Effects of Crude Oil, Low Point Pour Fuel Oil and Vacuum Gas Oil Contamination on the Geotechnical Properties Sand, Clay and Laterite Soils.

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ABSTRACT

A laboratory testing program was carried out on three selected soils namely, clay, laterite and sand fraction contaminated with used engine oil, low pour point fuel oil (LPFO) black and crude oil. The testing program was carried out to establish the effect of the contaminants on the engineering properties of the materials. Testing included Atterberg properties, compaction, consolidation, California Bearing Ratio (CBR), triaxial compression etc. on both clean and contaminated specimens. Contaminated specimens were prepared by mixing each soil type with 2, 4, and 6% by weight of the contaminants. The results obtained showed that the shear strength of sand and laterite increased with used engine oil contamination. The shear strength of clay soil increased with used engine oil contaminations at 2 and 4% LPFO contaminations. However, at 6% LPFO contamination and 2 to 6% crude oil contamination, the shear strength of clay decreased. The CBR values of the contaminated sand and laterite recorded higher values at 2% oil contaminations and subsequently decreased with further increase in oil content to 4% and 6%. The CBR values for the clay decreased with oil contaminations. Other deleterious changes included an increase in consolidation settlement for used engine oil contaminated laterite. However, the consolidation settlement of the contaminated clay soil generally decreases with all the contaminants.

Keywords - **Contaminated samples, California Bearing Ratio, Consolidation, Laterites, Shear Strength, Triaxial Compression.**

I. INTRODUCTION

The frequent destruction of oil pipelines by vandals has resulted in massive pollution of air, water bodies and the ground. This result to substantial release of crude oil and its refined derivatives oil and the subsequent fires that occurs (which often lasts for several hours). These releases collect in large pools, some of which cover extensive areas. Many are several meters long and penetrate deep down the affected areas. Also oil leakages/spillages from the storage tanks in the refineries/processing plants or as a result of on/off loading of the oil in various depots have caused various levels of contamination to the surrounding soils (Udiwal and Patel, 2010).

However, the massive usage of a low pour point fuel oil LPFO, (a petroleum product popularly known as black) in various industries, the frequent usage of another petroleum by-product vacuum gas oil (VGO or engine oil) in our vehicles, generators, etc., coupled with the indiscriminate disposal of the used product (engine oil) on the ground, also lead to the contamination of soils environment. Another source of soil contamination is cable insulating oil which is deemed a threat to public health and the environment, Jinlan *et al.* (2011). After these spillages/leakages, the oil migrates downwards under the force of gravity. The mobility of the oil in the soil depends on its viscosity, quantity of oil leaked/spilled and the permeability of the soil. During this downward movement through the unsaturated zone of the soil mass, there is absorption and reaction between the oil and the soil matrix tending to immobilise and attenuate the oil. In the case of a situation where the water table is far enough below the ground surface, the oil may be immobilised in the unsaturated zone before it reaches the water table. Contaminants like dual purpose kerosene (DPK or gas), premium motor spirit (PMS or petrol), automotive gas oil (AGO or gas) etc., exhibit evaporative tendencies due to the nature of their highly volatile inorganic compounds. While contaminants like low pour point fuel oil (LPFO), vacuum gas oil (VGO) exhibit a quick smearing tendency to the soil particles due to their viscous properties. Whichever the type of contaminants, their presence in large quantities and over a longer period of time will gradually penetrate deep into the soil strata and also pose significant environmental consequences.

Two levels of ground contamination have occurred, one resulting from discharging oil in the ground soil and the other resulting in the combustion products from the oil fires. These heavily contaminated sites pose significant environmental consequences and require remediation Benyahia *et al.* (2005). While remediation options abound, the objectives remain to clean up the sites at a minimum cost and as quickly as possible. Accordingly, understanding the physical, chemical and biological phenomenon that characterise soils and ground water is essential for the remediation.

Agencies in Nigeria often neglect the influence of the contamination on the soil strength, compressibility, and other geotechnical properties. The immediate concern is usually limited to pipe repairing, air and ground water pollution. Meanwhile, in connection with the remediation program and for any possible engineering application and utilization of the contaminated environments, knowledge of the geotechnical properties and behaviour of the contaminated soil must also be required. Consequently, since the possibilities of carrying out future construction works on these contaminated environments can never be ruled out, it is then imperative to conduct a testing program to find out the influence of the oil contamination to the bearing capacity and settlement of foundation footings. In addition, it is also important to investigate other relevant engineering properties of the contaminated soils such as compaction characteristics, CBR and the possible application of the soil in construction as a material or other engineering applications.

