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THE STATUS OF SOIL AT THE PERMANENT SITE OF THE NNAMDI AZIKIWE UNIVERSITY, AWKA, SOUTHEASTERN NIGERIA

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ABSTRACT

This paper presents an investigation on the properties of soils underlying the permanent site of the Nnamdi Azikiwe University, Awka, Nigeria. A total of 450 samples collected from 150 Hand auger drilled holes across the campus were subjected to different geotechnical tests. Geotechnical parameters tested for in the soil samples were mechanical analysis, Atterberg limits, compaction, CBR, bulk density, natural moisture content and shear strength. Results indicated that the soils consisted of predominantly sand-sized grains overburden (either ***SM*** or ***SC***); percentage of fines ranged from 7 to 72%, sand 28 to 93% and gravel 0 to 40 %. Liquid limit values ranged from minimum value of 15 (at depth 0 to 1.5m) to maximum value of 78 (at depth ≥1.6m), while Plasticity index values ranged from non-plastic samples to a maximum value of 41. Plots of samples in the plasticity chart revealed the fines are predominantly clays and silts of low plasticity (***CL - ML***), and less amount of organic silts (***MH*** or ***OH***). Medium to high plasticity resulting from moderate to high clay content of the soil suggests volumetric changes, especially when the site is waterlogged. The bearing capacity and settlement (in particular compressibility) analyses confirmed that most locations within the site have low stability. A number of sampled points have their compression index values above 0.20, suggesting that those points would experience moderate compressibility over engineering time.

Keywords: Awka, soil investigation, geotechnical tests, settlement analysis, structural failure.

INTRODUCTION

The ground is a product of dynamic natural and anthropogenic processes and there exhibits a variety of characteristics and properties which is not homogeneous and isotropic. Geophysical, geotechnical and environmental engineering involve assembling and assimilating limited facts about these characteristics and properties in order to understand or unravel the behavior of the ground and groundwater on a particular site under certain conditions. The efficiency of any building or structural projects on the earth surface, to a large extent, depends on suitability of its foundation material.

In Nigeria, several factors could lead to failure of structural projects. They may include poor construction material, improper designing, quackery on the side of the building personnel involved and expansive foundation soil (Ede, 2010), amongst others. Expansive soils are generally known to cause instability in foundations, in particular and failures of most structural projects, in general. Currently, some existing buildings at the permanent site of the Nnamdi Azikiwe University are exhibiting evidences to suggest imminent failure. The site is located within the Awka Capital Territory of Anambra State, along the Enugu-Onitsha Dual Carriage way near the Amansea Boundary of the Anambra and Enugu States of Nigeria. It is underlain by the Imo Shale. Shale is a problem soil that is notoriously unpredictable, especially the soft non-indurated type, which undergoes volumetric changes when subjected to changes in moisture content as a result of annual rainy and rainy seasons. The volumetric change problem is well pronounced on almost all roads within the University Campus and is also evident in cracks on some buildings at the Science Village of the University. Shale is also an aquiclude and consequently results in waterlogged terrains.

Geology

The Nnamdi Azikiwe University, Awka, site is underlain by the Imo Shale (Fig. 1 and Table 1 summarize the stratigraphy of the Anambra Basin within which the study area lies). The dominant lithology of this formation is shale. Occurrences of siltstone, sandstone and laterite are noted, and they overlie the shale (depth of overburden ranges from 0.0 – 3.5m) in most locations within the University site. The *in-situ* shale (fresh sample) is bluish to dark colored. The siltstone and sandstone are milky to brownish, while the laterite is generally dark brownish to reddish in color (Fig. 2).

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pronounced on almost all roads within the University Campus and is also evident in cracks on some buildings at the Science Village of the University. The site lies at an elevation of approximately 150ft and is generally undulating in the SE direction.

