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EFFECTS OF COMPACTIVE EFFORTS ON GEOTECHNICAL PROPERTIES OF SPENT ENGINE OIL CONTAMINATED LATERITE SOIL

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Abstract

Investigation of the effects of compactive efforts and spent engine oil (SEO) contamination on the geotechnical properties of lateritic soils was made. Contaminated specimens were prepared by mixing lateritic soil with up to 10 % SEO by dry weight of the soil in step concentration of 2 % and subjected to geotechnical tests. Results indicated a decrease in the fine content, decrease in liquid limit, maximum dry density (MDD) and unconfined compressive strength (UCS) with up to 10 % SEO content. No general trend was observed in the optimum moisture content (OMC) with increasing SEO content. The MDD, OMC and UCS values increased with increase in the compactive effort. Regression analysis of the results showed that optimum moisture content, fine content and compactive effort significantly influence the soils UCS values. Analysis of variance showed that SEO and compactive effort has significant effect on the parameters with the exception in one case. The results of laboratory tests showed that geotechnical properties of the SEO contaminated soil were immensely impaired.

Keywords: Spent engine oil, Lateritic soil, Compaction, Unconfined compressive strength, Regression, Analysis of variance.

1. Introduction

Laterites soils are residual soils formed by the weathering and decomposition of rocks under tropical condition [1-3]. They are rich in sesquioxides and low in primary silicates but may contain appreciable amounts of quartz and kaolinite. The presence of iron oxides in lateritic soils gives it the red coloration ranging

Nomenclatures

ML	Low plasticity silty soil
R	Coefficient of determination
R^2	Correlation coefficient values

Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ANOVA	Analysis of Variance
BS	British Standard
BSH	British Standard Heavy
BSL	British Standard Light
CI	Compactive effort
GPS	Global Positioning System
MDD	Maximum Dry Density, Mg/m^3
NSS	Not statistically significant
OCS	Oil contaminated soil
OMC	Optimum Moisture Content, %
PF	Percentage fine, %
PI	Plasticity index, %
SEO	Spent Engine Oil
SS	Statistically significant
UCS	Unconfined compressive strength, kN/m^2
USCS	Unified Soil Classification System
WAS	West African Standard

from light through bright to brown shades. Laterites are found in tropical countries with intermittently moist climate, the six main regions of the world in which laterites occur are Africa, India, South East Asia, Australia, Central and South America [1].

According to Oluremi and Osuolale [4], lateritic soils from borrow pits can become contaminated with oil due to some human activities such as location of mechanic workshops on lateritic soil deposited area, accidental spillage of crude oil, leakage of underground oil and petroleum tanks, accidental spillage of petroleum product, motor spare parts market, etc. Also, contamination of shoreline soil might be due to the oil washed ashore while the surrounding soils of the processing plants can become contaminated during the refining processes [5]. Using such areas as construction sites or borrow pits will raise a concern for the effect of the oil contamination on the soil. It has been reported that the strength properties and compressibility behaviour of such soils are drastically reduced and made unsuitable for supporting engineering structures [6, 7].

Oil contaminated soil (OCS) has been defined by [8], as any earthen material or artificial fill that has human or natural alteration of its physical, chemical, biological or radiological integrity resulting from the introduction of crude oil, any fraction or derivative thereof such as gasoline, diesel, or used motor oil or any oil based product. Oil waste dumping, production, pollution, and spills wreak havoc on the surrounding wildlife and habitat. It is in this vein that geotechnical engineers are faced with increasing challenges as a result of oil spills and hence the need for laboratory studies in order to develop methodologies for testing, identification, classification, studying of engineering behaviour, studying of stabilization, utilization and remediation technologies for such soils.

The purpose of this study was to investigate the effect of spent engine oil on the geotechnical properties of lateritic soils. The approach used in this study is that of artificial contamination of the soil with spent engine oil in the laboratory in agreement with other researchers [7, 9, 10] which is a limitation to this study since on site crude oil contaminated soil samples cannot be obtained.

2. Materials and Methods

The two materials used in this study are the laterite soil sample and spent engine oil. The methods employed in preparing the samples for the various tests carried out are in accordance to the procedure outlined in [11, 12] respectively.