II. LITERATURE REVIEW

Remediation efforts have often dominated attempts to restore polluted soils to their normal conditions because of the strong visual impacts they have on the environment. Geotechnical properties of contaminated soils are equally important if infrastructural projects located on oil contaminated sites are to be sustained. The saturation of soil by fluids characterized by physico-chemical properties that differ from water has been found to have a deteriorating effect on its mechanical and filtration parameters, plasticity, swelling and other properties Mashalah *et al.* (2007). The interests generated by contaminated soils on the engineering properties of soils have spurred many researches. The compressibility of contaminated fine-grained soils was examined by consolidation test (Meegoda and Ratnaweera, 1994). Also, Al-Asnad *et al.* (1995) carried out a Geotechnical investigation of oil contaminated Kuwaiti sand as a result of the destruction of Kuwait's oil production facilities at the end of the gulf war. Although the soil samples from the bottom of the oil lakes could not be taken at the time of their investigation, they decided to employ reference sand called Jahra sand (typical surface desert sand in Kuwait) and duplicate contamination by mixing it with crude oil in the appropriate amount found in a pilot area in the field. The results of their findings revealed a reduction in permeability and strength and an increase in compressibility with oil contamination. Again Ashraf (2011) studied the effects of motor oil contamination duration on over-consolidated clay and reported decreases in the Atterberg properties, unconfined compressive strength, but increases in the permeability and compression and swell potential of the contaminated soil. Furthermore the motor oil contamination led to close packing of the clay particles. This view is corroborated by Rehman *et al.* (2007) and Mohammad and Shahaboddin, (2008) who also concluded that the compression behaviour of montmorillonite indicated that the particles tend to coagulate and to behave like granular materials in the presence of organic contaminants. Liquid limit and consolidation parameters of highly plastic clay tend to decrease while shear strength parameters increase in the presence of organic pollutants Murat and Yildiz (2010).

The engineering properties of oil contaminated sand were also investigated by Mashalal *et al.* (2007) who reported decreasing values of strength, permeability, maximum dry density, optimum water content and Atterberg limits values with increases in contaminant content. To see the behaviour of oil contaminated sand under foundation footings Ahmed Nasir (2009) conducted experimental and theoretical studies of strip footings on oil-contaminated sand and found that the load-settlement behaviour and ultimate bearing capacity of the footing can be drastically reduced by oil contamination. The bearing capacity is decreased and the settlement of the footing is increased with increasing depth and length of the contaminated sand layer. Vijay (2000) and Sanjay *et al.* (2002) had also conducted tests to determine the geotechnical properties of oil contaminated sands and the test results indicated that the compaction characteristics are influenced by oil contamination. The angle of internal friction of the sand based on total stress condition was found to decrease with the presence of oil in the pore spaces. One-dimensional compression characteristics of the sand were significantly influenced by oil contamination, resulting in a decrease in the value of the constrained modulus with increase in the degree of oil saturation. The suitability of petroleum contaminated soils in road construction was studied by Hossam *et al.* (2005) and found that in construction applications including stabilizing the soil with cement, mixing it with crushed stone aggregate for use in road bases or sub bases, and using it as a fine aggregate replacement in hot mix asphalt concrete, there was good potential for use in road construction.

Novelty studies on the effects of oil contamination on soils include the works of Annette *et al*. (2012), who examined the effects of Estonian oil shale semi-coke deposits with emphasis on their shear strength while Hossam *et al*. (2008), investigated the permeability and leaching of hot-mix asphalt concrete containing oil-contaminated soils and Agamuthu *et al*. (2010), attempted phytoremediation of soil contaminated with used lubrication oil using *Jatropha Curcas*. Studies that combined bioremediation efforts and geotechnical properties include Singh *et al*. (2009) and Alessandro et al. (2012), both studies found decreasing geotechnical properties with increased saturation of the contaminants.