Hydrogeology

Water table lies within 2 to 3m below the surface of native ground during the investigation; testing was carried out in the peak of dry season (January – February). Ditches in the site also showed water at a similar elevation. The low-lying portions of the site area are generally water-logged, suggesting low permeability of the underlying soil (i.e., aquiclude). Flow direction of the surface water is in the northeast direction.

Physiography and climate

The permanent site of the Nnamdi Azikiwe University falls within the highland region of a low asymmetrical ridge or Cuesta in the northern portion of the Awka-Orlu Uplands (Aghamelu *et al*., 2011b). The Cuesta trends roughly southeast to northwest, in line with the geological formations that underlie it. It is highest in the southeast, about 410 m above mean sea level, and gradually decreases in height to only 33 m in the northwest on the banks of the Anambra River and the Niger River.

The major river that drains the area is the perennial the Anambra River and its tributaries, which usually overflow their banks at the peak of the rains. Stunted trees and pockets of derelict wood land exist where the lithology has undergone high degree of laterization. Elsewhere, typical characteristics of the tropical rain forest are displayed; multitude of evergreen trees, climbing plants, parasitic plants that live on the other plants, and creepers.

Two main seasons exist in the Awka area, the dry season which lasts from November to March and the rainy season which begins in April and ends in October with a short period of reduced rains in August commonly referred to as "August break". Temperature in the dry season ranges from 20 to 38°C, and results in high evapotranspiration, while during the rainy season temperature ranges from 16 to 28°C, with generally lower evapotranspiration. The average monthly rainfall ranges from 31mm in January to 270mm in July, with the dry season experiencing much reduced volume of rainfall unlike the rainy season, which has high volume of rainfall. Average annual rainfall varies from 1,500 to 1,650mm. Aghamelu *et al*. (2011b) pointed out that the climatic conditions prevalent in the Awka area might be responsible for the development of *in situ* lateritic covers in some parts of the area.

The purpose of this research is to provide the results, as well as findings regarding the subsurface soil conditions at the various points sampled by means of geotechnical analysis, and make recommendations where necessary. Hence, the objectives of the site investigation were identification of the various soil and horizons, groundwater levels encountered in test pits and recommendation of suitable foundation types, levels and California Bearing Capacity (CBR) values for pavement design.

MATERIALS AND METHODS

Field Investigation

The master Plan of the University Campus is indicate the construction of some multi-storey buildings, roads, stadium, shopping centre and other civil engineering structures in different locations within the University. Some of these projects are at various stages of development; some already developed, while some are either under construction or proposed. To assess the engineering properties and bearing capacities of the foundation soils within the area marked out for these construction works, in particular and that of the entire Campus in general, soil samples were collected from 150 sampling points spread across, about 2,500sq km, area of the campus.

A 6-in diameter Hand Auger was deployed for the sample collection for all the tests except for the Triaxial shear strength; a 2inch diameter tube, fixed at the end of an Adapter (special device for the purpose), was utilized for the collection of soil samples for the triaxial shear strength tests. Depths vary from 0 to 3.5m; range of depths of drilling was restricted by difficulty in drillability of the underlying shale in some locations and close of water-table to the surface at the other locations. The sampling points were selected by preference (joint decision with the client). The description and exact locations of the points are given in the detailed report of the investigation (Aghamelu and Ezeh, 2010).

The soils were characterized on-site using field classifications in accordance with Visual-Manual procedure (American Society for Testing and Material, ASTM D2488, 1989) and were logged at the time of drilling. These logs were then updated as appropriate using laboratory test results and the Unified Soil Classification System (USCS) using ASTM D2487 (1989).

