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Experimental Investigation on the Bearing Capacity of Selected Soils in Ayedaade Local Government Area, Osun State, Nigeria

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ABSTRACT: *As a result of the importance of foundation in engineering construction, it is important to investigate the bearing capacity of construction soils, this study therefore investigated the bearing capacity of soils in Ayedaade Local Government Area, southwest Nigeria. To achieve the aim of this study, soil samples were collected from selected 20 construction sites in the study area. Using standard procedures, preliminary and geotechnical tests such as natural moisture content, particle size analysis, specific gravity, Atterberg limits, compaction and triaxial tests were conducted on the soil samples. Subsequently, Terzaghi's bearing capacity equations were employed, alongside already determined shear strength parameters, to estimate the bearing capacity of different footing geometry (circular, square and strip footing). Results showed that majority of the soil samples are well-graded and could also be classified as A-2-4. Results of triaxial tests also showed that the soils are all c-ϕ soils. 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.*

KEYWORDS: Bearing capacity, building, construction, foundation, structure

INTRODUCTION

In construction engineering, soil has the highest usage; either as a construction material or as a support system. Every engineering structure such as a building, a road, a bridge etc. will have to be rested and founded on foundations in such a manner that the structure does not get settled or tilted, or damaged due to some kinds of failure of the foundation (Adeyemi, *et al*., 2014). The function of a foundation is to transfer the load of the structure to the soil on which it is resting. A properly designed foundation transfers the load to the soil without overstressing it. Overstressing can result in either excessive settlement or shear failure of the soil, both of which cause damage to the structure (Das, 2010). Therefore, the soil must be capable of carrying the load from any engineering structure placed upon it without a shear failure and with the resulting settlement being tolerate for that structure (Bowles, 1997).

Thus, geotechnical and structural engineers who design foundations must evaluate the bearing capacity of soils. The engineering characteristics of a soil should be known before determining its suitability for a project and not just properties gotten via visual inspection. It is therefore paramount that knowledge of the soil and its properties be acquired so as to avoid failure of structures, which could lead to loss of materials, money and sometimes even lives. Investigations should be carried out in order to predict the behaviour and performance of soil as a construction material or as a support for engineered works.

Adunoye and Agbede (2013) modelled the relationship between bearing capacity and fines content of soil using square footing and non-linear regression. The results of the study showed that the bearing capacity of soil samples generally reduced with increase in fines content. The developed model was also found to be valid and revealed that a non-linear relationship exists between the bearing capacity of square footing and fines content of the studied soils.

Atat *et al* (2013) studied the allowable bearing capacity for shallow foundation in Eket Local Government Area, Akwa Ibom State, Southern Nigeria. The results of their study showed that allowable bearing capacity increased with increase in shear modulus, shear wave velocity and depth. Adunoye and Agbede (2014) also studied the specific contributions of cohesion and angle of internal friction to bearing capacity of soil, making use of Terzaghi's bearing capacity equations and multiple linear regression statistical analysis tool. The study revealed a low level of variance between experimental values and model values of bearing capacity.

Owoyemi and Awojobi (2016) assessed the index properties and bearing capacity of soils for infrastructure foundations in Malete, Northcentral Nigeria. Using standard procedures, they determined the geotechnical properties and bearing capacity of selected soil samples. They found that the geotechnical properties determined varied significantly with depth except for specific gravity. Also, penetration resistance obtained from cone penetration test ranged from 700 kN/m^2 to 950 kN/m^2. The average safe bearing capacity estimated for strip footing at depth of 1 m was not less than 473 kN/m^2 anywhere in the study area. They concluded that the highest bearing capacities were associated with the lateritised basement top, which implies that the safest depth to place infrastructure foundations in the area is the depth where lateritised basement rock is encountered. Adunoye and Agbede (2017) also studied the relationship between bearing capacity of circular footing and fines content of selected lateritic soils, using regression analysis. They concluded that the developed relationship (model) was found to be valid for the selected locations.Ogunbiyi *et al.* (2017) carried out an assessment of the load-bearing capacity of soils in some selected areas of Osogbo, Osun state, Nigeria. They employed standard penetrometer tests on soils at the selected locations and at depths ranging between 0.5 m and 1.9 m. They found that

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the bearing capacity ranged between 137.42 kN/m^2 and 340.5 kN/m^2; and concluded that structures can be built on the selected locations since the soils possess adequate strength to support structural load, thereby providing additional support for any selected foundation.

