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ASSESSMENT OF SOIL BEARING CAPACITY OF VARIOUS LOCATIONS WITHIN THE NEW PERMANENT SITE OF THE NIGERIAN ARMY COLLEGE OF ENVIRONMENTAL SCIENCE AND TECHNOLOGY MAKURDI, BENUE STATE.

BY

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Abstract

In the engineering context, soil is a complex material resulting from the weathering of rocks and plays a crucial role in supporting structural foundations. The study focused on determining the soil bearing capacity at the Permanent Site of the Nigerian Army College of Environmental Science and Technology. The investigation revealed that the site's soil is uniform in terms of profile, particle size, and non-plasticity properties across all six locations studied. The soil is characterized by silt and predominantly fine sand content with little to no clay. The natural moisture content ranged from 4.3 to 19.6% during the sampling period. The grading curves showed high percentage of fine passing BS standard sieves no. 8 (2.36 mm) and no. 40 (0.425mm) while less percentage passed no. 200 (0.075mm). The percentage passing these Sieves ranged from 99.3 to 100% for Sieve no. 8; 58.2 to 70.6% for Sieve no. 40 and 1.2 to 23.3% for Sieve no. 200 respectively. The specific gravity and maximum dry density varied across locations. The apparent cohesion was low, and the angle of internal friction ranged from 4^0 to 6^0 degrees. The allowable bearing capacity increased with depth, ranging from 25.9 to 70.8kN/m^2. The soil was found to be predominantly fine-grained sand with low bearing capacity and high erodibility. Groundwater was discovered at depths not exceeding 3 m at some locations. The study recommends pad foundation with ground beams for simple structures and raft or pile foundation for complex and tall buildings.

Keywords: *Soil, Shear strength, Bearing capacity, footing, Structure, Foundation depth*

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INTRODUCTION

Engineering soil can be referred to as complex material comprising of surface and sub-surface materials formed from the decomposition of parent rock during weathering process. During construction, structures are supported by foundations located on the soil. Stability of this foundation is affected by two important factors such as soil bearing capacity and the settlement. When soft soils shrink or expand, the foundations usually settle in a way as to induce stress on the super structure with consequential instabilities leading to general failures. Most structural contracts neglect the time and task details for proper determination of soil characteristics relevant for the development of foundations to withstand stress variability of peculiar environments. Loose sand can be subject to large settlements and these settlements tend to occur quickly due to the free draining granular nature of sands. This can pose foundation challenges and loose sand requires densification in order to provide sufficient settlement control and bearing pressure for new structural foundation. Research has shown that depth of footing, size of foundation, cohesion, unit weight, angle of internal friction, types of footing and depth of water table are factors affecting bearing capacity of soil (Dixit and Patil, 2010; Alawode, et al., 2020).

According to Andrew (2021), failure to understand and account for the ground bearing pressure prior to building a structure could lead to catastrophic consequences such as collapsing at a later stage. Therefore, the determination of soil stability and mapping of predictive foundation statistics for different structural grades in the Institution's permanent site is a measure to understand and ensuring safe and optimal performance of structures to be developed in the near future.

Furthermore, failure of structures is imminent as a result of the use of wrong foundation type corresponding to the engineering strength (bearing capacity) of the soil present on the site. Therefore, determination of the most suitable and economical foundation type for different types in building construction is of utmost importance.

LITERATUR REVIEW

In geo-technical engineering, a soil or a soil deposit may be defined from a civil engineering context as uncemented or weakly cemented accumulation of mineral particles, which are formed by the weathering (disintegration) of rocks (Odeyemi, et al., 2012). A soil can further be defined as an unconsolidated material which is made up of solid particles produced by the disintegration of rocks (Arora, 2009; Odeyemi, et al., 2012).). Bearing capacity as a technical term is the ability of soil to support the loads transmitted on it through the foundation footing. applied to the ground (Venkatramaiah, 2006; Popova et al., 2020).