Laboratory Analyses

Laboratory analyses were performed on the samples collected from 150 Hand Auger drilled boreholes, 131 for classification and foundation bearing capacity analyses and 19 for subgrade analysis. The tests carried out on the soil samples included; mechanical analysis, Atterberg limits, compaction, California Bearing Ratio (CBR), bulk density, natural moisture content and shear strength. These tests followed procedures specified by Lambe

(1951), British Standard Institute, BSI 1377 (1990) and Bailey (1976). Scalping was employed such that materials used for the compaction tests (Modified Standard Proctor) passed the ¾ in. (i.e., 19.05mm) mesh of the BSI test sieves, while the CBR mould was preferred to enable immediate determination of CBR values at varying moisture contents and compaction densities.

The samples for the shear strength tests were compacted at optimum moisture contents to simulate the best possible field moisture compaction condition. The test was essentially an unconsolidated undrained shear strength test; without pore pressure measurement. Each test specimen was subjected to all-round confining pressure, δ_3 and loaded to failure with increased vertical pressure, δ_1. With the of δ_3 and corresponding δ_1, the Mohr circles and envelopes of failure were constructed to determine the angle of shearing resistance, ϕ (recorded in^0) and cohesion, c (recorded in kN/m^2) of the specimens.

Settlement and Bearing capacity analyses

The Settlement and Bearing capacity analyses carried out in this study followed a procedure outlined by Aghamelu *et al*. (2011a). The procedure was utilized because it has been shown to be significantly appropriate to the estimation of behaviour of a shallow foundation similar to the present study.

Table 1. Sedimentary succession of the Anambra Basin.

<table>
<tr><td>Age*</td><td>Epoch</td><td>Geological Unit</td></tr>
<tr><td>54</td><td>Eocene</td><td>Ameki/Nanka Formations</td></tr>
<tr><td rowspan="2">63</td><td>Paleocene
Danian</td><td rowspan="2">Imo Formation
Nsukka Formation
Ajali Formation</td></tr>
<tr><td rowspan="2">Maastrichtian</td></tr>
<tr><td>75</td><td>Mamu Formation</td></tr>
<tr><td>82</td><td>Campanian</td><td>Nkporo Shale/Enugu Shale</td></tr>
</table>

*in million year ago.

Table 2. Summary of the results of geotechnical analyses on studied soils.

Parameter	Range	Average	StD*	No.**
Grain Size Distribution				
Fines (%)	7 – 72	46	114	415
Sand (%)	28 – 93	68	122	415
Gravel (%)	0 – 40	22	108	415
Atterberg limits				
Liquid Limit	15 – 78	56	202	388
Plastic Limit	NP – 49	31	188	388
Plasticity Index	NP – 42	23	-	388
Compaction				
Maximum Dry Density (Mg/m^3)	1.64 – 1.94	1.77	64	150
Optimum Moisture Content (%)	6.8 – 21.4	12.4	96	150
California Bearing Ratio (CBR)				
CBR, after 24 hrs soaking (%)	48 – 72	59	77	150
Shear Strength				
Cohesion (kN/m^2)	0 – 46	28	88	125
Angle of shear resistance (^{o})	12 – 37	22	63	125
Density				
Bulk density (Mg/m^3)	1.33 – 2.20	1.86	106	150
Natural moisture content	12.5 – 22.7	18.4	86	150
Classification				
USCS	SM, SC, CL-ML, MH, OH	-	-	-

*Standard deviation, *Number of samples tested, NP Non plastic (plastic limit test was not possible)

Table 3. Results of the site bearing capacity analysis*.

