagbaka extension, Akure, Southwestern part of Nigeria. The geophysical survey comprised of twenty-six (26) vertical electrical sounding data acquired using Schlumberger configuration. These VES locations were evenly distributed across the survey site. The engineering geological aspect involved twenty-six (26) soil samples from different pits located on the earlier conducted VES locations. This allowed for easy correlation of results from both methods and the geotechnical survey results were also used to control the VES interpretations.

The geophysical results delineated four geoelectric layers across the study area. These includes; the topsoil, lateritic clayey with coarse sand, weathered/fracture basement and fresh bedrock. The VES results also showed that the study area can be grouped into moderate and high competent zones. The results of the geotechnical investigation show that the site is underlain by layers of stiff to very stiff lateritic clay and sand at a depth of 2 m, this correlates well with VES result.

Therefore, the choice of foundation materials in the study area must reflect the characteristics of the clayey material. Shallow foundation is therefore considered suitable for civil engineering structures because of the presence of these competent materials. However, foundations of large civil engineering structures within the study area should rest safely high competent layer (bedrock) in the moderate competent zone. This study has again showed the advantage of combining geophysical and geotechnical methods in engineering site characterization.

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