Study of Soil Bearing Capacity of Various Sites with Designs of Various Structural Foundations

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ABSTRACT

The study to determine the soil bearing capacity at Benue State Polytechnic Ugbokolo was carried out. Findings of the investigations revealed that the site is underlain by uniform soil materials based on the similarity of the profile and the plasticity properties with exceptions at locations C and E. The geotechnical properties established were a result of fine sand and predominant silt and clay content in the soil. The grading curves revealed high percentage of fine passing 0.075 mm BS standard sieve. The grain size ranged from 71.4 to 92.7 % passing 0.075 mm standard sieve with exception of samples from location 3 with grain size between 39.7 to 40.7 %. The liquid limits stand between 19.6 to 36.0 %, while the plasticity index (P1) falls between 11.3 to 20.2 % with exception of location C with average value of 4.0 %. The soils have exhibited moderate linear shrinkage recorded between 2.9 % to 10.7 %. Specific gravity obtained ranged between 2.19 to 2.74. The maximum dry density values obtained ranged from 1.90 to 2.14 g/cm^3, with optimum moisture contents ranging from 9.2 to 14.2 % respectively. The apparent cohesion of the soils ranged between 5.0 KN/m^2 and 31.3 KN/m^2 while angle of internal friction is between 2^0 and 5^0. The allowable bearing capacity at the depth of 1m falls between 28.1 KN/m^2 and108.9 KN/m^2 at location B, whereas at 2m depth, the values were 42.2 KN/m^2 at C and 99.5 KN/m^2 at location D. For design of simple office complex, lecture halls and residential quarters, pad foundation is recommended at minimum depth range between 1m to 1.5 m link with ground beam below the ground level. Whereas, for more complex and high raised buildings within the Polytechnic, raft to pile foundation type may be required as design permits.

Keywords: Soil, Bearing capacity, Shear strength, foundation, Load, Structure and Design.

INTRODUCTION

Structures are supported on foundations carried by soils. When soils shrink or expand, the foundations usually settle in a way as to put 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.

Andrew (2021) noted that the bearing capacity, also referred to as the ground bearing pressure is significant in geotechnical engineering as a measure of the ability of the ground to support any structural weight put on it. He also claimed that 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.

The determination of soil stability and mapping of predictive foundation statistics for different structural grades in the Polytechnic is a proactive approach to ensuring safe and optimal performance of structures to be developed in the future.

LITERATURE REVIEW

In geo-technical engineering, a soil or a soil deposit may be defined from a civil engineering point of view as un-cemented 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 it affects is the capacity of soil to support the loads applied to the ground (Andrew, 2021). That is, the maximum average contact pressure between the foundation and the soil such that no shear failure is caused (Popova et al., 2020).

Murthy (2010) defines foundation as an integral part of a structure which stability derives from the stability of the supporting soil. He further posited that two major factors that link structural stability with soil stability include: the foundation being stable against any shear failure of the soil and settlement of the foundation must not exceed the tolerance level of the super structure to avoid damage. Soft soil normally suffers large settlements under loads without actual shear failure because the allowable bearing capacity is based on the maximum allowable settlement (Coduto, et al., 2016).

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.

The shear strength parameters which include cohesion (c) and angle of internal friction () are obtained from Mohr circle (or envelope) plot of shear stress against normal stress. The mean soil bearing capacity by Terzaghi's method was adopted to determine the foundation type and depth for different structural predictions. According to Murthy (2010) and Venkatramaiah (2006), Terzaghi, in 1942 found that the ultimate bearing capacity of foundations is:

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

Shape factor was introduced to modify the bearing capacity factors for the square, circular and rectangular footings:

For Square foundation, $q_u = 1.3\, cN_c + \gamma D_j N_q + 0.4\, \gamma B N_\gamma$ (2)

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

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For Rectangular foundation;

$$q_u = cN_c(1 + 0.3\frac{B}{L}) + \gamma D_j N_q + \frac{1}{2}\gamma N_\gamma(1- 0.2\,\frac{B}{L})$$

Where:

c = unit cohesion, γ = effective unit weight (from specific gravity), B = width or diameter, L = length of footing, D = depth of footing whereas N_c, N_q and N_γ are reduced bearing factors for local shear failures (Murthy, 2010).