Foundation was seen by Murthy (2010) as an integral part of a structure which gains its stability from the supporting soil. He further revealed the two major factors that are responsible for the structural stability any foundation as: the foundation should be stable against any shear failure of the soil and secondly, the settlement of the foundation must not be in excess of the tolerance level of the super structure to prevent failure. According to Coduto, et al. (2016), soft material like clay undergoes large settlements when loaded structurally without actual shear failure because the allowable bearing capacity is not exceeded.

The most commonly used types of bearing capacities are the ultimate bearing capacity and the allowable bearing capacity. However, it is the allowable soil bearing capacity that is mostly used in designs as its design is based on the maximum allowable settlement (Hussain, 2020). Andrew (2021) gave the types of bearing capacity of soil as: ultimate bearing capacity

(q_u), Net ultimate bearing capacity (q_{nu}), Net safe bearing capacity (q_{ns}), Gross safe bearing capacity (q_s), Net safe settlement pressure (q_{np}) etc.

Three modes of failures that constrain soil bearing capacity depend on the shear strength of the soil, shape, depth and type of the foundation (Venkatramaiah, 2006). These limiting failure types are: general shear failure, local shear failure and punching shear failure.

Murthy (2010) stated that the steps to selecting a foundation include: understand the superstructure and the load to transmit to the foundation, obtain the subsoil characteristics and ascertain the best-fit types of foundation for the soil/structure pair. It also include: Taking a detailed study of loads, subsurface conditions and footing size (Saurav, 2022), for estimated settlement in predicted structural stability as well as estimating the cost of each matched type of foundation.

Shear strength parameters; cohesion and angle of shearing resistant are obtained from Mohr envelope with shear stress plotted against normal stress. The Terzaghi's bearing capacity method was adopted to determine the foundation type and depth for different structural predictions. Terzaghi in 1942 found out that the ultimate bearing capacity of foundation types are shown in equations 1 to 4 (Murthy, 2010 and Venkatramaiah, 2006):

Strip foundation, $q_u = cN_c + \gamma D_f N_q + \frac{1}{2}\gamma B N_\gamma$ (1)

Rectangular foundation; $q_u = cN_c(1 + 0.3\frac{B}{L}) + \gamma D_f N_q + \frac{1}{2}\gamma N_\gamma(1 - 0.2\frac{B}{L})$ (2)

Circular foundation, $q_u = 1.3\, cN_c + \gamma D_f N_q + 0.3\, \gamma B N_\gamma$ (3)

Square foundation, $q_u = 1.3\, cN_c + \gamma D_f N_q + 0.4\, \gamma B N_\gamma$ (4)

Where:

q_u = ultimate bearing capacity c = unit cohesion, γ = effective unit weight (from specific gravity), B = width or diameter,

L = length of footing, D_f = depth of footing whereas $N_{c,}N_q$ and N_γ are reduced bearing factors for local shear failures (Murthy, 2010).

The bearing capacity factors can be obtained from use of Formula or Table with respect to angle of internal friction(ϕ), as shown in equations 5 to 7 and Table 1 respectively.

$N_q = tan^2(45^o + \phi/2).e^{\pi tan\phi}$ (5)

$N_c = (N_q - 1)cot\phi$ (6)

$N_\gamma = 1.8(N_q - 1)tan\phi$ (7)

Table 1: Terzaghi's Bearing Capacity Factors (Venkatramaiah, 2006)

Bearing capacity factors	**Angle of Internal Friction (ϕ)**										
	0^o	5^o	10^o	15^o	20^o	25^o	30^o	35^o	40^o	45^o	50^o
N_c	5.7	7.3	9.6	12.9	17.7	25.1	37.2	57.8	95.7	172.3	347.5
N_q	1.0	1.6	2.7	4.4	7.4	12.7	22.5	41.4	81.3	173.3	415.1
N_γ	0.0	1.5	1.2	2.5	5.0	9.7	19.7	42.4	100.4	297.5	1153.0