III. MATERIALS AND METHODS

A. Sampling

Soil samples (6kg) were collected from 3 different locations to cover the variety of soils normally encountered in Geotechnical practice. The samples include clay, sand and laterite soils taken at depths judged to be the deepest infiltration of the oil contaminants. All the locations are in the semi-arid regions of Northern Nigeria. In order to simulate the contamination of the soils, different proportions of the contaminants namely, used engine oil; Black oil and crude oil were mixed with the samples. The amount of contamination was calculated as a per cent by weight of the dry uncontaminated soils and then mixed with the predetermined weight of the dry test samples. Water equivalent to the calculated natural moisture content of the soil material was employed and then mixed thoroughly for the test. Each sample was mixed with 2, 4 and 6% of the contaminants while 0% contaminant content was used as a control. The samples were conveyed to the laboratory and the following tests carried out on them. Physical tests, Atterberg tests, compaction, California Bearing Ratio Test (CBR), Consolidation test and undrained triaxial compression test. All the tests were carried out in the Central laboratory of Bayero University Kano in accordance with BS 1377 (1990).

IV. RESULTS

Table 1.0: Physical Characteristics of Clean Soil Sample.

PROPERTIES/SAMPLES	0% contamination		
	Sand	**Clay**	**Laterite**
Description	Poorly graded sand fraction	Inorganic Dark silty clayey material	Reddish Laterite material
Gravel	0	0	0
Coarse sand	14.45	0	7.15
Fine sand	73.85	13.80	17.55
Silt/clay	11.70	86.20	75.30
Specific Gravity	2.430	2.620	2.680
Nat. Moisture Content, %	12.40	21.81	16.17
Optimum Moisture Content, %	20.50	14.00	21.60
Maximum Dry Density [Mg/m^3]	1.530	1.730	1.600
Un-soaked CBR, %	11.67	4.95	4.82
% Passing BS sieve No 19mm	100	100	100
% Passing BS sieve No 7	100	100	90.46
% Passing BS sieve No 36	99.97	100	82.45
% Passing BS sieve No200	11.70	87.51	75.38
Liquid Limit, %	-	26.12	42.70
Plastic Limit, %	-	20.60	30.86
Plasticity Index, %	NP	5.52	11.84
Shrinkage limit,%	-	10.00	2.86
AASHTO	-	-	A-2-7[6]

A. Physical and Atterberg Properties

The results of the physical tests on the soil samples with no contaminant content are shown in Table 1. From the sieve analysis results, the grain size distribution curve of the sandy soil can be described as predominantly sand fraction with 11.70% of clay/silt content. It can however be classified as poorly graded (SP) according to the unified soil classification system. The soil has a natural moisture content of 12.40% and a specific gravity of 2.43. The maximum dry density of the uncontaminated sandy soil is 1.53Mg/cm^3 at an optimum moisture content of 20.50%. The uncontaminated sand is non-plastic and does not have attributes of Atterberg properties. The properties of the clay and the laterite samples are also given in Table 1.0 for the clean or uncontaminated samples. When mixed with the oil contaminants the soils exhibit Atterberg properties as shown in Table 2. The sand samples exhibited consistent non-plastic behaviour over the range of the contaminated oil content and as such not shown in Table 2. All the oils did not have any effect on the Atterberg properties of sand as is the case with the clean sand which properties were non-plastic. For the clay and laterite samples the Atterberg properties shown in Table 2 did not exhibit any clear trend. The liquid limit decreased as the *used oil content* increased from 2% to 6%. The plastic limit, plasticity index and the shrinkage properties did not show any consistent changes in properties. When the Used engine oil was applied to the laterite samples the changes in properties followed that of clay. The effects of Black oil and crude oil on the samples gave similar behavioural patterns. The results of the Atterberg tests followed the patterns observed by Ashraf (2011), Mashalah (2007) and Murat and Yildiz (2010). All studies indicated decreased liquid limits with increasing contaminant content.

B. CBR Tests

The results of the tests using contaminated soil samples are shown in Figure 1 for sand and Figures 2 and 3 for clay and laterite samples respectively. The CBR value for the clean sand is 11.67%. With the addition of the contaminants, the CBR value increased by 76%, 77% and 6% at the 2% level of contamination of used engine oil, LPFO and crude oil respectively. Subsequently, the CBR values decreased with increase in contaminant content at 4% and 6% level. The percentage decrease of the CBR ranges from 57-75% of used engine oil, 24-54% for LPFO and 13-41% for crude oil contaminations for the respective soil samples of sand, clay and laterite. It must be noted that for all the samples and for all the contaminants used, the CBR values at 4% and 6% levels were lower than the values at zero per cent level of contaminations.

