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Modelling of Circular Footing on Lateritic Soil

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ABSTRACT

This work modelled circular footing on lateritic soil. This was done by studying the relationship between bearing capacity of circular footing and fines content of lateritic soil. Lateritic soil samples were collected and subjected to laboratory tests, including tests leading to the determination of bearing capacity (using circular footing). Bearing capacity was determined for the natural soil samples. The samples were separated into fines and coarse components and later remoulded in varying proportions of fines: coarse content, from 0:100 in 10% increments. Bearing capacity was computed for all the remoulded soil samples. Regression analysis was then used to determine the relationship between the bearing capacity of circular footing and fines content of the soil. The model was found to be valid for the selected locations.

Keywords: *Bearing capacity, circular footing, fines content, lateritic soil, modeling*

1. Introduction

Soil is a natural material derived mostly from rocks and rocky minerals; and it possesses an inherently variable and complex character. The bearing capacity is the most important soil property which governs the design of foundation. Bearing capacity and the settlement are the two important parameters in the field of geotechnical engineering. Civil engineering projects such as buildings, bridges, dams and roadways require detailed subsurface information as part of the design process. Bearing capacity of soil is affected by various factors like change in level of water table, eccentric loads, inclined loads dimensions of the footing, soil strength, soil weight and surcharge, particle angularity, relative density, porosity, particle size distribution, water content, etc. [1, 2, 3, 4, 5, 6, 7].

USCS (Unified soil classification system) and the AASHTO (American Association of Highway and Transport Officials) define fines as soil particles passing through sieve No. 200 (75µm opening) . The fines content of a soil consist of clay and silt. The fines content in coarse soils determine the composition and type of soil and affect certain soil properties such as permeability, particle friction and cohesion. The fines content in soil also plays an important role in phase problems including minimum and maximum void ratios and porosity [8]. Fines in soil have also been found to affect the liquefaction potential, compressional characteristics and stress strain behaviour of soil [9, 10].

Bearing capacity of foundation has been determined variously using both experimental investigations and numerical/theoretical analyses [11, 12, 13]. Several laboratory experiments have been performed to determine the ultimate bearing capacity of foundations. However, these investigations are limited in scope as results obtained from such experiments are typically problem-specific and are difficult to extend to field problems with different material or geometric parameters. Therefore, there have been considerable interest in the development of models for shallow foundation behaviour [14, 15, 16, 17, 18, 19, 20].

Several numerical methods for bearing capacity problems have so far been adopted. Each problem was solved with certain assumptions and results were compared to laboratory testing. Very few rigorous numerical studies have been undertaken to determine bearing capacity behaviour [11]. Ref. [21] modelled the relationship between bearing capacity and fines content of soil, using square footing.

The aim of the study was to establish specific relationship between fines content and bearing capacity of circular footing on a lateritic soil. The specific objectives were to: (i) determine the fines content and bearing capacity of selected soil samples; (ii) develop models relating fines content and bearing capacity; and (iii) validate the developed models.

2. MATERIALS AND METHODS

The experimental procedure adopted was as reported by Ref. [21]: Samples of lateritic soil were collected from three selected locations in Obafemi Awolowo University (OAU) campus, Ile-Ife, Nigeria. Classification and identification tests were carried out on the soil samples in the laboratory. The natural moisture contents of the soil samples were determined after which the samples were air dried in the laboratory. Specific gravity of each soil sample was also determined.

Sieve analysis (of particles larger than 75μm) according to ASTM D422-63 or BS 1377(1990: Part 2: section 9) and hydrometer analysis (of particles smaller than 75μm) according to ASTM D1556-90 or BS 1377(1990: Part 2: section 9) were used to determine the grain size distribution of the soil samples. Atterberg limits (plastic and liquid limits) tests according to ASTM D4318-93 or BS 1377(1990: Part 2: sections 4 and 5) were carried out on samples passing sieve size 425μm.

Laboratory compaction tests using standard proctor method, according to ASTM D1140-54 or or BS 1377(1990: Part 2: section 3), were also carried out on the soil samples to determine the optimum moisture contents (OMCs) and the maximum dry densities (MDDs). The cohesion (c) and angle of internal friction (ϕ) of each soil sample were obtained from Unconsolidated-Undrained (UU) triaxial test.

The soil samples were soaked in water containing 4% sodium hexametaphosphate, a dispersing agent (commercially named Calgon) in the laboratory for 12-24 hours so that all the fines would get soaked and detached from the coarser soil samples. The soil was then washed through sieve size No. 200 with 75μm opening. The soil passing 75μm sieve size was oven dried and referred to as 100% fines. The soil sample retained on sieve 75μm opening was also oven dried (after thorough mixing) and referred to as 100% coarse.

