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Geotechnical Stabilization Potential of Cement Admixed with Rice Husk Ash on the Crude Oil Polluted Laterite Soil: A Case Study of Ebendo, Delta State, Nigeria

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Abstract
Crude oil pollution of the environment is one of the greatest concerns to Nigeria's oil-rich Niger Delta and most oil producing regions of the world, with far-reaching effects on the ecosystems. In this study, the influence of oil pollution on geotechnical properties of laterite soil and possibility of stabilization with rice husk ash (RHA) and ordinary Portland cement (OPC) were investigated. Soil sample categorized as A-2-6 and CL was artificially contaminated with 0, 2, 4, 6, 8, and 10% crude oil. The consistency limits, specific gravity (SG), Compaction, Uniaxial compressive strength (UCS) and California Bearing Ratio (CBR) tests were carried out on both uncontaminated and contaminated soil samples. The 10% contaminated specimen was further stabilized with admixture of OPC and RHA using different percentages (0-10%) by mass of soil. A significant decrease in SG, maximum dry density (MDD), CBR and UCS was revealed but with an increase in consistency limits and optimum moisture content (OMC) as the volume of crude oil increased from 0 to 10%. However, stabilization of the contaminated soil with OPC and RHA improved the soaked CBR and UCS. The addition of OPC (0-10%) enhanced the UCS and CBR of the 10% polluted soil from 25-119 kN/m2 and 2-18.3%, respectively, while the treatment with RHA increased the UCS and CBR values from 25-60 kN/m2 and 2-4.4%. The results of research clearly show that oil contamination had considerable influence on soil properties but addition of 10% RHA or 8% OPC can be adopted to restore and enhance the geotechnical properties of the polluted laterite soil.

Keywords: Crude oil contamination, Lateritic soil, Rice husk ash, Soil stabilization, Strength properties.

Introduction
Crude oil leakage and spillage to the environment have become one of the greatest concerns of many oil-rich countries including Nigeria. These have harmful effects on the quality of human life, animals, microorganisms and plants. Other major impacts of these oil spillages and leakages are the variations in chemical and physical characteristics as well as the engineering behaviour of soil, with a far-reaching effects on the structures it supports (Khosravi *et al*., 2013; Oluremi and Adedokun, 2019; Elsaigh and Oluremi, 2022). Pollution can cause considerable increase in plasticity of soil, bearing capacity failure, increase settlement, reduce soil permeability or prevent soil drainage, groundwater pollution and other likely effects. Soil pollution could also increase project cost for the proposed construction work due to extra geotechnical and chemical analyses of soil to ascertain the level of pollution, as well as necessity for soil remediation or stabilization.
Some works had been performed to investigate the impacts of oil contamination on geotechnical features of soils. Rahman et al (2007) studied the index and strength properties of high plasticity clay with oil pollution and found that the addition of oil increases the consistency limits, cohesion, and MDD with a decrease in OMC of this soil. Khamehchiyan *et al*. (2007) examined index and strength characteristics of the oil polluted sand and clay. The study observed a decrease in consistency limits, MDD, OMC, strength and permeability of the two soils. According to Kermani and Ebadi (2012), oil contamination of fine-grained soil resulted in increase in consistency limits, MDD, friction angle, and compression index with a corresponding reduction in OMC and cohesion of soil. Khosravi *et al*. (2013) examined the geotechnical

features of the kaolin clay polluted with gas oil and found a rise in liquid limit (LL), plasticity index (PI) and cohesion while a reduction was observed for soil compressibility and friction angle. Effects of oil products on index and strength parameters of soil were examined by Rasheed *et al*. (2014), and found that the SG, the plasticity index (PI), MDD, OMC, CBR and cohesion of the soil reduced with a rise in friction angle, LL and PL of the soil. Nwachukwu *et al*. (2020) experimentally studied the impacts of oil pollution on index and strength parameters of clay soil. The findings indicated an increased consistency limits and OMC, but a reduction in SG, bulk density and MDD of soil. Abdelhalim *et al*. (2022) investigated the impacts of oil pollution on index and strength characteristics of the lateritic soils having two soil classifications. A considerable decrease in consistency limits, bulk unit weight, optimum fluid content, angle of friction, cohesion and permeability were observed.

