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Geotechnical Assessment of Subsoil Integrity for Foundation Design in OWERRI, Nigeria

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Abstract:
Background: *The geotechnical investigation was carried out to determine the subsoil condition for appropriate shallow foundation design. Sampling was done up to a 4 m depth. The study revealed that the top stratigraphy layer of dark organic silty soil was followed by a reddish-brown poorly graded medium-density sand. The engineering geological properties were influenced by the quality of clay, silt, and predominantly sand content. The soils are fairly erosion-resistant, with low compressibility and excellent drainage capability.*
Materials and Methods: *The particles are slightly cemented with a wide range of grainsizes between 0.6 mm and 0.12 mm. The effective size (D10) of all sizes falls between 0.12mm and 0.16mm. (D30) between 0.25mm and 0.36mm, while (D60) has a 0.6mm maximum. The co-efficient of uniformity (Cu) is between 3.67 and 5.0, while the coefficient of curvature falls between 1.03 mm and 1.36 mm, indicating poorly graded uniform sand.*
Results: *The average plasticity index (PI) is 19.57. The average soil unit weight is 17.26 KN/m2 with a specific gravity ranging from 2.50 to 2.60.The average cohesion of the soil is between 0.86 KN/m^2 and 8.72 KN/m^2 and the angle of internal friction is between 21.53^o and 27.22^o with a bulk density of 17.21 kg/m^3 to 19.58 kg/m^2.*
Conclusion: *The soil has an average bearing capacity of 210.26 KN/m^2 with an average settlement of 0.85 mm.*
Key words: *Geotechnical investigation, foundation design, bearing capacity, shear strength.*

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I. Introduction

Engineering structures are supposed to be founded on a foundation that provides strength and low compressibility to ensure the safety and durability of the structure. Geotechnical studies are done to determine the competency of the soil in carrying the superstructure, which is dependent upon the index and design properties of the underlying soil that transmit the weight of the structure to the subsurface. Such studies are often neglected, leading to either over-design or under-design of structural foundations. While the latter can result in wrong design and wasteful spending, the aftermath of the former could be painful, such as building collapse and loss of human life and properties. One of the greatest causes of building collapse is foundation failure, and one of the greatest causes of foundation failure is insufficient knowledge of ground conditions (Abam, 2021).In order to forestall such occurrences, it becomes necessary to conduct detailed geotechnical studies before foundation design. This is even more necessary in the Niger Delta because of its peculiar environmental and geological settings. Many civil structures have been designed incorrectly and wastefully due to a lack of adequate knowledge of soil behavior and the application of geotechnical parameters to soil (Ademila, 2018).

However, there is a growing popularity of geotechnical investigations to determine subsoil competency. This may be attributed to the incidence of building collapses, especially within the Niger Delta subregion. According to Abam (2018), Lagos State recorded 139 cases of building collapse between 1978 and 2013 (see table 1). The goal of this research is to conduct a subsoil engineering geological investigation in order to determine the geotechnical parameters suitable for foundation design in the hope that it will allow for an appropriate foundation design for the superstructure.

II Study Area

The study area, Owerri, is part of the eastern lowlands of the Niger Delta, south of Nigeria (Teme, 2018). The area is flat land with scarce surface vegetation, with an observed borrow pit at the side. Its geographical boundaries are between latitudes 5024 'N and 5035 'N of the Equator and between longitudes 6058 'E and $7^0$06'E of the Greenwich Meridian, which is within the tropical rainforest belt of Nigeria.

