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Fines Content and Angle of Internal Friction of a Lateritic Soil: An Experimental Study

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Abstract: - Soils in nature are mixture of fine and coarse soils. Fines in soil play a major role in the geotechnical properties of soil. The research focused on experimental study of the relationship between fines content and internal friction angle of lateritic soil. This was with a view to obtaining empirical relationships between the two parameters. Three samples of reddish brown tropical soils were obtained. The samples were subjected to laboratory analysis in their natural states and the index properties were determined. The fines contents were separated from the coarse components of the soils, and the samples were remoulded in varying ratios (fines:coarse). The resulting samples were subjected to triaxial tests to determine the shear strength parameters. Quantitative relationships between fines content and angle of internal friction of the soil samples were developed. The polynomial relationships gave the best relationship between the fines content and angle of internal friction of the soil samples.

Keywords: - *Angle of internal friction, correlation, fines content, lateritic soil, triaxial test*

I. INTRODUCTION

The shear strength of a soil mass is the internal resistance per unit area that the soil mass can offer to resist failure along any plane inside it [1]. When this resistance is exceeded failure occurs. Shear strength of a soil refers to the maximum or limiting value of shear stress induced within its matrix before yielding. Shear strength within a soil matrix is due to cohesive and frictional forces between adjacent particles. Therefore, the soil shear strength is to some extent surface dependent. Any action that will hinder or promote the interlocking or welding of soil particles will invariably affect soil shear strength [2]. The shear strength is usually made up of: (a) internal friction or the resistance due to interlocking of the particles, represented by an angle, ϕ; (b) cohesion or the resistance due to the forces tending to hold the particles together in a solid mass. The cohesion of a soil is generally symbolized by the letter 'c'. The law governing the shear failure of soils was first put forward by Coulomb and is given in equation as

$$s = c + \sigma \tan\phi \qquad (1)$$

where s is the shear strength and σ is the normal stress. Therefore, angle of internal friction, ϕ is one of the important parameters considered as a typical characteristic for reconnaissance of granular soils. Angle of internal friction could be described as a measure of the ability of a unit of rock or soil to withstand a shear stress. It is the angle (ϕ), measured between the normal force (N) and resultant force (*R*), that is attained when failure just occurs in response to a shearing stress (S). Its tangent (S/N) is the coefficient of sliding friction. Its value is determined experimentally. Determination of shear strength parameters must take place prior to analytical and design procedures in connection with foundations, retaining walls and earth retaining structures [3].

Fines in soils consist of silts and clays while coarse component consists of sands and gravels. As defined by Unified Soil Classification System (USCS) and the American Association of State Highway Transportation Officials (AASHTO) fines in soil are soil particles passing through sieve No. 200 (75µm opening). The fines contents 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 [4]. Fines have also been found to affect the liquefaction potential, compressional characteristics and stress-strain behaviour of soil [5, 6, 7, 8]. According to Wang *et al.*[9], fines content could affect the dynamic response of soils significantly. Tatlisoz *et al.* [10] studied the effect of fines on mechanical properties of soil-tyre chip mixtures and found out that the fines have significant effect on the mechanical properties of the soil-tyre mixture. During dynamic compact loading, dynamic forces disrupt the soil skeleton and force the particles to compact into a denser arrangement. Obviously, the fines contents play an important role on the mechanical response of soils, especially when the soils are subjected to loading. Ayodele[11] 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 [12].

Bello[13] analyzed the shear strength of some compacted lateritic soils. Bareither *et al* [3] studied the geological and physical factors affecting the friction angle of compacted sands and developed a multivariate regression model that can be used to predict friction angle, ϕ of compacted sands from comparable geological origins based on effective particle size, D_{10}, maximum dry unit weight d_{max}, and Krumbein roundness R_s. As reported by Bareither *et al* [3], methods to predict the friction angle of granular materials from physical and engineering properties have also been presented in NAVFAC [14]. NAVFAC [14] presents one of the most widely referenced correlations, where ϕ is estimated with respect to USCS classification and dry unit weight or relative density. The correlation presented in Schmertmann [15] provides an estimate of ϕ based on relative density and generalised material descriptions. The method in Terzaghi *et al* [16] uses a secant definition for the friction angle that is a function of effective normal stress as well as generalized material descriptions and porosity.