The above reviews on influence of the oil spoilage on the engineering features of soils revealed that there is no clear agreement or consistency on the findings from the existing studies. Although all these reviews focused on the index and strength, there were differing results and this necessitates further work for validation especially on properties of laterite soil, which is a common road construction material in Nigeria and other tropical countries. Thus, this work assessed the impacts of crude oil contaminations on index and strength characteristics of the laterite soil. As way of stabilizing or remediating the polluted soil, the influence of ordinary Portland cement (OPC) and rice husk ash (RHA) on properties of the contaminated soil was evaluated. The experimental works included the determination of specific gravity, Atterberg limits, OMC, MDD, UCS and CBR of the oil polluted soil samples while CBR and UCS were determined on the treated soil samples.

Materials and Methods

Materials employed were laterite soil, crude oil, rice husk ash and cement. The experimental methods employed were in accordance to provisions of BS 1377 (1990) and BS 1924 (1990).

A deep-brown with mottled greyish patches of laterite samples were obtained at a cellar pit in Ebendo, Delta State, Nigeria (Latitude 189770.0ºN and longitude 439200.0ºE). The disturbed soil samples were obtained at 2m depth below the ground. Soil samples were air-dried, pulverized and allowed to pass through BS sieve No. 4 (4.75mm) to determine its particle size distribution (PSD). The oil sample was obtained from Emu-Ebeno Marginal Oil Field, Delta State. The physicochemical test was conducted on the obtained crude oil specimen to determine its composition and the result was compared with the recommended standard values. Rice husk used was collected from Abakaliki, Ebonyi State, Nigeria, and was calcinated into ash at Chemical and Petrochemical Laboratory of the River State University in an incinerator at a temperature of 520ºC in one hour for highly reactive RHA (Mehta, 1979; Behak, 2017). The ash and the natural soil sample were analyzed by employing X-ray florescence (XRF) analyzer at the same institution to determine their chemical compositions. Dangote cement (42.5R) was purchased from one of the retail shops in Port Harcourt metropolis in River State, Nigeria.

The obtained soil specimen was first air-dried, pulverized and allowed to pass through BS sieve size 4.75 mm before its usage without addition of any additive, in accordance to BS 1377 (1990) provisions so as to have a uniform colour and representative soil specimen for geotechnical tests. The soil samples were thereafter contaminated with 0-10% (at interval of 2%) crude oil by mass of the lateritic soil. The contaminated specimens were left in different containers at the laboratory for two months to be saturated before geotechnical tests were done on them. Representative specimens of the contaminated samples, which show distinctive changes in appearance from brown to dark colours with increasing contents of the oil, are presented in Figure 1.

The effects of contaminations on index and strength properties of the soil were investigated by performing Atterberg limits, specific gravity, compaction, CBR and UCS tests on both the unpolluted and polluted soil samples. The 10% crude oil contaminated soil, which showed lowest geotechnical results, was then stabilized with the OPC and RHA. The additives (OPC and RHA) proportions were varied from 0-10% by mass of laterite soil (at 2% intervals). After mixing, the strength (CBR and UCS) tests were carried out on each of the combinations and their results were recorded.

A. Natural soil

B. 2% Contamination

C. 4% Contamination

D. 6% Contamination

E. 8% Contamination

F. 10% Contamination

Figure 1: Representative samples of crude oil contaminated laterite soil

Results and Discussion

Results and discussions of all materials and experimental tests carried out in this study are comprehensively presented as follows.

