INVESTIGATION OF SOILS AND BEARING CAPACITY IN SELECTED CONSTRUCTION SITES

Abstract

Considering the importance of soil and foundation in the construction of engineering structures, it is important to investigate the bearing capacity of engineering soils. This study therefore investigated the bearing capacity of soils in Ife-East Local Government Area, southwestern Nigeria.Soil samples were collected from selected construction site within the study area. Using standard procedure, preliminary and geotechnical tests such as natural moisture content, particle size analysis, specific gravity, Atterberg limits, compaction and triaxia; were conducted on the soil samples. The bearing capacity of the soil samples was computed for different footing types (circular. square and strip footings) using Terzaghi's bearing capacity equations. Results showed that all the soils fell into A-2-4 group, according to American Association of State Highway and Transportation Officials (AASHTO) classification standard. Also, using Unified Soil Classification System (USCS), it was observed that 75% of the samples were well-graded sand (SW) and 25% were poorly graded sand (SP). For square footing, the bearing capacity values ranged from 269.12KN/m^2 to 3340.85KN/m^2; for circular footings, the values ranged from 267.90KN/m^2 to 3313.47KN/m^2; and for strip footings, the values ranged from 221.58KN/m^2 to 2700.54KN/m$^{2.}$

It was concluded that all the tested samples were c-ϕ soils, and all the soils could be described as excellent to good foundation materials.

Keywords: Bearing capacity, Construction engineering, Engineering soil, Foundation, Structural stability

INTRODUCTION

The magnitude of loading that causes shear failure tooccur beneath a foundation is termed the bearing capacity of the soil. This capacity is governed by the fabric ofthe rock and soil beneath the foundation. Bearing capacity failure occurs as the soil supporting the foundationfails in shear, which may involve either a general, local or punching shear failure mechanism (Bowles, 1997).The bearing capacity of soil is an important consideration in construction projects. Dams, bridges abutmentand temporary support structures (false work) during construction are all examples of structures that can be supported by underlying soils (Jeffrey and Andrew, 2006).

The bearing capacity of soil is the maximum average contact pressure between the foundation and the soil which should not produce shear failure in the soil. For different failure mechanisms different methods of analysis are used. Estimation and prediction of theultimate bearing capacity of a foundation is one of the most significant and complicated problems ingeotechnical engineering. The soil must be capable of carrying the load from any engineering structure placed uponit without a shear failure and with the resulting settlement being tolerate for that structure (Bowles, 1997).

The study of engineering behaviour of different types of soils is extremely important to Civil Engineers becauseevery engineering structure such as a building, a road, a bridge, and monuments will have to be rested andfounded on foundations in such a manner that the structure does not get settled or tilted, or damaged due to somekinds of failure of the foundation. The strength of the soil to withstand loadsunder different site conditions,therefore, becomes an important factor in designing safe foundation for the structure (Ayininuola and Ayodeji, 2016).

Considering the importance of soil in construction engineering, it is paramount that knowledge of the soil and its properties (especially bearing capacity) be acquired so as to avoid failure of structures which could lead to loss of materials, money and sometimes even lives. This has necessitated investigation of bearing capacity of soils.

Studies have been conducted on the bearing capacity of soils in different locations (Adeyemi *et al*, 2014; Adunoye and Agbede, 2014). Waghmare and Patil (2012) investigated some soils and their bearing capacity at some different construction sites.They conducted the geotechnical investigation for the study and construction based on the foundation depth and using standard procedure. They also obtained the necessary input for design of foundations from the record of trial pits bore hole and testing of soils collected from different site locations and depths..