The specific relationship between fines content and angle of internal friction of soil is not clear. Also, there is need to advance the effect of fines on angle of internal friction of soil, ϕ. Therefore, in this research it is tried to provide a proper correlation (quantitative relationship) between the angle of internal friction and the fines content of lateritic soils. The primary objectives were to (i) determine the effects of fines content on angle of internal friction ϕ of selected soil samples; and hence (ii) develop regression models (equations) relating fines content to the angle of internal friction ϕ of the soil samples.

II. MATERIALS AND METHODS

2.1 Materials

The soil samples used in this research work are a natural material, that is, reddish brown lateritic soil from three selected locations in Obafemi Awolowo University (OAU) campus, Ile-Ife, Southwestern Nigeria (between latitude 7° and 28°N and longitude 4° and 34°E). The method of disturbed sampling was employed. The soil samples were obtained at depths of 0.60 – 1.00m and the locations are designated as S1, S2 and S3. Fig. 1 is a location map of OAU showing the sampling locations[12].

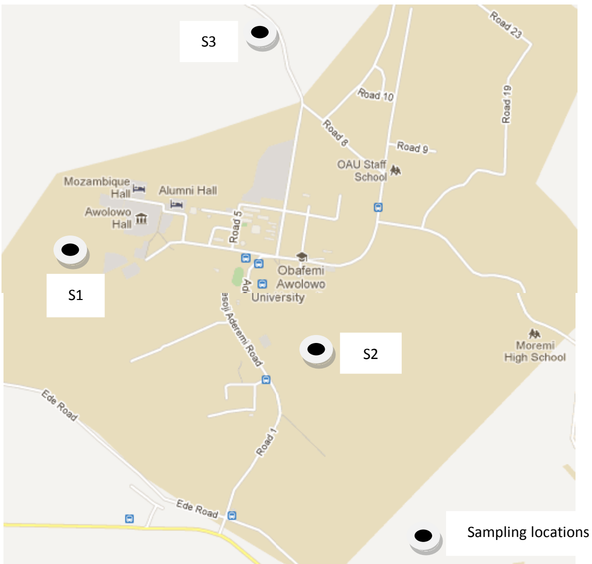

Figure 1: Location map of OAU campus (Google, 2012)

2.2 Methods

Some of the methods for this work were as described by Adunoye and Agbede [17] and Adunoye [12]. Laboratory tests were carried out to determine the index properties of the sample specimen in accordance with BS 1377 [18]. The soil samples were then 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 [19].

The resulting samples were allowed to homogenise and compacted in the laboratory using standard proctor test to determine the optimum moisture content (OMC) and the maximum dry density (MDD) of each sample. The values of the OMC were used in subsequent unconsolidated undrained triaxial tests (Adunoye and Agbede, 2013). The remoulded soil samples were then subjected to unconsolidated-undrained triaxial test, in accordance with BS 1377 [18], to determine their shear strength parameters (i.e c and ϕ).

Quantitative relationships between fines content and angle of internal friction of soils were then developed using regression analysis . The validity of the developed relationships was verified by the coefficient of determination (R^2), which 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.

III. RESULTS AND DISCUSSION

Index properties of the soil samples are summarized in Table 1 Sample S2 has the highest fines content of 55.00%, liquid limit (LL) of 41.00% and plastic limit (PL) of 30.73%. Sample S1 on the other hand, has the lowest fines content of 32.70%, LL of 45.29% and PL of 32.68%. Sample S1 has the highest plasticity index (PI) of 12.61%, which implies that sample S1 has the highest inherent swelling potential shrinkage tendency [12, 17].