Chemical characterization of rice husk ash and cement

The results of chemical characterization conducted on the rice husk ash (RHA), cement and natural soil, which show the oxide compositions of these materials, are presented in Table 1. From the table, the sum of the Silica (SiO_2), Alumina (Al_2O_3) and Ferrite (Fe_2O_3) for the RHA is 83.97%, which is higher than 73.15 reported by Okafor and Okonkwo (2009) but quite similar to 82.52% of Ayininuola and Olaosebikan (2013). This result shows that the rice husk ash used is a good pozzolan, which falls into Class F pozzolan or mineral admixture, in accordance with ASTM specification C618 (2014). According to Tastan et al. (2011), this rice husk ash as categorized into Class F fly ash has potential to form Calcium Silicate Hydrates (CSH), Calcium Aluminate Hydrates (CAH) and Calcium Alluminate-Sillicate Hydrate (CASH) due to the reaction of fly ash with the soil. The lime content (1.51%) of RHA is significantly lower when compared to that of cement (60-67%). The ratio of silicon oxide (SiO_2) to sesquioxides (Al_2O_3 + Fe_2O_3) for the natural soil from the Table 1 is 1.13. The specification is that the soil is a laterite if the silica to sesquioxide ratio is lower than 1.33, lateritic soil if the ratio is in the range of 1.33 to 2.0 and greater than 2.0 means the soil is non-lateritic (Bell, 1993). This result therefore indicates that the soil sample is a Laterite. The higher content of the silicon oxide in the soil is an indication that the soil is chemically inert and structurally stable (Meshida and Akanbi, 2007; Apata and Adedokun, 2020), and the soils that exhibit these properties are able to withstand traffic loads and surface deformations (Apata and Adedokun, 2020). The results of the physicochemical test conducted on the Brent crude oil sample were presented as shown in Table 2. The specific gravity and other properties are within the standard recommended for ideal crude oil content.

Table 1. Oxide Composition of the RHA and Cement

Chemical constituents	RHA (%)	Cement (%)	Laterite soil
SiO_2	81.20	17-25	40.10
Al_2O_3	1.51	3-8	22.70
Fe_2O_3	1.27	0.5-6	12.94
CaO	1.55	60-67	<0.0015
MgO	2.30	0.5-4	0.26
SO_3	0.17	1-2	-
Na_2O	0.14	-	-
K_2O	2.04	-	0.38
P2O5	6.45	-	-
V2O5	-	-	3.28
ZrO	-	-	0.99
TiO_2	-	-	1.06
CuO	-	-	0.05
MnO	-	-	0.08
Cr_2O_3	-	-	0.03
SiO_2 +Al_2O_3+Fe_2O_3	83.97		
SiO_2/(Al_2O_3+Fe_2O_3)			1.13

Geotechnical features of the natural soil

Results of various experimental soil tests performed on the natural soil were presented in Table 3. The soil is deep-brown in colour due to the presence of iron oxide. The percentage passing through BS sieve No. 200 is 34%, that of liquid limit (LL) is 33 (< 40%) and plasticity index (PI) is 17.1% (>11%). Based on these results, the soil is classified as clayey A-2-6 soil, which is rated as a good subgrade for roads, with Group Index (GI) of zero in relation to AASHTO (2002) Soil Classification. Also, the soil is clayey soil with low plasticity (CL) on the Unified Soil Classification System (USCS) (ASTM 1992). The soil has MDD, OMC and specific gravity of 1.87 g/cm^3, 10.3% and 2.47, respectively, while the corresponding soaked CBR and UCS values are 3.2 and 49 kN/m^2. Figure 2 shows gradation curve of the natural soil. The results from the gradation curve revealed that the soil sample contained silty clay (34%) with mixtures of 36% fine sand and 30% medium sand. Since the soil is a silty clayey sand and the percentage finer than 75 µm was less than 34%, this soil is a good subgrade material for road construction.

Table 2. Physicochemical Properties of the Crude Oil

Parameter	Content	Standard
Specific gravity	0.97	0.80 – 0.99
API gravity	13.88	< 20
Flash point	80.30	< 120
Sulphur	3.70	< 10
Carbon residue	2.55	< 10
Water content	0.003	< 0.10
Kinematic viscosity	0.82	< 5.0
Pour point	-16.00	< 30.0
Cloud point	-25.00	< 40.0
Nickel	2.40	< 5.00
Vanadium	0.57	< 2.0
Nitrogen	0.13	< 1.0
Insoluble matter	1.00	< 5.0
Hydrogen	11.19	< 20
Carbon	85.70	< 100
Oxygen	0.09	< 2.0

Table 3: Geotechnical features of the naturally unstabilized soil

Experimental features	Values
Specific gravity	2.47
Percentage finer (Sieve No. 20)	34.0
LL (%)	33.4
PL (%)	16.3
PI (%)	17.1
USCS	CL (Low plasticity clayey sand)
AASHTO	A-2-6 (0)
OMC (%)	10.3
MDD (Mg/m^3)	1.87
CBR (%, Soaked)	3.2
UCS (kN/m^2)	49