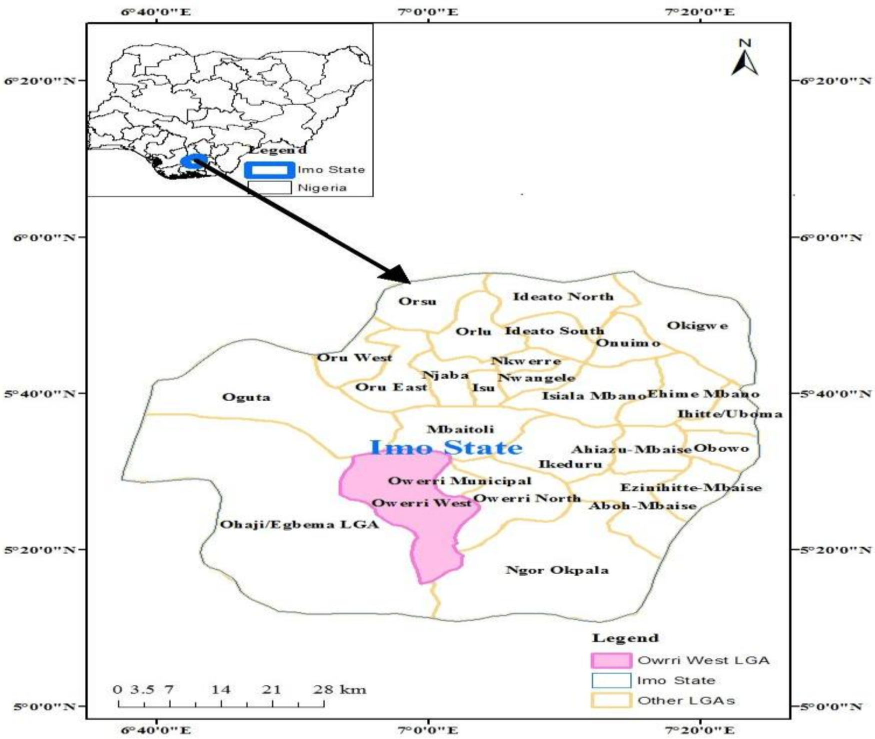

Figure 1: Geographic map of Study area

Table 1: Sampling Points

Sampling Point	Northing	Easting	Depth (m)
BH1	$05^0 91' 40''$	$7^0 0' 17''$	4
BH2	$05^0 29' 40''$	$7^0 0'$	4
BH3	$05^0 29' 40''$	$7^0 0' 18''$	4
BH4	$05^0 29' 40''$	$7^0 0' 19''$	4
BH5	$05^0 29' 41''$	$7^0 0' 19''$	4
BH6	$05^0 29' 41''$	$7^0 0' 17''$	4

Geographically, the area is characterized by non-concretionary sandy soil with clay. It consists of an unconsolidated sand deposit that is porous and reddish brown in colour. This is typical of the Benin sands (Ejezie, 1986). The Benin formation (coastal-plain sands) is an extensive stratigraphic unit in the southeastern Nigerian sedimentary basin. It consists of very friable sand intercalated with shale and clay lenses (Short and Stauble, 1967). It also contains small isolated units of gravel, conglomerate, very coarse-grained sand, and sandstone in the Owerri area (Ananaba et al., 1993).

III Material and Methods

Both field and laboratory studies were carried out. Field methods involve sampling, visual inspection, and interpretation of samples. Sampling involved the collection of both disturbed and undisturbed samples at 6 sampling points for laboratory analysis. Disturbed samples were collected using percussion anger at every 0.75m of depth or when a change in lithology was observed. The disturbed were used to determine the index properties of the subsurface soil. From the relative undisturbed samples, the design parameters of the soil were determined. All tests and analyses were carried out in accordance with the British Standards (BS) and accepted engineering, geological, and scientific principles.

Sieve analysis of soils was done, and particle size distribution and grading curves were plotted. The Atterberg Limits (Liquid and Plastic Limits) were conducted. Other tests carried out included moisture content, unit weight, and bulk density, among others. A one-dimensional consolidation test was done using a fixed ring type Oedometer to determine consolidation, settlement, and related co-efficient. The bearing capacity of the soils was computed using an empirical method. Details are presented in subsequent sections.

IV. Result

The area is characterized by a top layer or dark organic soil which is composed of reddish loose materials. It is lateritic in nature with some clay. It is about 1.3m thick. It may have been leached and washed down from higher elevations. Beneath this top layers lies a reddish brown poorly graded medium sand.

Table 2: Summary of some geotechnical parameters

s/n	Soil Properties	Minimum	Maximum	average
1.	Natural Moisture Content %	11.11	18.18	14.68
2.	Bulk density KN/m^2)	1.81	1.84	1.83
3.	Specific gravity	2.50	2.67	2.60
4.	Uniformity Coefficient (C_u)	3.75	5.5	4.62
5.	Coefficient of curvature (C_u)	1.35	1.36	1.35
6.	Plasticiy index %	17.7	21.4	19.55
7.	Dry density kg/ m^{20}	16.92	17,28	17.19
8	Cohesion KN/ m^2	0.86	8.72	4.79
9.	Age of friction	21.53	27.22^o	24.38^o
10	Percentage fine %	4.03	6.07	0.011
11.	Settlement in mm	2.4	14.5	8.45
12	Sharing strength KN/ m^2	77.11	90.43	83.77
13	Bearing capacity KN/ m^2	171.4	260.6	216
14	Void Ratio €	0.52	0.52	0.52
15	Coefficient of Compressibility av in KN/ m^2	0.01944	0.000148	0.009794
16	Coefficient of Volume Compressibility CV in KN/ m^2	0.00095504	0.00010467	0.0005318
17.	Pre-condition Value in KN/ m^2			