Table 1: Index properties of soil samples (Adunoye, 2014)

Property	**Sample Identification**		
	S1	**S2**	**S3**
Natural moisture content (%)	19.74	16.90	17.05
Specific gravity	2.66	2.86	2.69
Percentage passing sieve No. 200 (Fines content)	32.70	55.00	41.07
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
OMC (%)	17.39	19.42	16.38
MDD (mg/m3)	1.77	1.91	1.71

Table 2 gives a summary of the values of shear strength parameters (c and ϕ) at various fines content of the soil samples. For sample S1, the ϕ values range between 42^o (for 10% fines) and 0^o (for 100% fines). This represents a decrease of 42^o (100%). For sample S2, the ϕ values range between 41^o (for 10% fines) and 0^o (for 100% fines). This represents 41^o (100%) decrease. Similarly, for sample S3, the ϕ values range between 36^o (for 10% fines) and 0^o (for 100% fines). This represents 36^o (100%) decrease. For all the samples, ϕ decreases as fines content increases. At 100% angle of internal friction is 0^o.

On the other hand and as earlier reported by Adunoye [12], for sample S1, the cohesion values range between 8 kN/m^2 (for 10% fines) and 63 kN/m^2 (for 100% fines). This represents 55 kN/m^2 (687.5%) increase. For sample S2, the cohesion values range between 5 kN/m^2 (for 10% fines) and 67 kN/m^2 (for 100% fines). This represents 62 kN/m^2 (1240%) increase. Similarly, for sample S3, the cohesion values range between 10 kN/m^2 (for 10% fines) and 66 kN/m^2 (for 100% fines). This represents 56 kN/m^2 (560%) increase. The cohesion generally increases with increase in fines content of the soils. This is so because cohesion is majorly dependent on clay content in soils [20].

Table 2: Values of shear strength parameters at various fines contents

% Fines	Angle of internal friction, ϕ (degrees)			Cohesion, c (kN/m^2)		
	S1	S2	S3	S1	S2	S3
10	42	41	36	8	5	10
20	39	40	29	10	9	14
30	31	32	27	20	13	19
40	28	30	22	26	19	31
50	27	29	16	41	28	38
60	20	24	13	49	34	46
70	12	19	8	52	51	49
80	5	9	5	57	59	62
90	2	3	2	59	62	64
100	0	0	0	63	67	66

The results of the correlations between fines content and ϕ are as shown in Figs.2 to 4, while Table 3 gives a summary of the equations representing relationships between ϕ and fines content of soil samples. Considering the values of R^2 all the empirical equations are valid for the soil samples as they are all close to 1. However, the linear relationships cannot be said to be valid. This is because there cannot be negative angle of internal friction (Fig. 2). Polynomial relationships give the highest R^2 values for all the samples (0.980 for S1; 0.980 for S2 and 0.994 for S3). This could be as a result of the fact that polynomials have the attractive property of being able to approximate many kinds of functions [12, 21].. The polynomial equations fit the data best and thus give the best representations between fines content and angle of internal friction of the soil samples.

IV. CONCLUSION

From the findings of this research work, the following conclusions are made in relation to the objectives of the research: (i) The angle of internal friction of the studied soil samples generally decreased with increase in fines content; (ii) the best fitting between fines content and cohesion of the soil samples was found by the polynomial expression: $\phi = -0.000f^2 - 0.456f + 47.16$; $\phi = -0.002f^2 - 0.19f + 43.06$; $\phi = 0.001f^2 - 0.571f + 41.4$. Where ϕ is angle of internal friction in degrees and f is fines content in % . The empirical equations are valid for the soil samples and test procedure used in this research. More experiments with various soils and from different locations are required to generalise these expressions.

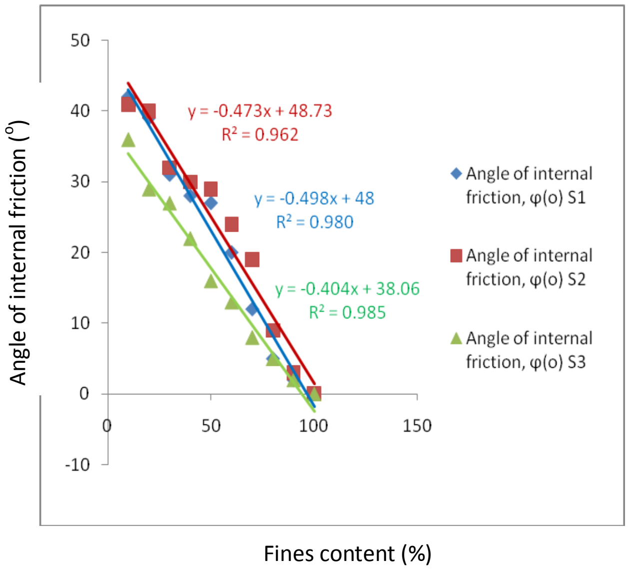

Figure 2: Angle of internal friction vs Fines content (Linear)