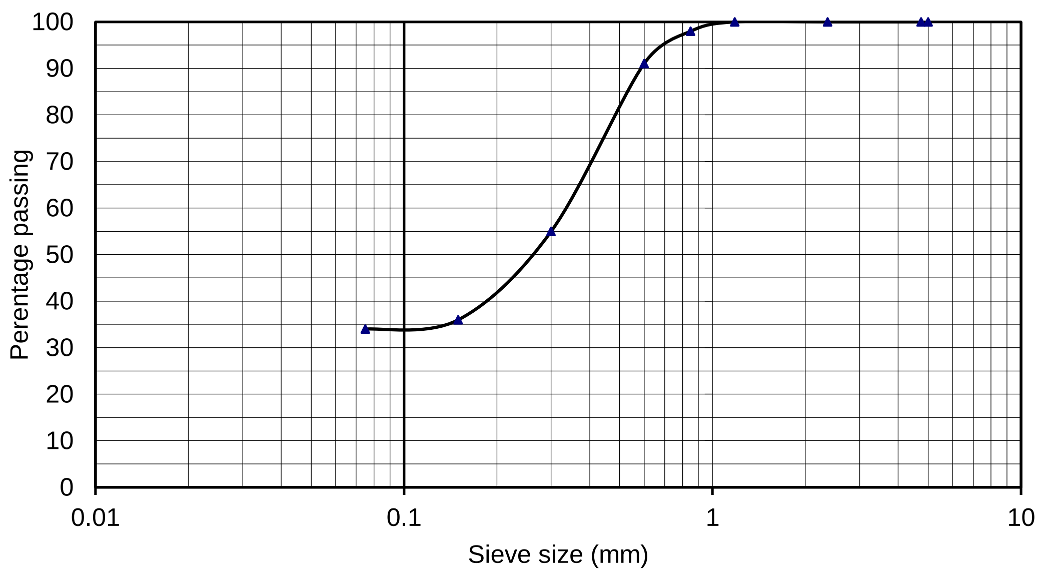

Figure 2: Gradation curve for the natural soil

Influence of crude oil pollution on the geotechnical features of the laterite soil

Specific gravity

The influence of oil contamination on the specific gravity (SG) of this soil is shown in Figure 3. The natural soil had the specific gravity value of 2.47. For 2-10% oil contaminated samples, the SG value reduced from 2.43 to 2.24. The results clearly showed that specific gravity decreased with increasing contamination of the soil, although the specific gravity increased slightly at 4% contamination, however, the value is below that of natural soil. This reveals that the addition of oil lowered the specific gravity of soil, and this agrees with the findings of previous studies (Ijimdiya, 2007; Rasheed *et al*., 2014; Oluremi *et al.*, 2015 and Nwachukwu *et al.,* 2020). The decreased in SG of the polluted soil could be due to low SG of the crude oil, and these results evidently show that oil pollution has considerable negative impacts on the specific gravity of soils.