Table 3 Grainsize Distribution Pattern

	D_{10}	D_{30}	D_{60}	C_U	C_C
BH1	0.2	0.38	0.70	3.5	1.03
BH2	0.22	9.38	0.70	3.18	0.93
BH3	0.12	9.25	0.60	5.0	2.0
BH4	0.12	0.25	0.60	5.0	1.04
BH5	0.13	0.25	0.55	4.23	0.8
BH6	0.15	0.28	0.55	3.67	0.95
Average					

Atterberg Limits

The Consistency Limits (Liquid and Plastic Limits) are presented in table 4. The values for Liquid Limit range from 32.26% to 36.50% with an average of 35% while the plastic limits range from 14.6-17.3% with an average of 15.8%. The natural moisture content in between 12.0% and 18.18% with an average of 15.05 which is low.

Table 4: Consistency Limits

	Natural w Moisture content (%)	Liquid Limit (LL) %	Plastic Limit (PL) %	Plasticity Index (PI)	34	Bulk Unit Weight	Dry Unit Weight
BH1	14.86	34.00	17.3	17.7	2.50	1.81	19.36
BH2	12.00	35.00	14.6	21.4	2.65	1.80	16.92
BH3	13.33	36.10	15.7	20.3	2.64	1.87	17.15
BH4	18.18	35.00	15.6	20.4	2.51	1.82	17.28
BH5	14.29	34.80	16.2	18.7	2.65	1.84	19.57
BH6	17.65	35.10	15.4	19.8	2.50		
Average	15.05	35.00	15.8	19.5			

Consolidation Properties

The coefficient of volume compressibility (M_v) and the coefficient of consolidation (C_v) were determined at pressure ranging from 10 to 800KN/m^2. Values of both M_V and C_V are presented in Table 5. The M_v varies from 0.0009502KN/m^2 to 0.001416360 while the C_V ranges from 0.0005994KN/m^2 in BH6 to 0.003742KN/m^2 in BH3. The values are given with the corresponding changes in void ratios. Figure 4 is a plot of void ratio against pressure.

Table 5 Consolidation Validity

S/N	Applied Pressure in Kn/m^2	Final Dial reading (10^-2)	ΔH in mm change in Thickness	Change in void ratio $\Delta e = \frac{\Delta H}{H}(1 + ef$	Void Ratio	$a_0 = \frac{\Delta e}{\Delta p} \in kn/m^2$	$m_v = \frac{av}{1+e_0} \in kn/m^2$
1	0	39			1.02706		
2	10	63	-0.24	-0.01944	1.00762	0.001944	0.00095902
3	20	109-2	=0.462	-0.037422	0.970198	0.0037422	0.00186399
4	50	216	-1.068	0.086508	0.88369	0.00028836	0.00146360
5	100	380	-1.64	-0.13284	0.75085	0.00126568	0.00141042
6	200	536	=1.56	-0.12636	0.62449	0.00012636	0.00072170
7	400	684	-1.48	-0.11988	0.50461	0.0005994	0.00036987
8	800	810	-1.26	-0.10206	0.40255	0.0002552	0.00016957
9	0	665	1.45	0.11745	0.52	0.0001468	0.00010467

Shear Strength

The shear strength properties of the soil were determined by shear box test on remolded specimen of 60x60x120mm. The shear box tests were done using 24kg, 44kg and 64kg loads.

The empirical computation was done using the Mohr-Columb relationship.

$Ʈ = c + \delta n \tan\theta$ …………………………………1

Where;

Ʈ = Shear strength

C = Cohesion

Θ = Angle of internal friction

δn = Maximum normal stress = 177.8KN/m^2

The result is presented in table 5

Table 6: Bearing Capacity Parameters

Borehole #	Cohesion KN/m^2	Angle of Internal Friction	Shear Strength	Dept?
BH1	2.01	22.9	77.11	3
BH2	3.53	23.6	81.28	2 (shear strength)
BH3	0.86	26.2	80.17	2 (c + δn tanθ)
BH4	8.09	24.85	90.43	3 (where Θis max normal stress
BH5	4.84	21.53	74.98	2
BH6	8.73	25.65	94.09	4

Bearing Capacity Computations

The Terzaghi equation for ultimate bearing capacity computation (based on laboratory results) was used. This is given for a square foundation in Smith (1982:282) as;

$q_{ult} = 1.3CN_c + ■DN_q + 0.4■BN_y$ ……………………………2

(For a shallow foundation where $D/B \leq 1.0$)

Where:

q_{ult} = ultimate bearing capacity of soil in KN/m^2

■ = Unit weight of soil (KN/m^2)

B = breath of square footing (m)

D = depth of foundation (m)

N_y, N_c & N_q = bearing capacity factors for unit weight, cohesion and surcharge pressure respectively. See details in Table 7.