2.1. Materials

The soil used in this study was a natural reddish brown laterite taken from a borrow pit along Ogbomoso - Ilorin express way in Ogbomoso, Oyo State, Nigeria. The borrow pit is located on Latitude 08^0 10.249'N and Longitude. 004^o15.118'E as determined with Global Positioning System (GPS). Laterite soil was collected as a disturbed sample at a depth of 0.5 m after removing the top soil of about 0.3m below the ground surface. It has been reported by [2] that Nigerian laterite soils in general belong to the group of ferruginous tropical soils derived from acid igneous and metamorphic rocks. Artificial contamination of the lateritic soil with spent engine oil was used in the laboratory for this work relative to the approach used in the past research works of [9, 10].

The petroleum product utilized in this study was Spent Engine Oil (SEO) which was collected from Lutonia Technical Company, Orita Naira Junction, Ogbomoso, Oyo state, Nigeria. The petroleum product was collected in a closed container and stored in a cool dry place to prevent its thermal cracking under intense temperature.

2.2. Methods

Fundamental geotechnical tests: Atterberg limits, sieve analysis, compaction and unconfined compression test were carried out on both the natural and the SEO contaminated soil. The SEO contaminated soil was prepared by mixing a predetermined quantity of soil base on the quantity needed for each of the tests highlighted above with 0, 2, 4, 6, 8, and 10 % spent-engine oil by dry weight of the laterite soil. The procedure of each of the tests carried out is as discussed below.

2.2.1. Index properties

Atterberg limits test was carried out in accordance with British Standards [11, 12] to determine the index properties of the natural soil (0 % SEO) and 2 % to 10 % spent-engine oil contaminated soil.

2.2.2. Compaction

Compaction tests were carried out in accordance with [11] to determine the compaction characteristics of spent engine oil contaminated soil. Soil samples were mixed with 0, 2, 4, 6, 8, and 10 % spent-engine oil by dry weight of soil and were compacted with British Standard light (BSL), West African Standard (WAS) and British Standard Heavy (BSH) energy levels respectively.

2.2.3. The unconfined compressive strength (UCS)

The test was performed on the soil samples according to BS 1377; 1990 Part 7 using the British Standard light (BSL), West African Standard (WAS) and British Standard heavy (BSH) energy levels. The natural and spent engine oil contaminated soil samples were compacted in 1000cm^3 moulds at their respective optimum moisture content (OMC). The samples were extruded from the moulds and trimmed into cylindrical specimens of 38mm diameter and 75mm length. Three cylindrical specimens from the mould were cured for 14 days then placed in the lower platen of a compression testing machine and a compressive force was applied to the specimen with a strain control at 0.10 mm. Record was taken simultaneously of the axial deformation and the axial force at regular interval until failure of the sample occurred. The UCS in kN/m^2 was calculated from the Eq. (1).

$$\text{Compressive Strength} = \frac{\text{Failure Load}}{\text{Surface Area of Specimen}} \quad (1)$$

3. Results and Discussion

3.1. Index properties

The natural soil was a reddish brown soil with a liquid limit of 58 %, plastic limit of 50 % and plasticity index of 8%. The soil was classifies as A-5 (2) based on AASHTO classification [13] and low plasticity silty soil (ML) based on the Unified Soil Classification System, USCS [14]. Test results on the natural soil are summarized in Table 1.

3.1.1. Effect of spent engine oil contamination on the particle size distribution of lateritic soil

The particle size distribution curves for both the uncontaminated and contaminated soils are shown in Fig. 1. Results obtained showed that both the uncontaminated and contaminated samples contain high percentage of silt and clay. It was observed that there was a progressive decrease in the percentage of fines with increasing SEO content up to 4 % and thereafter the percentage of fines increased. The increase in the proportion of silt and fine fraction could be due to lack of bonding between the clay and silt sizes particles to form pseudo-sand sizes and of the sand sizes to form larger sand or clog sizes with increasing SEO content beyond 4 % SEO. The results of particle size distribution nearly followed the patterns observed by [6, 7] which indicated a decrease in clay and silt size particles with increase in the SEO content without any optimum. Based on this result, 4 % SEO content could be used to improve the particle size distribution of lateritic soil of this type and classification through aggregation of soil particles initiated by SEO film coating.