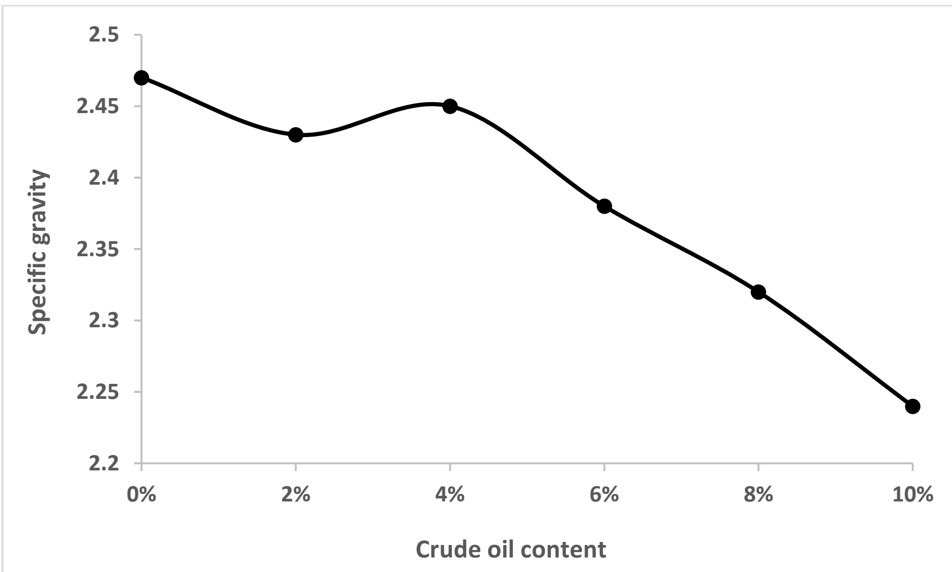

Figure 3: Influence of oil pollution on specific gravity of lateritic soil

Atterberg limits

Figure 4 indicates the influence of oil contaminations on LL, PL and PI of the lateritic soil. The LL, PL and PI values of the uncontaminated soil are 33.4, 16.3 and 17.1%, respectively. The LL and PL values increased slightly to 34.2% and 19.7% at 4% crude oil content but thereafter decreased to 33% and 17% at 10% crude oil contamination. However, the plasticity index value decreased from 17.1% at zero contamination to 14.5% at 4% contamination but increased slightly to 16% at 10% contamination. The results generally show a rise in the plasticity as the volume of oil increased, although the rate of increase depends on the amount of clay in the soil. That is, the higher the clay content, the higher the impact of the contamination. This trend of result is in agreement with the existing ones ((Rahman *et al.*, 2010; Khosravi *et al.*, 2013; Rasheed *et al*., 2014; Oluremi *et al.,* 2015 and Nwachukwu *et al.,* 2020). The increase can be attributed to soil micro transformation, which caused the expansion of inner layer of the clay minerals. The addition of oil glued the clay minerals and adsorbed water bonded to its surface. This mechanism raised the thickness of the diffused double layer, and thereby leads to increase in soil plasticity. Results reveal that the presence of oil makes the soil unfit geotechnically due to a rise in the plasticity of soil.

