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Research Paper

Assessment of Bearing Capacity and Compressibility of Soils of Enugu Shale, Southeastern Nigeria

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Abstract
Enugu and environs are urban area with serious developmental activities going on daily basis. There is little or no information on the bearing capacity of soils developed over Enugu Shale for researchers and developers to be studied in general before embarking local geotechnical properties of their individual sites. This paper aimed at determining the bearing capacity, safe bearing capacity and compressibility of soils in the study area to ascertain the suitability of the soils as site for shallow foundation. The laboratory tests were limited to particle size distribution analysis, Atterberg's limits and triaxial tests for shear strength parameters. Simplified Meyerhof's equation was deployed to determine the bearing capacity of the soils. Results of gradational analyses indicated that the foundation soils for shallow foundation in the study area are dominated by fines. The particle size distribution ranges from 21.67-93.97%, 6-72.52% and 0-54.97% of fines, sands and gravels respectively. The estimated values of bearing capacity, safe bearing capacity and compressibility range from 54-325 kNm^{-2}, 18-108 kNm^{-2} and 0.11- 0.5 respectively. Safe bearing capacity falls mostly within soft clays and silts while the compressibility is mostly within high to very high. This implies that stabilization of soils of the study area are needed before using them for sites for shallow foundation.

Keywords: *Bearing capacity, Safe bearing capacity, Compressibility, Shallow foundation, Enugu Shale, Meyerhof's equation*

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I. INTRODUCTION

The needs to mitigate disasters associated with collapse of buildings in Nigeria prompted the policy makers to initiate a compulsory code for construction through the Federal Ministry Works and Housing. This code involves detailed geotechnical investigations of site for construction. The foundation soils need to be studied in detail to guard against reoccurrence of ugly situation associated with collapse of buildings which sometimes involve deaths and loss of economic resources. The material study of foundation soils has helped to a larger extent in preventing the foundation failure associated with argillageous materials in the southeastern Nigeria. The soils developed over Enugu Shale need a special attention to overcome problems occasioned by swelling characteristics of clayey soils. Previous soil characterizations in the study area have been carried out by Nnamani and Igwe, 2020; Amadi et al. 2021; Nnamani, 2022; Onuoha et al. 2014; Adesina and Tijani, 2017; Ben-Owope et al. 2019 and have observed that the area is characterized by extensive exposition of swelling soils and irregular distribution of weak soils whose strength can be weak by addition of water which occurs in abundant due to climatic condition of the area under study.

Bearing capacity of soils have been analytically calculated by several authors such as Rankine, Hogentogler and Terzaghi, Prandtl, Terzaghi, Hansen, Vesic and Meyerhof. But these analytical procedures for determination of foundation stability and sustainability of engineering structures require that series of field and laboratory tests be conducted to obtain the needed components of the chosen equation. In most cases, these test apparatus are not readily available in the developing countries like ours and when available the cost implication of conducting the tests overwhelm developers thus making it rear possible for many builders to conduct the most needed tests for safety of engineering structure in the developing countries. Again, the supervising agencies who ought to see the implementation of the developed code prior to the construction of engineering structure are most a times collect bribe from the developers and such needed tests will not be conducted. These challenges have affected the objectives of government as regards to the protection of lives and properties in the developing nations. It is now a common occurrence whenever one tuning in to radio or television stations to listening to the news of the day but to behold the collapsed images of residential and commercial buildings with its attendant casualties and loss of economic valuables. In most cases, the costs saved by not doing these most important tests are lost in ten folds whenever this tragedy occurs.

There have been some research work in Enugu and environs where soils developed over Enugu Shale have been characterized to ascertain their geotechnical properties. However, there is no known work where bearing capacity of the entire Enugu urban and environs have been studied and detailed foundation strength characterized. This paper tends to use Meyerhof's bearing capacity equation to determine the bearing capacity and settlement estimations of Enugu urban and environs. These estimations were obtained based on field data and generated test results from the laboratory tests conducted on the soils developed over Enugu Shale. These tests were quite simple and economical on their own but are relevant to geotechnical determination of the study area through empirical calculations. Enugu is a fast growing city in the southeastern Nigeria and the need for the developers to follow the laydown rules for safety and sustainability of engineering structures cannot be overemphasized. This research work will go a run way in educating the developersand researchers to understand the safety involved in detailed study of site before proper construction of engineering structures.