C. Consolidation Settlement

The effects of the contaminants on consolidation settlement for the three soil samples are shown in Figures 4 to 6. In the case of the sand sample, the result indicates an increase in compressibility or

Table 2: Atterberg Limit Properties of Contaminated Soil Samples

Type of Contaminant	Contaminant Content (%)	Atterberg Limits			
		Liquid limit	Plastic limit	Plasticity Index	Shrinkage limit
Used Engine Oil	CLAY				
	2	27.25	14.95	5.52	10.00
	4	26.12	25.00	1.12	2.86
	6	23.90	12.37	11.53	2.50
	LATERITE				
	2	42.75	25.84	16.92	7.14
	4	42.75	25.59	17.17	12.14
	6	42.75	27.80	14.45	12.86
LPFO	CLAY				
	2	28.20	22.43	5.77	2.86
	4	28.00	14.18	13.83	2.14
	6	27.27	22.69	4.58	2.86
	LATERITE				
	2	46.00	42.27	3.74	8.57
	4	43.00	26.93	16.07	7.14
	6	41.60	26.35	15.26	12.86
Crude Oil	CLAY				
	2	27.23	21.78	5.45	1.43
	4	27.00	25.00	2.00	2.86
	6	26.30	17.55	8.75	2.14
	LATERITE				
	2	44.60	21.79	22.82	12.14
	4	44.12	41.89	2.23	7.14
	6	42.50	30.25	12.25	11.43

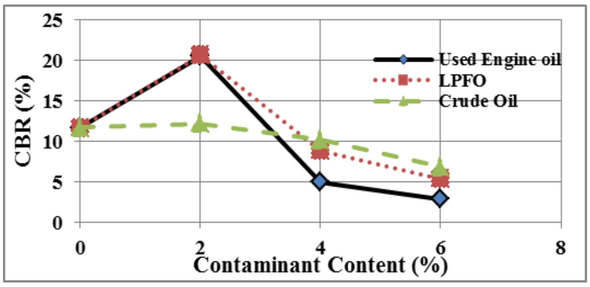

Figure 1: Effect of Contaminant Content on CBR of Sand

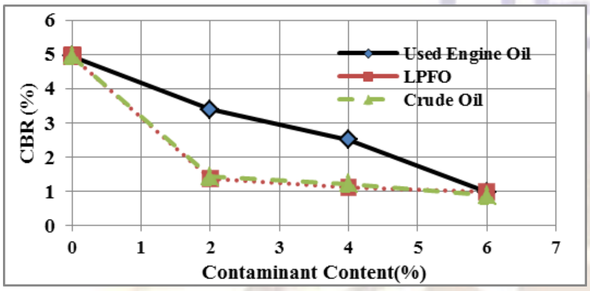

Figure 2: Effect of Contaminant Content on CBR of Clay

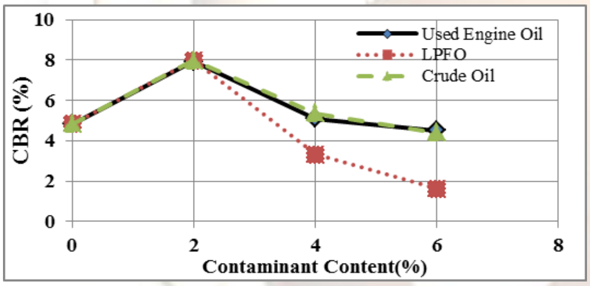

Figure 3: Effect of Contaminant Content on CBR of Laterite

volume decrease of the contaminated soil with applied loading. The results are in agreement with the findings of Al-Sanad *et al.* (1994) and Meegoda and Ratnaweera (1994) from their tests on cohesionless and cohesive soils respectively. The consolidation test on the uncontaminated clay gives the values of coefficient of consolidation (c_v), coefficient of volume decrease (m_v) and consolidation settlement (P_c) of 36.77m^2/year, 8.8x$10^{-3}$$m^2$/kN and 8.4x$10^{-4}$m respectively. The calculated consolidation settlement Pc reduces within the range of 2-26%, 26-67% and 21-70% with used engine oil, LPFO and crude oil respectively for the clay samples. The results indicate that the oil present in the soil reduces the void ratio; this implies that the initial stress increase due to loading was partly on the oil and partly imposed on the trapped pore-water.