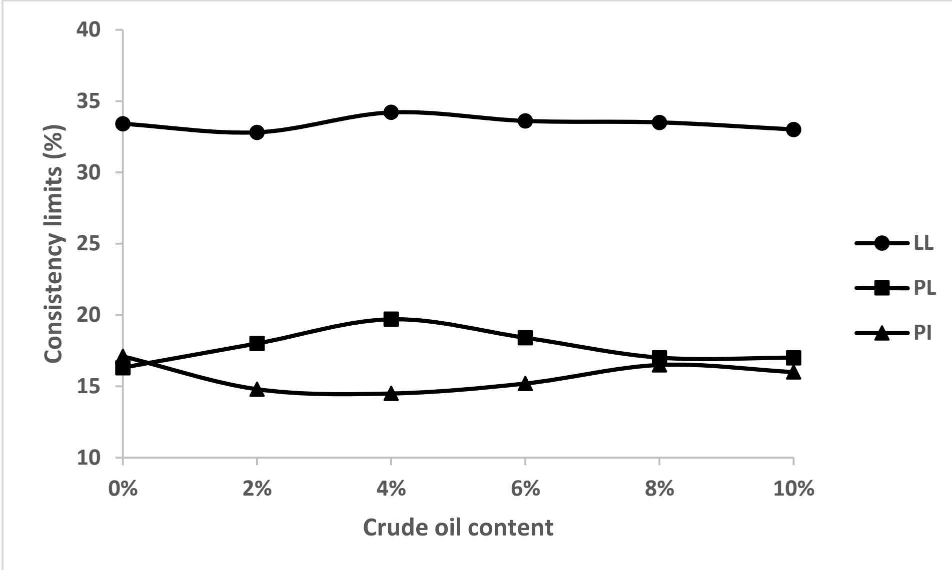

Figure 4: Influence of oil pollution on consistency limits

Compaction

Figure 5 indicates the impacts of oil contaminations on dry densities and moisture contents of the soil. Results from the two figures indicate a reduction in soil density with equivalent increase in moisture content upon contamination which affects negatively the compaction parameters of soil. The optimum moisture content (OMC) and maximum dry density (MDD) of the natural soil were 10.3% and 1.87 g/cm^3, respectively. For the contaminated soil samples, the MDD and OMC values varied from 1.82 g/cm^3 and 13.82% at 2% oil contamination to 1.52 g/cm^3 and 15.80% at 8% contamination, respectively. These results showed clearly the maximum dry density of the soil decreased with increasing dosage of the oil whereas optimum moisture content increased as the volume of the crude oil in the soil. The lower specific gravity of crude oil (≤ 1.00), compared to 2.47 of the soil, and could be responsible for the decrease in the MDD of the laterite soil with increasing oil dosage. The decrease in MDD could also results from an increase in the diffused double layer that cause the contaminated soil to be less packed together. This result is in line with findings of previous works (Rasheed *et al*., 2014; Oluremi *et al.,* 2015 and Nwachukwu *et al.,* 2020).

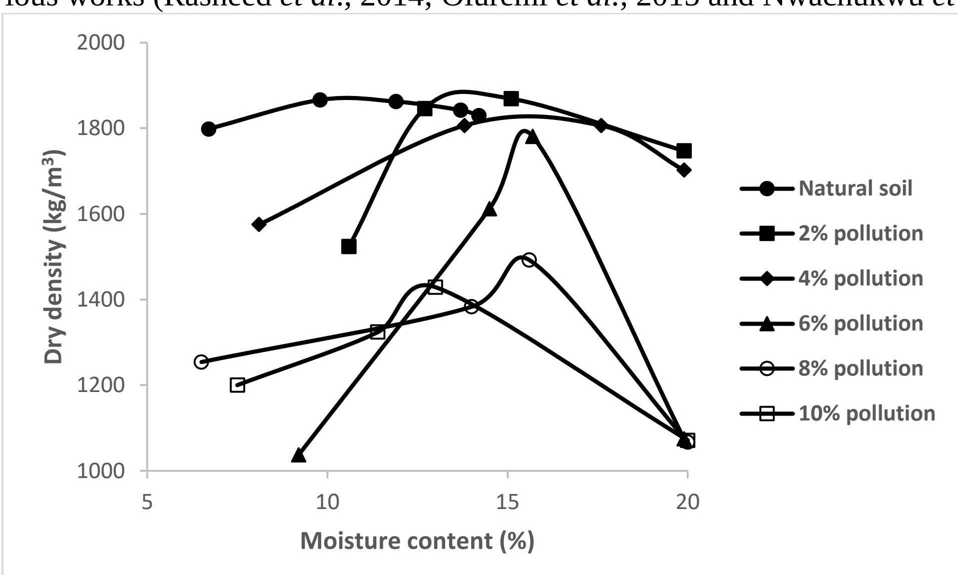

Figure 5: Influence of oil pollution on dry density and moisture content of soil

Strength characteristics

Figure 6 shows the impact of oil pollution on the soaked CBR and UCS of laterite soil. The values of UCS and soaked CBR of natural soil were 49 kN/m^2 and 3.2%, respectively. For 2-10% contamination, the CBR and UCS values decreased slightly with increasing oil content. The values dropped from 3.5% and 32 kN/m^2 at 2% contamination to 1.6% and 25 kN/m^2 at 10% contamination. With the reduction in the CBR value from 3.2% for unpolluted soil to 1.6% at 10% oil contamination, the implication of the result is that the addition of the crude oil changed the lateritic soil from sandy clay to clay. This reveals that the presence of oil in soil had adverse effect the strength parameters of the soil, and similar trend was established by Ijimdiya (2007) and Oluremi *et al.* (2015). The reduction in strength properties might result from the slippery of the soil grains over one another as a result of the lubricating impact of oil in presence of water.

