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Assessment of Foundation Instability Using Integrated Geotechnical and Geophysical Techniques: A Case Study of Giza, Keana LGA, Nasarawa State, North Central Nigeria

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Abstract

Engineering structures such as buildings, in Giza community (central Nigeria) have developed severe cracks, undergone differential settlement, and failed in some parts. These have been a disturbing situation to its inhabitants. Integrated geophysical, geotechnical, and hydrogeological techniques were employed to investigate the causes of this menace. Vertical Electric Sounding (VES) was used to delineate the subsurface geo-electric layers. Soil samples were analyzed for grain-size distribution, Atterberg Limit, moisture content, specific gravity, compaction, coefficient of permeability, and undrainedtriaxial test. Static water level measurements were carried out during wet and dry seasons to establish the zone of groundwater fluctuation. VES results revealed that foundations within the cracked zone are underlain by incompetent, low resistivity (2.77 – 24.8 Ωm) saturated clay (0.5-3.1m thick). The non-cracked zone is underlain by moderately competent, clayey sands (3.5-6.9m thick). Geotechnical results of the cracked zone revealed high plasticity (29-51%), high moisture content (10.11-12.02%,), and low permeability (4.26×10^{-5}-5.36×10^{-7}m/sec) which impedes drainage. Maximum dry density ranges from 1.76 – 1.88g/m^3 with corresponding optimum moisture content of 10.11 – 12.02%. Cohesion contributes more to the shear strength than angle of internal friction in the cracked zone, compared to the non-cracked zone, which shear strength is controlled by both. The groundwater fluctuation zone was found to be 1.1-6.2m and within the clay layer. The shallow zone of fluctuation saturates clays under foundation making it highly plastic. The soils experiences swelling and shrinking as water level rises and falls, which cause buildings to heave, crack, or settles differentially leading to failures.

Keywords: Cracks; Foundations; Giza; Geotechnical; Active zone.

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1. Introduction

Foundation problems associated with shales, having varying degree of damages were reported by Agbedeand Smart [1]; Henry and Igwe [2];Ola [3]; Uduji, Okagbue, and Onyeobi [4];and Una and his colleagues [5] in Makurdi, Awgu, Okigwe, Sokoto and Akpogu town respectively. Foundation as the connecting link between an engineering structure and the ground that support it, is meant to transmit the weight of the structure to the ground without causing the ground to respond to uneven and excessive movement. If a foundation does not meet these conditions it is considered to have failed in shear, causing distress on the engineering structures thereby affecting its serviceability. The distress would be evident in the development of cracks on walls (Fig.3), floors, and sometimes, on the foundation within the vicinity of the structure [1], foundation heave, settlement or even building collapse in severe cases.

Buildings in Giza community and the environs, Keana L.G.A of Nasarawa state, north central Nigeria, were observed to have undergone differential settlement (Fig.3), developed severe cracks and even failed in some parts. These cracks and failures are severe in the northern part of the study area. The distress is occurring on both light-weight and storey buildings, built with either mud-blocks or concrete-blocks. Lack of understanding of the engineering properties of shales as a prerequisite for erecting engineering structures such as building is a contributory factor to foundation instability in the study area. According Chen[6], diagonal cracks that develop below windows and above doors (Fig. 3) are a strong indication of swelling movement. Desiccation cracks (Fig. 2) were also observed to develop on the ground surface in the peak of dry season. This may be due to the change in moisture content, causing the clays to shrink as water evaporates. However, during the wet season the clay minerals will absorb water and swell, this phenomenon is typical of expansive clays. Emeh and Igwe [7]; Henry and Igwe [2]; Maduka and his colleagues [8]; and Una and his colleagues [5] worked on the shale of Awgu Formation, Benue Trough Nigeria and concluded that it is rich in smectite, a clay mineral responsible for shrinking and swelling. Chen [6] has discussed in details the mechanism of shrink-swell soils.Given the unprecedented success recorded by the integrated approach, different geoscientists in many parts of Nigeria have resorted to using the connected approach of geophysical and geotechnical techniques in subsurface engineering investigations. Oladunjoye and his colleagues [9], used the integrated techniques in preliminary geotechnical characterization of site in southwest Nigeria, and concluded that it is a well suited tool to characterize and delineate subsurface structure for engineering site investigations. Geotechnical and geophysical investigation techniques are the most cost-effective and rapid means of obtaining subsurface information, especially over large study area [10;11,12] worked on the application of geophysical and geotechnical analysis in engineering site evaluation in Nigeria. Also, Una and his colleagues [5] used an integrated geotechnical and geophysical investigation techniques to assess the spate of frequent building collapse in Akpugo, part of south eastern Nigeria. Reference [13] employed geophysical technique to investigate the subsurface engineering properties, evaluate groundwater potentials and determine the level of safety of the hydrogeological system in Ungwan Doka, Kaduna State. However, most researchers that used the integrated geotechnical and geophysical techniques in studying the subsurface foundation materials tend to ignore the role of groundwater level fluctuation on foundation instability. Considering the challenges of foundation on shale [14] noted that understanding of the local geology and groundwater conditions is vital for risk assessment and mitigation, while [15] deem it necessary to establish the highest and the lowest water level for the proper design of structures, as seasonal ground water level fluctuation affect the stability of foundations built on clays.

Foundation materials in the study area, located within a tropical region with distinct wet and dry seasons will undergo moisture changes. Therefore, groundwater level fluctuation will be studied in combination with geophysical and geotechnical investigations to assess foundation instability in Giza and environs, part of Awgu shale of the Central Benue Trough. These will help in establishing the cause of cracks and buildings failures, therefore, proffering appropriate mitigation measures. It would also serve as a baseline for further research on the area.

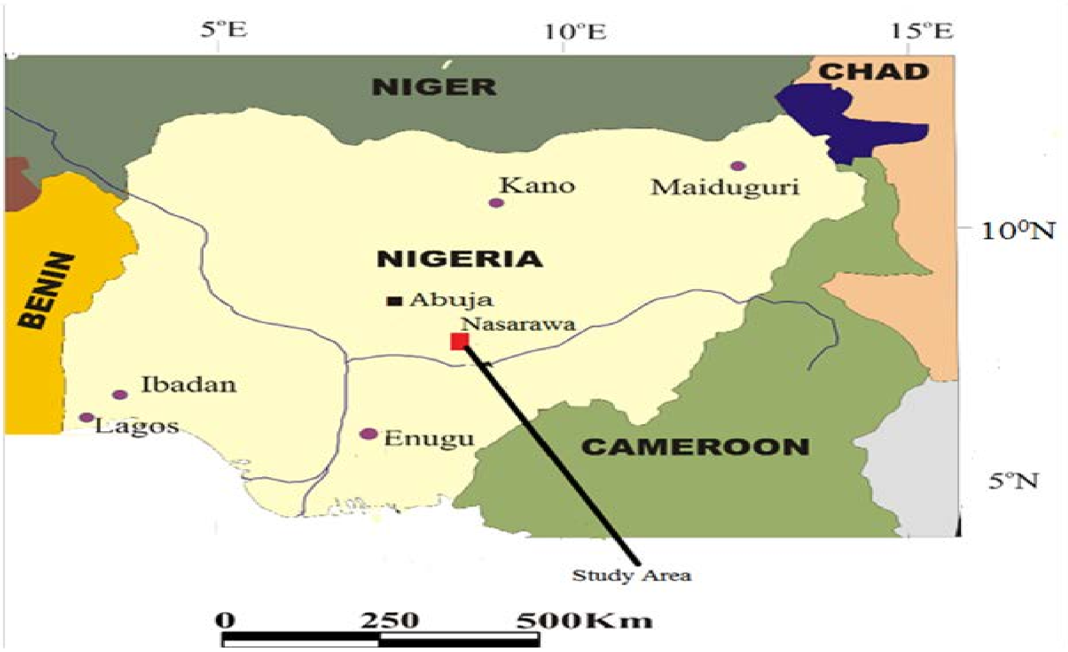

Figure 1: Map of Nigeria showing location of the study area

Figure 2: Dessication cracks on the ground surface

Figure 3: Vertical and diagonal Cracks on buildings

2. Geomorphology and Climate of the Study Area

The study area is located in the southeastern part of Nasarawa state, and lies within latitudes 8°11'- 8°12N, and longitudes 8°38'- 8°38.50E (Fig.1).It has a low to moderate relief with few scattered laterite capped hills of elevation ranging from 135m – 165m above mean sea level (Fig.4).