Table 1. Properties of the natural soil.

Property	Quantity
Percentage Passing BS No. 200 Sieve	40.4
Liquid Limit, %	58
Plastic Limit, %	50
Plasticity Index, %	8
Linear Shrinkage, %	10.2
AASHTO Classification	A-5(2)
USCS	ML
Maximum Dry Density, Mg/m^3	
British Standard light	1.61
West African Standard	1.66
British Standard heavy	1.74
Optimum Moisture Content, %	
British Standard light	18.1
West African Standard	16
British Standard heavy	15
Unconfined compression test, (kPa)	
British Standard light	149
West African Standard	269
British Standard heavy	285

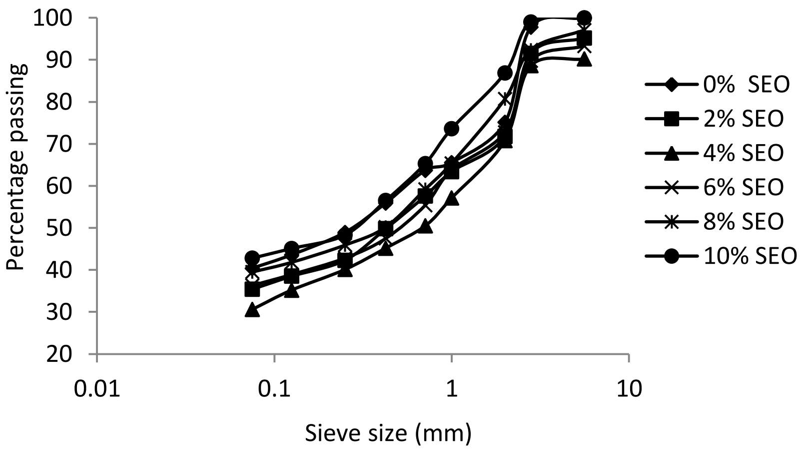

Fig. 1. Graphical representation of the particle size distribution for the variation in percentage of contamination with spent engine oil.

According to the specification of Nigerian Federal Ministry of Works and Transportation for the grain size distribution of particles, percentage passing BS sieve No 200 should not be greater than 35%. This implies that all the samples, except those contaminated with 2 - 4 % SEO, did not meet the standard for use as pavement material since their percentage passing Sieve No. 200 is greater than 35%.

3.1.2. Effect of spent engine oil contamination on the Atterberg limits of lateritic soil

Result of liquid limit test is shown in Fig. 2. The liquid limit ranged between 54 and 68%. The liquid limit of uncontaminated soil initially increased up to 4% SEO treatment. The addition of SEO to the soil caused micro-structural transformation of the soil, which led to inter layer expansion within the clay minerals. This is in agreement with the findings of [15, 16].

The crude oil might have enveloped both the clay minerals of the soil and the adsorbed water bonded to its surfaces leading to increase in liquid limit. No initial difference was noticed for the plastic limit with increase SEO content. The plasticity index also increased with progressive addition of SEO up to 4 % SEO indicating that the contaminated soil became less workable. This agrees with earlier works of [15, 16] on effects of crude oil contamination on the index properties, strength and permeability of lateritic clay and observed a trend of increase in plasticity index values with higher crude oil contamination. The results of the liquid limit tests for SEO content higher than 4 % followed the patterns observed by [17-19] which indicated a decrease in liquid limits and plasticity index with increasing content of contaminant.

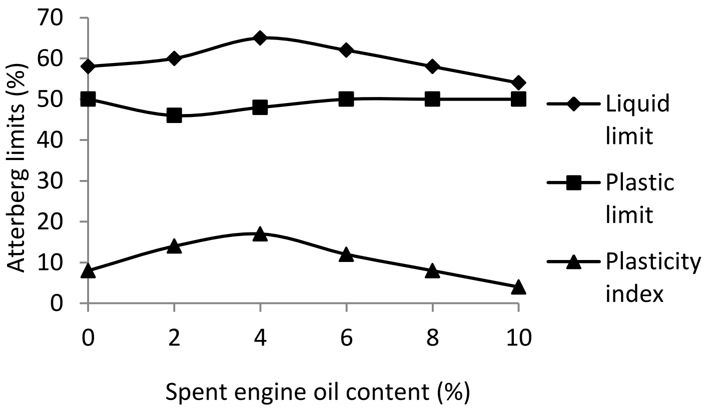

Fig. 2. Graph of consistency limits against various percentage of spent engine oil contamination.