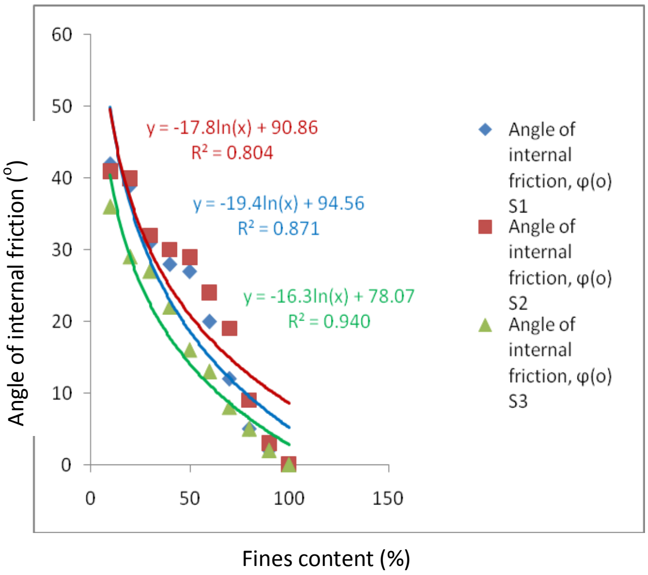

Figure 3: Angle of internal friction vs Fines content (Logarithmic)

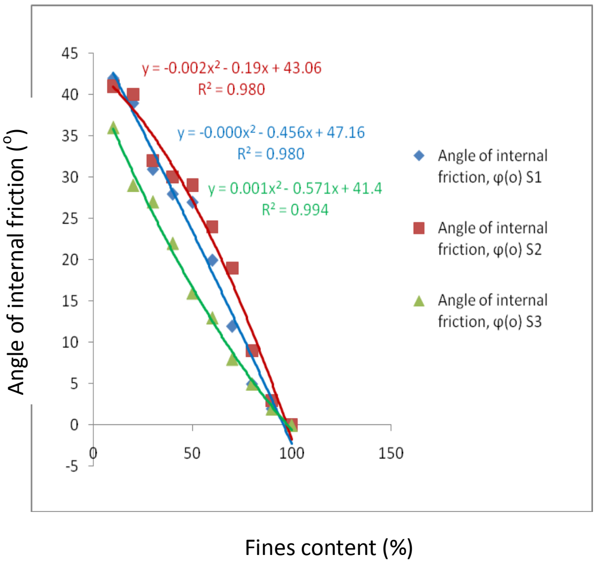

Figure 4: Angle of internal friction vs Fines content (Polynomial)

Table 3: Equations representing relationship between angle of internal friction and fines content of soil samples

Sample	Equation		
	Linear	Logarithmic	Polynomial
S1	$y = -0.498x + 48$; $R^2 = 0.980$	$y = -19.4\ln(x) + 94.56$; $R^2 = 0.871$	$y = -0.000x^2 - 0.456x + 47.16$; $R^2 = 0.980$
S2	$y = -0.473x + 48.73$; $R^2 = 0.962$	$y = -17.8\ln(x) + 90.86$; $R^2 = 0.804$	$y = -0.002x^2 - 0.19x + 43.06$; $R^2 = 0.980$
S3	$y = -0.404x + 38.06$; $R^2 = 0.985$	$y = -16.3\ln(x) + 78.07$; $R^2 = 0.940$	$y = 0.001x^2 - 0.571x + 41.4$; $R^2 = 0.994$

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