Bore-Hole No.	Location	Ultimate bearing capacity (kN/m^2)	Safe bearing capacity (kN/m^2)	Compression index
BH 1	Second main gate	375	150	0.16
BH 2	Chapel of Glory	420	168	0.19
BH 3	Bus Stop	539	216	0.14
BH 6	Electric Power Station	925	370	0.14
BH 7	Fire Station	1073	429	0.19
BH 11	Solar Panel	358	143	0.14
BH 13	Tower	352	141	0.18
BH 15	Day Care	480	192	0.15
BH 19	Law Faculty	317	127	0.05
BH 25	Conference Centre	423	169	0.05
BH 26	Guest House	309	124	0.09
BH 28	Central Bank Building	425	170	0.17
BH 29	Amphi Theatre	378	151	0.51
BH 30	Stadium	300	120	0.21
BH 35	SW Boundary	300	120	0.15
BH 37	Sports Complex	409	164	0.23
BH 38	Admin. Block	534	214	0.14
BH 40	Entrepreneur Centre	356	142	0.17
BH 42	Reserved area	391	156	0.11
BH 55	Water Reservoir	574	230	0.23
BH 57	New Law Faculty	354	142	0.09
BH 59	Male Hostel	332	133	0.12
BH 65	Female Hostel	1200	480	0.10
BH 66	Faculty of Agriculture	673	269	0.13
BH 69	Main Library	391	156	0.51
BH 70	Future Expansion	532	213	0.08
BH 84	Proposed Students' Hostel	299	120	0.08
BH 104	Alumni Centre	821	328	0.23
BH 108	Science Village	613	245	0.32
BH 112	Buka	580	232	0.34
BH 120	Faculty of Education	956	382	0.22
BH 124	Post Graduate School	440	176	0.16
BH 125	Department of Mech. Engineering	806	322	0.38
BH 127	Staff Canteen	998	400	0.24
BH 129	Natural Science Laboratory	658	263	1.80
BH 136	Shopping Complex	790	316	0.07

*mean values at depth range of 0 to 1.5m.

RESULTS AND DISCUSSION

Mechanical Analysis and Atterberg limits Analyses

The results of the tests are in table 2. The results showed that the soils consist of predominantly sand sized grains overburden (i.e., **SM** or **SC**, according to Unified Soil Classification System). The maximum occurrence of sand occurs at a drilled hole at Law Faculty of the University (depth range 0 to 1.5m), while the minimum occur at the Bus Station in the campus and at another hole within the Law Faculty (depth range both 1.6 to 2.5 m). Below the depth of 1.0 to 1.5m the soil samples generally recorded a significant reduction in sand sized particles, thus an increase in fines percentage. Field observation suggests that the gravels are associated with lateritic soils most probably derived from the underlying Imo Shale Formation.

Plots of samples in the Plasticity Chart (see Fig. 3) revealed the fines are predominantly clays and silts of low plasticity (**CL - ML**), and less amount of organic silts

Table 4. Comparison of results with Nigerian specification for general filling and embankment material.

Properties of material	Nigerian specifications[a]	Studied soils[b]	Remarks
MDD (Mg/m^3)	> 0.047	1.64 – 1.94	Favourable
OMC (%)	< 18	6.8 – 14.6	Favourable
LL	< 40	15 – 71	Unfavourable
PI	< 20	6 – 42	Unfavourable
% Passing No. 200 (%)	≤ 35	7 – 72	Unfavourable
CBR (24 hrs soaked) BS (%)	> 5	48 – 57	Favourable

[a]Nigerian Federal Ministry of Works (1970).
[b]range

Table 5. An engineering evaluation of some physical properties of the Imo Shale.

Physical properties			Imo Shale[a]	*Remarks*
Laboratory test and *in-situ observations*	Average range of values (Underwood, 1967)			
	Unfavourable	*Favourable*		
Cohesive strength (kN/m^2)	35 – 700	700 – 10,500	15 – 28	Unfavourable
Angle of internal friction (°)	10 – 20	20 – 65	5 – 46	Favourable
Dry density (Mg/m^3)	1.13 – 1.76	1.76 – 2.56	1.66 – 1.94	Favourable
Natural Moisture content (%)	20 – 35	5 – 15	14 – 19	Unfavourable
Predominant clay minerals	Montmorillonite, illite	Kaolinite, chlorite	-	Unfavourable

([a]data from Aghamelu *et al*., 2011b)

(**OM** or **OH**). LL ranges from minimum value of 15 (at points within the Law Faculty and Male Hostel, depth 0 to 1.5m) to maximum value of 78 (at Bus Station, depth ≥ 1.6m), while PI ranges from non-plastic samples (at the Fire Station, Solar Panel Station, Day Care and Administrative block) to maximum value of 41 (at a Multi Purpose Hall near the new Law Faculty, ≥ 2.6m). LL values were utilized for the settlement analysis in this study.