Using standard procedures and Terzaghi's bearing capacity equations, Alawode *et al.* (2020) undertook an assessment of bearing capacity of soils in Ile-Ife, southwestern Nigeria. They found that: 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 samples were c-ϕ soils, and they could be described as excellent to good foundation materials.There has not been any documented study on the bearing capacity in the study area. Therefore, this study investigated the bearing capacity of soils from selected locations in Ayedaade Local Government Area, Osun southwestern Nigeria. The objectives of the study were to: characterise soil samples collected from selected construction sites; determine the shear strength parameters of selected soil samples; and compute and analyze the bearing capacity of the soil samples.

Description of Study Area

The study area is Ayedaade Local Government Area (LGA). Ayedaade LGA is located in the western part of Osun State, southwest Nigeria, and has a population of 150,392 (Federal Government of Nigeria, 2007; Oladele *et al.*, 2011). It is bounded by Isokan, Irewole and Aiyedire local governments to the east and Ife North local government to the west (Figure 1). The people belong to the Yoruba speaking tribe and the major communities are Gbongan, Odeomu, Akiriboto, Wakajaiye, Orile Owu and Ogbaaga.

Figure 1: Mao of local government areas in Osun state, Nigeria (Orisadare, 2019)

MATERIALS AND METHODS

Materials and Equipment

The main materials used for this study were soil samples collected from selected construction sites in Ayedaade LGA of Osun State. The equipment and apparatus used for the study included: hand auger, core cutter, set of British Standard (BS) sieves, moisture cans and tray, weighing balance, drying oven, Cassangrande apparatus, Pycnometer, compaction apparatus, triaxial machine.

Methods

Soil sampling and preparation

Three major towns in the study area were randomly selected for sample collection. Soil samples were collected from 20 identified construction sites across the three major towns. Four samples were collected from Akiriboto, four were collected from Odeomu, while 12 samples were collected from Gbongan, which is the largest town in the study area. The method of sampling adopted was disturbed sampling and the depth of sampling is between 0.5 and 1.0 m. About 25 kg of soil samples were collected from each location with the aid of an hand auger, kept in polythene bags, properly sealed, labelled and transported to the geotechnical laboratory of the Department of Civil Engineering, Obafemi Awolowo University (OAU), Ile-Ife. At the laboratory, representative samples were taken for the determination of natural moisture content. Thereafter, the remaining quantities were spread and air-dried in preparation for subsequent laboratory analysis.

Preliminary and geotechnical analyses of soil samples

The following preliminary and geotechnical tests were conducted on the soil samples, using standard procedures as contained in BS 1377 (1990): grain size analysis, specific gravity test, Atterberg's limit tests compaction test and unconsolidated undrained triaxial test. From the grain size analysis and the resulting particle size distribution curves, coefficient of uniformity (C_u) and coefficient of gradation (C_c) were also determined as follows:

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

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

Where,

D_{10} = diameter corresponding to 10 % finer
D_{30} = diameter corresponding to 30 % finer
D_{60} = diameter corresponding to 60 % finer

Also, from the determined Atterberg limits, Plasticity Index (PI) was determined thus:

$$PI = LL - PL \quad (3)$$

Where:
LL = Liquid limit; PL = Plastic limit

Estimation of bearing capacity
After determining the shear strength parameters from the triaxial test, Terzaghi's bearing capacity equations (equations 4 – 6) were employed in estimating the bearing capacity of the soils, taking into consideration different footing geometry (strip footing, square footing and circular footing) and assuming typical footing of unit depth and unit width, with a factor of a factor of safety of 3. Equations (4) to (6) are the bearing capacity equations for circular footing, square footing and strip footing, respectively. The values of corresponding bearing capacity factors were obtained from Das (2006).