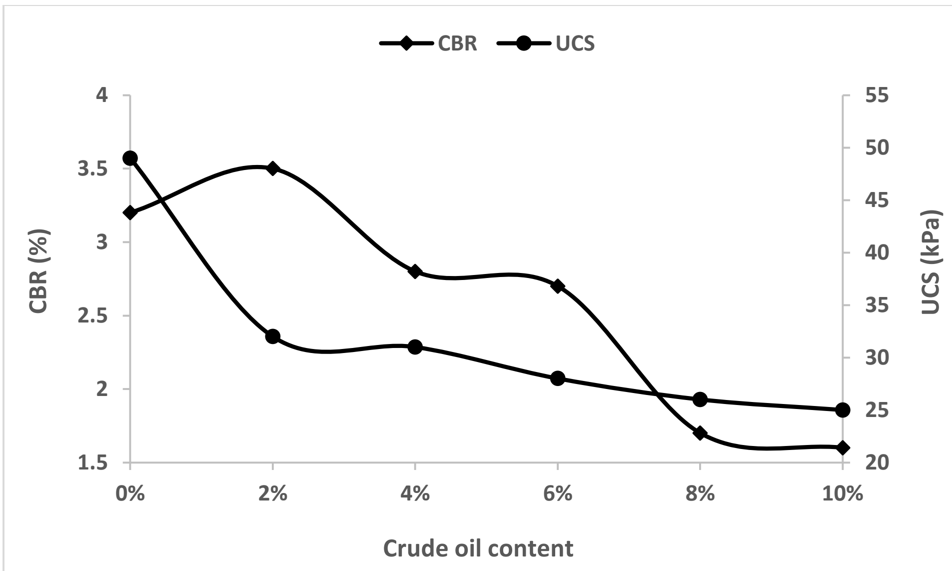

Figure 6: Influence of oil pollution on soaked CBR and UCS of the laterite soil

Impact of RHA and cement on the strength properties of oil polluted soil

Figure 7 presents the effect of RHA and cement on soaked CBR of oil polluted laterite soil. The soaked CBR observed for 10% contaminated soil was 1.6%, and this value increased from 2.5 - 4.4% and 8 – 18.3% for 2-10% addition of RHA and cement, respectively. It is evident from the result that the CBR of the treated soil increased with increasing percentage of RHA and cement in the samples, although the influence of cement on the CBR value is quite significant than that of RHA due to strong hydration reaction of cement and pozzolanic reaction between the liberated lime and siliceous materials in the soil to produce CAH and CSH. The increase in CBR in both admixtures might be due to the formation of cementitious compounds (CSH and CAH), which enhance the bond within the soil-additive mix, thereby leading to increasing strength of the RHA-cement-stabilized crude oil polluted laterite soil. With increase in CBR value from 1.6% for the 10% contaminated soil sample to 4.4% and 18.3% at 10% addition of RHA and cement respectively, the implication of the result is that the addition of RHA and cement changed the lateritic soil from clay to sandy clay and well graded sand respectively. This result is also consistent with results of previous studies (Prusinski and Bhattacharja, 1999; Adedokun *et al.*, 2022). These results clearly indicate that the addition of the RHA and cement can be used to restore and enhance the strength of the oil contaminated laterite soil.