Compaction and California Bearing Ratio tests

The values of maximum dry density (ρ_{dmax}) recorded by the compacted soil samples from the site range from 1.64 Mg/m^3 (at a point along the Law Faculty Road) to 1.94 Mg/m^3 (at a point along the proposed By-pass near the main entrance of the campus), as presented in Table 2. The samples recorded minimum optimum moisture content ($W_{opt.}$) value of 6.8 % (on samples from the proposed By-pass near the main entrance and future expansion area) and maximum value of 21.4% (on sample from a point along the Law Faculty Road). The average soaked California Bearing Ratio (CBR) value of the site subgrade is about 59%; maximum soaked CBR is 48% (on sample from a point along the Law Faculty Road) and maximum 72% (sample from a By-pass near the main entrance).

CBR has been correlated with pavement performance as well as used to establish design curves for pavement thickness (Sowers and Sowers, 1970). The CBR value of a construction material is often used as a benchmark in the assessment of its strength for pavement design according to Mannering and Kilareski (1998) and Wignall *et al*. (1999).

Bulk density and Triaxial shear strength tests

The results of the bulk density (ρ) and shear strength tests are summarized in table 3. The values were recorded on soil samples from a drilled hole at the southwest boundary of the campus and Faculty of Education, respectively. Sampling depths at the two locations were both at 0 to 1.5m. The strength tests results indicate that cohesion (c_u) and angle of shearing resistance (φ_u) of the tested samples ranged from 0 to 46 kN/m^3 and 12 to 37^0, respectively. The lowest c_u value was recorded on soil sample from the Bus Station and the site for the proposed Water Reservoir, while the highest value was recorded on soil sample from the Electric Power Station. The lowest φ_u value was recorded on soil sample from the Solar Panel Station and the highest value on sample from the Faculty of Agriculture. The strength parameters values were utilized in this report for bearing capacity analysis.