The pulverized fines and the coarse fractions were added together in varying ratios (fines:coarse) from 10:100 to 100:0 in 10% increment. The ratio started with 10:100 and not 0:100 because, laboratory compaction test could not be carried out on the sample containing 0% fines (i.e. 100% coarse) and thus cohesionless. This is because the process of lubrication which aids compaction is limited to soils containing fines and cohesionless soils are compacted or densified by vibration and not by impact which laboratory compaction utilizes (Multiquip, 2004).

Each soil sample with varying percentage of fines content was compacted in the laboratory using standard proctor test to determine the optimum moisture content (OMC) and the maximm dry density (MDD) of each sample. The values of the OMC were used in subsequent UU triaxial tests.

The unconsolidated-undrained triaxial test was conducted on different combinations of fines : coarse of each soil sample, in accordance with BS 1377, and the c and ϕ were thus determined from the resulting Mohr circle/diagram. The c and ϕ were subsequently used to compute the bearing capacity of each soil sample using Terzaghi's (1943) computational method, i.e. Terzaghi's general bearing capacity equation for shallow circular footing ($Q_u = 1.3cN_c + \gamma DN_q + 0.3\gamma BN_\gamma$; where 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), assuming a typical circular footing of unit depth and unit width.

Correlations between the fines content and bearing capacity were made from the data obtained from the tests in the preceeding section. The relationships between the fines content and bearing capacity of circular footing were established by developing non-linear regression models. The validity of each model was verified by the coefficient of correlation (R), which ranges in value from 0 to 1. The closer the R is to 1, the better the representations of the relationship between the fines content and bearing capacity by the models developed. The developed models were validated and compared across the three different locations.

3. RESULTS AND DISCUSSION

The general description of the soil samples and location co-ordinates obtained from Geographical Positioning System (GPS) are as shown in Table 1. Table 2 shows the results of classification and index properties determination for the soil samples. Sample OD has the highest fines content of 55.00%, natural moisture content (NMC) of 16.90%, liquid limit (LL) of 41.00% and plastic limit (PL) of 30.73%. Sample TR on the other hand, has the lowest fines content of 41.22%, LL of 39.87% and PL of 31.01%. Samples NM and TR contain less clay than sample OD [21]. The compaction parameters of the soil samples in their natural states are shown in Table 3.

Table 4 gives the summary of the cohesion, angle of internal friction, and bearing capacity (circular footing) of the soil samples in their natural states. The results show that higher c or ϕ does not necessarily imply a higher bearing capacity for the samples (sample NM has the lowest c and ϕ, but it has the highest bearing capacity; while sample OD with the highest c and ϕ does not have the lowest bearing capacity). This agrees with Ref. [21].

The relationship between bearing capacity (circular footing) and fines content is shown in Fig. 1. A non-linear representation of the data is used. Regression analyses of the data give equations 1 to 3 which represent the relationship between bearing capacity (circular footing) and fines content for samples NM, OD and TR respectively.

$$b.c.= -0.006f^3+1.516f^2-145.4f+5914 \quad (1)$$
$$b.c.= -0.012f^3+2.871f^2-232.8f+7248 \quad (2)$$
$$b.c. = -0.004f^3+1.182f^2-109.3f+4027 \quad (3)$$

b.c. is bearing capacity (kN/m^2) and f is fines content in %.

The R^2 values obtained from linear regression are shown on Fig. 1, while the correlation coefficient (R) is 0.983, 0.992 and 0.988 for samples NM, OD, and TR respectively. Based on R^2 and R values, the models generated (Equations 1 to 3) give representations between the bearing capacity and the fines content. Table 5 presents comparison between model results (using equations 1 to 3) and experimental results (Table 4) for bearing capacities (circular footing) of soil samples. As observed, the level of variance is minimal. The variance could be attributed to some other factors which affect the bearing capacity of soil. Sample TR has the lowest variance between model and experimental values. Thus model for TR is the most reliable. The results of application of models across the three sampling locations are shown in Tables 6 to 8. The results show that model obtained for NM could be applied to TR location and OD model could be used for NM location.

4. CONCLUSION

This work determined the fines content and bearing capacity of selected lateritic soils. The specific relationship between fines content and bearing capacity of circular footings was determined, thus modeling circular footing on the selected lateritic soils. Model for TR was found to be the most reliable. NM model was found to be valid for TR location, while OD model was found to be valid for NM location.

The study is limited to: (i) relationship between fines content and bearing capacity of circular footing on lateritic soil; (ii) sample locations as indicated in this study; and (iii) shallow foundation (circular footing) of unit width and unit depth.