The area shows a dendritic drainage pattern (Fig.5), and is drained by minor tributaries of the River Benue such as Rivers Okpula and Owunobi, flowing almost parallel to one another. The vegetation falls within the forest savannah zone of Nigeria, rich in deep fertile alluvial soils. It is characterized by a tropical sub-humid climate with two distinct seasons, wet and dry. The wet season lasts from the beginning of May and ends in October.

The dry season is experienced between November and April. The annual average rainfall ranges between 1000mm and 1500mm, while the mean annual humidity is 70% and relative humidity 60% to 80% [16]. The annual temperature ranges between 25^0C -27.5^0C. A high temperature of 33^0C – 36^0C is experienced in the areas during the dry season [17].

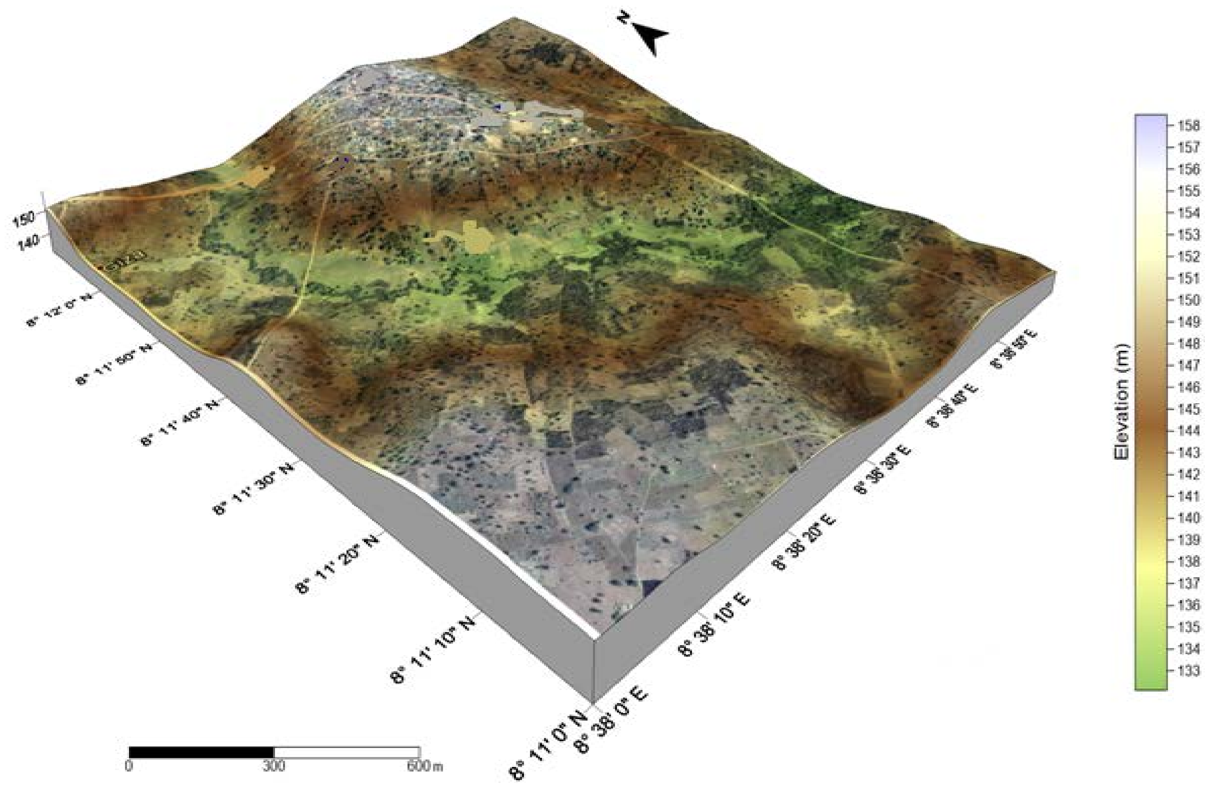

Figure 4: 3D topographic map of the study area

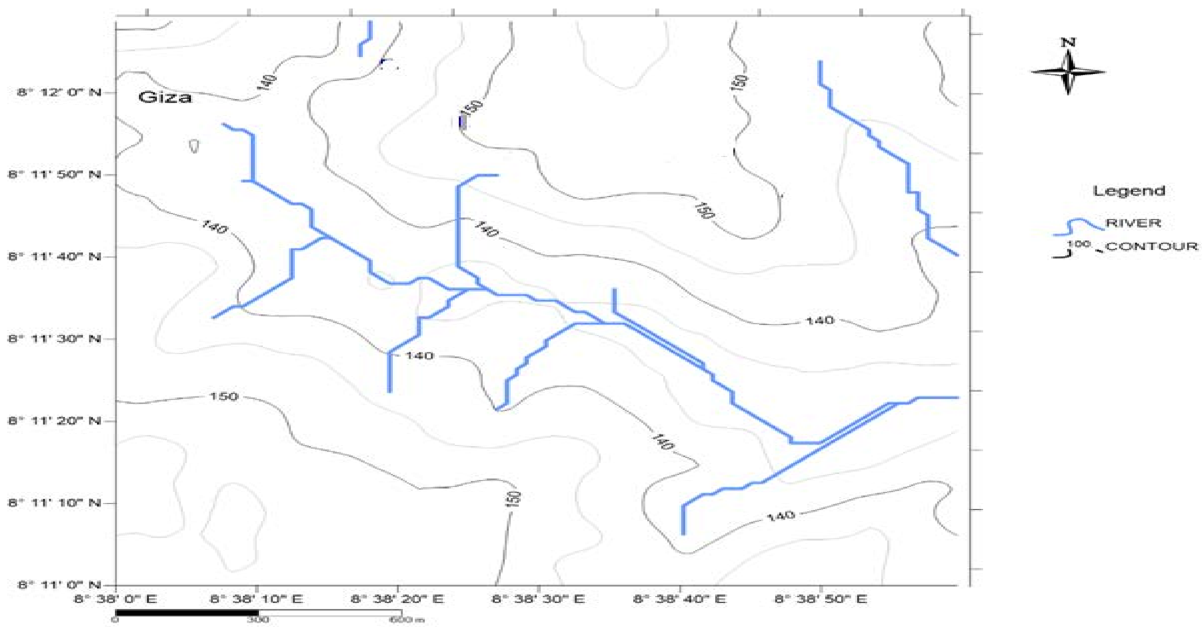

Figure 5: Drainage map of the study area

2.1 Geology of the Study Area

The geology of the study area falls within Benue Trough. It is generally accepted that the origin of this trough is connected with the stresses that developed following the continental separation of Africa and South America [18].The trough have been subdivided geographically into the upper, Middle, and lower Benue Trough for the ease of mapping. Middle Benue Trough is where the area lies and the stratigraphic succession is made up of six Upper Cretaceous lithologenic formations. This succession is made up of the Albian Asu River Group, the oldest [19] and 20], Consisting of bluish grey to brown shale and sandy shale, fine-grained micaceous sandstones [21]. Overlaying it, is Cenomanian – Turonian Keana and Awe formations sandstone with an intercalation of calcareous shale and limestone. The Cenomanian – Turonian Ezeaku formation consisting of hard grey to black shale and siltstone with frequent facies changes to sandsone or sandy shale[21]. With the Late Turonian – Early Santonian coal-bearing Awgu formation, which lies comformably on the Ezeaku formation, and Lafia formation (the youngest). The main geologic formation that outcropped in the area is the Awgu formation (Fig.6). The deposition of the Awgu Formation marked the end of marine sedimentation in this part of the middle Benue Trough. The formation is characterized by bluish-grey to dark-black carbonaceous shales, calcareous shales, limestones, sandstones, siltstones, and coal seams. The study areas occupy the northwest limb of the Keana anticlinorium of the Middle Benue Trough. The flank of the anticlinorium is marked by a complimentary synclinorium, described as the Giza synclinorium [20]. Other authors [19;22;23;20] have worked on the area but with specific interest in its economic geology.