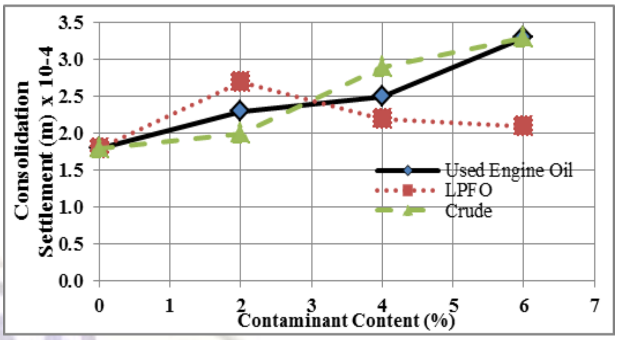

Figure 4: Effect of Contaminant Content on Settlement of Sand

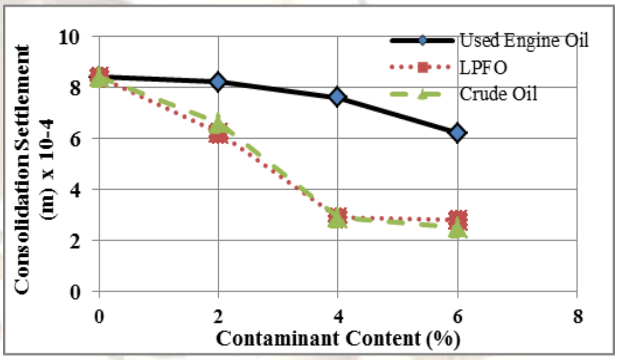

Figure 5: Effect of Contaminant Content on Settlement of Clay

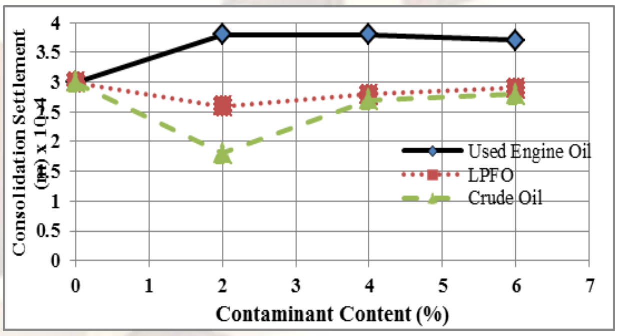

Figure 6: Effect of Contaminant Content on Settlement of Laterite

Therefore, the viscous properties of the contaminants greatly influences the rate at which the compression of the soil under applied loading is taking place as shown in Figures 5 for clay and Figure 6 for laterite. The consolidation test results for laterites showed an increase in coefficient of consolidation c_v at 2% and 6% used engine oil, 4 and 6% LPFO and 2, 4 and 6% crude oil contaminated soils. The remaining level of contaminations i.e. 4% used engine oil, 2% LPFO indicates a decrease in the c_v values. The consolidation settlement P_c of the laterite increased by 19.21% with used engine oil and subsequently decreased by within the range of 3-13% LPFO and 7-40% crude oil contaminations as illustrated in Figure 6.

D. Shear Strength

The results for shear strength are shown in Figures 7 to 9. For the sand sample the apparent cohesion and frictional angle increased by about 5-9% which corresponds to a decrease in the bearing capacity factors N_c, N_q and N_γ though insubstantial. The cohesion intercept subsequently increase with oil content. This change of behaviour is attributed to the viscous properties of the contaminants which helps in bringing the individual sand particles more close together hence making it into more compact configuration. The results however, signifies an increase in allowable soil bearing pressure and shear strength with various level of oil content. The increase in shear strength of between 17-23% for used engine oil, 6-16% for LPFO and 8-19% for crude oil are as shown in Figure 7.0.