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

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 internal friction ϕ.

RESULTS AND DISCUSSION

Description of sample locations
The Global Positioning System (GPS) description and depth of excavation of each sampling point is presented in Table 1.

Table 1: Description of sampling locations

Sample ID	Latitude	Longitude	Depth of sampling (m)
Sample 1	N70 29’ 14.2”	E40 20’ 43.3”	0.7
Sample 2	N70 29’ 12.0”	E40 20’ 48.9”	0.8
Sample 3	N70 29’ 25.5”	E40 21’ 11.0”	0.7
Sample 4	N70 28’ 40.9”	E40 20’ 26.4”	0.7
Sample 5	N70 28’ 40.2”	E40 20’ 27.7”	1
Sample 6	N70 28’ 29.1”	E40 20’ 33.8”	0.5
Sample 7	N70 27’ 56.6”	E40 19’ 24.2”	0.7
Sample 8	N70 28’ 02.3”	E40 19’ 24.7”	0.6
Sample 9	N70 28’ 37.9”	E40 20’ 07.8”	0.8
Sample 10	N70 29’ 09.6”	E40 20’ 33.8”	0.7
Sample 11	N70 31’ 01.2”	E40 22’ 45.7”	0.7
Sample 12	N70 31’ 07.1”	E40 22’ 53.2”	0.6
Sample 13	N70 29’ 35.8”	E40 21’ 41.1”	0.6
Sample 14	N70 28’ 56.9”	E40 21’ 20.0”	0.7
Sample 15	N70 28’ 31.3”	E40 22’ 24.6”	0.8
Sample 16	N70 28’ 23.2”	E40 21’ 58.7”	0.9
Sample 17	N70 28’ 19.0”	E40 21’ 55.1”	1.0
Sample 18	N70 28’ 11.1”	E40 21’ 02.7”	0.6
Sample 19	N70 27’ 57.0”	E40 21’ 12.5”	0.7
Sample 20	N70 27’ 51.4”	E40 21’ 11.2”	0.8

Results of preliminary and index properties tests

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

Sample 8 had the highest natural moisture content (w) of 27.23 %, while Sample 17 had the lowest natural moisture content of 9.31 % (see Table 2). Four samples, representing 20 % of the total soil samples, had natural moisture content higher than 20 %, while the remaining 80 % had moisture content values lower than 20%. Thirteen of the soil samples, representing 65 % of the total samples, had natural moisture content values ranging between 9 % and 15 %. Generally speaking, this shows relatively low natural moisture content. The result could be attributed to the fact that the samples were collected much after rainfall.

Sample 1 had the highest specific gravity (G_s) of 2.93, while Sample 4 had the lowest specific gravity of 2.38 (see Table 2). Also, 60 % of the soil samples had their specific gravity higher than 2.60, while the rest had specific gravity values less than 2.60. According to Bowles (2012), the specific gravity of clayey and silty soils may vary from 2.60 to 2.90; while for organic soils the value ranges from 1.00 to 2.60. It can therefore be concluded that majority of the tested soil samples are silty-clayey in nature.

The highest percentage of fines content was 2.78 % for Sample 15 (see Table 2), while the lowest value was 0.03 %, for Sample 18. The average percentage fines for the soil samples is 0.567%. Sample 5 had the highest coefficient of uniformity (C_u) of 16.72, while Sample 20 had the least coefficient of uniformity of 3.96. Sample 3 had the highest coefficient of curvature (C_c) of 1.86, while the lowest coefficient of curvature was 0.36 (Sample 2). For Sample 14, both C_u and C_c are indeterminate. This is as a result of the fact that less than 60 % of the soil particles passed sieve number 4, thus making D_{60} indeterminate. According to Jumikis (1962), on the average the 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 can therefore be deduced that only 1 sample (Sample 20), which accounts for just 5 % of the total soil samples, is silty; while the remaining 95 % of the samples could be categorized as silty-sandy soils.

