Investigation of Bearing Capacity of Soils in Parts of Osogbo, Osun State, Southwestern Nigeria

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Abstract: *When designing foundation for a structure there is need to determine the bearing capacity of the underlying soil on which the foundations will be laid. This study therefore investigated the bearing capacity of soils in parts of Osogbo, Osun state, southwestern Nigeria, with with a view to adding to the existing body of knowledge on bearing capacity of soils in the study area.Disturbed soil samples were collected from twenty different construction sites within the study area. The samples were subjected to the following preliminary and geotechnical tests, using standard procedure: natural moisture content, particle size analysis, specific gravity, Atterberg's limits, compaction and unconsolidated undrain triaxial. The shear strength parameters, obtained from the triaxial tests, were then inputed into the Terzaghi's bearing capacity equations to compute the bearing capacity for strip, circular and square footings. Results showed that: 30 % of the soil samples are A-2-4, 25 % are A-2-7 while 45 % are A-2-6 using American Association of State Highway and Transportation Officials (AASHTO); the soils are c-ϕ soils; and square footings had the highest bearing capacity while strip footing had the lowest. The study concluded that the selected soils can be described as fair to good foundation materials.*

Keywords: bearing capacity, foundation, Osogbo, shape of footing, soil strength

INTRODUCTION

Prior to any engineering project, a site geotechnical investigation must be carried out. This becomes very necessary following frequent incidences of collapsed buildings especially in the southern and the Niger Delta areas of Nigeria. Previous soil characterisations in these areas have observed that the area is characterised by widespread and irregular distribution of weak soils whose strength is further reduced by the presence of expansive clays in most locations (Alabo *et al*, 1984).

A properly designed foundation transfers the load throughout the soil without overstressing the soil. Overstressing the soil can result in either excessive settlement or shear failure of the soils, both of which cause damage to the structure. Thus, geotechnical and structural engineers who design foundations must evaluate the bearing capacity of soils. According to Aghamelu *et al*. (2011), bearing capacity analytical procedures for foundation stability abound. However, most existing procedures require that series of field and laboratory tests be conducted in order to generate most components of the adopted equation(s). Often times, these set of tests are time consuming, uneconomical, complex and require state-of-the-art equipment which are not readily available in Nigeria. This predicament has resulted to situations that range from total omission of site characterisation prior to site construction to neglecting the bearing capacity analysis aspect of the site investigation (Aghamelu *et al*, 2002).

The bearing capacity for strip, circular and square footings on undrained clay is one of the common topics in geotechnical engineering for researchers and engineers (Adunoye and Agbede, 2013; Nwankwoala and Warmate, 2014; Adunoye and Agbede, 2014; Adunoye and Agbede, 2017).Researchers and engineers have continuously investigated the geotechnical properties, including the bearing capacity, of foundation soils various locations in Nigeria (Ola, 1988; Ige and Ogunsanwo, 2009; Alawode *et al*, 2020; Adunoye *et al*, 2023 and Adunoye *et al*, 2024). However, there is presently no documented work on the assessment of bearing capacity of the soils in the study area. This study therefore aims to addd to the existing knowledge on bearing capacity in the study area. The results will also serve as useful aid for geotechnical/foundation engineers and researchers working in the study area.

Study Area

The study area is Osogbo, the capital city of Osun state in southwestern Nigeria. The city has a land area of approximately 47 km^2 and a population of about 820,000 (NPC, 2006; Encyclopedia, 2016). Figure 1 is a map of the study area.

Figure 1: Map of the study area

MATERIALS AND METHODS

Materials and equipment
The main material used for this study is soil samples of which were collected from selected construction sites in the study area. Hand auger was used for sample collection.in addition, in addition, the apparatus and equipment used are those for conducting moisture content, particle size analysis, specific gravity, Atterberg limits and compaction tests. Triaxial machine was used for the determination of shear strength parameters.