GENERAL DESCRIPTION OF THE STUDY AREA

The study area is located in southeastern Nigeria and the east of Anambra Basin. The study area covers Enugu and environs and is bounded by latitude $N6^{0}20^{1}$ and $N6^{0}50^{1}$; and longitude $E7^{0}25^{1}$ and $E7^{0}45^{1}$ (Fig.1)Anambra Basin has a successive sequence of lithologic unit ranging from Enugu/Nkporo Shale (Campanian), Mamu Formation (Lower Maastrichtian), Ajali Formation (Upper Maastrichtian) and Nsukka Formation (Danian). Enugu and environs are underlain by partlyMamu Formation in the western flank and Enugu Shale dominating the lithologic unit of the area under study.Mamu Formation is the coal-bearing stratigraphic unit of the Anambra basin. It comprises of heterolithic sediments of wave laminated and fine grained sandstone, alternating the thin beds of shale, mudstone and coal beds. The shales are light grey in colour without fissility of Enugu Shale. Enugu Shale is highly fissile with dark grey to black in colour with extraformationalclast. Figure 2 is the geological map of Anambra Basin showing the study area. The study area is within rainforest region of Nigeria. It has thick vegetation in the shaley area and sparsely vegetated on the sandstone area. Table 1 shows the location coordinates of sampling points.