MATERIALS AND METHODS

Two samples each were collected at five (5) sites (at various locations) within the polytechnic premises; the sites were evenly spread. Pits were dug at the depth of 1m and 2m for the samples. Ten samples were collected across the Institution. The field-sampling apparatus used includes an auger drill, spades, cutlasses, measuring tape, scope, etc. Locations of the Samples were as follows: Sample A was besides the institution's second gate; Sample B was besides the abandoned old ICT block; Sample C was about 80m behind Engineering office complex; Sample D was collected besides Estate department/female hostel and sample E was collected about 60m behind the Polytechnic petrol station. These samples were transported to the laboratory for experimentations.

The tests were carried out in accordance to BS 1377: 1990 and are as follows: Natural moisture content, Specific gravity, Grain size distribution analysis and Atterberg limits. Also soil compaction and Triaxial compression test were performed on the samples Bowles (1978).

Terzaghi's bearing capacity equation was adopted. The shear strength parameters (cohesion and angle of internal friction) were obtained from Mohr circle (or envelope) plot of shear stresses. The mean soil bearing capacity by Terzaghi's method was adopted to determine the foundation type and depth. For the purpose of this work, square foundation was adopted as follows:

$$q_u = 1.3\,cN_c + \gamma D_j N_q + 0.4\,\gamma B N_\gamma \qquad (5)$$

Where;

q_u = ultimate load for unit length of footing, c = cohesion, γ = effective unit weight (from specific gravity), B = width or diameter, L = length of footing, D = depth of footing, N_C, Nq and N_γ are bearing capacity factors and dependent on the angle of internal friction, ϕ.

RESULTS AND DISCUSSIONS

The summary of the results is presented in Table 1, whereas the various results obtained are discussed under each of the tests carried out.

Table 1: Summary of Engineering Properties of the Soils

Sample Location	A		B		C		D		E	
Depth (m)	1	2	1	2	1	2	1	2	1	2
Natural moisture %	16.9	19.0	18.0	19.2	12.5	15.3	17.2	18.8	16.7	17.6

Specific gravity	2.74	2.74	2.79	2.57	2.45	2.41	2.64	2.58	2.19	2.55
Percentage fine	86.2	92.7	88.9	87.0	40.7	39.7	83.5	80.5	79.7	71.4
Liquid limit (%)	32.0	36.0	28.5	33.0	19.6	19.8	30.2	35.0	28.2	33.8
Plasticity index (%)	14.5	20.2	16.0	11.3	4.1	3.8	16.9	19.1	16.7	11.6
Linear shrinkage (%)	8.6	10.0	7.9	10.7	2.9	6.4	7.1	10.0	5.7	7.1
Dry density (k N/m^3)	1.90	1.91	1.93	1.90	2.14	2.01	1.95	1.95	2.00	1.95
OMC (%)	13.5	14.2	13.3	13.1	9.2	9.3	13.2	12.8	11.3	13.0
cohesion (k N/m^2)	31.3	20.6	29.8	23.8	5.0	8.4	19.2	23.9	19.2	19.2
(Degree)	4	3	5	3	3	2	5	5	4	3
Unit weight k N/m^3	18.4	16.6	17.7	17.7	20.9	20.9	19.2	17.5	17.5	20.4
Bearing capacity (k N/m^2)	108.6	71.6	108.9	88.8	28.1	42.2	87.2	99.5	62.2	85.1

Natural moisture content

The natural moisture content showed: 16.9, 18.0, 12.5, 17.2 and 16.7 % for locations A, B, C, D and E respectively at a depth of 1m below the ground level, and 19.0, 19.2, 15.3, 18.8 and 17.6 % for A, B, C, D and E respectively at a depth of 2m below the ground level as shown in Table 1. The average natural moisture content are 17.9 %, 18.6 %, 13.9 %, 18.0 %, and 17.1 % for locations A, B, C, D and E respectively. Location C has the lowest moisture value (13.9 %) which is about 29.5 % lower than Location D (18.0 %). This is an indication that location C has a high drainage property compare to locations A, B, D and E.