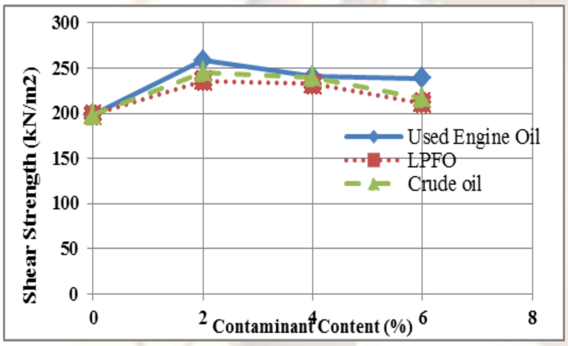

Figure 7: Effect of Contaminant Content on Shear Strength of Sand

The clay samples also indicated a decrease in cohesion intercept with an increase in frictional angle of the soil at varying level of contaminations. The reductions of the cohesion intercept can be attributed to the clay mineral particles resulted to large surface area to volume ratio and consequently experience surface forces which predominate over the mass-derived gravitational forces. These surfaces are derived from electro-chemical activity on the surface of the particles and the dominant influence of these surface forces resulted in a cohesion between individual clay particles. So as the oil migrates downward into the soil, it may be subjected to physical/chemical reactions and changes, or biological breakdown or become absorbed to the soil particle surfaces. Therefore it can be said that the three contaminants used have greatly affected negatively the dominant influence of these forces thereby reduces the cementation of the individual clay particles. The result however, indicates an increase in shear strength values of the soil, except at 6% LPFO and all crude oil contaminations. The percentage increase of shear strength for used engine oil contamination falls within the range of 2-7%. That of 2% and 4% LPFO contamination was within the range of 3-8%. However, the percentage decrease of shear strength at 6% LPFO was 15%, while the percentage decrease of shear strength for crude oil contaminations was recorded to be within the range of 0.1-7% as shown in Figure 8.

The laterite samples showed increase in shear strength from the 0% contaminant content to 2% content as contained in Figure 9. Beyond that there are progressive decreases in strength up to the 6% contaminant level for all the contaminants. These decreases were however, higher than the 0% content of the contaminants. At 2 to 6% used engine oil, the cohesion decreases by about 37-59%. At 2 and 4% crude oil mix, the cohesion of the laterites increases by about 9-21% and

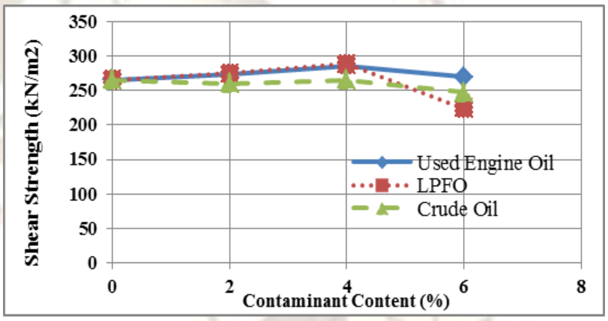

Figure 8: Effect of Contaminant Content on Shear Strength of Clay.

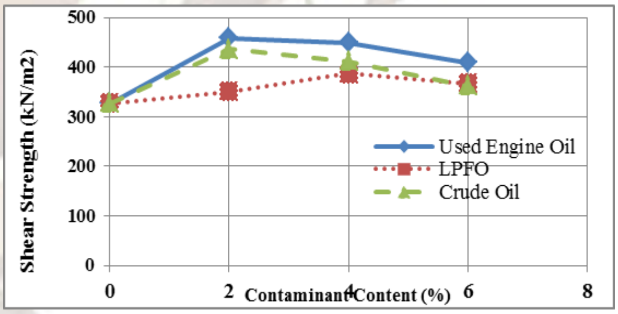

Figure 9: Effect of Contaminant Content on Shear Strength of Laterite.

subsequently decreases by about 54% at 6% crude oil mix. However, a decrease percentage of cohesion intercept of 60-67% was recorded for LPFO contaminated soils. It can therefore be deduced from the shear strength results that for all levels of contamination by used engine oil, LPFO and crude , the shear strength of the soil increases within the range of 20-29%, 7-15% and 10-25% respectively.

V. DISCUSSION

A laboratory testing program was carried out to determine the effect of used engine oil, LPFO and crude oil contamination on the properties of sand, clay and laterite. The amount of the contaminants employed varied from 2 to 6% to match field conditions. The lubrication properties of the contaminants have markedly increased the maximum dry density (MDD) of sand. The trend of the results showed continual improvement of the values with further percentage increment of oil content from 2-6%.