Alawode *et al* (2020) carried out the assessment of bearing capacity of soils in Ile-Ife town, Osun state, southwestern Nigeria.They found that 80 % of the tested soil samples belonged to A-2-7 class, according to American Association of State Highway and Transportation Officials (AASHTO) classification; while 70 % of the samples were well-graded sand (S. For strip footings, the bearing capacity values ranged from 83.15 kN/$m^2$to 2697.08 kN/m^2; for circular footings, the values ranged from 105.14 kN/$m^2$to 2791.83 kN/m^2; and for square footings, the values ranged from 105.20 kN/$m^2$to 2932.06 kN/m^2. They concluded that all the tested soils were c-ϕ soils, and could be described as excellent to good foundation materials. Similarly,

Muhammad *et al* (2022) investigated the bearing capacity of soil for for building and structural foundation design using the case study of Polo Area, Maiduguri, Nigeria. The authors investigated the soil in the study area using direct shear laboratory analysis on twenty representative soil samples across virgin area where future development is approaching. They adopted foundation widths of 0. 5 m, 1 m and 2 m. They found that the safe bearing capacity values for the soils ranges from 44.95 kN/m^2 to 411.11 kN/m^2 and 75.27 kN/m^2 to 397.31 kN/m^2 for 1 m and 1.5 m depths respectively. They concluded that the minimum footing size that could be used is 1800mm×1800mm using 400kN/m^2 safe bearing capacity.

Adunoye *et al* (2023) investigated the bearing capacity of soils in Ayedaade Local Government Area, Osun state, southwestern Nigeria. They observed that majority of the soils were well-graded and could also be classified as A-2-4. The soils were all c-ϕsoils. For each of the soil samples, square footing had the highest bearing capacity while strip footing had the lowest. It was also concluded that the tested soils are all excellent to good foundation materials

This study aimed at investigating the bearing capacity of selected soils at IFE East Local Government Area, Osub state, southwestern Nigeria, with a view to updating the body of knowledge on bearing capacity in slected locations. The s[ecific objectives of the study were to : (i) characterize selected soil samples; (ii) determine the shear strength parameters of selected soil samples; and (iii) compute and assess the ultimate bearing capacity of soil samples.

MATERIALS AND METHODS

Materials and equipment

The main materials used for this study were soil samples collected from selected construction sites within Ife East Local Government Area, Osun State, southwestern Nigeria. The equipment used for laboratory analyses were: moisture content apparatus, set of BS sieves (for sieve analysis), specific gravity apparatus, plastic limit apparatus, liquid limit apparatus, ccompaction apparatus and triaxial machine (for determination of shear strength parameters). Hand auger was used for sample collection.

Soil sampling and preparation

A total of 20 disturbed soil samples were collected fr0m 20 identified construction sites (One sample from each location) in the study area. The depth of sample collection varied between 0.5m and 1m (Alawode *et al*, 2020; Adunoye *et al*, 2023). About 25 kg of each sample was collected with the aid of a hand auger and placed in a polythene bag, wellsealed, and immediately taken to the Geotechnical Engineering 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), while the remaining soils were air-dried for subsequent laboratory tests/analyses.

Classification and engineering tests

Using standard procedure as outlined in BS 1377 (1990, the following classification and engineering tests were conducted on the soil samples: grain size analysis, specific gravity, Atterberg limits, compaction and triaxial.

Particle size characteristics were also determined from the particle size curves which were plotted from the grain size analysis, using equations (1) and (2). Plasticity index was also obtained using equation (3)

$$\text{Cu} = \frac{D_{60}}{D_{10}} \qquad (1)$$

$$Cc = \frac{D_{30}^2}{D_{10}\ x\ D_{60}} \qquad (2)$$

$$\text{PI} = \text{LL} - \text{PL} \qquad (3)$$

Where,

C_u=Coefficient of uniformity

C_c=Coefficient of gradation

D_{10}=diametercorrespondingto 10%finer

D_{30}=diametercorrespondingto 30%finer

D_{60}=diametercorrespondingto 60%finer

PI = plasticity index

LL=liquid limit;

PL=plastic limit

Computation of bearing capacity

The shear strength parameters (cohesion, *c* and angle of internal friction, ϕ) obtained from the triaxial tests were employed in Terzaghi’s (1943) bearing capacity equations (4) to (6), for circular footing, square footing and strip footing respectively, to compute the bearing capacity of the soil samples for different footing geometry – square footing, circular footing and strip footing, respectively. The values of bearing capacity factors were obtained from Das (2015) using the corresponding values of angle of internal friction (ϕ) obtained from the triaxial tests. According to Das (2015), the factor of safety should be at least 3 in all cases. Therefore, a factor of safety value of 3 was adopted. Unit width and unit depth were also adopted for each of the footings.