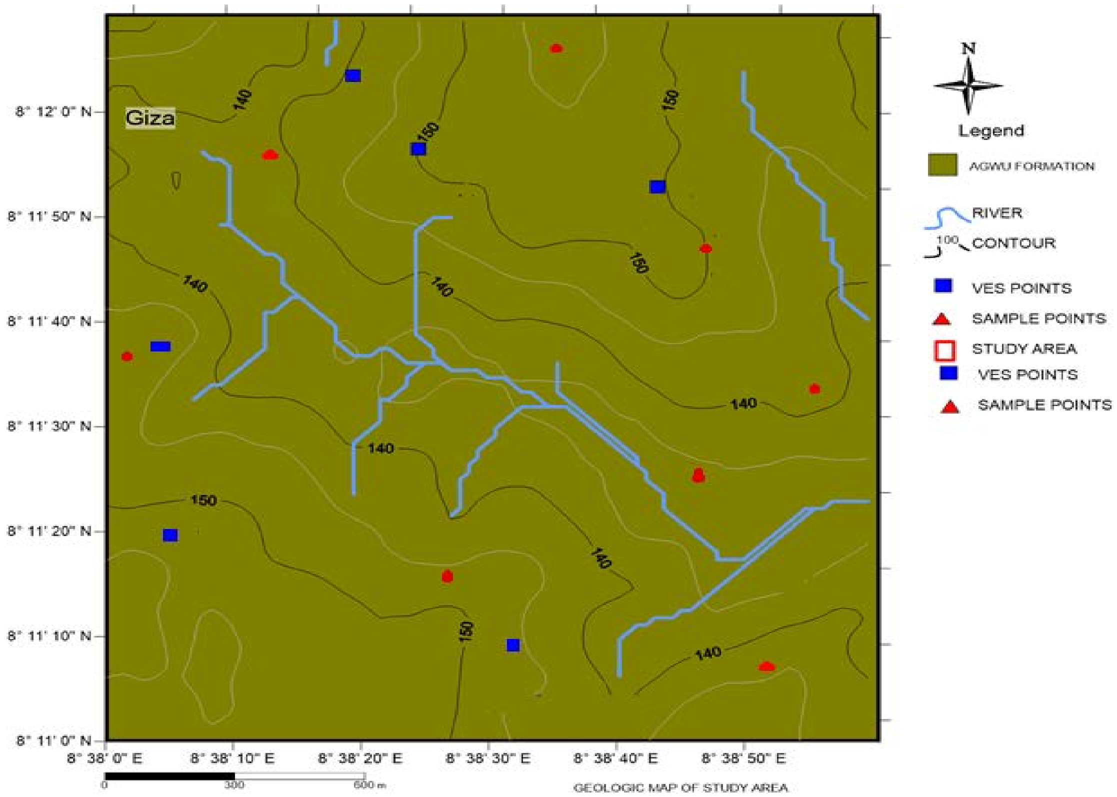

Figure 6: Geologic map of the study area

3. Methodology

A preliminary reconnaissance and field mapping was carried out, during which the rock type, soil type, topography and stream channels were identified. The study area was classified into cracked zone and non-cracked zone, referring to areas with severe foundation failures in the form of cracks, foundation heave, or settlement and areas with relatively stable foundations respectively. Geophysical investigations were carried out and samplings for geotechnical analysis were collected from both sites. The elevation above sea level was measured and used to plot the topographic map of the study area (Fig.4).

3.1 Geophysical Investigations

Geophysical investigation was conducted to delineate the subsurface stratigraphy and their respective thickness. Electrical resistivity method, using Vertical Electrical Sounding (VES) technique employing Schlumberger electrode configuration was adopted with current electrode spread (AB/2) varied from 1.0m to a maximum of 100m while the potential electrode spread (MN/2) was varied between 0.5 and 25m. The resistance value obtained at each measurement was multiplied by a geometric factor appropriate to the electrode spacing to obtain the apparent resistivity value. The VES data were plotted on log-log graphs with apparent resistivity (ρ_a) and half electrode (AB/2) values on the ordinate and abscissa respectively. The resultant curves were interpreted qualitatively through visual inspection and quantitatively through partial curve matching technique using IP12WIN software to generate the layered apparent resistivity and estimated thickness (Fig.7). This was done to delineate the lateral variation of subsurface lithology with depth (Table 1). Electrical resistivity contrasts existing between lithological sequences in subsurface can be used in the delineation of geo-electric layers [24].

3.2 Geotechnical Investigations

Soil samples were taken around areas with severe cracks and building collapse (Fig.3) and labeled as GZ1, GZ2, GZ3, GZ4, and GZ5, and from areas with relatively stable foundation designated as GZ6, GZ7 and GZ8 at a depth 1.0 and 1.5m, the sampling locations are shown in (Fig.5). The samples were analyzed in a laboratory for grain size distribution, Atterberg limit, natural moisture content, specific gravity, compaction, coefficient of permeability, and undrained triaxial tests. All tests were conducted in accordance with the American Society for Testing Materials (ASTM) standards. Grain size distribution test was conducted in accordance with ASTM D422 (2007) standard, Atterberg limit test was carried out following ASTM D4318-05 test procedure; natural moisture content determination , specific gravity, compaction test was performed using ASTM 689 standard, coefficient of permeability

3.3 Hydrogeological Investigations

The static water levels of hand dug wells and boreholes were measured during the wet and dry seasons. The water levels were measured using a SOLINT temperature, level, and conductivity (TLC) dip-meter. The lead of the electrical circuit is lowered into a well, as it touches water, the circle is completed and is indicated by a sound, and the reading from the calibrated tape is recorded. The elevations above sea level and coordinates (longitude and latitude) of the wells were also taken using Geographical Positioning System (GPS). The static water level measurements were taken very early in the morning when the water levels in the wells are not affected by withdrawal.

4. Results and Discussions

4.1 Geophysical Technique

VES results with inferred lithology, resistivity and thickness are summarized in Table 1. The curve types identified are QQ, KH, QH, and HKH type (Fig.7). The stratigraphy of the cracked zone comprised of clays, sandy clays, clayey sands and shales having resistivity and thickness range of 2.77 – 24.8 Ωm, 16.5 – 52 Ωm, 356 – 377 Ωm, and 0.5 – 3.1m, 1.5 - 30m, 7.5 – 45m respectively. Foundations within this zone are underlain by very low resistivity saturated clays [25] due to its poor drainage. The non-cracked zone is composed of compact topsoil of high resistivity (384 – 643 Ωm) extending from the top to a depth between 0.4 – 0.9m, underlain by clayey sands/sandy clays, 6.5 – 20m thick, with varrying resistivity of 74 – 243 Ωm. Clay of 9.8 – 53m thick having resistivity of 7.4 - 8 Ωm is underlain by shale. Mosallanezhad and Moayedi [26], noted that the thickness of soil layer among other factors influences bearing capacity. Generally, the soils around the cracked zone are considered incompetent, while soils around non-cracked zone are moderately competent, according to [27] classification for foundation materials Table 2.

Table 1: Interpretation of the electrical resistivity data

VES No.	LAYERS	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	CURVE TYPE	INFERRED LITHOLOGY
	1	384.00	0.4	0.4		Topsoil
	2	243.00	6.5	6.9		Sandy clay
1	3	8.00	46.2	53.1	QQ	Clay
	4	4.65	--	--		Shale
2	1	24.80	2.0	2.0		Topsoil
	2	377.00	7.5	9.5	KH	Clayey sand
	3	1.38	30.1	39.6		Clay
	4	42.75	--	--		Shale
3	1	208.00	3.1	3.1		Topsoil
	2	16.50	30.9	24.0	QH	Sandy Clay
	3	1.62	20.5	53.5		Clay
	4	20.50	--	--		Shale
4	1	52.73	0.5	0.5		Topsoil
	2	2.77	1.5	2.0	HKH	Clay
	3	358.60	25.5	27.5		Clayey Sand
	4	1.76	10.5	38.0		Clay
	5	50.17	--	--		Shale
5	1	507.00	0.9	0.9		Topsoil
	2	221.00	7.5	9.5	QH	Clayey Sand
	3	17.90	30.1	39.6		Clay
	4	2.32	--	--		Shale
6	1	643.00	0.6	0.6		Topsoil
	2	78.20	19.4	20.0	QH	Sandy Clay
	3	7.40	9.8	29.8		Clay
	4	18.66	--	--		Shale

Table 2: Lithologic competence rating in terms of apparent resistivity values [27].