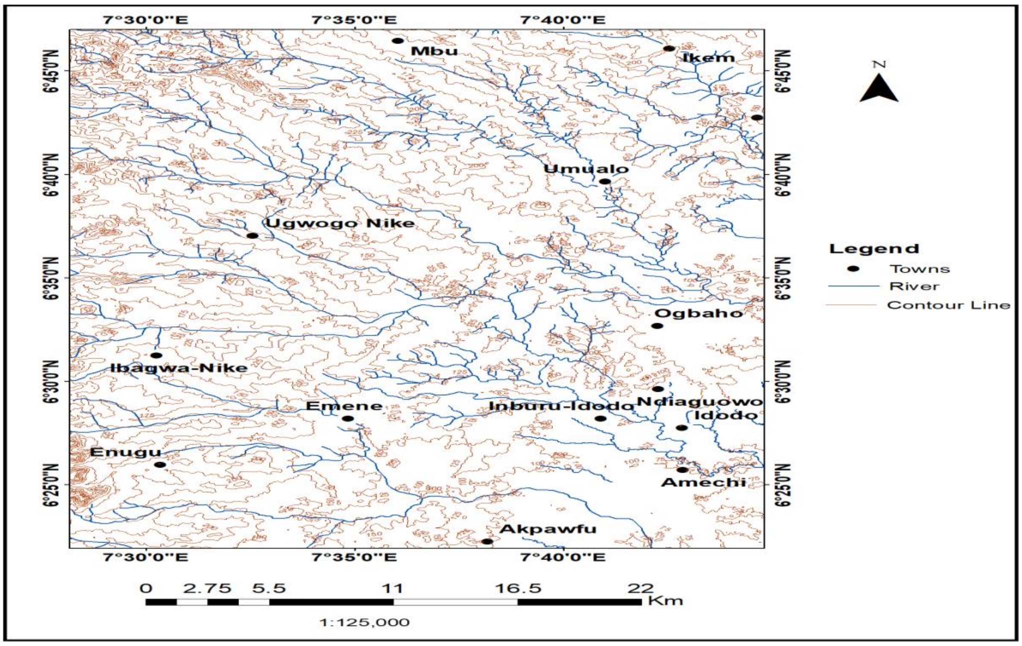

Figure 1: Map showing the area extent of the study area

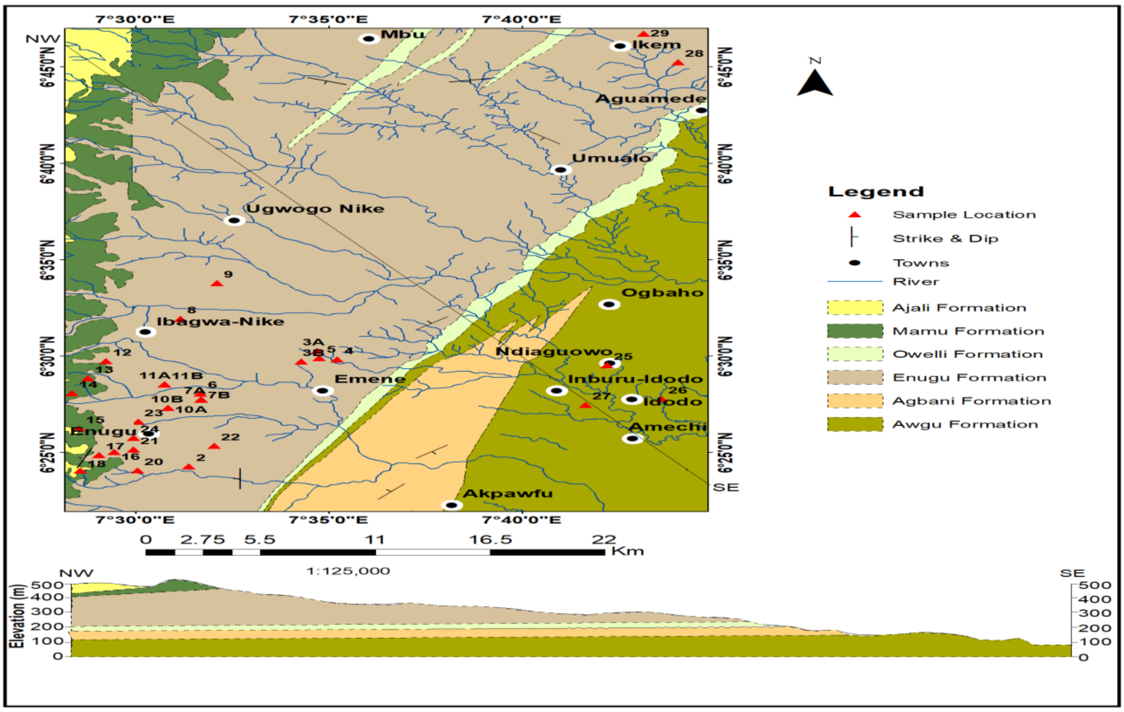

Figure 2: The geologic map of the study area

Table 1: Location coordinates of the collected samples in the study area

	STATION	LAT(N)	LONG(E))	ELEVATION(m)	DEPTH(m)
1	2	N06^{0}24^{1}14.5^{11}	E007^{0}31^{1}22.1^{11}	163.5	0.5
2	3A	N06^{0}29^{1}55.1^{11}	E007^{0}34^{1}30.5^{11}	172	0.5
3	3B	N06^{0}29^{1}55.1^{11}	E007^{0}34^{1}30.5^{11}	171	1
4	4	N06^{0}29^{1}48.8^{11}	E007^{0}35^{1}13.4^{11}	147.5	0.5
5	5	N06^{0}29^{1}53.2^{11}	E007^{0}34^{1}45·3^{11}	177	0.5
6	6	N06^{0}28^{1}03.1^{11}	E007^{0}31^{1}41.0^{11}	198	0.5
7	7A	N06^{0}27^{1}45.3^{11}	E007^{0}31^{1}41.9^{11}	200	0.5
8	7B	N06^{0}27^{1}45.3^{11}	E007^{0}31^{1}41.9^{11}	199	1
9	8	N06^{0}31^{1}55.6^{11}	E007^{0}31^{1}09.5^{11}	219.5	0.5
10	9	N06^{0}33^{1}46.8^{11}	E007^{0}32^{1}06.6^{11}	212	0.5
11	10A	N06^{0}27^{1}18.6^{11}	E007^{0}30^{1}50.0^{11}	159	0.5
12	10B	N06^{0}27^{1}18.6^{11}	E007^{0}30^{1}50.0^{11}	158	1
13	11A	N06^{0}28^{1}31.9^{11}	E007^{0}30^{1}45.6^{11}	168	0.5
14	11B	N06^{0}28^{1}31.9^{11}	E007^{0}30^{1}45.6^{11}	167	1
15	12	N06^{0}29^{1}44.4^{11}	E007^{0}29^{1}14.6^{11}	191	0.5
16	13	N06^{0}28^{1}50.9^{11}	E007^{0}28^{1}46.8	216	0.5
17	14	N06^{0}28^{1}04.0^{11}	E007^{0}28^{1}21.4^{11}	189	0.5
18	15	N06^{0}26^{1}14.2^{11}	E007^{0}28^{1}32.9^{11}	247	0.5
19	16	N06^{0}24^{1}48.1^{11}	E007^{0}28^{1}53.5^{11}	272	0.5
20	17	N06^{0}24^{1}51.3^{11}	E007^{0}29^{1}03.1^{11}	282	0.5
21	18	N06024^{1}04.0^{11}	E007^{0}28^{1}34.6^{11}	265	0.5
22	19	N06^{0}22^{1}53.6^{11}	E007^{0}27^{1}48.0^{11}	202.5	0.5
23	20	N06^{0}24^{1}03.2^{11}	E007^{0}30^{1}03.6^{11}	169	0.5
24	21	N06^{0}25^{1}08.6^{11}	E007^{0}29^{1}57.4^{11}	196	0.5
25	22	N06^{0}25^{1}20.1^{11}	E007^{0}32^{1}02.7^{11}	199	0.5
26	23	N06^{0}26^{1}35.2^{11}	E007^{0}30^{1}04.0^{11}	173	0.5
27	24	N06^{0}25^{1}44.9^{11}	E007^{0}29^{1}57.0^{11}	221	0.5
28	25	N06^{0}29^{1}31.4^{11}	E007^{0}42^{1}11.4^{11}	91	0.5
29	26	N06^{0}27^{1}45.9^{11}	E007^{0}43^{1}35.9^{11}	80	0.5
30	27	N06^{0}27^{1}27.6^{11}	E007^{0}41^{1}38.6^{11}	83.5	0.5