Methods

Soil sampling
A total of 20 soil samples were collected from 20 identified construction sites in the study area, using disturbed sampling method. The depth of sample collection varied between 0.5m and 1m (Arora, 1988). The samples were collected with the aid of a hand auger, placed in polythene bags, well-sealed, labelled and immediately transported to the Geotechnical Engineering Laboratory (the Laboratory) of the Department of Civil Engineering, Obafemi Awolowo University (OAU), Ile-Ife, Nigeria. At the Laboratory, representative samples were taken for natural moisture content determination (using the oven method), after which the remaining soils were air-dried for subsequent laboratory tests and analyses.

Preliminary and geotechnical tests on soil samples
The following preliminary and geotechnical tests were conducted on the selected soil samples, using standard procedure as outlined in BS 1377 (1990): natural moisture content, particle size analysis, specific gravity, Atterberg limits, compaction, and shear tests.

Computation and analysis of bearing capacity of soil samples
The results of shear tests were used to determine the shear strength parameters (cohesion, c and angle of internal friction, ϕ) of the soils from the resultant Mohr circle diagram. The c and ϕ were subsequently input into the Terzaghi's (1943) bearing capacity equations (1) to (3) to determine the bearing capacity for circular, square and strip footings respectively. Unit width and unit depth were adopted for each footing geometry. The values of bearing capacity factors were obtained from Das (2015) using the corresponding values of c and ϕ obtained from the triaxial tests. The factor of safety used is 3.0 (Das, 2015).

$$Qu = 1.3c\text{Nc} + \gamma D\text{Nq} + 0.3\gamma B\text{N}\gamma \qquad (1)$$
$$Qu = 1.3c\text{Nc} + \gamma D\text{Nq} + 0.4\gamma B\text{N}\gamma \qquad (2)$$
$$Qu = c\text{Nc} + \gamma D\text{Nq} + 0.5\gamma B\text{N}\gamma \qquad (3)$$

Where,
Qu = ultimate bearing capacity (kN/m^2);
c = cohesion (kN/m^2);
γ = effective unit weight of soil (kN/m^3);

D = depth of footing (m);
B = width of footing (m);
Nc, Nq and Nγ are bearing capacity factors, which depend on the values of angle of internal friction ϕ.

RESULTS AND DISCUSSION

Description of sample locations
The Geographic Positioning System (GPS) description of sampling points is presented in Table 1.

Results of preliminary and geotechnical tests
The results of preliminary and geotechnical tests on soil samples are presented in Table 2.
Sample 12 had the highest natural moisture content (w) of 32.78 % while Sample 6 had the least natural moisture content of 1.39 %. Five samples, representing 25 % of the soil samples, had natural moisture content higher than 20 %; while the remaining 75 % had natural moisture content less than 20 %. Variations in values of natural moisture content can be attributed to climatic condition at the time of sample collection, and the topography of the sampling area.

Samples 3 had the highest specific gravity (Gs) of 3.5 while Sample 12 had the lowest specific gravity of 1.38. Also, 35 % of the soil samples had their specific gravity greater than 2.60 while 65% had their specific gravity less than 2.60. According to Das (2006), the specific gravity of clayey and silty soils may vary from 2.60 to 2.90; it can then be deduced that 35 % of the soil samples collected are silty-clay. The highest percentage of fine content was 2.40 (for Sample 4) while the lowest was 0.00 (for Samples 6, 17, and 18). That is, the three samples had no fine content

Sample 11 had the highest plasticity index of 56.71 % while sample 14 had the least value of 2.76 %. Classification of the soil samples, using the results of the index property tests and according to American Association of State Highway and Transportation Official (AASHTO) standard showed that 30 % of the samples belong to A-2-4 category; 25 % are A-2-7 while 45 % are A-2-6.

Sample 12 had the highest OMV value of 24.60 % while Sample 19 had the lowest value of 10.10 %. Also the highest MDD test was 2052 kg/m^3 (for Sample 6) while the lowest MDD was 1337 kg/m^3 (for Sample 20). 85 % of the soil samples had OMC within the range 10 % - 20 % while the remaining 15 % had OMC within the range 20% - 30%. Likewise, 80 % of the soil samples had MDD within the range 1300 kg/m^3 – 1700 kg/m^3 while 20 % of the samples had MDD within 1700 kg/m^3 – 2100 kg/m^3. According to Murthy (2002), the more the soil is compacted, the greater is the value of cohesion and the angle of shearing resistance and thus soils compacted with high moisture become saturated with a consequent loss of strength; that is, the greatest shear strength is attained at a moisture content lower than the OMC) for. Since most of the soil samples had lower moisture content before their MDD were obtained, it can be predicted that majority of the samples are likely to have high bearing capacity.