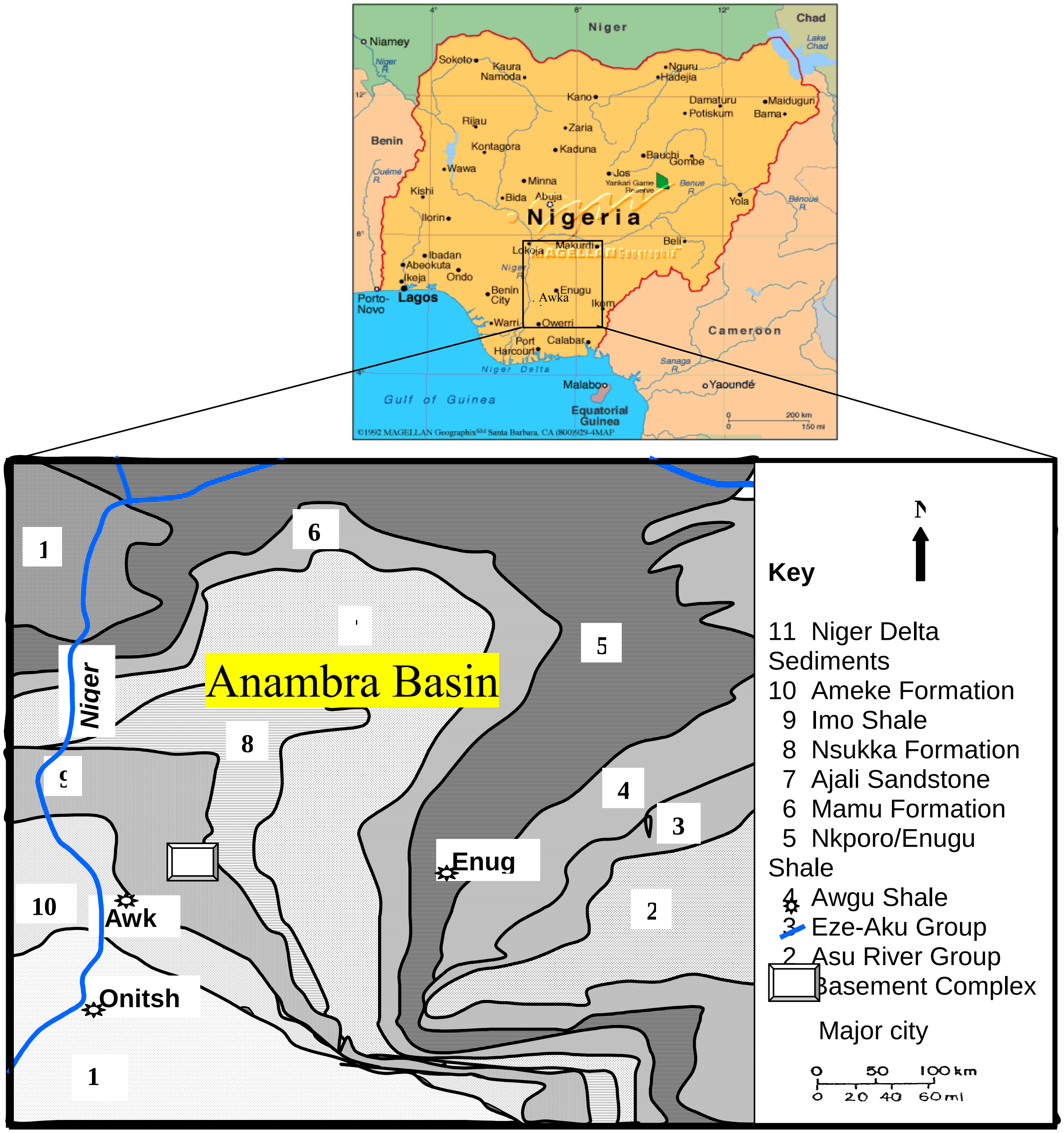

Fig. 1. Geological map of southeastern showing the position of the Anambra Basin and lateral distribution of the Imo Shale (Adapted from Aghamelu *et al*., 2011b).

Settlement and Bearing capacity characteristics

The results are summarized in table 3. Based on the results the site is unsuitable to fairly suitable for most engineering construction. Medium to high plasticity resulting from moderate to high clay content of the soil suggests volumetric changes, especially when waterlogged. The considerably high ρ_{dmax} value and W_{opt} may imply that less moisture would be needed during field compaction on the soil, for use as fills and embankment materials. High soaked CBR values (all significantly about 5%) may be used to rate the subgrade as fair to good; the standard soaked CBR values for filling and embankment material is >5% (Nigerian Federal Ministry of Works and Housing, 1970). It should, however, be noted that the testing depth was limited to 0.8 – 2.0m which is the generally recommended depth for pavement subgrade material assessment. The underlying shale, in addition to other expansive components, is bound to influence the pavement constructed on the site, especially under heavy traffic.