II. METHODOLOGY

Soil Sampling

Thirty soil samples were collected from twenty-seven sampling points. Disturbed soil samples were taken at intervals where changes in soil characteristics were observed with varying depth at 0.5m and 1m. A six inches diameter hand auger was used for the collection of soil samples for the tests. The collected samples were wrapped in polyethylene bags to retain their natural moisture content before moving the samples to laboratory.

Laboratory Tests

Particle Size Distribution Tests

This was done using BS standard sieve which was placed on the sieve shaker with sample being tested for. A balance scale with accuracy to measure 0.1 percent of the weight of the sample was used. The samples were dried to a constant weight at a temperature of 110 $\pm$ 5 ºC and weighed. About 300g of the samples were used. The oven-dried samples were sieved through the various BS sieve with help of an electric shaker. After shaking for about 10 minutes, the material retained on each sieve was weighed. And cumulative weight passing through each sieve was calculated. A graph of cumulative percentage passing through various BS sieve were plotted against the sieve sizes in a semi-log graph.

Atterberg's Limit

The liquid limit test was done in accordance with BS 1377 (1990) test. The samples were dried, crushed in mortar and then sieved through a 425μm aperture sieve size, after which the samples were thoroughly mixed with water on a bowl to form a homogeneous paste of soil. The paste was then placed on the casagrande's apparatus and parted by drawing groove through the centre of the hinge. The opening was closed by lifting and dropping the casagrande's apparatus until the parted opening by grooving tool was closed. The number of blows at which this closure occurred was recorded and a little quantity of the soil sample was taken and moisture content of the sample was determined. The value of moisture content obtained and their respective number of blows were plotted on a semi-logarithm graph. The liquid limit was obtained as the moisture content corresponding to 25 blows. This procedure was repeated several times for the same sample with varying water content.

Shear Strength

The triaxial test was conducted on the soil samples by means of applied stress. Stress was applied to the soil sample being tested for in a way that the resulted stresses along one axis were different from the stresses in the perpendicular direction. This was achieved through triaxial apparatus which has two parallel platens and the soil sample was placed in between the platens. This allowed applied stress in one direction (vertical direction) and fluid chamber allowed another applied stress to the soil sample in the perpendicular directions. The compressive stresses in the triaxial apparatus caused shear stress to develop in the sample. The stress was increased and deflections monitored until the fracture of the soil sample occurred. From the test, angle of internal friction and cohesion were obtained.