The results of the oil contaminated clay showed an increase of the MDD with 2-4% used engine oil and a decreased of the MDD value at 6%. Likewise, the MDD of the LPFO contaminated clay increases but without any change at all level of contamination. Although the MDD values of the crude oil contaminated clay increases, the trend showed an improvement from 2-4% and subsequent decrease at 6% oil content.

However, the results of the used engine oil and crude oil contaminated laterite showed an increase of the maximum dry density (MDD) at all levels of the contaminations. The trend showed same values at 2-4% and a slight decrease at 6% level of contaminations. Meanwhile the LPFO contaminated laterite appreciated at 2% level of contamination and subsequent decrease of the value at 4-6% contaminations. Generally the CBR values of the oil contaminated clay decrease with increase in oil content from 2-6% with all contaminants. The CBR values of contaminated laterite increases at 2-4% used engine oil and crude oil. Further increment of the oil contents to 6% decreases the CBR values. However, at 2% LPFO contaminated laterite the CBR value increase and subsequently decreases with further increment of oil content from 4-6%. The CBR values of contaminated sand showed an increase at 2% level of contamination with all the contaminants and subsequent decrease of the values with further oil content from 4-6%.

Oil contamination resulted to general decrease of compressibility of clay soil. The trend showed a gradual decrease of consolidation settlement with further percentage increase (2-6%) of all the contaminants. Used engine oil contamination increased the compressibility of laterite. The trend as obtained from the consolidation settlement values, showed the same effect at 2-4% and gradual decrease of the values at 6% oil content. However, LPFO and crude oil contamination decreases the consolidation settlement values of the laterite. The results showed that with gradual increment of the oil content from 2-6%, the values were gradually increasing. Oil contaminations resulted generally to decreased compressibility of sand. The trend of the results showed a gradual decrease of consolidation settlement values of the sand with further percentage increment from 2-6% for used engine oil and crude oil. However, the consolidation settlement values of the LPFO contaminated sand goes down with further percentage increment of the oil from 2-6%.

The shear strength of oil contaminated clay gradually increases at 2-4% used engine oil and LPFO contaminations, but decrease with further oil content at 6%. Meanwhile the shear strength of crude oil contaminated clay decrease at 2% level of contamination, and then slightly increases at 4% contamination. At 6% level of contamination, the shear strength value of the crude oil contaminated clay drastically decreased. Generally the shear resistance values of oil contaminated laterite increases with all the contaminants. The trend of the results showed a gradual increase of the values at 2-4% contamination and then dropping at 6% level of the contamination for all contaminants. The general trend of the results showed an increase in shear resistance values of the contaminated sand with all the contaminants. The increases of the values are higher at 2% contaminations and gradually dropping down with further percentage increment of the contaminants from 4-6%.

VI. CONCLUSION

It is apparent from the discussions that the following conclusions can be made.

In all the oil contaminated sand and laterite studied, the engineering properties in terms of shearing resistance of the soils increases with 2-6% level of contamination. Similarly, the shear resistance of oil contaminated clay increased with 2-6% used engine oil and 2-4% LPFO contaminations. Therefore this implies that for the maximum dosage of 6% of all the contaminants except LPFO and crude oil contaminated clay, all the soils can be used in engineering works to advantage.

In the case of CBR, the dosage of 2% level of contamination with all the contaminants for sandy soil showed the material could be used for engineering purposes especially road construction. However, maximum dosage of 2% LPFO contaminated laterite and 2-4% used engine oil and crude oil contaminated laterite, the material could also be employed as subgrade material in road construction. Meanwhile, all dosages (2-6%) of the contaminants used with clay should be avoided in road construction unless stabilisation of the contaminated soil will prove worthwhile.

Oil contaminated sand with the level of contaminants has resulted to increase in consolidation settlement. Therefore structures within the vicinity of such contaminated soils should be safeguarded to avoid increase in settlement of the foundation footings. The test program carried out in this project is only limited to immediate effect of the contamination. Different situations may arise on the contaminated sites as the contamination will be exposed to all weather conditions, which can lead to evaporation of some volatile compounds of the contaminants.

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