Table 2: Results of p**reliminary and index properties** tests

Sample ID	w (%)	G_s	Fines content (%)	C_u	C_c	LL (%)	PL (%)	PI (%)
Sample 1	11.14	2.93	0.08	5.38	0.52	61.2	41.43	19.77
Sample 2	15.29	2.9	0.5	9.88	0.36	45	34.05	10.95
Sample 3	9.5	2.75	0.44	5.2	1.86	56.6	30.41	26.19
Sample 4	13.94	2.38	0.28	8.2	1.76	33.1	21.46	11.64
Sample 5	19.89	2.67	0.14	16.72	0.68	51.8	36.55	15.25
Sample 6	9.57	2.58	0.22	5.13	1.04	46.7	19.46	27.24
Sample 7	25.98	2.52	0.66	7.55	1.34	67.4	45.12	22.28
Sample 8	27.23	2.7	0.1	5.74	0.74	67	46.43	20.57
Sample 9	20.01	2.5	0.49	6.92	1.2	50.8	23.91	26.89
Sample 10	10.98	2.79	0.11	8.33	1.49	45.56	24.06	21.5
Sample 11	10.24	2.66	0.28	16	1.03	41.83	21.06	20.77
Sample 12	18.2	2.67	0.37	8.33	1.33	37	28.57	8.43
Sample 13	9.78	2.48	0.46	6.44	0.58	36.8	22.3	14.5
Sample 14	9.62	2.71	1.83	-	-	60.61	36.67	23.94
Sample 15	20.03	2.39	2.78	7.64	0.64	48.6	33.27	15.33
Sample 16	9.34	2.75	0.2	12.14	0.85	45.7	25.36	20.34
Sample 17	9.31	2.79	0.18	9.49	0.69	61.7	47.8	13.9
Sample 18	11.52	2.42	0.03	4.07	0.84	39.2	16.4	22.8
Sample 19	18.72	2.45	2.1	10	0.59	57	42.59	14.42
Sample 20	11.46	2.74	0.09	3.96	0.8	43.1	20.09	23.01

The highest value of liquid limit (LL) was 67.4 % (Sample 7), and the least was 33.10 % (Sample 4). Also, the maximum plastic limit (PL) values was 47.80 % (Sample 17) and the minimum value was 16.4 % (Sample 18). In addition, 27.24 % (for Sample 6) was the highest plasticity index (PI), while the lowest PI was 8.43 % (Sample 12). The average values for LL, PL and PI were 49.84 %, 30.85 % and 18.98 %, respectively. According to Whitlow (1995), a soil having LL value less than 35 % has low plasticity; 35 % and 50 % has intermediate plasticity; while 50 %

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- 70 % LL indicates high plasticity and 70 % - 90 % indicates very high plasticity in a soil. On this basis, 5 % of the tested soil samples has low plasticity; 50 % has intermediate plasticity and 45 % has high plasticity.

The soil classification using the results of the index properties according to American Association of State Highway and Transport Officials (AASHTO) and Unified Soil Classification System (USCS) are presented in Table 3. From AASHTO classification, it can be deduced that 15 % of the soil samples are A-2-6, 5 % are A-2-4, while the remaining 80 % are A-2-7. In the same vein, using USCS classification, 65 % of the soil sample are well-graded sand, fine to coarse (SW); while 35 % are poorly graded sand (SP). The soils can therefore be regarded as excellent to good foundation materials (Das, 2010).