Bearing Capacity Analysis

The bearing capacity parameters were obtained from triaxial analysis. While Terzaghi equation as modified by Meyerhof was used to determine the bearing capacity of the study area. There are several bearing capacity equations by different scholars but Meyerhof's equation was used as it is more accurate in determining the bearing capacity of cohesive soils. The Meyerhof's equation is as follows; $\mathbf{q_u = cN_C + q_oN_q + 0.5ByN_y}$ eqn 1

Where; q_u is ultimate bearing capacity

C is cohesion

q_o is surcharge (weight of the soil above foundation level)

Y is unit weight of soil (KNm^{-3})

B is width of foundation which was assumed to 0.5m

N_c, N_q and N_y are bearing capacity factors and they depend on cohesion (c) and angle of internal friction (ϕ).

The surcharge (q_o) and unit weight of soil (y) are given by the following equations 2 and 3, respectively;

$\mathbf{q_o = yD}$ eqn2

where; D is the depth of foundation

$\mathbf{y = \rho g}$ eqn3

where; ρ is the specific gravity

g= acceleration due to gravity.

The values of the bearing capacity factors (N_C, N_q and N_y) were obtained using Meyerhof's chart in Table2.

Table 2: Bearing Capacity Factors for Meyerhof's Equation

Angle φ (Degrees)	Nc	Nq	Nγ
0	5.1	1	0
1	5.38	1.09	0
2	5.63	1.2	0.01
3	5.9	1.31	0.02
4	6.19	1.43	0.04
5	6.49	1.57	0.07
6	6.81	1.72	0.11
7	7.16	1.88	0.15
8	7.53	2.06	0.21
9	7.92	2.25	0.28
10	8.34	2.47	0.37
11	8.8	2.71	0.47
12	9.28	2.97	0.6
13	9.81	3.26	0.74
14	10.37	3.59	0.92
15	10.98	3.94	1.13
16	11.63	4.34	1.37
17	12.34	4.77	1.66
18	13.1	5.26	2
19	13.93	5.8	2.4
20	14.83	6.4	2.87

The safe bearing capacity (q_s) was estimated using the following equation, according to Sowers and Sowers, (1970).

$\mathbf{q_s = \frac{qu}{SFM}}$ eqn4

where; SFM is safe minimum permissible safety factor taken to be equal 3.

Settlement Analysis

Settlement was estimated using compressibility equation by Terzaghi and Peck in Aghamelu, et al. 2011 as follow**; $\mathbf{C_c = 0.009\ (LL-10)}$** eq5

Where; C_c is the compression index

LL is liquid limit

III. RESULTS AND DISCUSSIONS

Particle Size Distribution Analysis

The results of the sieve analyses of the tested soil samples showed that the soils consist of particles ranging from 21.67 – 93.97%, 6 - 72.52% and 0 – 54.97% of fines, sands and gravels respectively with mean values of 69.65%, 23.68% and 6.57% for fines, sands and gravels. Particle size distribution curves of the studied soil samples are shown in fig.3 and the dominance of fines over sands and gravels are shown in fig.4 with the showing non-uniform distribution of particles in the study area which implies poorly graded soils.