$Q_u = 1.3cN_c + \gamma DN_q + 0.3\gamma BN_\gamma$ (4)
$Q_u = 1.3cN_c + \gamma DN_q + 0.4\gamma BN_\gamma$ (5)
$Q_u = cN_c + \gamma DN_q + 0.5\gamma BN_\gamma$ (6)

Where,

Q_u = 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);
N_c, N_q and N_γ are bearing capacity factors, which depend on the values of angle of internalfriction ϕ.

RESULTS AND DISCUSSION

Description of Sample Locations

Figure 1 presents the locations of the sampling points, while the Geographic Position System (GPS) locations of the sampling points are presented in Table 1.

Figure 1: Locations of sampling points

Results of preliminary tests

The results of the preliminary and classification tests conducted on the soil samples are presented in Table 2.

Table1: GPS location of sample collection points

		Collection of Samples	
S/N	**Sample ID**	**Latitude**	**Longitude**
1	IELGA1	7°28'46.2"N	4°31'39.4"E
2	IELGA2	7°28'43.5"N	4°30'20.5"E
3	IELGA3	7°28'20.1"N	4°30'48.0"E
4	IELGA4	7°27'11.5"N	4°31'09.7"E
5	IELGA5	7°28'41.6"N	4°31'48.6"E
6	IELGA6	7°29'23.4"N	4°31'13.5"E
7	IELGA7	7°29'19.1"N	4°31'14.5"E
8	IELGA8	7°29'07.0"N	4°31'20.0"E
9	IELGA9	7°29'08.5"N	4°31'27.0"E
10	IELGA10	7°29'17.5"N	4°31'28.2"E
11	IELGA11	7°27'44.5"N	4°31'37.2"E
12	IELGA12	7°28'08.3"N	4°32'18.7"E
13	IELGA13	7°28'24.8"N	4°32'47.5"E
14	IELGA14	7°28'15.0"N	4°32'32.9"E
15	IELGA15	7°28'59.8"N	4°32'01.8"E
16	IELGA16	7°28'17.5"N	4°31'08.4"E
17	IELGA17	7°28'35.1"N	4°31'25.0"E
18	IELGA18	7°28'24.3"N	4°31'23.3"E
19	IELGA19	7°28'47.9"N	4°32'49.5"E
20	IELGA20	7°28'54.0"N	4°31'04.9"E

Sample IELGA19 had the highest natural moisture content of16.64 % while Sample IELGA2 had the lowest natural moisture content of4.04 %. 50% of the soil samples had their moisture content values higher than 10 % and the remaining 50 % had their moisture content values lower than 10 %.
Sample IELGA5 had the highest specific gravity of 2.87 while Sample IELGA19 had the lowest specific gravity of 2.50. According to Bowles (1996), the specific gravity of clayey and silty soils may vary from 2.6 to 2.9 while organic soil ranges from 1.0 - 2.60. It is clear from Table 2 that, only 25 % of the soil samples had their specific gravity lower than 2.60 while the rest had theirs greater than or equal to 2.60. It can therefore be deduced that majority of the soil samples collected are silty-clayey soils in nature.
Results of grain size analysis (Table 2) showed that sample IELGA11 had the highest fines content (0.95 %) and sample IELGA2 had the lowest value of fines content (0.19 %). Also, sample IELGA6 had the highest coefficient of uniformity value of 25.768 while sample IELGA10 had the least coefficient of uniformity value of 0.992. Sample IELGA8 had the highest coefficient of curvature (1.785) while the lowest coefficient of curvature was 0.20(for sample IELGA10). According to Jumikis (1962), on the average,a soil is sandy if C_u is between 10 and 20; silty, if C_u is between 2 and 4 and clayey if C_u is between 10 and 100. It could therefore be concluded that 90% of the soil samples are silty-sandy in nature.
The highest value of liquid limit that was obtained was 26 %, for sample IELGA7 while the least value was 14 %, for sample IELGA5. Also, the plastic limit had a maximum value of 37% (for sample IELGA19) and the minimum of 19 % (for sample IELGA9). The mean liquid limit and plastic limitfor the soil samples were 20.35 % and 29.00 %respectively. According to Whitlow (1995), a soil having liquid limit less