Apparent Resistivity range (Ωm)	Lithology	Competence rating
<100	Clay	Incompetent
100–350	Sandy clay	Moderately competent
350–750	Clayey sand	Competent
>750	Sand/laterite/bedrock	Highly competent

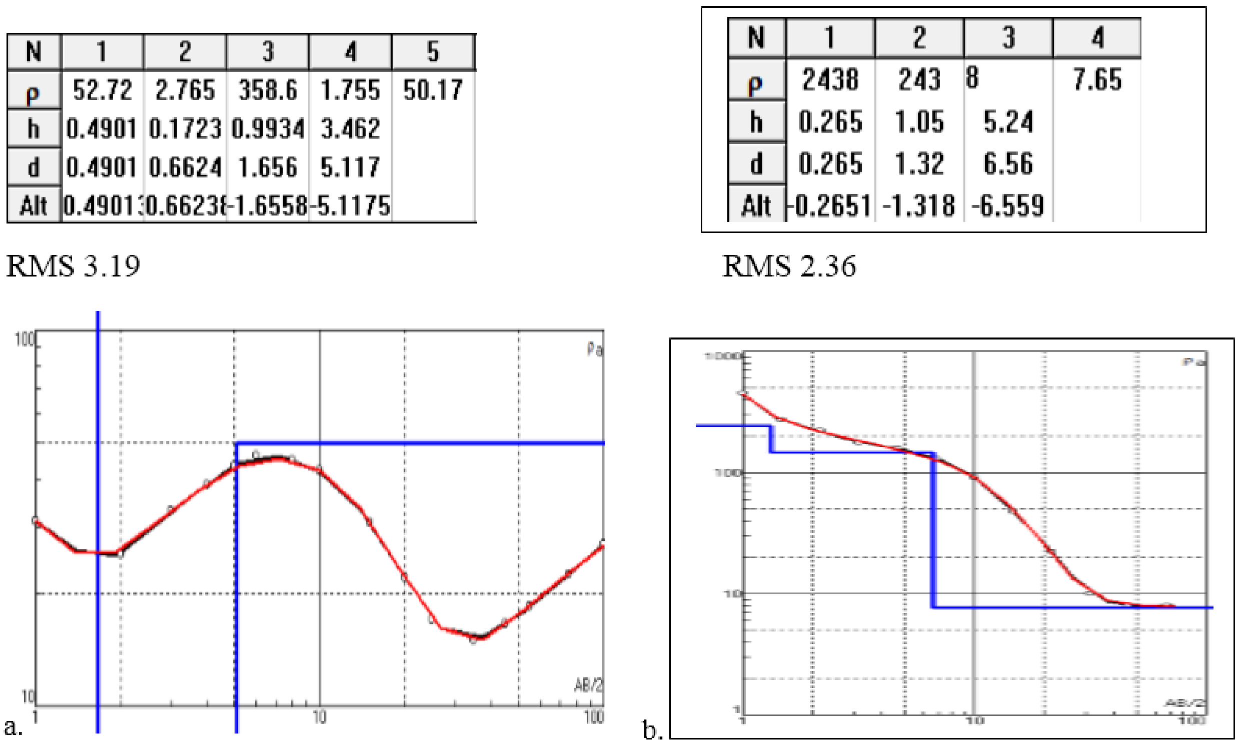

Figure 7: 1-D resistivity model curves of the study area: (a) for VES 1, and (b) for VES 4

4.2 Geotechnical Technique

4.2.1 Grain Size Analysis

The results of the grain size distributions are illustrated in Table 4. The samples contained 41% to 78% of clays, 12% to 28.3% silts, and 9% to 35% sands (Table 3). Sample GZ5 contained the highest amount of clay (78%). The distribution curve (Fig.8) aligning to the left was described by [25] as fine grained soils, having its unique engineering characteristics. The shale samples from the cracked zone contained higher amount of clays 59 to 78%, compared to 26 – 50% from the non-cracked zone. The clay content is greater than the ≤ 35% limit set by Nigerian specification for construction, as reported by [28].

Clay content controls soil's plasticity [15], and chemical and physical behavior of soils [29].The high amount of clays in the cracked zone impedes drainage leading to saturation of clay, high hydrostatic pressure, reduced shear strength, and high plasticity which could be responsible for the severe cracks and foundation failures within this zone. Results of the non-cracked zone showed appreciable amount of sands 26.9% – 33%, while the cracked zone contained just 10- 14%sands in its samples. Sands in the non-cracked zone will facilitate drainage; reduce compressibility and increased shear strength making foundations around this zone relatively stable. Celik and Canakci [30] reported that the amount of sand content has a significant effect on the shear strength, compaction, and compressibility parameters of fine grained soils.