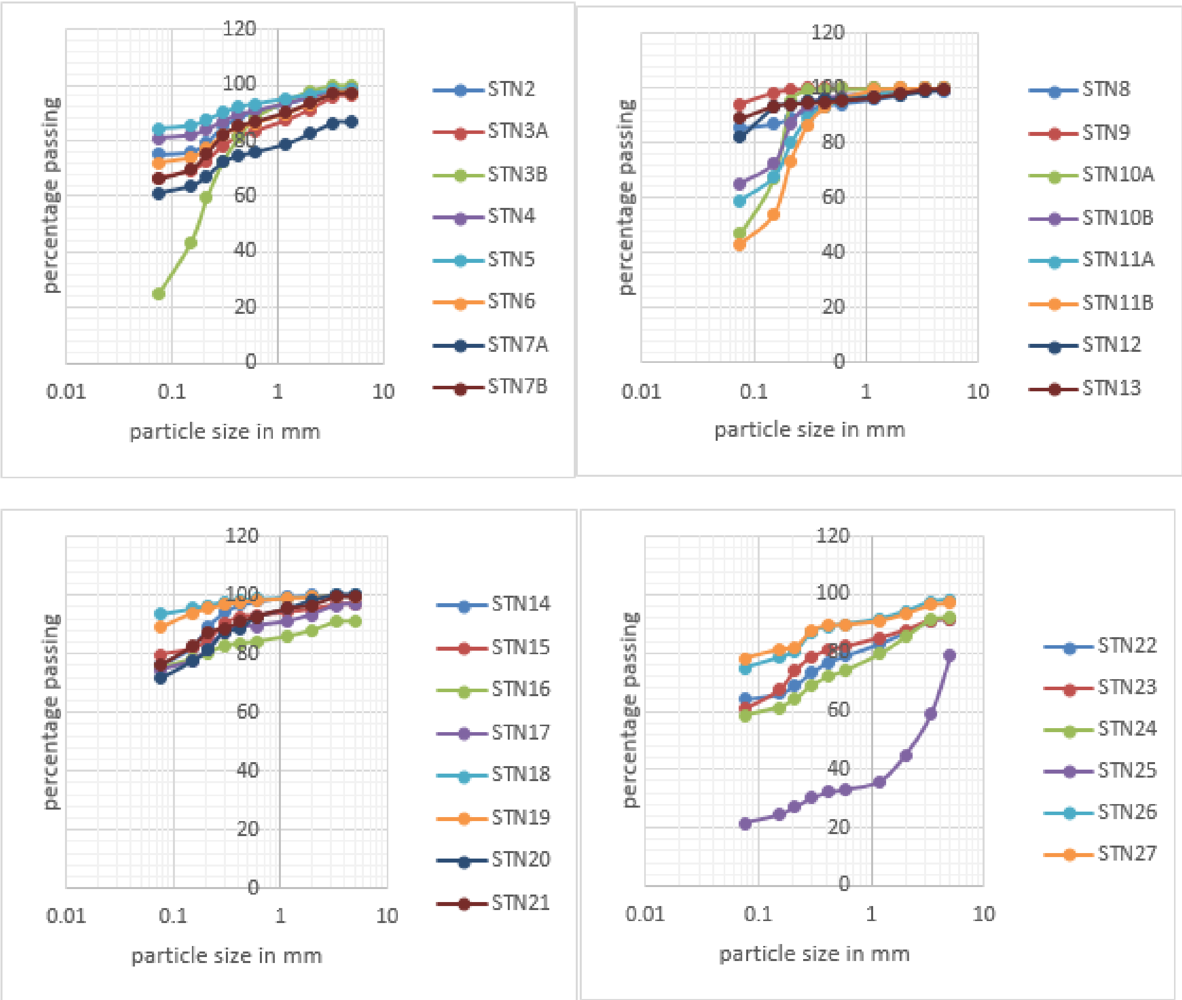

Figure 3: Particle size distribution curves for the studied soil samples

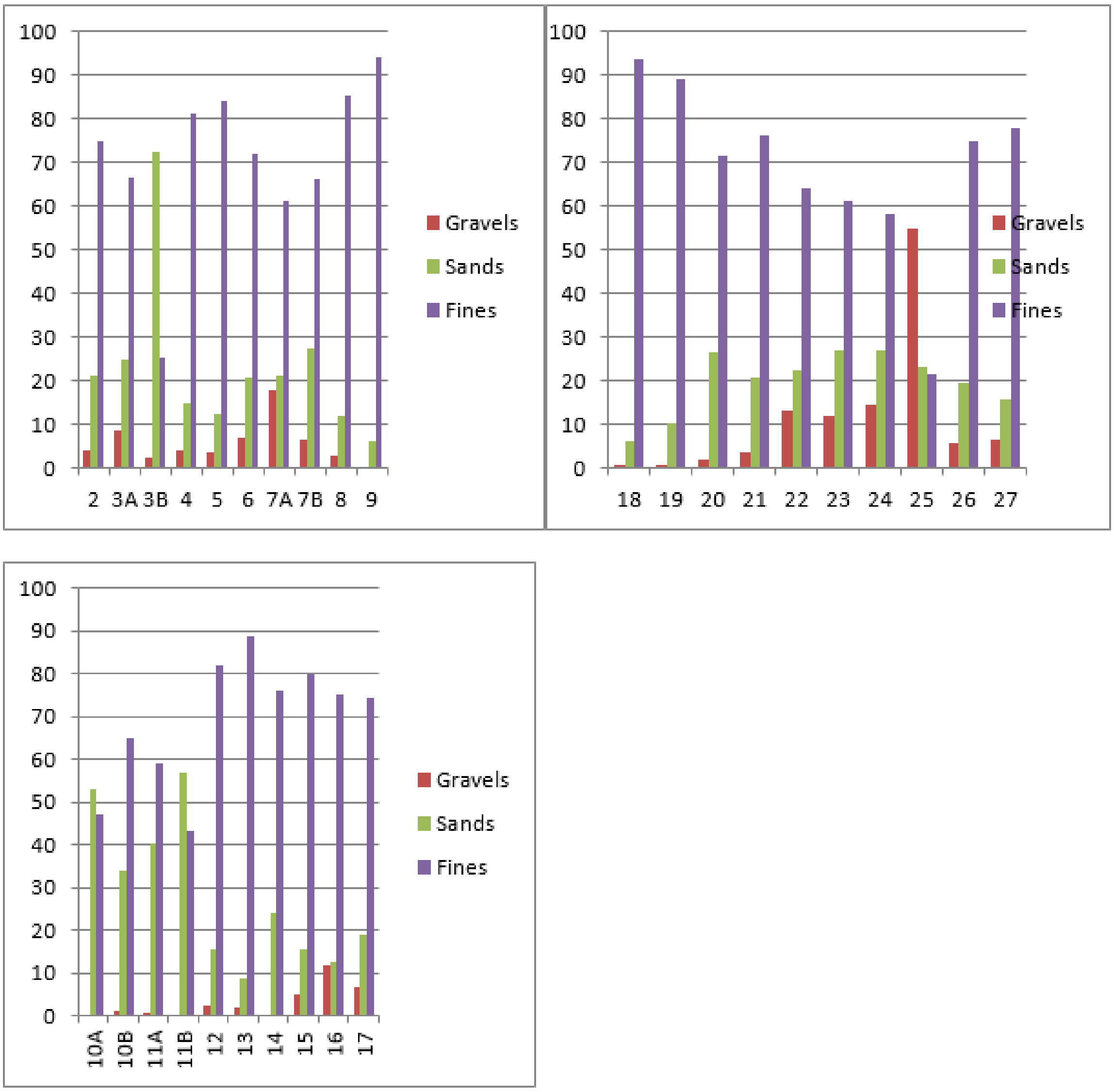

Figure 4: Bar charts showing the dominance of fines over sands and gravels

Atterberg's Limits

Atterberg's limit test results show that liquid limits, plastic limits and plasticity index range from 22 – 66%, 0 – 39% and 0 – 39% respectively Table 3. The plasticity of the soil samples range from low to high. Studied soil samples are most dominated by fines fig.4. Fines have implication in the plasticity of soils. The finer the particle size, the greater the amount of adsorbed water due to high surface charge and consequently higher liquid limit which as well impact on the plasticity of the soil. Sowers and Sowers, 1970 noted that high plasticity usually has the ability to retain higher amount of water in the diffused double layer, especially through adsorption. The excessive water increases the swelling potential of the soil and degree of compressibility.

Table 3: The table showing geotechnical properties of the study area

STATION	C(KNM^{-2})	Ø(^{0})	Compressive strength(KNM^{-2})	p (Kg/m3)	Y(KN/M3)	qo	Qu	qs	LL(%)	PL	PI	Cc
2	30.21	4.42	63.25	2.69	26.9	13.45	206	69	59	28	31	0.44
3A	13.49	7.84	72.93	2.65	26.5	13.25	122	41	51	25	26	0.37
3B	22.37	5.49	63.57	2.65	26.5	13.25	166	55	56	17	30	0.41
4	30.55	5.22	68.89	2.63	26.3	13.15	219	73	66	31	35	0.5
5	30.36	5.14	67.35	2.59	25.9	12.95	218	73	63	27	36	0.48
6	27.53	6.32	75.38	2.64	26.4	13.2	210	70	59	39	20	0.44
7A	27.86	5.85	70.76	2.62	26.2	13.1	201	67	40	26	14	0.27
7B	26.82	5.85	61.12	2.64	26.4	26.4	216	72	44	27	17	0.31