Results of compaction tests

Variation of the maximum dry density (MDD) and optimum moisture content (OMC), obtained from compaction tests, shown in Figure 1. The highest OMC of the soils tested was 25.00 % (Sample 1), while the lowest OMC was 12.50 % (Sample 12). 80 % of the soil samples had OMC within the range 10 % - 20 %, while the remaining 20 % had OMC within 20 % - 30 %.

Also, the highest MDD obtained was 1992 kg/m^3 (for Sample 18), while the lowest was 1415 kg/m^3 (for sample 8). Only 20 % of the soil samples had MDD within the range 1000 – 1600 kg/m^3, while 80 % of the soil samples had MDD within 1600 – 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 (OMC). Therefore, since majority of the tested soil samples had lower moisture content before their MDD were obtained, it could be said that majority of the soil samples are likely going to have high bearing capacity values .

Table 3: Soil classification

Sample ID	AASHTO	USCS
Sample 1	A-2-7	SP
Sample 2	A-2-7	SW
Sample 3	A-2-7	SP
Sample 4	A-2-6	SW
Sample 5	A-2-7	SW
Sample 6	A-2-7	SP
Sample 7	A-2-7	SW
Sample 8	A-2-7	SP
Sample 9	A-2-7	SW
Sample 10	A-2-7	SW
Sample 11	A-2-7	SW
Sample 12	A-2-4	SW
Sample 13	A-2-6	SW
Sample 14	A-2-7	SP
Sample 15	A-2-7	SW
Sample 16	A-2-7	SW
Sample 17	A-2-7	SW
Sample 18	A-2-6	SP
Sample 19	A-2-7	SW
Sample 20	A-2-7	SP

Results of unconsolidated undrained triaxial test

The values of shear strength parameters (cohesion, *c* and angle of internal friction, ϕ) obtained from triaxial tests are presented in Table 4. The soils are of varying shear strength parameters from one location to another. Sample 14 had the highest cohesion of 88 kN/m^2, while Sample 6 had the lowest cohesion of 5 kN/m^2. The highest internal friction angle was 38^o (for Sample 6), while the lowest internal friction angle was 10^o (for Samples 11 and 17). 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 indicates fine soils. 25 % of the tested soil samples had internal friction between 26^o and 48^o and could therefore be categorised as granular soils; while the remaining 75 % could be classified as fine soils.