MATERIALS AND METHODS

A total of eighteen samples were collected from six dug pits at various locations within the Proposed New Permanent Site of the Institution. These include: the Administrative block site where samples A1, A2 and A3; B1, B2, and B3 were collected; Male students Hostels where

samples C1, C2 and C3 were obtained; Female students quarter where sample D1, D2 and D3 were collected; Also, samples E1, E2 and E3 were obtained from the Staff quarters, while F1, F2 and F3 were sampled from the School of Environmental Sciences. The sample locations were evenly spread and samples were collected from Pits at a specified debt of 1m, 2m and 3m below the existing ground surface. Hand auger, shovels, tape measure, round scoop and digger were amongst the apparatus used during the field sampling processes. GPS device was employed to determine the sample location coordinates and height above mean sea level. The laboratory investigations were conducted in accordance with Part 2 of BS 1377: 1990 and ASTM 1994. These tests include: Atterberg's limits, Grain size distribution analysis and Natural moisture content while others included shear strength and Specific gravity tests were carried out on the samples.

Terzaghi's approach to bearing capacity analysis was adopted. The shear strength parameters were derived by plotting the graph of shear stress against normal stress. The general formula for square footing was adopted in this work to determine the average soil contact pressure as stipulated by Terzaghi and shown in equation 5.

$$q_u = 1.3\, cN_c + \gamma D_f N_q + 0.4\, \gamma B N_\gamma \quad (8)$$

Where;
q_u = ultimate load for unit length of footing, c = cohesion, γ = unit weight, B = width or diameter, L = length of footing, D_f = depth of foundation whereas N_c, N_q and N_γ are named the bearing capacity factors for cohesion, surcharge and wedge of soil respectively (Sutton, 1975 and Murthy, 2010).

RESULTS AND DISCUSSIONS

The sample location coordinates and geologic map of Benue State are shown in Table 2 and Figures 1a and 1b respectively. Also the engineering properties of the sample soils investigated are presented in Table 3. The results are discussed under each of the tests carried out.

Geology/Location of the Study Area

The study area is lies within the valley of River Benue, Makurdi. According to Geological Survey of Nigeria 1994, Makurdi as the capital of Benue State, comprises of basically a sedimentary environment. The sedimentary terrain comprises of mainly of sandstone. It has grain size distribution and stratigraphic signatures suggestive of fluvial environment.