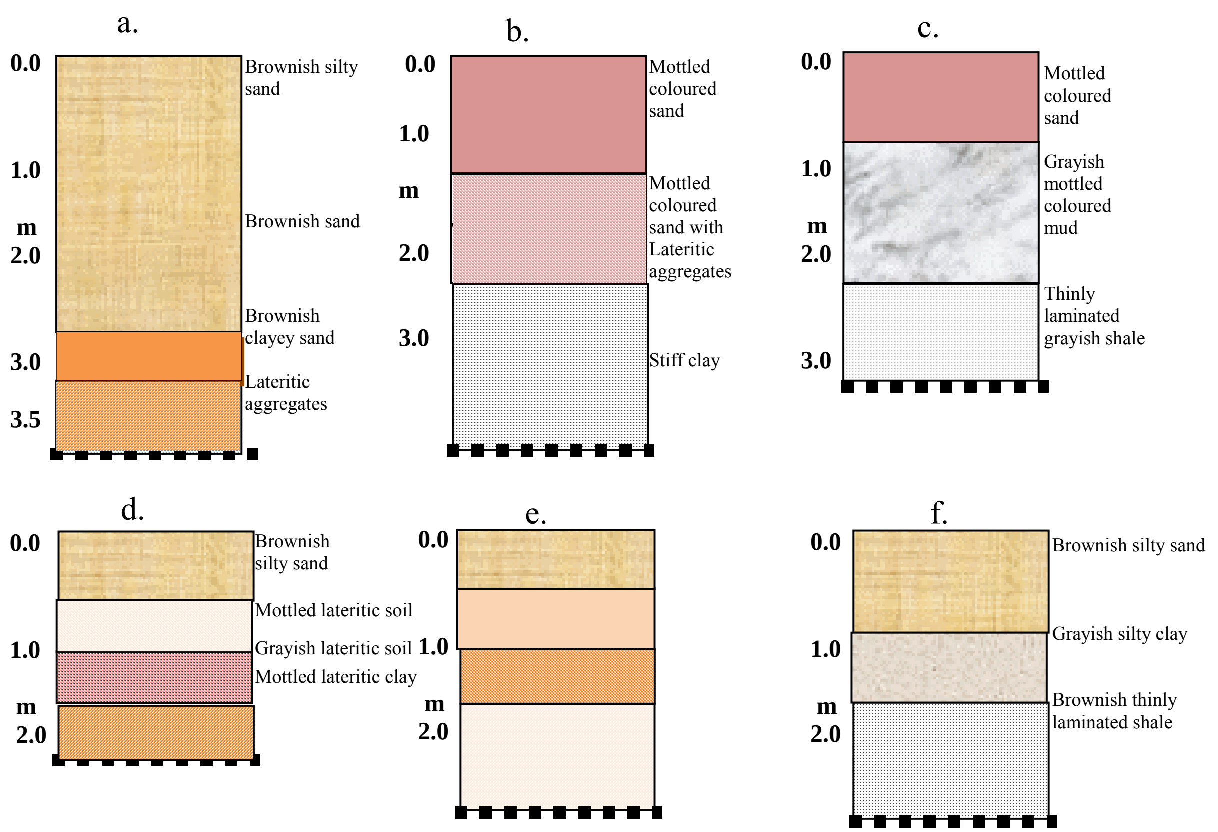

Fig. 2. Soil logs from some of the sampled points [a). Second front gate, b). Chapel of Glory, c). Stadium, d). Fuel Station, e). Science Village and f). Library].

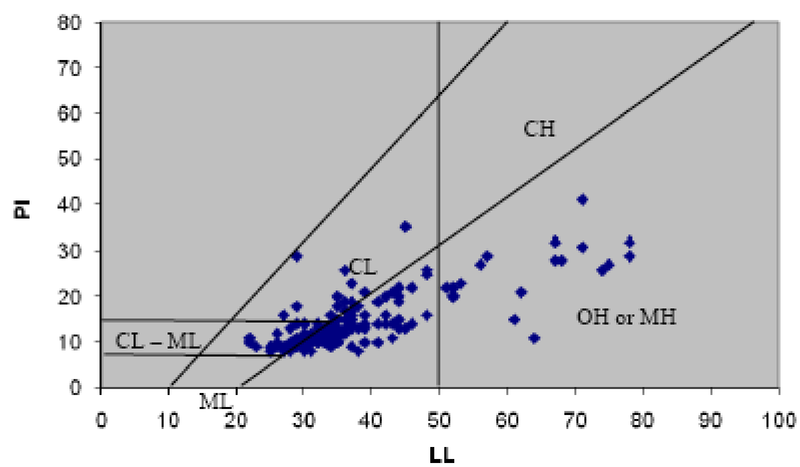

Fig. 3. Plots of the soil samples in the Plasticity Chart.