Based on the Atterberg limits and particle size distribution of samples, the natural soil was classified as A-5 (2) by AASHTO classification and ML according to the Unified Soil Classification System for 0% SEO, A-7-5(1) and ML for 2% SEO, A-7-5(2) and ML for 4% SEO, A-7-5(1) and ML for 6% SEO, A-5(1) and ML for 8% SEO, A-5(2) and ML for 10% SEO.

3.2. Effect of spent engine oil contamination on the compaction characteristics of lateritic soil

The aim of carrying out compaction test was to determine the optimum moisture content (OMC) and the maximum dry density (MDD) values of the samples. No general trend was established for OMC with increase in SEO content; however, MDD reduced for natural soil and SEO contaminated soil samples as the percentage of SEO content increased as shown in Figs. 3 and 4 respectively. Moreover, as the compactive effort increased, the maximum dry density increased also. The reduction in MDD values with increased SEO content reflects the effect of lubrication imparted on the soil due to the presence of SEO in it which facilitated compaction by slippage of soil particles into empty voids and hence reduced the amount of water needed to reach maximum dry density [20]. This decrease in MDD could be attributed to the fact that oil had partially occupied the soil particle interstitial spaces which resulted in some loosening of the soil matrix.

Even though there was increasing formation of pseudo-sand soil clogs which resulted from the bonding nature of the pore fluid formed in the presence of spent engine oil, the presence of oil might cause the slippery of the soil aggregates formed over one another, the effect which also increased with increased SEO content. However, the effect reduced with increase in the energy level. This might be due to the changes in viscosity of the pore fluid, rearrangement in the soil structures with elimination of void and replacement of macropores with micropores and hence increase in the density of the soil matrix. The change in the composition of the pore fluid would also affect the microstructure of the clayey lateritic soil [21].

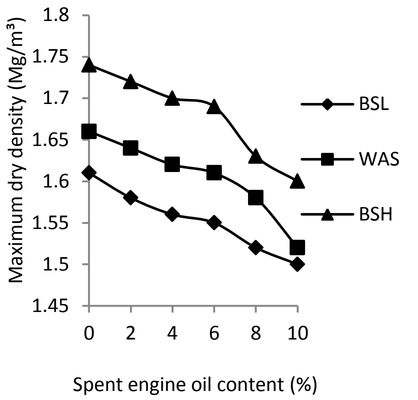

Fig. 3. Variation of maximum dry density with spent engine oil content.

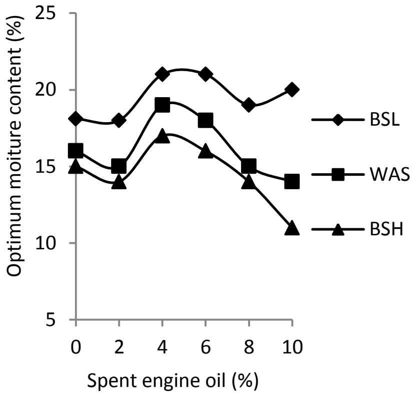

Fig. 4. Variation of optimum moisture contents with spent engine oil content.

3.3. Effect of spent engine oil contamination on the unconfined compressive strength of lateritic soil

Unconfined compressive strength test was carried out on natural soil and the contaminated soil samples. The results, as shown in Fig. 5, reflected that as the percentage of SEO content increased, its unconfined compressive strength reduced from values of 149, 269 and 285 kPa for the natural soil sample to the lowest value of 75, 142, 236 kPa for 10 % SEO contaminated soil at BSL, WAS and BSH compactive effort respectively. Higher strengths were recorded with increase in the compaction energy. Similar results were obtained for oil contaminated residual soils by [6, 21- 23].

The decrease in the UCS might be resulted from the weak bonding within the soil matrix initiated by lubrication action of the SEO which caused the soil grains to glide over one another. This is similar to the results of California bearing ratio (CBR) and UCS reported in [16, 24, 25].

