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Statistical Modelling of the Relationship Between Bearing Capacity and Fines Content of Soil using Square Footing

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Abstract

This paper focuses on the use of non-linear regression to model the relationship between bearing capacity and fines content of soil, using square footing. This is with a view to providing a faster and economical method for determining the bearing capacity of soil. Lateritic soil samples were collected and subjected to laboratory tests/analysis which include: determination of particle size; separation of fines content from the coarse fraction by wet sieving; reconstitution of the fines and the coarse fractions in varying proportions of fines to coarse ratios, from 0:100 in 10% increments; and laboratory tests leading to the determination of the bearing capacity. Statistical (non-linear regression) models were then developed and evaluated to ascertain the relationship between bearing capacity of square footing and fines content of the soil samples. The results of the study showed that the bearing capacity of soil samples generally reduced with increase in fines content. The developed model was found to be valid and revealed that a non-linear relationship exists between the bearing capacity of square footing and fines content.

Keywords: bearing capacity, coarse fraction, fines content, square footing.

1. Introduction

Soil particles can be broadly divided into two – coarse and fines content. According to USCS and the AASHTO, soil particles passing through sieve No. 200 (75μm opening) are referred to as fines, while the particles retained are referred to as coarse particles. Basically fines in soil consist of clay and silt. The fines content in coarse soils are carefully considered because they 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 (Lade *et al*. 1998). Fines have also been found to affect the liquefaction potential, compressional characteristics and stress strain behaviour of soil (Naeini and Baziar, 2004; Cabalar, 2008). Ayodele (2008) studied the effect of fines content on the performance of soil as sub-base material for road construction and found out that the engineering properties of the studied soil samples generally reduced with increase in fines content.

A number of factors affect bearing capacity of soil. Such factors include soil strength, foundation width, foundation depth, soil weight and surcharge, particle angularity, relative density, porosity, particle-size distribution and water content (Baker, 1983; Beard and Sifers, 1988). The determination of the bearing capacity of foundations has been developed through both experimental investigations and numerical/theoretical analyses (Yien, 2008; Merifield *et al*., 1999; Salgado *et al*., 2000; Shiau *et al*., 2003).

A great deal of laboratory testing has been performed to predict the ultimate bearing capacity of foundations. However, the investigations are typically limited in scope. Results obtained from laboratory testing are typically problem specific and are difficult to extend to field problems with different material or geometric parameters. There have been several numerical methods for bearing capacity problems so far. 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 (Yien, 2008).

Existing methods for the determination of soil bearing capacity is based on its geotechnical properties. This study therefore takes into consideration the previous problem results (in terms of equations, tables and principles), and uses regression analysis to determine the specific effects of fines content on bearing capacity of soil using square footing as case study. The study plays a significant role in the area of bearing capacity estimation of footings for geotechnical engineering.

2. Materials and Methods

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: section9) 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. The results of particle size distribution and Atterberg limits were used to classify the soil according to AASHTO and USCS classification systems.

Laboratory compaction tests using standard proctor method, according to ASTM D1140-54 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 : coa

rse 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 square 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 square footing of unit depth and unit width.

The data obtained from the tests in the preceeding section were then used to establish correlations between the fines content and bearing capacity. The relationships between the fines content and bearing capacity were established by developing non-linear regression models. The validity of each model was verified by the coefficient of determination (R^2). R^2 compares estimated and actual y-values, and ranges in value from 0 to 1. The closer the R^2 to 1, the better the representations of the relationship between the fines content and bearing capacity by the models developed. The correlation coefficient (r) between the data obtained for each soil sample for the bearing capacity was also used to reflect the similarity between the three data sets. The developed model was also evaluated with the bearing capacities of the soil samples in their natural states using square footing.

3. Results and Discussion

Table 1 gives the general description of the soil samples and location co-ordinates obtained from Geographical Positioning System (GPS). Results of classification and index properties determination for the soil samples are as shown in Table 2. 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. The particle size curves (Figure 1) for the three samples have some measure of resemblance. Figure 2 shows compaction characteristics of the soil samples in their natural states.

The summary of the cohesion, angle of internal friction, and bearing capacity of the soil samples in their natural states are presented in Table 3. 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.

The relationship between bearing capacity (for square footing) and fines content is shown in Figure 3. 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 (for square footing) and fines content for samples NM, OD and TR respectively.

$$\text{b.c.} = -0.007f^3 + 1.881f^2 - 172.2f + 6565 \quad (1)$$

$$\text{b.c.} = -0.014f^3 + 3.305f^2 - 265.1f + 8042 \quad (2)$$

$$\text{b.c.} = -0.005f^3 + 1.404f^2 - 124.9f + 4380 \quad (3)$$

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 Figure 3, while the correlation coefficient (r) is 0.985, 0.993 and 0.989 for samples NM, OD, and TR respectively. Based on R^2 values, the models generated (Equations 1 to 3) give representations between the bearing capacity (for square footing) and the fines content. Table 4 presents comparison between model results (using equations 1 to 3) and experimental results (see Table 3) for bearing capacities (of square 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.