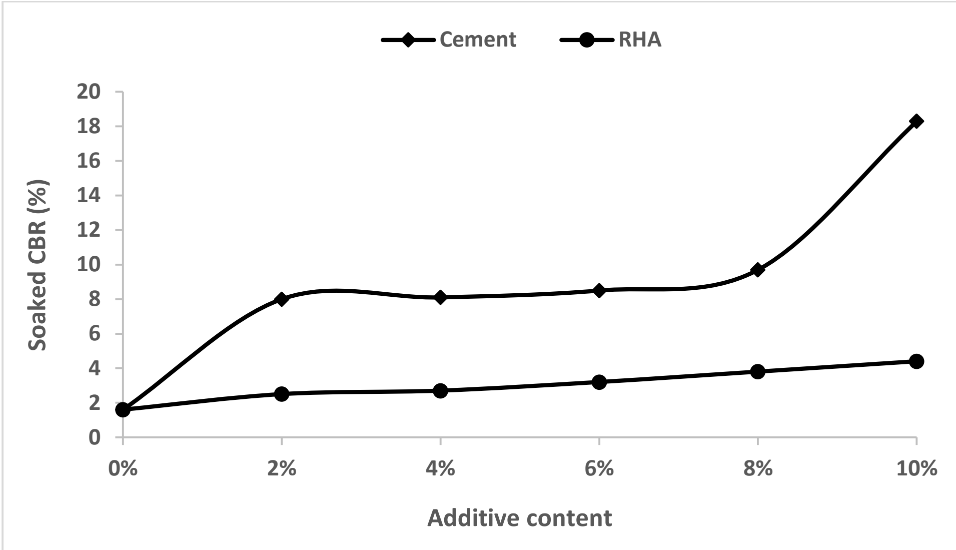

Figure 7: Influence of RHA and Cement on CBR of the oil polluted soil

The impact of RHA and cement on UCS of the oil crude polluted soil is presented in Figure 8. The UCS value of the 10% contaminated soil was 25 kN/m^2, which increased from 25 – 60 kN/m^2 and 27 – 119 kN/m^2 for 2-10% addition of RHA and cement, respectively. These results indicated that the UCS of the treated soil increased as the content of RHA and cement in the samples increased, although the impact of cement on the UCS value is more significant than that RHA as this may be attributed to strong hydration reaction of cement and pozzolanic reaction between the liberated lime and siliceous materials in the soil to produce CAH and CSH. The increase in UCS is due to formation of cementitious compounds like CSH and CAH in the RHA-OPC-treated crude oil contaminated laterite soil. This result also agrees with results of the previous studies reported by Prusinski and Bhattacharja (1999). The results generally revealed that the addition of 8% cement or 10% RHA is able to restore the crude oil contaminated soil back to near its original strength.

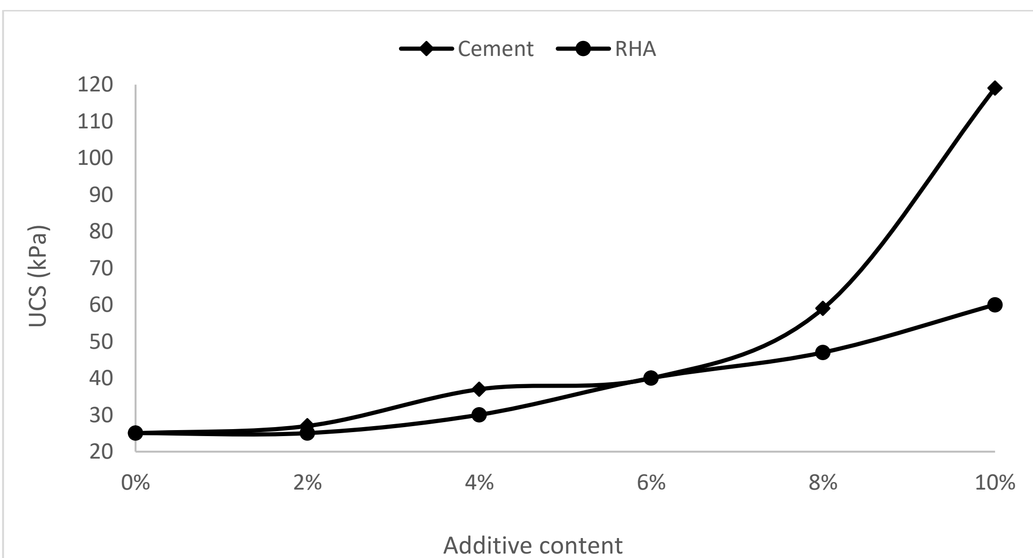

Figure 8: Influence of RHA and Cement on UCS of the oil polluted soil

Conclusions

Influence of oil pollution on the index and strength characteristics of the laterite soil and subsequent remediation using cement and RHA were evaluated, with the following stated conclusions.

i. The soil is classified as A-2-6 and CL (clayey soil with low plasticity) soil, which is rated as a good subgrade for roads. In addition, the natural soil can be further classified as a laterite based on the silica sesquioxide ratio of 1.13 with higher silica content, which is an indication that the soil is chemically inert and structurally stable.
ii. The results indicate that crude oil contamination of the soil has significant effect on the geotechnical features of the soil as the liquid and plastic limits of the soil increased as the crude oil contamination increases. The values of these parameters were higher compared to that of natural soil, however, the specific gravity and plasticity index decreased with increasing oil contamination.
iii. The contaminant decreased the maximum dry density of the laterite soil.
iv. Similar trend of reduction in CBR and UCS of the soil with increasing crude oil contamination was observed.
v. The stabilization of the crude oil contaminated soil with ordinary Portland cement and rice husk ash enhanced the uniaxial compressive strength and California bearing ratio of the soil.
vi. The use of 8% cement or 10% rice husk ash was able to restore the 10% crude oil contaminated soil back to near its original strength, and this is recommended for the use of the crude oil contaminated laterite soil as a subgrade material in earthworks construction.

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