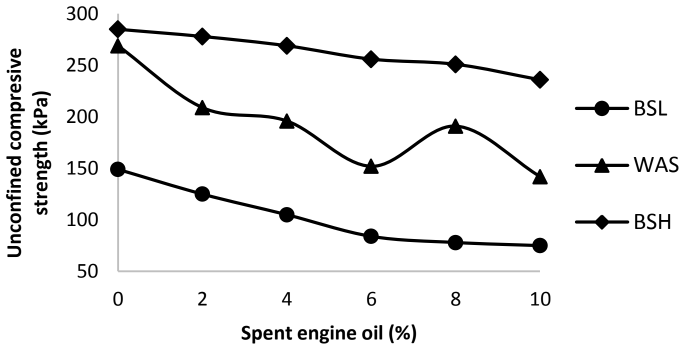

Fig. 5. Variation of Compressive strength (UCS) with spent engine oil content.

4. Regression Analysis of Strength Indices

Results of regression analysis showed that the unconfined compressive strength was influenced by the grading properties, compaction characteristics and compactive effort applied. This agrees with previous statements by Gidigasu (1976) who stated that the behaviour of laterite soil used in pavement structure has been found to depend mainly on their particle size characteristics, the nature and strength of the particles and the degree to which the soils have been compacted.

The geotechnical properties considered for this analysis include the spent engine oil content, maximum dry density, optimum moisture content, percentage fine, plasticity index using compactive effort as a deterministic parameter with compactive effort index values of -1, 0 and 1 for British Standard light, West African Standard and British Standard Heavy compactive efforts respectively. The percentage of fine, optimum moisture content and compactive effort has the most significant effect on the unconfined compressive strength with positive coefficients. The correlation coefficient values (R^2) shows a strong relationship between UCS and the parameters in Eq. (2) with R^2 value of 66.8%. The regression equation is:

$$\text{UCS} = 1679 - 19.5\text{SEO} - 974\text{MDD} + 60\text{MC} + 146\text{CI} - 1.96\text{PI} + 108\text{PF} \quad (2)$$

R^2 = 66.8%,

where: UCS = unconfined compressive strength, SEO = Spent engine oil,
MDD = Maximum dry density, OMC = Optimum moisture content,
CI = Compactive effort, PI = Plasticity index, PF = Percentage fine.

The conceptual regression model, as shown in Eq. 2, developed using Minitab R15 shows a strong correlation between the measures UCS values obtained by laboratory test and the predicted values from the model with coefficient of determination R = 0.887, R = 0.861 and R = 0.696 for BSL, WAS and BSH compaction energy respectively(see Figs. 6-8). An absolute percentage error of

2.12-28.05%, 1.96-17.32%, and 0.18-71.17% for BSL, WAS and BSH compaction energy were recorded (see Table 2).

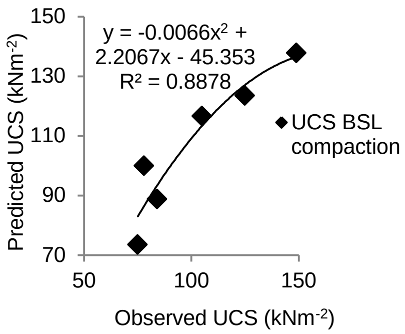

Fig. 6. Variation of measured UCS values against predicted UCS values from the model for BSL compaction.

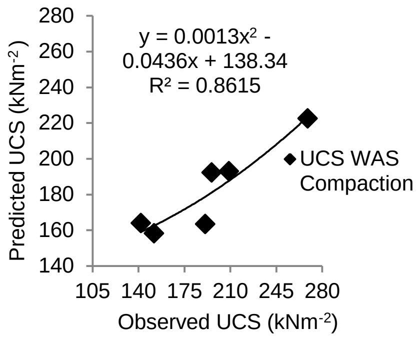

Fig. 7. Variation of measured UCS values against predicted UCS values from the model for WAS compaction.