Table 1: Description of sampling points

Sample ID	Latitude	Longitude	Altitude above sea level (m)	Depth of excavation (m)
Sample 1	N7° 74' 8955.00''	E4° 51' 8672.00''	267	0.7
Sample 2	N7° 76' 3172.00''	E4° 53' 781.00''	245	0.6
Sample 3	N7° 78' 7245.00''	E4° 51' 115.00''	257	0.7
Sample 4	N7° 78' 522.00''	E4° 54' 1008.00''	264	0.8
Sample 5	N7° 78' 0172.00''	E4° 53' 7987.00''	261	0.7
Sample 6	N7° 79' 2615.00''	E4° 51' 2902.00''	270	0.9
Sample 7	N7° 79' 7439.00''	E4° 56' 6261.00''	274	0.8
Sample 8	N7° 80' 0332.00''	E4° 55' 1944.00''	270	0.8
Sample 9	N7° 79' 4923.00''	E4° 53' 944.00''	266	0.6
Sample 10	N7° 81' 2883.00''	E4° 58' 5677.00''	267	0.7
Sample 11	N7° 81' 2635.00''	E4° 58' 572.00''	282	1
Sample 12	N7° 46' 1741.1224''	E4° 33'7957.068''	293	0.8
Sample 13	N7° 44' 4151.076''	E4° 34'2934.984''	263	0.8
Sample 14	N7° 46' 4845.144''	E4° 34' 2413.2''	242	0.9
Sample 15	N7° 46' 1467.552''	E4° 32'5315.316''	245	1
Sample 16	N7° 79' 7434.00''	E4° 56' 6261.00''	265	1
Sample 17	N7° 47' 7682.28''	E4° 32' 3052.68''	263	1
Sample 18	N7° 47' 4.92504''	E4° 30'27.97956''	255	0.7
Sample 19	N7° 47' 4.97184''	E4° 30'27.93024''	250	0.7
Sample 20	N7° 47' 42.72072''	E4° 32' 7.3212''	292	0.8

Results of triaxial tests (values of c and ϕ presented in Table 2) showed that the soils are of clearly different shear strength parameters from one location to another. Sample 4 had the highest c of 170 kN/m^2 while Sample 12 had the lowest c of 1 kN/m^2. The highest value of ϕ was 50^0 (for Sample 12) while the lowest value was 3^0 (for Sample 7). According to Murthy (2002), the internal friction angle is within 26^0 and 48^0 for granular soils while angle of internal friction less than 26^0 is for fine soils. Therefore, 15 % of the soil samples are granular soils while the remaining 85 % are fine soils.

Bearing capacity values.
Table 3 presents the computed values of bearing capacity for strip, circular and square footings. Considering the circular footing, the highest bearing capacity was 2004.41 kN/m^2 (Sample 6), while Sample 9 had the lowest bearing capacity of 384.99 kN/m^2. In the case of strip footing, Sample 6 had the

highest bearing capacity of 2009.62 kN/m^2 while Sample 9 had the lowest bearing capacity of 395.73 kN/m^2. For square footing, Sample 6 had the highest bearing capacity of 1983.91 kN/m^2 and Sample 9 had the lowest bearing capacity of 367.32 kN/m^2. Results showed that higher c or ϕ does not necessarily imply a higher bearing capacity for the samples, for any of the footing shapes.

The shape of footing was found to be an important factor which governs the bearing capacity of the soils. The square footing was found to have the highest bearing capacity followed by circular footing, while strip footing had the lowest bearing capacity for all the soil samples, This could be attributed to the combined effects of different values of bearing capacity factors; that is, coefficients of terms for each case differ from one another.