than 35% has low plasticity, between 35% and 50% has intermediate plasticity, while 50% - 70% liquid limit indicates high plasticity and 70% - 90% shows very high plasticity in a soil. The tested soil samples could therefore be described as having low plasticity.

Table 2: Results of preliminary tests

Sample ID	Natural moisture content, w (%)	Specific gravity, Gs	Fines Content (%)	D10	D30	D60	Cu	Cc	LL (%)	PL (%)	PI (%)
IELGA 1	8.59	2.51	0.24	0.276	0.784	3.672	13.3	0.606	23	23	0
IELGA 2	4.04	2.73	0.19	0.357	0.673	2.281	6.389	0.556	20	36	-16
IELGA 3	5.32	2.69	0.33	0.352	0.458	1.851	5.259	0.322	23	23	0
IELGA 4	11.02	2.69	0.43	0.175	0.658	4.452	25.44	0.556	19	33	-14
IELGA 5	4.31	2.87	0.68	0.278	0.572	0.875	3.147	1.345	14	33	-19
IELGA 6	6.39	2.6	0.51	0.125	0.731	3.221	25.77	1.327	16	34	-18
IELGA 7	9.57	2.54	0.45	0.117	0.137	0.693	5.923	0.231	26	25	1
IELGA 8	14.52	2.68	0.56	0.115	0.413	0.831	7.226	1.785	21	23	-2
IELGA 9	13.54	2.52	0.57	0.196	0.473	0.968	4.939	1.179	19	19	0
IELGA 10	12.42	2.67	0.59	0.983	0.438	0.975	0.992	0.2	17	35	-18
IELGA 11	9.29	2.63	0.95	0.483	0.974	4.385	9.079	0.448	17	23	-6
IELGA 12	4.8	2.8	0.57	0.372	0.869	3.279	8.815	0.619	17	28	-11
IELGA 13	10.37	2.69	0.31	0.391	0.862	3.194	8.169	0.595	19	24	-5
IELGA 14	14.35	2.69	0.61	0.365	0.816	3.793	10.39	0.481	20	34	-14
IELGA 15	5.74	2.56	0.77	0.328	0.794	3.274	9.982	0.587	22	25	-3
IELGA 16	9.1	2.74	0.65	0.384	0.916	4.19	10.91	0.521	25	36	-11
IELGA 17	14.19	2.77	0.5	0.279	0.728	3.281	11.76	0.579	22	25	-3
IELGA 18	13.02	2.64	0.63	0.283	0.842	3.632	12.83	0.69	23	33	-10
IELGA	16.64	2.5	0.66	0.22	0.73	3.49	15.3	0.68	19	37	-18