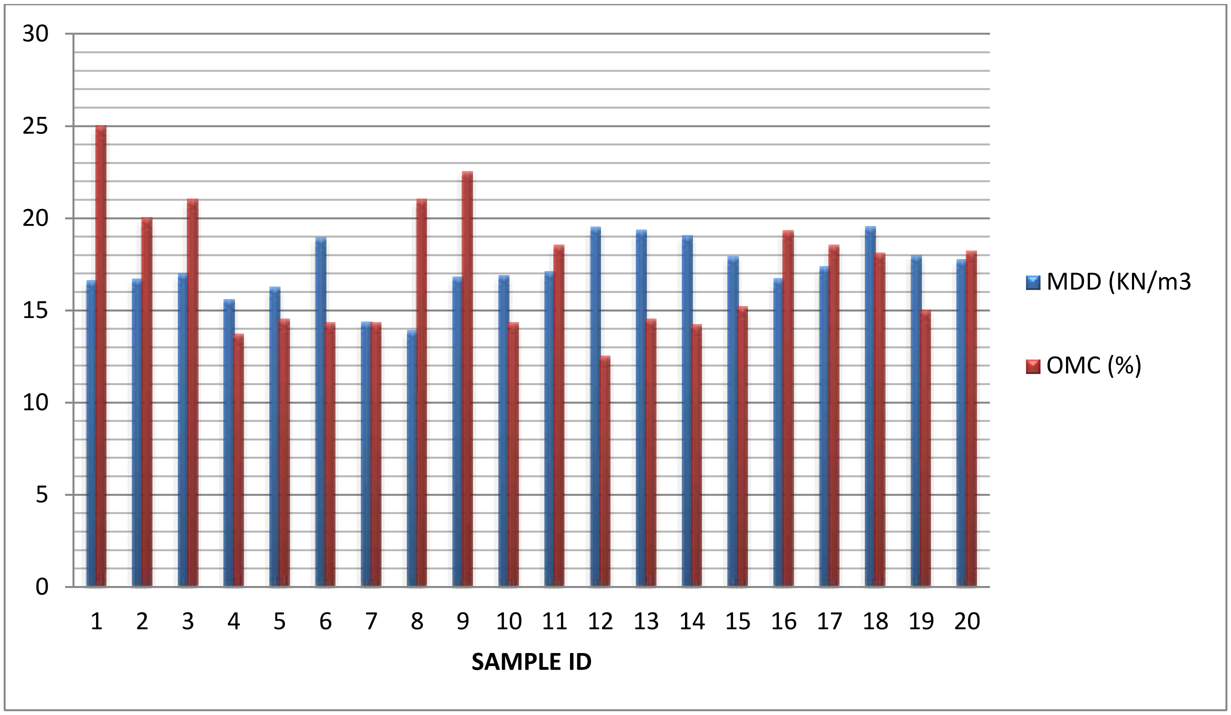

Figure 1: Variation of MDD and OMC of the soil s

Bearing Capacity of Soil Samples

The values of bearing capacity for various footing geometry (circular, square, footing) are presented in Table 4. For each of the footing geometry (shapes), Sample 6 had the highest bearing capacity (754.71 kN/m^2 for circular footing; 765.56 kN/m^2 for square footing; and 705.11 kN/m^2 for strip footing). Sample 17 also had the least values of bearing capacity for each of the footing shapes (74.82 kN/m^2 for circular footing; 75.14 kN/m^2 for square footing; and 62.01 kN/m^2) for strip footing). It was observed that higher values of ϕ implies higher bearing capacity values for all the tested soil samples and footing geometry (shapes). The shape of footing was also found to be an important factor affecting the values of bearing capacity of 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 tested soil samples. This is attributable to the combined effects of different values of bearing capacity factors, that is, the coefficient of each term for each case differ from one another.

Table 4: Shear strength parameters and bearing capacity of soil samples

Sample ID	Cohesion, c (kN/m^2)	Angle of internal friction, ϕ (º)	Bearing capacity (kN/m^2)		
			Circular footing	Square footing	Strip footing
Sample 1	62	21	563.00	565.81	451.20
Sample 2	55	18	408.76	410.60	327.13
Sample 3	24	28	452.74	460.49	392.37
Sample 4	22	31	551.82	563.58	486.44
Sample 5	21	16	466.53	470.59	388.27
Sample 6	5	38	754.71	765.56	705.11
Sample 7	22	26	341.82	346.94	292.42
Sample 8	48	25	595.44	599.70	483.08
Sample 9	34	11	168.83	169.51	135.54
Sample 10	35	16	239.88	241.28	194.70
Sample 11	28	10	132.86	133.18	106.59
Sample 12	24	22	282.01	285.83	241.01
Sample 13	8	32	388.38	405.55	387.77
Sample 14	88	14	489.72	490.52	384.75
Sample 15	32	16	224.03	225.49	183.11
Sample 16	37	12	193.35	194.13	155.07
Sample 17	14	10	74.82	75.14	62.01
Sample 18	40	17	293.50	295.37	239.01
Sample 19	44	21	419.74	422.79	342.50
Sample 20	47	15	291.58	292.86	233.79

CONCLUSION

The bearing capacity of soils in Ayedaade Local Government, Southwest Nigeria was investigated. Based on the objectives of this study, the following conclusions are made: though the soils are heterogenous, majority of are well-graded, with intermediate to high plasticity and could be described as excellent to good foundation materials; the soils are all *c*-ϕ soils; the value of bearing capacity is greatly influenced by the nature of foundation soil and shape; square footing presented the highest values of bearing capacity values, while strip footing had the lowest bearing capacity’

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