The wide range of strength parameters (cohesion and angle of shear resistance) shown by the soil samples from the site suggest wide suitability, which may range from moderate to fair bearing capacity as foundation material. However, the bearing capacity and settlement (in particular compressibility) analyses show some locations within the site have low stability; lowest at a point within the Future Expansion reserve, where the ultimate bearing capacity (q_o) is 222 kN/m^2, 291 kN/m^2 and 360 kN/m^2 at the depth ranges of 0 to 0.5m, 1.6 to 2.5m and 2.6 to 3.5m, respectively.

Other locations which recorded low stabilities include Solar Panel Station, Tower in the front of the

Administration block, Law Faculty, proposed Guest House, Stadium, Reserved area, proposed Multipurpose Hall, New Law Faculty, Male Hostel, Faculty of Agriculture, Future expansion reserve, Proposed Students' Hostel and Science Village. Safe bearing capacities of these locations were, as would expect, very low; range from 89 - 1446 kN/m^2. Reasonable stabilities were noted at other locations, especially at the Fire Station. Maximum compression index is 0.51% (at the main library). According to Sowers and Sowers (1970), soils with compression index values that ranged from 0 to 0.19 would have slight or low compressibility, those with compression index values ranging from 0.20 to 0.39 would have moderate or intermediate compressibility, while those with compression index values of 0.40 and above would high compressibility. This suggests that the soil around the main library would experience moderate compressibility and the building projects constructed on it would settle marginally, over an engineering time.

CONCLUSIONS

The field soil geotechnical investigation and soil sample testing program identified the soil underlying the studied site to be primarily shale, with weathered shale, laterite and sandstone to siltstone overburden. The overburden ranges in thickness between 0 and 3.0m. The overburden materials are generally porous and permeable (aquiferous), but infiltration of meteoric (or surface water) is being restricted by the dense, somewhere fissile, underlying shale (most probably the Imo Shale Formation).

The general subsurface stratification, however, was apparent from the subsurface investigation. This was owing to high degree of disturbance associated with the sampling method adopted. Low drillabilty of the underlying shale, which may be misinterpreted to mean high strength as foundation material, and high water table (with respect to mean-sea-level) hampered the sampling depth capacity of the hand auger.

In view of the observed characteristics of the underlying soils on the campus, excavation (i.e., stripping of the soil prior to pavement and building foundation construction) of the expansive top or residual soils should be carried out with conventional earthmoving equipment, especially where they the thin in thickness and also fail to meet a number of requirements for material used as filling and embankment material (see Table 4). The excavated soils can be reused for landscaping purposes at other locations on the campus.

Construction of foundations on different bearing stratums usually increases the risk of differential movements of the foundations. It is therefore recommended that all of the foundations for individual buildings should be founded on the same bearing stratum. The following options are considered appropriate:

- Slab on ground (founded on residual soil or on the unweathered shale bedrock)
- Stiffened raft (founded on residual soil)
- Pad footing (founded on the unweathered shale bedrock)

A stiffened raft option may, however, be the best option as it provides a stiffer foundation solution than a slab on ground but it does not completely eliminate differential movement. Previous study (Aghamelu *et al*., 2011b) has also revealed that the unweathered underlying Imo Shale might be unsuitable as foundation material (see Table 5).

Good drainage should be constructed in other to control runoffs and other surface water bodies, thereby preventing flooding. Slope stability problems may occur where the slope is high. This should be put into consideration while designing the structure in those sloppy areas. Heavy traffic may be restricted where soil investigation indicated materials that would be poor to fair as pavement subgrades.

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