19				8	9	1	1	6			
IELGA 20	14.44	2.7	0.86	0.59 3	0.98 3	3.74 1	6.30 9	0.43 6	25	31	-6

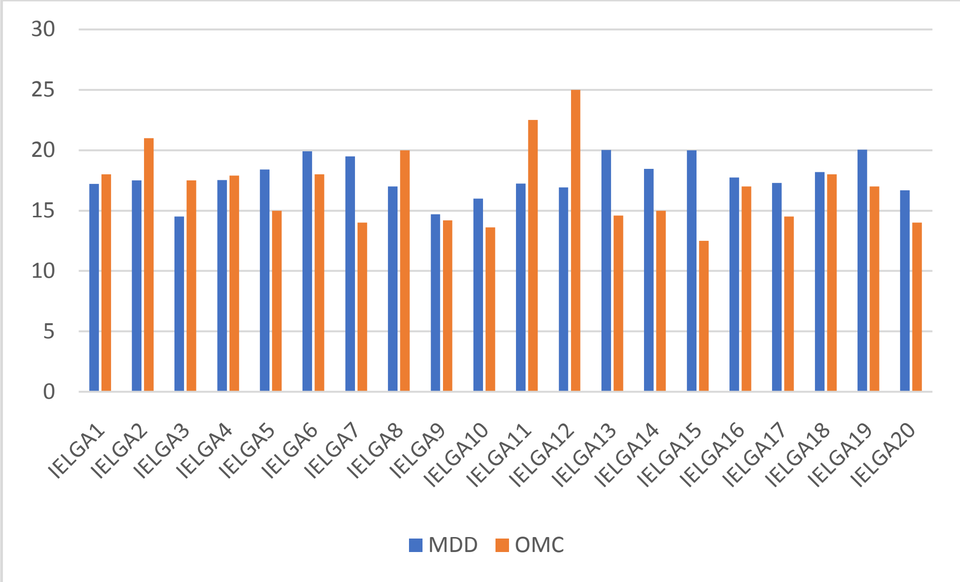
Soil classification, using the obtained index properties and adopting the American Association of State Highway and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS) standards is presented in Table 3. AASHTO classification showed that all the soil samples were A-2-4. In the same vein, USCS classification showed that 75% of the soil sample were well graded sand, fine to coarse (SW) while 25% were poorly graded sand (SP). The soils could therefore be regarded as excellent to good foundation materials (Das, 2015).

Results of compaction tests

The variation of the maximum dry density (MDD) and optimum moisture content (OMC) is shown in Figure 2. The highest OMC of the soils tested was 25.0 % (for sample IELGA12) while the lowest OMC was 12.5% (for sample IELGA15); and the highest and lowest MDD values of 2005 kg/m^3(forsample IELGA19) and 1450 kg/m^3(for sample IELGA3, respectively.

Table 3: Soil classification

Sample ID	AASHTO	USCS
IELGA1	A-2-4	SW
IELGA2	A-2-4	SW
IELGA3	A-2-4	SP
IELGA4	A-2-4	SW
IELGA5	A-2-4	SP
IELGA6	A-2-4	SW
IELGA7	A-2-4	SP
IELGA8	A-2-4	SW
IELGA9	A-2-4	SP
IELGA10	A-2-4	SP
IELGA11	A-2-4	SW
IELGA12	A-2-4	SW
IELGA13	A-2-4	SW
IELGA14	A-2-4	SW
IELGA15	A-2-4	SW
IELGA16	A-2-4	SW
IELGA17	A-2-4	SW
IELGA18	A-2-4	SW
IELGA19	A-2-4	SW
IELGA20	A-2-4	SW



Figre 2: Variation of MDD and OMC

90 % of the soil samples had OMC within the range 10% - 20% while the remaining 10% had OMC within 20% -30%. Only 15 % of the soil samples had MDD within the range 1000kg/m^3 – 1600 kg/m^3 while 85 % of the samples had MDD within 1600kg/m^3 – 2000 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 optimum moisture content for maximum dry density. It could therefore be predicted that majority of the soils would have high bearing capacity values, considering the fact that most of the samples had low moisture content before attaining their MDD..

Results of triaxial tests

The values of the shear strength parameters (c and ϕ) obtained from unconsolidated undrained triaxial tests, and computed bearing capacity (for different footing geometry) are presented in Table 4. The soils are of different shear strength parameters from one location to another. Sample IELGA7 had the highest cohesion (78 kN/m^2) while sample IELGA13 had the lowest cohesion of 11 kN/m^2. The highest internal friction angle was 33^o(for sample IELGA13) while the lowest internal friction anglewas 11^o(for samples IELGA11). According to Murthy (2002), the internal friction angle is within 26^o and 48^o for granular soils while internal friction angle less than 26^o is for fine soils. Therefore, 25% of the soil samples, with internal friction angle ranging between 26^o and 48^o, could be classified as granular soils; while the remaining 75% could in turn be classified as fine soils.