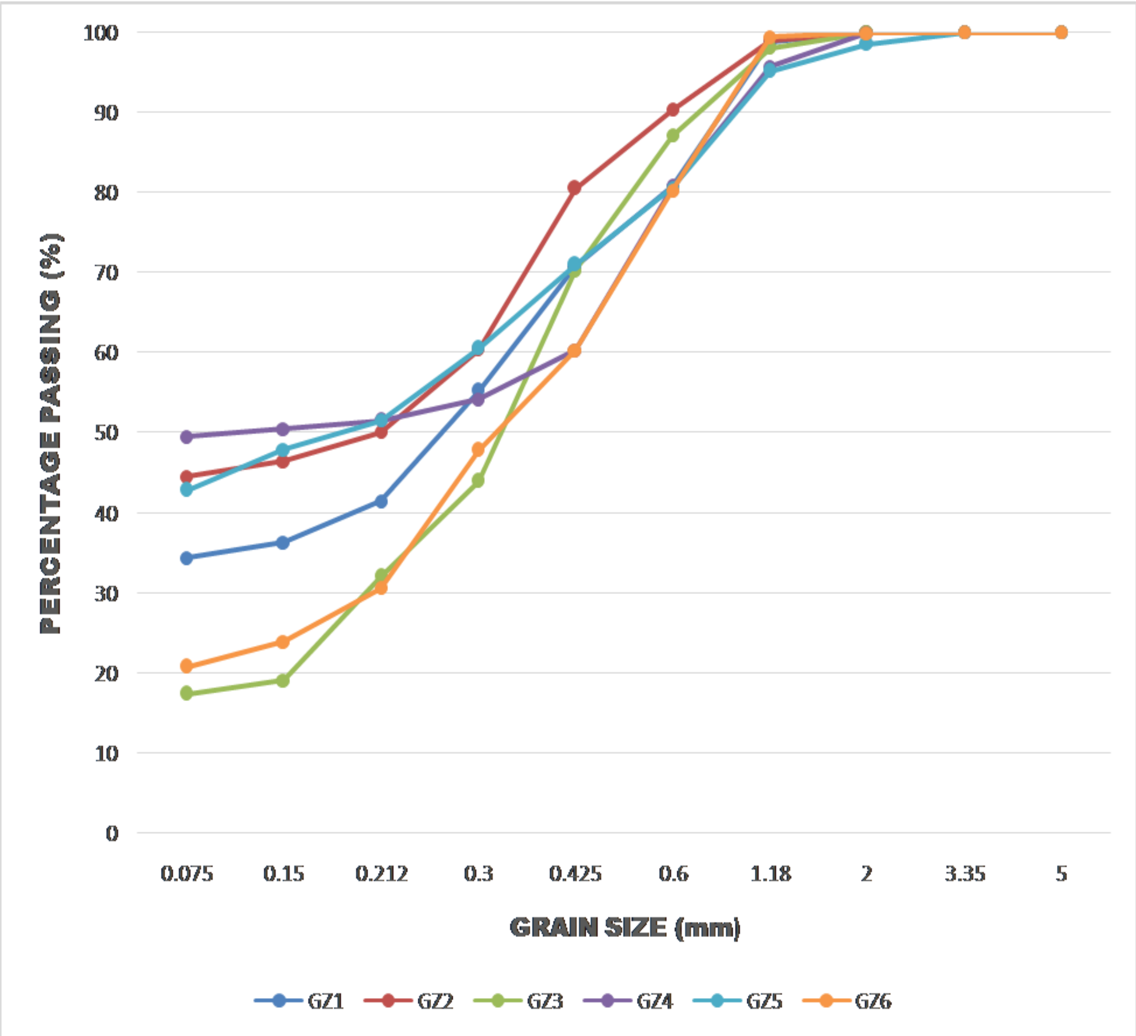

Figure 8: Grain size distribution curve

Table 3: Summary of geotechnical test results

	Geotechnical Test	Parameters	GZ1	GZ2	GZ3	GZ4	GZ5	GZ6	GZ7	GZ8
1	Grain-size analysis	Sands (%)	10.0	9.0	14	13.0	10.0	26.9	35	33
		Silts (%)	28.3	16.0	27.0	19.4	12.0	23.0	20	26
		Clays (%)	61.7	75.0	59	67.6	78.0	50.1	45	41
2	Atterberg Limits	Liquid Limit (%)	46	50	45	48.2	70	29	30	27
		Plastic Limit (%)	10.6	11	8.0	13.0	19.0	9.5	11	10
		Plasticity Index (%)	35.4	39	37	35.2	51	19.5	19	17
3	Consistency indices	Liquidity index (%)	31.76	42.25	45.51	20.88		21.19	13.3	23.5
		Consistency index (%)	68.24	57.49	54.49	79.12	101	78.81	86.7	76.5
4	Compaction	Max. Dry Density (g/cm^3)	1.85	1.78	1.88	1.76	1.73	1.88	1.83	1.89
		Opt. Moisture Content (%)	10.11	12.02	11.31	11.21	12.02	10.65	9.0	8.58
5	Specific gravity	(G/CM^2)	2.66	2.67	2.86	2.59	2.77	2.68	2.56	2.68
6	Moisture content	(%)	20.21	27.58	24.84	20.35	18.33	16.84	13.52	14
7	Permeability	m/sec	5.61×10^{-5}	7.16×10^{-6}	6.41×10^{-6}	7.21×10^{-6}	5.36×10^{-7}	2.26×10^{-5}	1.67×10^{-6}	1.55×10^{-6}
8	Undrained triaxial test	Cohesion (C) (KN/m^2)	27	34	36	30	33	29	25	27
		Frictional Angle (ϕ) (°)	12	11	12	15	14	12	16	18

4.2.2 Atterberg Limit

Atterberg limit test results summarized in Table 5, showed that Liquid Limit (LL) ranges from 27-70%, the Plastic Limit (PL) ranges from 8-19%, while the Plasticity Index (PI) ranges from 29-51%, according to [27] LL is a sufficiently good indicator of shrink-swell potential for natural soils. Sample GZ8 exhibit the lowest LL (27%) and PI (17%), which is due to the appreciable amount of sand in the clays, while Sample GZ5 shows the highest LL (70%) and PI of 51%. The Liquid Limit (LL) of the cracked zone ranges from 46%-70%, the Plastic Limit (PL) ranges from 11-19%, the Plasticity Index (PI) ranges from 39-51%, while the non-cracked zone records LL range of 27% – 30%, PL of 9.5% – 11%, and PI of 17.19.5. According to [31] LL is a sufficient good indicator of shrink-swell potential for natural soils. Soils from the cracked zone have LL > 60% and PI > 35%, which is above the limits recommended by FMWH, 1974 (LL < 40%, PI<12%) for foundation materials.

Based on these values, the soils are considered to have high expansive potential [6] Table 3, and contained either bentonite, montmorillonite, or smectite [32]. This is consistent with the findings of [2]; [33]; [8]; and [5]. Sowers and Sowers [34] described soils with PI >31% as highly plastic, highly compressible, with low permeability and low hydraulic conductivity most samples from the cracked zone falls within this category.

Table 4: Soil expansivity prediction by liquid limits and plasticity index [6]

Degree of expansion	Liquid limit	Plasticity index
Low	< 30	0 - 15
Medium	30 - 40	10 - 35
High	40 - 60	20 - 55
Very high	> 60	> 35

The cracked zone is dominated by inorganic clays of medium to high plasticity (Fig.9), earning the Unified Soil Classification System (USCS) notation CH and MH, and A-7-6 class of the American Association of State and Transportation Officials (AASHTO), this soil is known for high expansion [6], high compressibility [15], poor drainage and compaction characteristics, thus making it a poor foundation material. While the non-cracked zone, is classified as inorganic clays of low plasticity CL (Fig.9). Distress on engineering structures, manifesting as cracks on walls and floors of buildings (Fig.3), are as a result of volume change in the expansive clays [35]. The high liquidity index of the cracked zone 31.76 – 45.51% denotes that the soil's water content is near to its LL [15], and is prone to consistency changes, swelling and shrinkage as water content fluctuates [36]. The non-cracked zone recorded high consistency index, 78.81 – 86.5% implying a relatively firm soil [15]. Due to the high clay content and PI, soils from the cracked zone showed very high activity (Fig.10) ranging between 0.56 and 0.75, compared to the low activity of 0.4 in the non-cracked zone. Expansive soils have been stabilized using fly ash [37], wood ash-lime [7] or rice husk to improve the engineering properties of expansive soils.