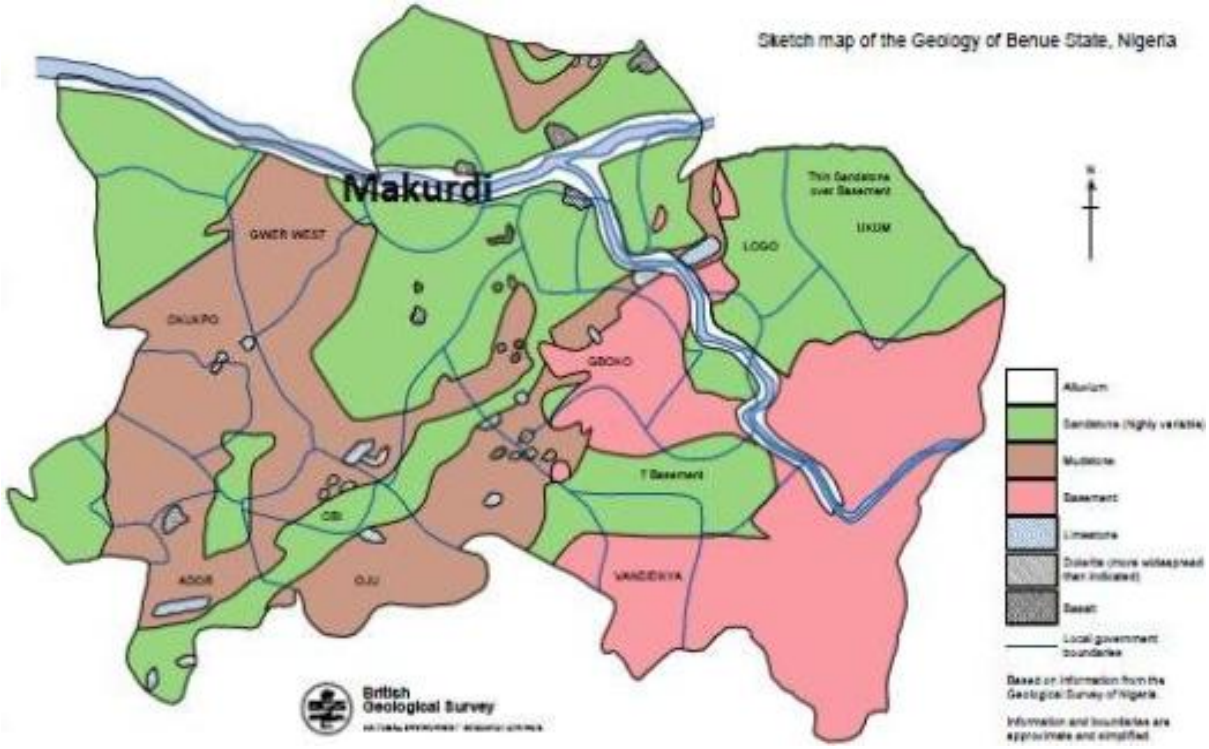


Figure 1a: Geological Map of Benue State, Nigeria (Source: Obiora, et al., 2015)



Figure 1b: Makurdi Local Government

Table 2: Description of Sample Locations

Sample location and ID		Sample depth below ground surface (m)	Latitude	Longitude	Height above mean sea level (m)
A1	Administrative block	1	N 7° 45' 56''	E 8° 32' 19''	133
A2		2			
A2		3			
B1		1	N 7° 46' 17''	E 8° 32' 12''	133
B2		2			
B3		3			
C1	Male students hostel	1	N 7° 46' 14''	E 8° 32' 36''	140
C2		2			
C3		3			
D1	Female students hostel	1	N 7° 46' 27''	E 8° 32' 55''	145
D2		2			
D3		3			
E1	Staff quarters	1	N 7° 46' 41''	E 8° 31' 56''	117
E2		2			
E3		3			
F1	School of Environmental Sciences	1	N 7° 45' 56''	E 8° 32' 28''	132
F2		2			
F3		3			

Table 3: Engineering Properties of the Sample Soils from NACEST New Permanent Site

Sample ID	A			B			C			D			E			F		
Depth (m)	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Natural moisture %	10.4	9.8	8.6	4.3	5.2	7.5	8.0	16.1	19.6	6.3	10.1	11.0	8.0	9.0	8.7	4.7	15.5	16.4
Average natural m.c %		9.6			5.7			14.6			9.3			8.6			12.2	
Specific gravity	2.59	2.32	2.56	2.56	2.61	2.61	2.70	2.68	2.71	2.64	2.81	2.59	2.72	2.66	2.75	2.62	2.59	2.61
Average specific gravity		2.49			2.59			2.70			2.68			2.71			2.61	
Percentage finer than BS Sieve no. 8	100	100	99.3	99.6	99.7	99.8	99.9	99.8	99.8	100	100	100	99.8	98.7	94.7	99.9	100	99.9
Percentage finer than BS Sieve no. 40	67.3	73.0	60.9	60.1	61.4	60.4	70.6	70.0	67.4	63.8	62.5	58.2	67.0	60.5	58.5	67.5	69.3	67.5
Percentage finer than BS Sieve no. 200	14.6	23.3	16.7	10.0	14.3	8.3	8.0	7.2	1.2	12.3	20.9	21.6	14.7	18.5	15.8	12.3	13.8	12.3
Plasticity index (%)	Non Plastic																	
Dry density (kN/m^3)	1.82	1.88	1.90	1.82	1.81	1.95	1.79	1.78	2.1	1.82	1.93	1.94	1.84	1.90	1.98	1.8	1.82	1.88
OMC (%)	13.0	14.3	12.5	14.7	15.0	11.8	12.8	13.5	14.9	12.5	14.0	13.9	14.8	15.0	11.0	15.0	15.4	14.7
cohesion (kN/m^2)	6.0	7.8	8.8	5.8	6.5	7.2	5.5	5.0	5.0	10.0	9.1	10.5	5.5	6.3	6.5	4.7	5.0	5.5
φ (Degree)	5	5	4	5	6	6	4	4	5	5	4	5	4	5	6	4	5	5
Unit weight kN/m^3	19.6	18.5	18.3	17.0	17.5	17.8	17.6	16.7	17.0	19.2	2.13	19.8	17.7	19.0	20.5	16.5	17.0.	17.6
Bearing capacity (kN/m^2)	35.1	46.6	58.0	32.0	51.3	66.0	29.7	36.0	48.1	47.6	53.5	70.8	30.0	55.7	70.1	25.9	39.1	50.9