Bearing capacity values

The computed values of bearing capacity (for circular, square and strip footings) and the adopted bearing capacity factors are presented in Table 4. Results showed that higher values of ϕ imply higher bearing capacity for the samples for all the footing types. It was observed that the shape of footing was 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, the coefficient of each term for each case differs from one another. Considering the square footing, the highest bearing capacity was 3340.85kN/m^2(for soil sample IELGA12), while soil sample IELGA16) had the lowest bearing capacity of 269.12kN/m^2. In the case ofcircular footings, sample IELGA12 also had the highest bearing capacity of 3313.47kN/m^2 while sample IELGA16 had the least value (267.90kN/m^2).For strip footing, sample IELGA12 had 2700.54kN/m^2 as the highest bearing capacity while sample IELGA16 had 221.58kN/m^2 as the lowest bearing capacity.

CONCLUSION

Bearing capacity of soils in Ife East Local Government, Osun state, Nigeria have been investigated. In line with the set objectives, the following conclusions are made: all the soils are of A-2-4 class, majority are well graded sand (SW); the soils are all c-ϕ in nature; for each of the locations, square footing has the highest value of bearing capacity while strip footing has the lowest value, which confirms the fact that the values of bearing capacity are influenced by the nature of foundation soil and shape. and circular footing was found to have intermediate magnitude in all cases.

Table 4: Results of triaxial test and bearing capacity computation

	Bearing Capacity (kN/m^2)

Sample ID	Cohesion, c (kN/m^2)	Internal friction angle, ϕ (^{o})	N_c	N_q	N_γ	Γ	Square footing	circular footing	Strip footing
IELGA 1	39	15	12.86	4.45	1.52	17.2	739.00	736.39	591.15
IELGA 2	21	29	34.24	19.98	16.18	17.49	1397.40	1369.10	1209.98
IELGA 3	47	23	21.75	10.23	6	14.5	1512.06	1503.36	1214.09
IELGA 4	29	12	10.76	3.29	0.85	17.52	469.25	467.76	377.13
IELGA 5	32	18	15.12	6.04	2.59	18.4	759.19	754.42	618.80
IELGA 6	39	20	17.69	7.44	3.64	19.9	1073.91	1066.67	874.18
IELGA 7	78	19	16.56	6.7	3.07	19.5	1833.78	1827.79	1452.26
IELGA 8	55	21	18.92	8.26	4.31	17	1522.51	1515.18	1217.66
IELGA 9	23	29	34.24	19.98	16.18	14.7	1412.62	1388.84	1200.15
IELGA 10	25	31	40.41	25.28	22.65	15.98	1862.08	1825.88	1595.20
IELGA 11	34	13	11.41	3.63	1.04	17.24	574.08	572.28	459.49
IELGA 12	65	29	34.24	19.98	16.18	16.92	3340.85	3313.47	2700.54
IELGA 13	11	33	48.09	32.23	31.94	20.02	1588.71	1524.76	1493.95
IELGA 14	47	21	18.92	8.26	4.31	18.45	1340.22	1332.26	1081.40
IELGA 15	24	22	20.27	9.19	5.09	20	856.94	846.76	721.18
IELGA 16	16	11	10.16	2.98	0.69	17.75	269.12	267.90	221.58
IELGA 17	35	18	15.12	6.04	2.59	17.3	810.37	805.89	656.10
IELGA 18	48	17	14.6	5.45	2.18	18.2	1026.10	1022.13	819.83
IELGA 19	43	18	15.12	6.04	2.59	20.05	987.08	981.89	797.23
IELGA 20	21	16	17.69	7.44	3.64	16.68	631.32	625.25	525.95

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