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Table 1: Description of sampling locations

S/N	Sample ID	Latitude	Longitude	Elevation (m) above sea level
1	NM	N7°31'4.74"	E004°30'47.7"	276
2	OD	N7°30'13.5"	E004°31'47.0"	262
3	TR	N7°32'20.4"	E004°31'03.7"	306

Table 2: Index properties of the soil samples (Adunoye and Agbede, 2013)

Property	NM	OD	TR
Natural Moisture Content (%)	19.74	16.90	17.05
Specific Gravity (Gs)	2.66	2.86	2.69
Liquid Limit, LL (%)	45.29	41.00	39.87
Plastic Limit, PL (%)	32.68	30.73	31.01
Plasticity Index, PI (%)	12.61	10.27	8.86
Percentage passing sieve No. 200 (Fines content)	32.70	55.00	41.07
Percentage clay sized particles	14.51	27.48	24.74
Percentage silt sized particles	18.19	27.52	16.33

Table 3: Compaction parameters of the soil samples in their natural states

Compaction Parameters	NM	OD	TR
Optimum moisture content, OMC (%)	17.39	19.42	16.38
Maximum dry density, MDD (Mg/m^3)	1.77	1.91	1.71
Maximum bulk density, MBD (Mg/m^3)	2.08	2.29	1.99

Table 4: Summary of the cohesion, angle of internal friction and bearing capacity (circular footing) of the soil samples in their natural states

Sample	Cohesion, c (kN/m^2)	Angle of internal friction,ϕ (^{o})	Bearing Capacity(kN/m^2)
NM	21	13	2194.87
OD	36	17	1264.71
TR	35	15	1197.91

Table 5: Comparison between model results and experimental results for bearing capacities of soil samples

Sample	% Fine	Bearing Capacity(kN/m^2)		% Variance	Remark
		Natural State	**Generated Model**		
NM	32.70	2194.87	2570.67	17.12	Model validated
OD	55.00	1264.71	1132.28	10.47	Model validated
TR	41.07	1197.91	1254.51	3.06	Model validated

Table 6: Result of application of NM model to all three locations

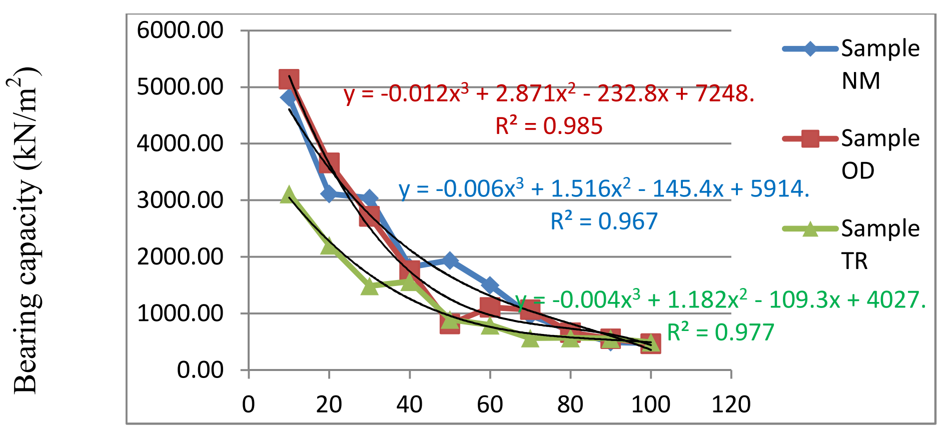
Sample	% Fine	Bearing Capacity(kN/m^2)		% Variance	Remark
		Natural State	Generated Model		
NM	32.70	2194.87	2570.67	17.12	Model validated
OD	55.00	1264.71	1504.65	31.47	Not recommended
TR	41.07	1197.91	2051.91	6.51	Recommended

Table 7: Result of application of OD model to all three locations

Sample	% Fine	Bearing Capacity(kN/m^2)		% Variance	Remark
		Natural State	Generated Model		
NM	32.70	2194.87	2285.78	4.14	Recommended
OD	55.00	1264.71	1132.28	10.47	Validated
TR	41.07	1197.91	1662.45	38.78	Not recommended

Table 8: Result of application of TR model to all three locations

Sample	% Fine	Bearing Capacity(kN/m^2)		% Variance	Remark
		Natural State	Generated Model		
NM	32.70	2194.87	1576.93	28.15	Not recommended
OD	55.00	1264.71	925.55	26.82	Not recommended
TR	41.07	1197.91	1234.51	3.06	Validated



Fines content (%)

Fig. 1: Relationship between bearing capacity (circular footing) and fines content of soil samples