Table 2: Results of preliminary and geotechnical tests

Sample ID	w (%)	Gs	Fines content (%)	PI (%)	AASHTO Classification	OMC (%)	MDD (Kg/m³)	c (kN/m²)	ϕ (°)
Sample 1	15.7	3	0.62	17.23	A-2-7	18.1	1646	43	**25**
Sample 2	9.03	2.89	0.44	20.62	A-2-6	10.7	1980	34	**8**
Sample 3	8.27	3.5	1.04	17.33	A-2-6	15.4	1976	27	25
Sample 4	8.15	2.88	2.4	19.99	A-2-6	10.35	1892	10	8
Sample 5	12.31	3.13	1.21	22.7	A-2-7	16.3	1835	35	25
Sample 6	1.39	2.86	0	16.03	A-2-6	10.7	2052	95	18
Sample 7	3.27	1.82	0.56	19.03	A-2-6	11.7	1789	53	3
Sample 8	3.15	2.56	0.41	9.9	A-2-4	11.5	2030	35	8
Sample 9	4.95	1.82	0.31	14.82	A-2-6	17	1829	6	23
Sample 10	2.07	2.33	0.69	50.3	A-2-7	17.6	1636	15	32
Sample 11	3.86	2.63	0.94	56.71	A-2-7	14.2	1632	19	33
Sample 12	32.78	1.38	0.2	11.59	A-2-7	24.6	1434	1	50
Sample 13	15.26	1.67	0.41	7.76	A-2-4	15.6	1711	80	11
Sample 14	22.76	1.81	0.21	2.76	A-2-4	24	1544	31	24
Sample 15	9.92	2.07	0.4	10.28	A-2-4	11.3	1839	88	14
Sample 16	16.64	1.91	0.21	13.83	A-2-6	15.6	1750	43	22
Sample 17	10.97	2.2	0	21	A-2-6	10.6	1855	40	9
Sample 18	21.71	2.15	0	7.35	A-2-4	20.01	1768	54	19
Sample 19	26.12	2.05	0.21	11.81	A-2-6	10.1	1800	30	25
Sample 20	26.92	1.79	0.2	9.49	A-2-4	18.7	1337	70	25

CONCLUSION

The bearing capacity of soils in parts of Osogbo town has been investigated. Laboratory tests and analyses showed that": 30 % of the tested soils belong to A-2-4 category, 25 % belong to A-2-7 category, and 45 % belong to A-2-6 category, according to AASHTO classification; 30 % of the soil are clayey sands, 15 % are well graded sand with clay, 20 % are poorly graded sand with clay, 5 % are well graded sand with silt, 5 % are clayey gravel, 5 % are well graded gravel with clay, 15 % are silty sands, and 5 % are poorly graded sand with silt; the soils are c-ϕ soils ; square footing had the highest bearing capacity 1nd strip footing had the lowest. The soils ranged between fair to good foundation materials, the bearing capacity of the soils is generally sufficient. Bearing capacity is greatly influenced by the nature and type of foundation soil and shape of footing.

Table 3: Bearing capacity values

Sample ID	Bearing Capacity (kN/m^2)		
	Circular footing	**Square footing**	**Strip footing**
Sample 1	1649.84	1663.27	1352.52
Sample 2	424.52	425.19	383.14
Sample 3	1176.30	1192.43	1004.99
Sample 4	1943.57	1944.22	1506.27
Sample 5	1416.50	1431.46	1182.56
Sample 6	2004.41	2009.62	1983.91
Sample 7	480.09	480.19	375.04
Sample 8	1666.82	1667.51	1294.10
Sample 9	384.99	395.73	367.32
Sample 10	1444.08	1487.07	1331.88
Sample 11	1851.38	1902.07	1678.64
Sample 12	571.95	609.75	634.35
Sample 13	1374.21	1375.37	1071.73
Sample 14	1145.76	1156.45	949.90
Sample 15	1464.68	1466.95	1149.52
Sample 16	1316.68	1325.39	1072.63
Sample 17	519.39	520.19	411.91
Sample 18	1294.66	1299.98	1037.03
Sample 19	1247.82	1262.50	1051.00
Sample 20	1987.22	1999.44	1866.32

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