Specific gravity

The specific gravity results obtained are; 2.74, 2.79, 2.45, 2.64 and 2.19 for A, B, C, D and E at 1m depth, whereas 2.74, 2.57, 2.41, 2.58 and 2.55 were obtained for sample A, B, C, D and E at 2m as shown in Table 1. The average value of specific gravity for locations A, B, C, D and E were 2.74, 2.68, 2.43, 2.61 and 2.37 and ranged from 2.19 for sample in location C at 2m to 2.79 for sample in location A at 2m depth respectively as displayed in Table 1.

Particles size distribution

The percentage finer than sieve 0.075 mm (no. 2oo) was 86.2 %, 92.7 %, 88.9 %, 87.0 %, 40.7 %, 39.7 %, 83.5 %, 80.5 %, 79.7 % and 71.4 % for samples at locations A, B, C, D and E at 1m and 2m below the ground surface respectively as presented in Table 1. The grain size ranged from 39.7 – 92.7 % passing (no. 200) standard sieve. Samples from the location C recorded lowest fines (with grain size between 39.7 to 40.7 % and are predominantly sand with gravel. Maximum coarse sand size from most locations treated was below 0.24 % with exception of Location C whereas fine sand content ranged from 6.4 % in sample A to 11.5% in sample B, both at 2m depth. From the result obtained, the percentage finer than no. 200 standard sieve vary from 86.2 % – 92.7 % and 79.7 % – 71.4 % for locations A and B respectively with respect to depth. These percentage variations (7.5 % for location A samples and 11.6 % for location E samples) recorded higher than samples from other locations.

Liquid and plastic limits

The liquid limits (LL) are ranged from 19.6 % at location C to 36.0 at location A. The LL limit values are: 32.0, 36.0, 28.5, 33.0, 19.6 and 19.8 % for locations A, B and C while 30.2, 35.0, 28.2 and 33.8 % are obtained from locations D and E at 1 and 2 m depth respectively. The samples obtained from location C recorded the lowest LL value (19.6 and 19.8 %). This is an indication of low clay fine content compare to the samples from location A, B, D and E. The value of PI obtained from locations A, B, C, D and E at 1 m and 2 m depth are: 14.5, 20.2, 16.0, 11.3, 4.1, 3.8, 16.9, 19.1, 16.7, 11.6 %. The least value of PI (3.8 %) is obtained at location C. Linear shrinkage (LS) value of 8.6, 10.0, 7.9, 10.7, 2.9 and 6.4 % were obtained from locations A, B and C samples while 7.1, 10.0, 5.7 and 7.1 % are obtained from locations D and E at 1m and 2m depth respectively. Generally, all the samples have shown low to moderate values LL, PI and LS. However, the samples from location C exhibited the least values (19.6 – 19.8 %, 4.1 – 3.8 % and 2.9 – 6.4%) of liquid limit, Plastic limit and Linear shrinkage at 1 m and 2m depth respectively as shown in Table 1.

Compaction parameters

The moisture –density results obtained, recorded maximum dry density (MDD) as follows: 1.90, 1.91, 1.93, 1.90, 2.14 and 2.01 g/cm^3 from locations A, B and C while 1.95, 1.95, 2.00 and 1.95g/m^3 were obtained from locations D and E at 1m and 2m depth respectively while the corresponding optimum moisture contents (OMC) are: 13.5, 14.2, 13.3, 13.1, 9.2 and 9.3 % from locations A, B and C while 13.2, 12.8, 11.3 and 13.0 % from locations D and E respectively at 1m and 2m depth. From these results, the MDD of 2.14 g/m^3 is recorded for sample C which is highest value of MDD at 1m depth with OMC recorded as 9.2 %, which is the lowest value of OMC obtained.

Shear strength

The average cohesion recorded are 31.3, 20.6, 29.8, 23.8, 5.0 and 8.4 k N/m^2 obtained from location A, B and C and 19.2, 23.9, 19.2 and 19.2 from locations D and E at 1m and 2m depth. These results have shown that the samples at location C have the lowest value of 5.0 and 8.4 k N/m^2. This can be attributed to its high coarse content. The bulk unit weight of 18.4, 16.6, 17.7, 17.7, 20.9 and 20.9 k N/m^3 which is recorded from locations A, B and C and 19.2, 17.5, 17.5 and 20.4 k N/m^3 from locations D and E respectively at 1m and 2m depth while an angle of internal friction (φ) are obtained as 4^0, 3^0, 5^0, 3^0, 3^0, 2^0, 5^0, 5^0, 4^0 and 3^0 for locations A,B, C, D and E respectively at 1m and 2m below the ground surface, as shown in Table 1.