5. Conclusion

It has been revealed that: the bearing capacity of the studied soil samples generally reduced with increase in fines content; non-linear relationships exist between fines content and the bearing capacity; and the developed regression models is valid for the selected soil samples. The developed models are limited to the following conditions: (i) sample locations as shown in this study (ii) shallow square footing of unit width and unit depth; and (iii) relationship between fines content and bearing capacity of soil.

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Table 1: Description of Soil Samples from Selected Locations

S/N	Sample Identification	Location		
		Geographic Location	GPS	
			X(m)	Y(m)
1	NM	New Market	831305	666962.31
2	OD	Opa Dam	829768	668709.31
3	TR	Tonkere Road	833669	667366.31

Table 2: Index Properties of the Soil Samples

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

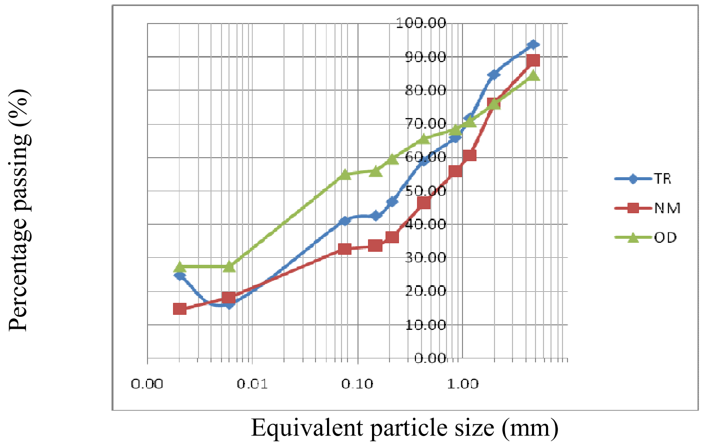

Figure 1: Particle size distribution curves for the soil samples

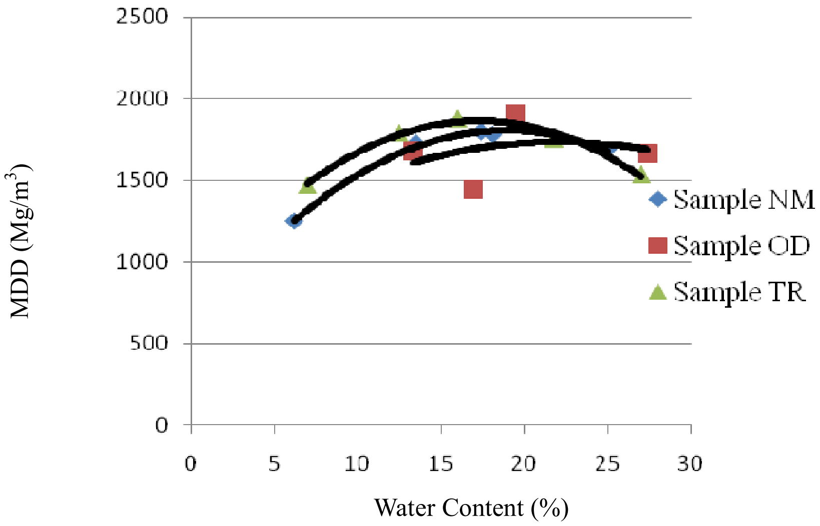

Figure 2: Compaction Characteristics of the soil samples in their natural states

Table 3: Summary of the Cohesion, Angle of Internal Friction and Bearing Capacity 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	2279.45
OD	36	17	1282.97
TR	35	15	1213.71

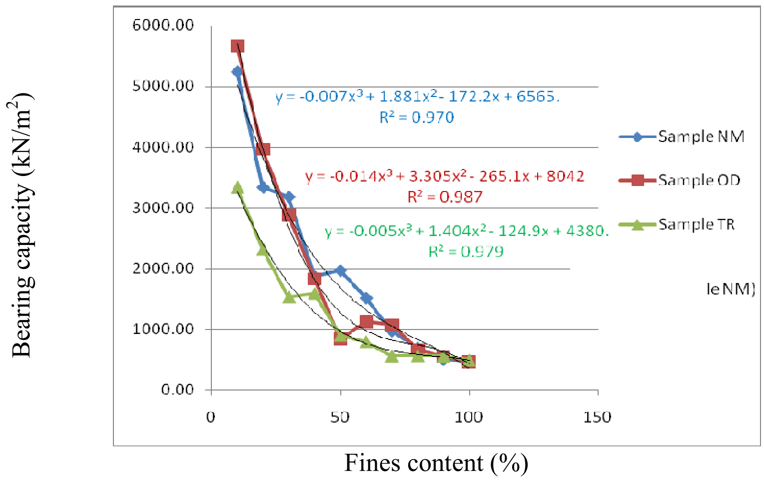

Figure 3: Relationship between bearing capacity and fines content of soil samples

Table 4: 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	2279.45	2700.63	18.48	Model validated
OD	55.00	1282.97	1129.88	11.93	Model validated
TR	41.07	1213.71	1272.17	4.82	Model validated