Natural moisture content

The Average natural moisture content showed: 9.6, 5.7, 14.6 and 9.3 % for locations A, B, C and D while 8.6 and 12.2 % were recorded for samples E and F respectively up to the depth explored as shown in Table 3. Sample at location C has the lowest moisture value of 5.7 %, which is about 63 and 51% lesser than Locations D (9.3 %) and E (8.6 %) respectively. Ground water was discovered at depths not exceeding 2 and 3m below the ground surface at locations C, E and F. This is responsible for high greater value of natural moisture content found at these (C and F) locations.

Specific gravity

The specific gravity results obtained were 2.59, 2.56, 2.70, 2.64, 2.72 and2.62 for A, B, C, D, E and F at 1m depth; 2.32, 2.61, 2.68, 2.81, 2.66 and 2.59 were obtained for sample A, B, C, D, E and F at 2m and 2.56, 2.61, 2.71, 2.59, 2.75 and 2.61 were also recorded for these locations respectively as shown in Table 3. The average value of specific gravity for locations A, B, C, D and E were 2.49, 2.59, 2.70, 2.68, 2.71 and 2.61 respectively. These values fall within the specific gravity range (2.3 – 2.9) for sand sizes.

Particles size distribution

The percentage passing 2.36 mm and 0.425mm BS Sieves ranged from 99.3 to 100% and 58.2 to 70.6 % respectively. 14.6, 23.3 and 16.7% obtained from samples A at 1m, 2m and 3m depth were finer than 0.075mm BS Sieve. Samples C showed lowest values (8.0, 7.2 and 1.2%) of particle size passing 0.075mm Sieve as shown in Table 3. Also the percentage by weight of particle size finer than 0.425mm BS Sieve for samples A, B, C and D at 1m, 2m and 3m depth were 67.3, 73.0 and 60.9%; 60.1, 61.4 and 60.4%; 70.6, 70.0 and 67.4%, and 63.8, 62.5, 58.2% respectively, whereas 67.0, 60.5 and 58.5 %; 67.5, 69.3 and 67.5% were recorded from 0.425mm for samples D and F at 1m, 2m and 3m respectively. Greater values of percentage passing were recorded with Sieves no. 8 and 40 and lesser percentage for Sieve no. 200. These results revealed that the sample soils were predominantly fine sand with less amount of silt content.

Liquid and plastic limits

There was no evidence of plasticity as this cannot be ascertained using the liquid limit device as specified by BS 1377; Part2, 1990. This development was attributed to the cohesionless nature of the sample soils studied.

Compaction parameters

The moisture-density results obtained, recorded maximum dry density (MDD) values at 1m, 2m and 3m depth as follows: 1.82, 1.88 and 1.90 g/m^3 for A; 1.82, 1.81 and 1.95 g/cm^3 for B; 1.79, 1.78 and 2.1 g/m^3 for C; 1.82, 1.93 and 1.94 g/cm^3 for D; 1.84, 1.90 and 1.98 g/cm^3 for E and 1.80, 1.82 and 1.88 g/cm^3 for F respectively. The values of corresponding optimum moisture content at 1, 2 and 3m depths were; 13.0, 14.3 and 12.5% for samples A; 14.7, 15.0 and 11.8 % for B; 12.8, 13.5 and 14.9 % for C; 12.5, 14.0 and 13.9 % for D; 14.8, 15.0 and 11.0 % for E and 15.0, 15.4 and 14.7 % for F respectively. The results in Table 3 has Shown that sample C has the lowest value of MDD at 1m and 2m depth, while a highest value was recorded at 3m depth.