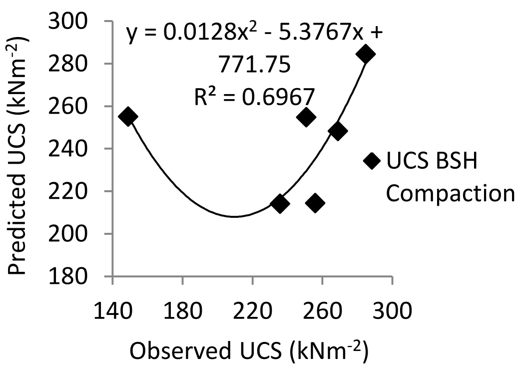

Fig. 8. Variation of measured UCS values against predicted UCS values from the model for BSH compaction.

Result shows that the degree of correlation between the soil parameters and the UCS values decreased with increase in the compactive effort as indicated in the gradual change of the curves from concave pattern through to convex pattern as shown in Figs. 6 to 8.

4.1. Analysis of Variance

Statistical analysis of all the results obtained for the parameters (UCS, SEO, MDD, OMC, CI, PI, PF and MDD) using analysis of variance (ANOVA) with respect to the compactive efforts produced statistically significant (SS) results as shown in Table 3. Using the F-distribution test at 95 % level of significance, compactive effort has significant effect on the outcome of the results recorded from the ANOVA test.

Table 2. Measured UCS values and predicted UCS values from the model.

Compactive effort	SEO content (%)	Observed UCS (kN/m^2)	Predicted UCS (kN/m^2)	Absolute error	% Error
BSL	0	149	137.7	11.3	7.58
	2	125	123.4	1.6	1.28
	4	105	116.6	11.6	11.05
	6	84	88.7	4.7	5.6
	8	78	99.88	21.88	28.05
	10	75	73.41	1.59	2.12
WAS	0	269	222.4	46.6	17.32
	2	209	192.96	16.04	7.67
	4	196	192.16	3.84	1.96
	6	152	158.26	6.26	4.12
	8	191	163.44	27.56	14.43
	10	142	163.93	21.93	15.44
BSH	0	285	284.48	0.52	0.18
	2	149	255.04	106.04	71.17
	4	269	248.24	20.76	7.72
	6	256	214.34	41.66	16.27
	8	251	254.74	3.74	1.49
	10	236	214.01	21.99	9.32

Table 3. Analysis of variance for unconfined compressive strength.

Variable	Source of Variation	Degree of freedom	F_{CAL}	p-value	F_{CRIT}	Re-mark
UCS 14 Day Curing	SEO Compactive Effort	5 2	2.167 23.521	0.13948 0.00017	3.326 4.103	NSS SS
Maximum Dry Density	SEO Compactive Effort	5 2	56.682 204.72	5.17E-07 7.7E-09	3.326 4.103	SS SS
Optimum Moisture Content	SEO Compactive Effort	5 2	6.253 32.624	0.006994 4.14E-05	3.326 4.103	SS SS
Plasticity Index	SEO Compactive Effort	1 10	5.990 -	0.034408 -	4.965 -	SS SS
Percen-tage Fine	SEO Compactive Effort	1 10	7.476 -	0.021043 -	4.965 -	SS SS

SS = Statistically significant; NSS = Not statistically significant at 5 % level

5. Conclusion

Base on the preliminary investigations and various geotechnical tests conducted on the natural reddish brown lateritic soil classified as ML and A-5(10) according to Unified Soil Classification System and AASHTO mode of soil classification respectively, the following conclusion were drawn.

- The natural soil had liquid limit of 58 %, plastic limit of 50 % and plasticity index of 8%. The liquid limit of the soil initially increased from 58 to 62 % when treated up to 4% SEO while the plastic limit did not record any initial change with SEO treatment. The plasticity index initially increased with higher SEO contents.
- The MDD values decrease with increase in SEO contents but increased with higher compaction energies. However, no general trend was observed for OMC values with higher SEO content.
- In the case of UCS, a general trend of decreased was observed with SEO treatment while higher UCS values were recorded with increase in compaction energy.
- Regression analysis revealed that optimum moisture content, percentage fine and compactive effort significantly influence the soils UCS values. Analysis of variance showed that SEO and compactive effort has significant effect on the consistency and strength indices of the soil.
- SEO contamination has negative effect on the geotechnical properties of soils thereby rendering it unsuitable for engineering purposes without remediation or stabilization processes to restore it to its pristine state.

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