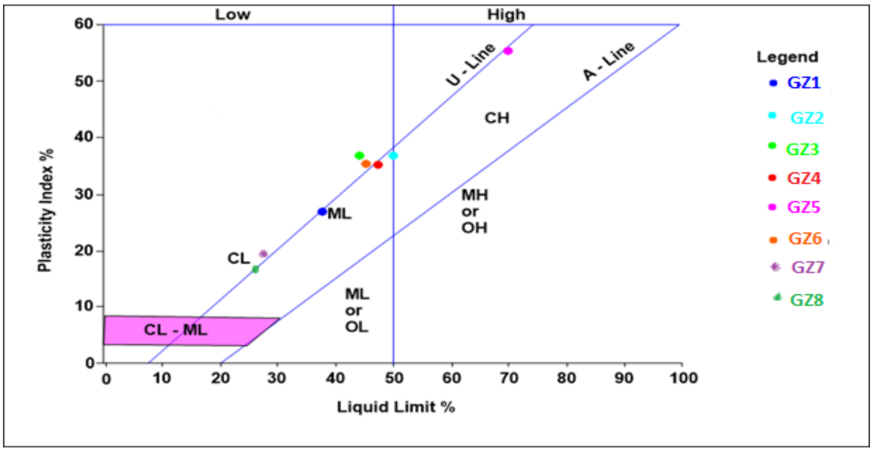

Figure 9: Summary of geotechnical test results

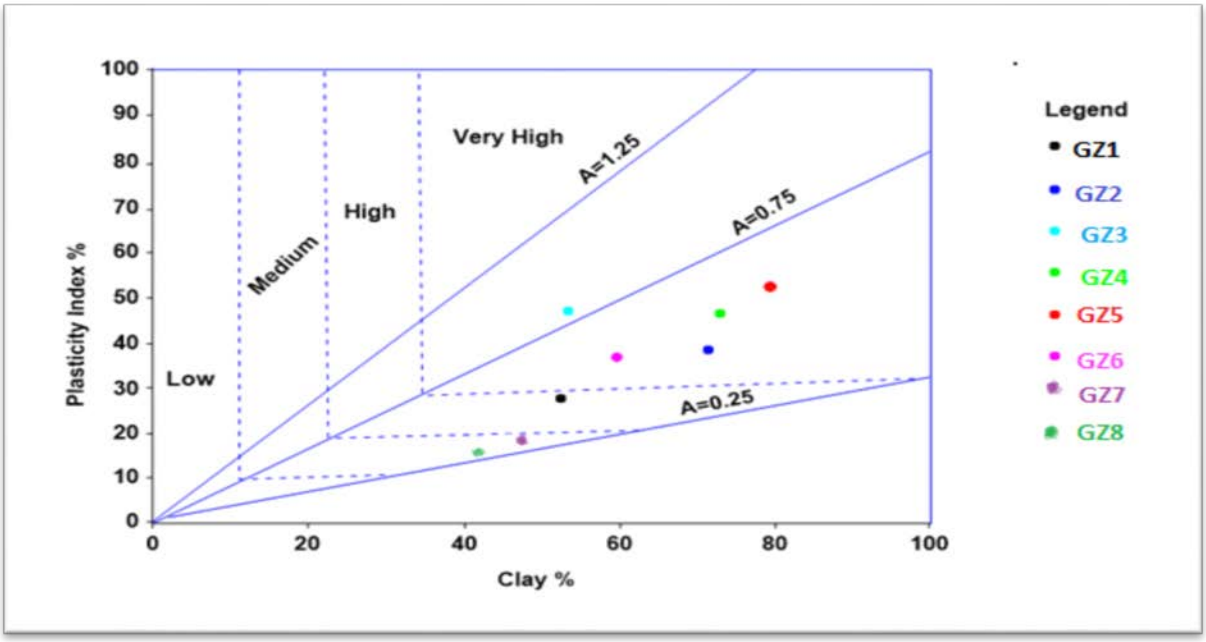

Figure 10: Activity chart for all samples

4.2.3 Natural Moisture Content

Results of the natural moisture content are shown in Table 5. Moisture content is a measure of the water holding capacity of soils, depicting the clay content and type of material [34]. Water content of the cracked zone samples in its natural state ranges between 18.33% and 27.58%, which is higher than the 13.52% – 16.84% for the non-cracked zone. This is consistent with the result of the grain size analysis and Atterberg limit test, which revealed high clay content (CH-type), high plasticity and high clay activity in soils of the cracked zone, as high water content induce weathering and increases clay activity [8]. This soil exhibit poor permeability, thereby, retaining water within its interstices, leading to increase in plasticity and shrink-swell potentials. According to Rao,Phanikumar, and Sharma [38], swell potential depends on soil's initial water content. The effects of water content and fines content on engineering property are linked [39], high clay content denotes water affinity, the combined effects may be responsible for the weak engineering properties of the cracked zone, which may help explain the cracks and foundation instability around this sites. As much as possible water should be prevented from the foundations especially within the cracked zone by means of drainage.

4.2.4 Specific Gravity

The specific gravity (Gs) results are summarized in (Table 5), with the cracked zone having Gs range of 2.66 – 2.77 this falls within the range gotten by [1], but slightly higher than that of [5] both on expansive clays. The values are also within general range for most inorganic clays [15]. The non-cracked zone showed Gs range of 2.56 – 2.68, which implied a weak and non-durable soil. Generally, low Gs values are associated with clay mineralogy and weathering of feldspar that gave rise to clay. Given the Gs values, the soils may be said to be free of organic matter as soils containing organic matter and porous particles may have specific gravity values below 2.0.

4.2.5 Compaction

Results of the compaction test (Table 3) revealed that Maximum dry densities (MDD) ranges between 1.77-1.89 g/cm^3, while optimum moisture content (OMC) is within the range of 8.56-12.02% (Fig.11). Samples GZ3, GZ6, and GZ8 have higher MDD (1.88,1.88, and 1.89g/cm^3) but lower OMC (11.31, 10.65% and 8.58%) respectively. Sample GZ5 has the lowest MDD (1.77g/cm^3) and the highest OMC (12.02%),The Maximum dry density (MDD) for the cracked zone ranges between 1.73-1.88 g/cm^3, while optimum moisture content (OMC) is within the range of 10.11-12.02% (Fig.10), low MDD and high OMC is an indication of weak soil [40]. The non-cracked zone showed higher MDD between 1.88 - 1.89g/cm^3, and lower OMC 8.58 - 10.65%. Jegede (1999) noted that soils with high MDD and low OMC, are the best soil for foundations. Results of the compaction curve for all samples are illustrated in (Fig.11), and agreed with that of [2] and [5] which showed that soils with expansive potential have lower MDD and high OMC. The dry density of soil is one of the factors which affect the swelling characteristic of expansive soils [41]. The high clay content, high natural moisture content and low permeability of the cracked zone soils may have affected the dry density, foundations around this site may easily fail in shear. For an increased MDD and lower OMC, a higher compactive effort should be used [42] thus, increased shear strength. According to [43] classifications, Table 3, soils around the cracked zone are rated as poor to fair foundation materials. Before laying foundation, soils within this zone should be compacted on wet side of optimum moisture content, as this will increase shear strength minimize swelling potentials.

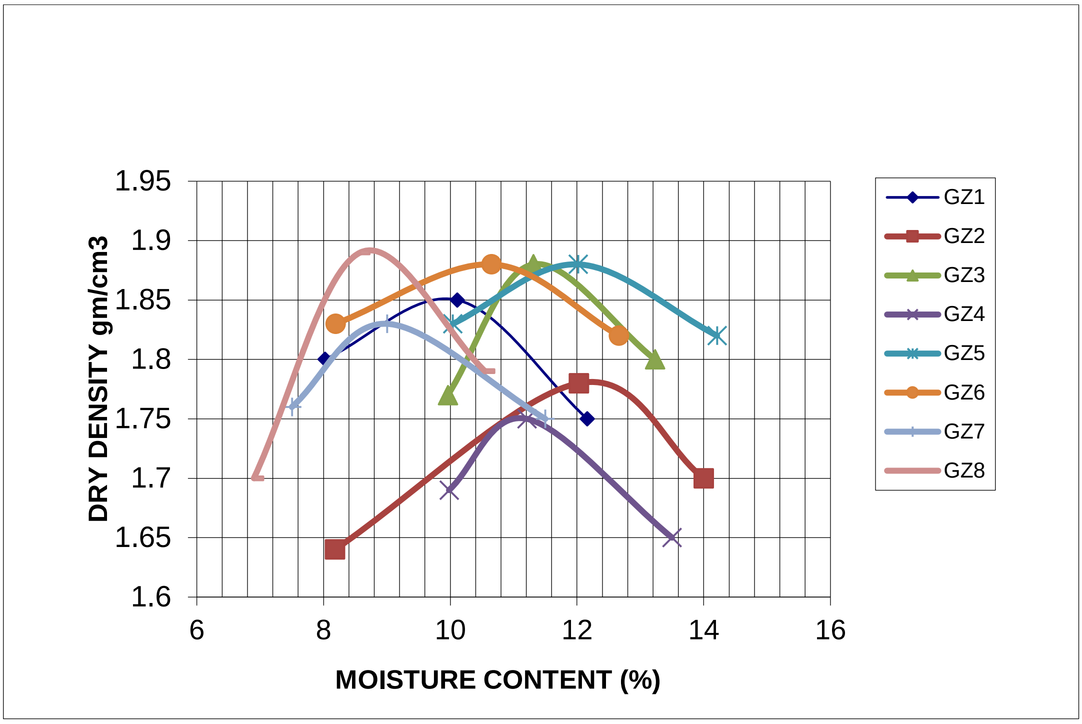

Figure 11: Compaction curve for all samples

Table 5: Soil compaction grading [43]

Maximum dry density (MDD) (g/m3)	General value as a sub-grade foundation material
Over 2121	Excellent
1958–2121	Good
1795–1958	Fair
1632–1795	Poor
1142–1632	Very poor

4.2.6 Coefficient of Permeability

The coefficient of permeability test (K) result summarized in Table 5, recorded lower K-values for the cracked zone between 7.16 x 10^{-6} m/sec and 5.36 x 10^{-7}m/sec, while that of the non-cracked zone is high and ranges between 2.26 x 10^{-5}m/sec and 1.55 x 10^{-6}m/sec. The low coefficient of permeability of the cracked zone could be resulting from high clay content which impedes drainage, while the high permeability of the non-cracked zone, may be due to its low clay content and appreciable amount of sands. Arora [15] reported that soil's saturation ratio is inversely proportional to its saturation. Due to high plasticity, expansive soils areas have low drainage system [15;44]. According to Sowers and Sowers [34] high plasticity decreases permeability as well as hydraulic conductivity. This also implies that excess pore water pressure will develop, thereby reducing the effective stress and thus, decreased shear strength upon loading. Given the soils high expansive potentials, it should be excavated and backfilled with cohesive non-expansive soils and compacted, or partially replaced with granular soils (sands and gravel) as it will increase drainage, effective stress and thus, increased shear strength.