Shear strength

The apparent cohesion recorded from all the sample locations at 1m, 2m and 3m depth were 6.0, 7.8 and 8.8 kN/m^2 for A; 5.8, 6.5 and 7.2 kN/m^2 for B; 5.5, 5.0 and 5.0 kN/m^2 for C; 10.0, 9.1

and 10.5 kN/m^2 for D; 5.5, 6.3 and 6.5 kN/m^2 for E and 4.7, 5.0 and 55.5 kN/m^2 for F. The angle of shearing resistance recorded were; 5, 5 and 4^o for A; 5, 6 and 6^o for B; 4, 4 and 5 ^{o} for C; 5, 4 and 5 ^{o} for D; 4, 5 and 6 ^{o} for E and 4, 5 and 5^o for F respectively. These results revealed that Samples at Location D yielded the highest values of cohesion. This may be attributed to high fine percentage passing 0.075 mm BS Sieve as shown in Table 3.

Bearing capacity

The allowable bearing capacity values obtained from these locations at 1, 2 and 3m depth below the ground surface were 35.1, 46.6 and 58.0 kN/m^2 for samples A; 32.0, 51.3 and 66.0 kN/m^2 for B; 29.7, 36.0 and 48.1 kN/m^2 for C; 47.6, 53.5 and 70.8 kN/m^2 for D; 30.0, 55.7 and 70.1 kN/m^2 for E and 25.9, 39.1 and 50.9 kN/m^2 for samples F respectively. These results showed that the soil deposit at the study area up to the depth considered were predominantly fine grain sand with characteristic low bearing capacity values and high erodibity tendency.

For design of foundation, equation 6 and 7 is recommended as follows:

$$q_a = \frac{Q}{A} \quad (9)$$

where:

$$q_a = \frac{q_u}{f} \quad (10)$$

q_a = Allowable bearing capacity
q_u = Ultimate bearing capacity for square footing expressed in equation 8
f = Factor of safety (which is usually 3)
Q = Design impose foundation load and
A = Area of foundation footing

Conclusions

The allowable bearing capacities of the sample soils analyzed at various locations within the NACEST New Permanent Site recorded average values at 1m, 2m and 3m depth below the ground surface as: 33.4,40.5 and 60.7 kN/m^2 respectively. The average safe bearing pressures obtained at locations A, B, C and D were 46.6, 49.8, 38.0 and 57.3 kN/m^2 respectively, whereas 52.0 and 38.7 kN/m^2 were obtained from samples E and F. As at the time the samples were collected from the site, there was evidence of groundwater recorded within the depth studied at locations C, E and F. The bearing capacity results obtained have tremendously buttress the effect of depth on the bearing capacity of soil as the values increased with increasing depth. These results showed that the soils deposit at the study area up the depth investigated, were predominantly fine grain sand with characteristic low bearing capacity values and high erodibity tendency under the influence of runoff.

5.2 Recommendations

i. The average bearing capacity revealed from the investigations showed that the underlying sub surface) material has are homogenous and possesses a characteristic low bearing capacity values and high erodibity. Therefore a foundation depth not less than 2m is recommended.
ii. Average Safe Bearing Capacity not exceeding 60 kN/m^2 should be considered for design of foundation in all the locations within the Institution's New Permanent Site.
iii. For design of simple office complex, lecture halls, staff and students' residential quarters, pad footing restrained with ground beam should be applied in all the locations.

iv. The design foundation formula given below is recommended as follows:

$q_a = \frac{Q}{A}$

where:

$q_a = \frac{q_u}{f}$

q_a = Allowable bearing capacity

q_u = 1.3 cN_c + $\gamma D_j N_q$ + 0.4 $\gamma B N_\gamma$ (square foundation)

f = Factor of safety (which is usually 3)

Q = Design impose foundation load and

A = Area of foundation footing

Q = Design impose foundation load,

A = Area of foundation footing.

v. For complex and tall buildings within the New Permanent Site, raft or pile foundation type should be adopted to ensure a maximum stability of the foundation.

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