8	32.52	7.21	92.12	2.65	26.5	13.25	259	86	48	25	23	0.34
9	4.51	6.89	18.19	2.61	26.1	13.05	54	18	27	-	-	0.15
10A	6.07	7.02	20.23	2.6	26	13	69	23	27	20	7	0.15
10B	28.34	11.72	137.96	2.68	26.8	26.8	325	108	24	12	12	0.13
11A	30.22	3.12	50.07	2.6	26	13	195	65	27	20	7	0.15
11B	1.42	10.62	13.06	2.58	25.8	25.8	78	26	28	-	-	0.16
12	25.05	4.93	53.67	2.65	26.5	13.25	177	59	22	13	9	0.11
13	27.28	5.3	65.08	2.65	26.5	13.25	198	66	38	28	10	0.25
14	28.74	11.67	138.36	2.65	26.5	13.25	292	97	34	23	11	0.22
15	38.03	3.1	58.68	2.65	26.5	13.25	242	81	46	29	17	0.31
16	27.8	6.91	81.08	2.65	26.5	13.25	222	74	28	12	16	0.16
17	33.66	5.53	77.36	2.65	26.5	13.25	240	80	42	22	20	0.29
18	37.75	4.03	67.1	2.65	26.5	13.25	253	84	38	20	16	0.25
19	12.19	14.85	157.45	2.63	26.3	13.15	179	60	50	24	26	0.36
20	28.74	6.69	81.9	2.65	26.5	13.25	219	73	42	22	20	0.29
21	26.97	10.8	122.54	2.65	26.5	13.25	260	87	32	17	15	0.2
22	30.58	5.93	74.18	2.65	26.5	13.25	220	73	48	35	13	0.34
23	22.83	10.51	115.55	2.58	25.8	12.9	225	75	29	20	9	0.17
24	27.6	7.08	81.12	2.65	26.5	13.25	224	75	44	31	13	0.31
25	36.15	7.4	97.25	2.57	25.7	12.85	284	95	55	25	30	0.41
26	36.94	5.58	81.44	2.62	26.2	13.1	261	87	46	27	19	0.32
27	26.97	6.83	79.89	2.65	26.5	13.25	207	69	54	33	21	0.4

Shear Strength

The results of triaxal tests conducted on the soil samples show that the angle of internal friction and cohesion range from 4.42 – 14.85^o and 1.42 – 38.02KNm^{-2} Table 3. The results have shown that the study area has good cohesion and low angle of internal friction. The undrained compressive strength as obtained in Table 3, derived its strength from cohesion. The poor grading of the soils can be attributed to the cause of low angle of internal friction in the area while good cohesion can be attributed to high fines content in the area. The undrained compressive strength shows that the study area is dominated by low to medium strength. Shear strength governs the capability of soils to support load from engineering structure and stability of slope. The bearing capacity of a soil is dependent on its shear strength.

Bearing Capacity of the Study Area

The estimated values for bearing capacity, safe bearing capacity and settlement in the studied soil samples from the study area are presented in Table 3. The results show that the study area has low bearing capacity and safe bearing capacity which are consistent with shear strength results. The study area has high to very high compressibility. These shows there will be bearing capacity problem in the foundation soils and necessary caution needs to be applied when building any engineering structure in the study area.

Table 4: Presumed bearing values for types of cohesive soils

Category	Type of rocks and soils	Presumed bearing value
Cohesive soils	Very stiff bolder clays & hard clays	300 to 600 kNm^{-2}
	Stiff clays	150 to 300 kNm^{-2}
	Firm clays	75 to 150 kNm^{-2}
	Soft clays and silts	<75 kNm^{-2}

IV. CONCLUSION

The need for detailed geotechnical investigation for foundation cannot be over emphasized. Simple but very important site geotechnical investigations were carried out in soils developed over Enugu Shale and environs. These laboratory and empirical analyses were done to provide insight on the nature of the shallow foundation soils in Enugu and environs. It is important to note that test results helped in analyzing field observations in the study area.

Bearing capacity of the study area indicated that the estimated safe bearingcapacity of the soils is mostly below 100 kNm^{-2}. This implies that the study area is dominated by firm clays to soft clays and silts. It is advisable to take necessary precautions to improve the quality of the soils of the area before using the area as site for light weight engineering construction for shallow foundation. In as much as these geotechnical investigations and improvement of soils in the study area requires additional cost to the developers but cost implications of the failure of foundation and its catastrophic consequences cannot be overstressed.

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