4.2.7 Undrained Triaxial Test

The results of the undrained triaxial tests are summarized in Table 5. Cohesion (C) and angle of internal friction (Ø) are the important parameters in shear strength, bearing capacity [45]. The cohesion (C) and frictional angle ranges from 27 – 36KN/m^2, 11 - 15^0, and 23 – 29 KN/m^2, 12 - 18^0 for cracked and non-cracked zones respectively. Cohesion (C) contributes more to shear strength within the cracked zone than the frictional angle (Ø). This is directly related to the binding forces within the pores of clays relative to its low frictional contact, high water content reduces angle of internal friction. The non-cracked zone will have higher shear strength. This is due to the good proportion of clay-sand, where the clays provide the required cohesion (C), while the sands, good frictional contact between its particles. The combination of both cohesive and frictional strength, results in a higher shear strength compared to just one. **T**he Mohr view plots are illustrated in (Fig. 12a & 12b). The C and Ø of the cracked zone is in tandem with [2], but contradict [5] result, where both C and Ø of expansive soils are decreasing. A low cohesion and low angle of internal friction indicates lower shear strength, bearing capacity loss, which in turn makes a poor site for engineering construction.

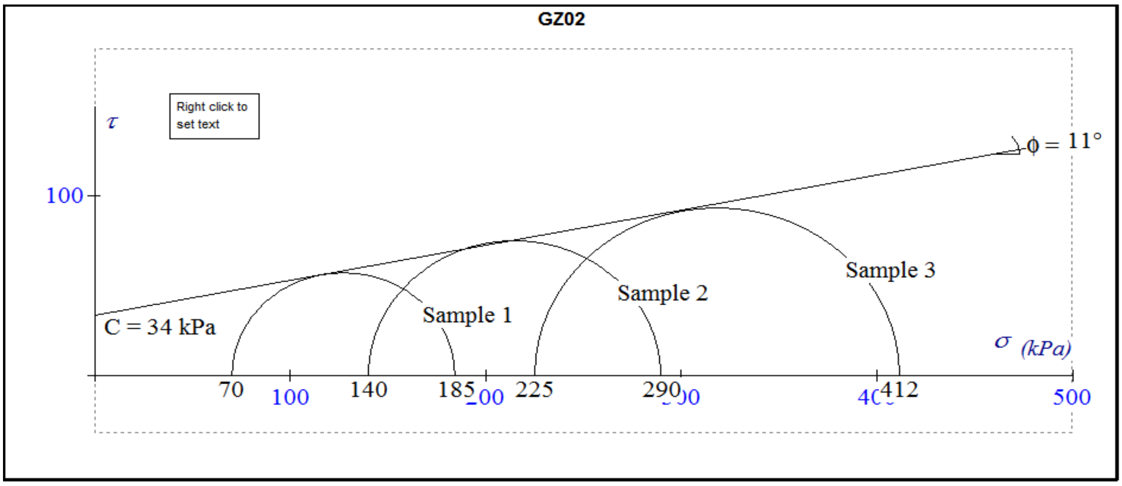

Figure12: a: Morh view plot for crack zone.

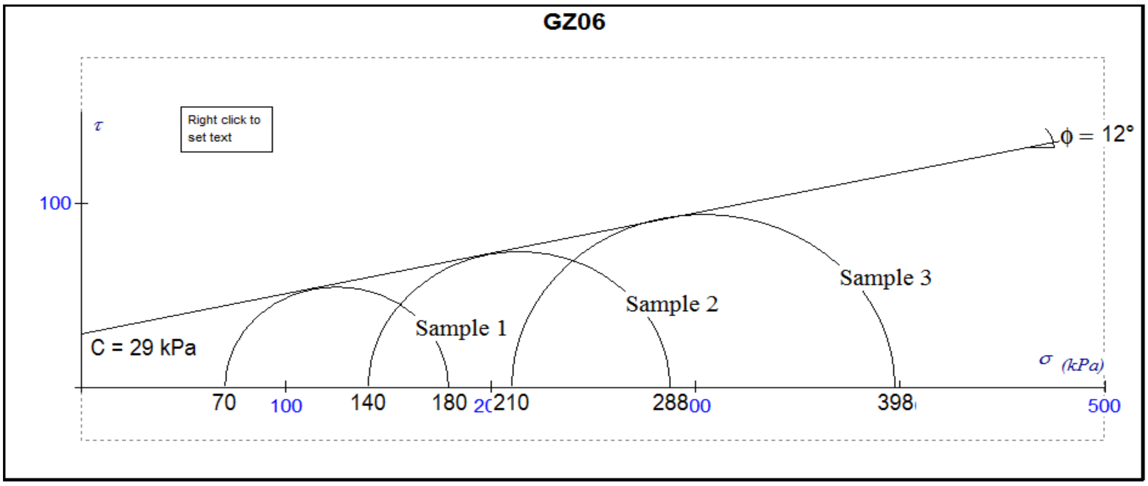

Figure 12b: Morh view plot for non-cracked zone

4.3 Hydrogeology

Ground water level fluctuation affects hydrostatic pressure and hence the shear strength of the soil. As the ground water level changes with season, it becomes necessary to establish the highest and the lowest water level for the proper design of structures [15]. Static water levels around the cracked zone, is peaked at 0.7 m and deepest at 6.9m in wet season, peaked at 2.0m and deepest at 13.2m in the dry season. Groundwater level fluctuation within this zone, varied between 1.1 and 6.1m, soils will experience high moisture content fluctuation at this depth. Different groundwater drawdown can cause uneven ground settlement [46], this agreed with the findings of Chinnaswamy and Chew Chiat [47]. Liu and Liu [48] reported that groundwater level declining resulting from over-abstraction has led to land subsidence and ground fissure in Shanxi Province, China. The non-cracked zone is peaked at2.2m and deepest at 8.5m in wet season, and peaked at 5.5m with deep of 10.2m as the deepest for dry season. Fluctuation around this zone is deeper ranging from 1.7 to 3.3m. The Zone of fluctuation in expansive soils is known as the 'Active zone' and corresponds to the depth at which expansion and contraction occurs [42]. Groundwater flows from the non-cracked zone (recharge areas) towards the cracked zone (discharge areas) indicated by arrows. (Fig.13). The shallow zone of fluctuation occurs within the clayey layer. This causes foundations in the cracked zone to cyclic swelling and shrinking as the water level rises and falls respectively, with season. The incompetency of clays as foundation materials, high plasticity, poor drainage, and shallow zone of fluctuation may explain the phenomenon behind foundation failures in the cracked zone.