Bearing capacity

The allowable bearing pressures obtained from locations A, B and C are: 108.6, 71.6, 108.9, 88.8, 28.1 and 42.2 k N/m^2 and 87.2, 99.5, 62.2 and 85.1kN/m^2 from locations D and E respectively at 1m and 2m depth. At the depth of 1m below the ground surface, the values fall between 28.1 k N/m^2 at location C and 108.9 k N/m^2 at location B, whereas at 2m depth the values ranged from 42.2 k N/m^2 at location C to 99.5 k N/m^2 at location D as shown in Table 1. For simple office complex, lecture halls and residential quarters, pad foundation is recommended at minimum depth range between 1m to 1.5 m below the ground level. Whereas, for more complex buildings within the Polytechnic, raft to pile foundation type may be required as design permits.

For foundation design (equation 6) is recommended as follows

$$q_a = \frac{Q}{A} \qquad (6)$$

where:

q_a = 1.3 cN_c+ $\gamma D_j N_q$ + 0.4 $\gamma B N_\gamma$ (Allowable bearing capacity for square footing) as shown in equation (5).

Q = Design impose load and

A = Area of foundation footing

CONCLUSIONS

The allowable bearing capacities of the sample soils collected at various locations within the Polytechnic are as follows: locations A: 108.6 k N/m^2; B: 108.9 k N/m^2, C: 28.1 k N/m^2, D: 87.2 k N/m^2 and E; 62.2 k N/m 2. The soil samples were collected from excavated holes at the depth of 1 m below the existing ground surface. Whereas locations A: 71.6 k N/m^2; B: 88.8 k N/m^2, C: 42.2 k N/m^2, D: 99.5 k N/m^2 and E; 85.1 k N/m^2 respectively at a depth of 2m below the existing ground surface. The average safe (allowable) bearing pressures obtained at locations A and Dare 90.1 k N/m^2 and 98.9 k N/m^2 respectively, while that of locations C, D and E are 35.2 k N/m^2, 93.4 k N/m^2 and 73.7 k N/m^2 respectively. At the time the samples were explored, there was no evidence of groundwater within the depth studied. There fore the groundwater level is considered beyond 2m below ground surface at the various locations under consideration.

RECOMMENDATIONS

- The average bearing capacity (A: 90.1 k N/m^2; B: 98.9 k N/m^2; C: 35.2 k N/m^2, D: 93.4 k N/m^2 and E: 73.7 k N/m^2) obtained from locations A, B, C, D and E showed that the underlying material at the depth under consideration is not homogenous. The exceptions are sample from locations C and E with average bearing capacity of 35.2 k N/m^2 and 73.7 k N/m^2
- Average Safe Bearing Capacity not exceeding 100 k N/m^2 should be considered for design of foundation within the locations A, B and D. Whereas, allowable bearing pressures not exceeding 60 KN/m^2 should be considered for locations C and E.
- For design of simple office complex, lecture halls, staff and students' residential quarters, pad foundation is recommended at locations where the allowable bearing capacity does not exceed 100 KN/m^2 at minimum foundation depth of 1m to 1.5 m below the ground level. Whereas pad footing linked (restrained) with ground beam (chain foundation) should be adopted within locations where the safe bearing capacity does not exceed 60 kN/m^2. The foundation design formula given below is recommended as:
  $q_a = \frac{Q}{A}$
  where:
  $q_a = 1.3\, cN_c + \gamma D_j N_q + 0.4\, \gamma B N_\gamma$ (Allowable bearing capacity for square footing)
  Q = Design impose load and
  A = Area of foundation footing
- Should the case be a more complex and high raised buildings within the Polytechnic, raft to pile foundation type should be considered for use as design permits.
- Care must be taken during the design of the foundation footings, to ensure that the bearing capacities of the foundation soils are not exceeded.

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