Table 7: Bearing Capacity

	Sample	D (m)	γ (Kn/m^2	C	Ø(⁰)	Nc	Nq	Ny	Quit	Qa
BH1	1m	2	17.36	2.009	22.9	20.8	10.7	8.1	538.32	179.4
BH1	2m	2	16.92	2.009	22.9	22.25	11.85	9.35	585.67	195.2
BH1	3m	2	17.15	3.53	23.62	19.87	10.24	7.77	548.0	183.0
BH2	1m	2	17.57	0.86	26	20.8	10.7	8.1	549.0	171.0
BH2	2m	2	17.57	8.09	24.85	22.25	11.85	9.35	513.10	260.6
BH3	3m	2	17.36	8.09	24.85	20.8	10.7	8.1	781.83	234.3
BH3	5m	2	16.92	4.84	21.53	22.25	11.85	9.35	702.75	222.5
BH4	2m	2	17.15	8.72	25.65	19.87	10.24	7.77	683.08	227.7
BH4	3m	2	17.57	8.29	21.95	20.8	10.7	8.1	714.01	238.0
BH5	4m	2	17.57	0.86	27.22	22.25	11.85	9.35	572.70	190.9

Factor of Safety used = 3

From the table, the values for the bearing capacity range from 179.4KN/m^2 to 260.6KN/m^2 with an average of 216.0KN/m^2

Settlement

Settlements are vertical movements of structures in the ground as a result of applied stress from the structure. The expected settlement was estimated from the relationship after Smith (1982);

$S_c = Mv.\Delta\delta.H$ ……………………………2

where S_c = total settlement

M_v = coefficient of vol. compressibility

H = height of compressible layer

$\Delta\delta$ = Effective vertical stress imposed in the soil by the super structure

Table 8 shows the estimated settlement expected.

	Thickness of Layer	Coefficient of compressibility MV	Δδ (KN/m^2)	Estimated Settlement (mm)
BH1	1.5	0.0009590	187.5	0.267
BH2	2	0.00018689	187.5	0.070
BH3	1.6	0.00014636	187.5	0.044
BH4	1.5	0.0002552	187.5	0.072
BH5	2	0.0001468	187.5	0.055
BH6	1.6	0.00018836	187.5	0.086

Source: Computed data

The empirical computation was done using the mohr-columb relationship.

$Ʈ = C + \delta n \tan\theta$

Where Ʈ= shear strength.

The index properties of the underlying in-situ soil are very important in the design considerations for foundation type. Specific gravity, natural moisture content, liquid and plastic limits, plasticity index, bulk unit weight, and grain size distribution were some of the index properties determined. Also, the angle of internal friction, cohesion, shear strength, bearing capacity, and settlement were determined as design parameters. A summary of the geotechnical properties of the area as determined from field and laboratory analysis is presented in table 2. Two geological units are revealed by the bearing from the surface to about 4 m depth. The top layer (0-1.3m) is unconsolidated, dark organic silt soil, followed by a layer of poorly graded, medium-density sand. Moisture content is an indicator of the shear strength of a soil as there is an inverse relationship between moisture content and shear strength (Ʈ). The moisture content of between 12.00 and 18.18 is low (Ademola, 2018). Also, the critical moisture content in terms of Atterberg Limits indicates the soils are of low to slightly organic clayed sand. The particles are slightly cemented with a wide range of grain sizes between 0.6 mm and 0.12 mm.

The coefficient of uniformity (C_u) of between 3.67 and 5.00 and the coefficient of curvature (C_c) of between 1.03 and 1.36 are indicative of poorly graded uniform sand as the percentage of five is below 5%. This is an indication of low compressibility with excellent drainage capabilities.

The average cohesion of between 0.86KN/m^2 and 8.72KN/m^2 with an internal frictional angle between 21.53^0 and 27.22^0 is a reflection of the low percentage of five fractions. The average bearing capacity of the soil is 210.26 KN/m^2.

II. Conclusion

The detailed engineering geological properties of the soil as revealed in the study have been presented. These properties are influenced by the quantities of silt, clay and sand content. From the analysis, the soils are fairly erosion resistant and low in compressibility with excellent drainage capabilities.

The average settlement value of 0.84 mm is not significant. As a result, the depth investigated (0–4.0 m) would be ideal for shallow foundations.

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