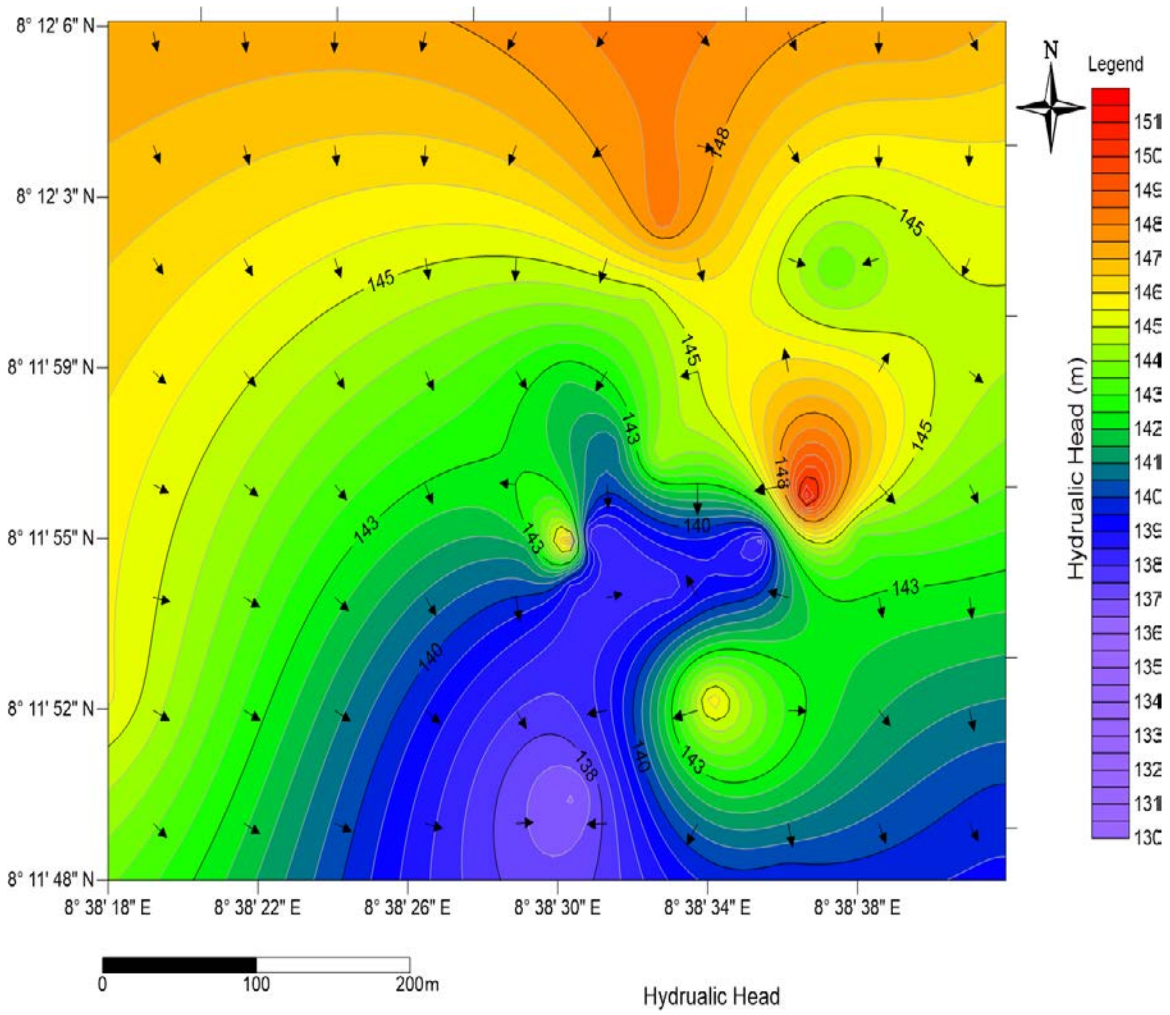

Figure 13: Hydraulic head map showing direction of groundwater flow

4.4 Comparing the Engineering properties of the Expansive Soil with that of other Established Expansive Shales and Nigerian Specification

Geologically, the study area is underlain by Awgu (Fig.5) shale of the middle Benue Trough (MBT). The engineering properties are compared with that of Makurdi shale (MBT) [1], Abakaliki shale [49], Igumale shale [50], and Awgu shale of the southern Benue Trough (SBT) [8]. All five Shales, falls within the CH and A-7-6 class of the USCS and AASHTO classification respectively. This implies that they have similar engineering properties. Sowers and Sowers [33;28; 7], reported that CH soils are associated with poor to fair compaction, high compressibility, high expansive characteristics, low drainage and poor stability as its moisture changes. The mean percentage fines for all shales is within the same range of 90-92%, with Awgu Shale (SBT) having slightly higher 97% fines, which may be attributed to high degree of weathering that have affected the shales. The amount of fines/clays in a soil greatly influences its engineering properties. Atterberg limit showed that the LL are on the high side for all shales, with Abaliki shale recording the lowest 60% and Awgu shale (SBT) recording the highest 78%. Awgu shale (MBT) recorded the least PL with 19%, while Igumale shale reported the highest PL of 27%, Makurdi, Abakaliki, and Awgu (SBT) shale recorded 26%, 20%, and 22% respectively. The PI values showed high and slight variation between Awgu (MBT) and (SBT) having 56% and 51%, compared to Makurdi, Abakaliki, and Igumale shale having mean PI of 48, 45 and 40% respectively.Awgu shale (SBT) have the higher MDD of 1.95kg/m^3, which is considered good [43], while the MDD of the study area range between 1.76 – 1.88kg/m^3, which is slightly above Abakaliki shale with a mean value of 1.86kg/m^3. Igumale shale recorded the least MDD of 1.50 kg/m^3, and is considered very poor [43]. The corresponding OMC showed similar values for all shales (12%), compared to Igumale's 22%.

The lower MDD of the Igumale shale can be attributed to its high natural moisture content of 25%. The Gs values are closely related (2.55, 2.50, 2.58), however, Awgu shale (MBT) showed higher Gs of 2.87. The cohesion values varied, with Abakaliki shale having a mean value of 51kPa, Awgu shale (MBT) with 36kPa slightly above Awgu shale (SBT) with 30kPa. The angle of internal friction also varied greatly, with Awgu shale (MBT) exhibiting mean value of 14^0, Abakaliki shale 28^0, and Awgu shale (SBT) 18^0, while Makurdi and Igumale shales were not tested for shear strength.

Considering the range of the LL, PI and percentage fines for all shales, the soils are highly compressible, according to [42] compressible grading, highly plastic [6] and exhibit high to very high degree of expansion [14]. Comparatively, Awgu shale (MBT) shows a higher expansive potential than the Makurdi, Abakaliki, and Igumaleshales. The Abakaliki shale with a high cohesion and angle of internal friction, high MDD and the lowest LL and PI, makes it a better foundation material and exhibit lower swelling potential compared to other shales. Awgu shale (SBT) having highest percentage of fines, LL and PI even though it recorded high MDD, cohesion and angle of internal friction, exhibit high swelling potential and as such a poor foundation material. However, Awgu shale (MBT) of the study area exhibit MDD and OMC values within the Nigerian specification as construction material for general filling and embankment (Table 6), while the LL and PI are above the specification [28]. Equally, the LL and PI result are above the specification for sub-base course and base course (Table 6). Therefore, the study area has poor foundation materials and as such should be stabilized before erecting any building or construction of pavements.

Saboo and Pradhan [51] stabilized expansive soil and achieved maximum increase in strength using 8% lime content, while [52] used industrial wastes such as fly ash and dolochar as stabilizers which decreases index properties and increases drainage.

Table 6: Comparison of results from the study area, with the Nigerian specification for construction

Properties of materials	Nigerian specification	Study area
General filling and embankment		
MDD	>0.047	1.76 – 1.88
OMC (%)	<18	10.11 – 12.02
LL (%)	<40	39 - 70
PI (%)	<20	25.2 - 51
Passing no #200	≤ 35	51 - 91
Soaked CBR (BS)	>5	Not Tested
Sub-base course		
LL (%)	<35	39 - 70
PI (%)	<16	25.2 - 51
CBR West African Standard	≥ 25	Not Tested
Base course		
LL (%)	≤ 30	39 - 70
PI (%)	≤ 13	25.2 - 51

5. Conclusion

This study has investigated the causes of foundation instability using geophysical, geotechnical, and hydrogeological techniques. Results of the geophysical investigations revealed low resistivity, incompetent saturated clay underlying foundation in the cracked zone. While a relatively more competent Clayey sand is underlying the non-cracked zone.Geotechnical results of the cracked zone revealed high clay content on the soils, these soils showed high plasticity, low permeability which leads to its poor drainage. It also recorded high natural moisture content, which could results from high saturation of the clays. Cohesion contributes more to Shear strength in this zone than angle of internal friction. The low dry density and high moisture content makes the soils weak as foundation materials. The non-cracked zone showed a relatively good proportion of sand-clay which enhances its drainage, and as such, soils around this zone are not submerged in water. Shear strength in this zone is higher, as both parameters cohesion and angle of internal friction are relatively higher.The depth of groundwater fluctuation in the cracked zone was established at 1.1- 6.1m, and found to be within the clay layer. Groundwater flows from the non-cracked areas towards the cracked areas. The incompetency of the saturated clays as foundation materials, high plasticity, poor drainage, and shallow zone of groundwater fluctuation may be responsible the failure in shear of foundation materials, resulting in distress on the engineering structures such as buildings and pavement. By comparing the plasticity and other geotechnical properties of the cracked zone with other well documented expansive soils around the Benue Trough, the study area has one of the highly expansive soil (Awgu shales) within the Benue Trough.For the first time, the geotechnical properties of Giza was assessed, the findings can be used by engineers for proper design of foundations.

6. Recommendations

Based on the findings discussed above, we recommend that:

i. The shrink-swell soils in the cracked zone should be excavated to a depth of at least 0.5m to 1.0m and replaced with a non-expansive soil and compacted before laying foundation.
ii. Foundation should be laid below the zone of groundwater fluctuation “Active zone”.
iii. As much as possible, water should be prevented from the foundation by the provision of adequate drainage.
iv. Lime stabilization can also be employed, given its rich Ca^{2+} and Mg^{2+} ions which will replace the $Na^{+}$and K^{+}, thereby decreasing the soil’s plasticity and swelling potential significantly.
v. Stabilization with rice husk, wood ash, and cement have recorded some success, as such can be employed too.
vi. High compactive effort should be used during compaction to achieve greater shear strength.

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