COMPARATIVE ASSESSMENT OF ENGINEERING PROPERTIES OF UNCONTAMINATED AND NATURALLY CONTAMINATED COASTAL SOIL

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Abstract

This research is an assessment of crude oil pollution on soil. The effect of crude oil pollution on engineering properties of soil was carried out in this research using laboratory experimental test methods which include: sieve analysis, Atterberg limits, compaction and California bearing ratio (CBR) tests on the samples collected. A comparative analysis based on the experimental test results obtained on the two samples of which one was collected from the oil spill affected location (contaminated soil) and the other sample is the non-oil affected soil (uncontaminated soil) to serve as control for the index and engineering properties. The results from sieve analysis and Atterberg limits tests classifies both soil samples (contaminated and uncontaminated) as Silty soil and as A-2-4 and A-2-6 soil respectively, using AASHTO specifications. The compaction test for the contaminated soil has maximum dry density (MDD) and optimum moisture content (OMC) values of 2.042 Mg/cm^3 and 10.3%, while the uncontaminated soil has MDD and OMC values of 2.059 Mg/cm^3 and 11.7% respectively. The CBR test result for the contaminated soil was far less than 1% (i.e., 0.27%), while that of the uncontaminated soil was 12%. The results indicated a decrease in strength, maximum dry density, optimum water content and Atterberg limits of the contaminated soil, therefore making the soil unsuitable for some Civil Engineering construction works.

Key words: contaminated soil, uncontaminated soil, compaction, consistency test, California bearing ratio, Scan electron microscope

Introduction

Most oil spills are unintentional, they occur during land and sea based transportation; as a result of storage tank leakage, or while oil is being drilled. There are also instances where oil may be intentionally spill, as occurred during the Persian Gulf War in 1991. (Tajik, 2004). Soils may become contaminated with oil if there is an oil spill or leakage. For restoration and reclamation of the contaminated sites in these situations, significant duties are required.

The environmental challenges in Nigeria especially in Niger Delta have become a source of great concern, due to the activities of crude oil mining in the area. The Niger Delta environment which is known for its rich biodiversity and sustenance of traditional livelihoods of its local people for centuries has been under severe threat from anthropogenic factors including oil and gas mining activities. Akinwumiju *et al*. (2020) showed that between 2006 and 2019 about 7,943 oil spill incidents have occurred in the Niger Delta. As a result, farmers and agricultural extension workers are the worst hit in the event of an oil spill. Hence, it is evident that there is a nexus between oil production and Niger Delta rural livelihoods. However, at the moment, there is no universal framework that accurately and systematically measures or shows the multifaceted impacts of crude oil pollution in the Niger Delta.

Natural resources like land are adversely affected by land pollution (Afangideh *et al.*, 2015; Nnaji *et al.*, 2014). This pollution or contamination effect can also be from oil spill. Oil spill is the release of liquid petroleum hydrocarbons into the natural environment as a result of human activities. Oil-spill pollution is hazardous and problematic worldwide (Aisen, and Oboh 2015; Arinze, 2016; Das and Chandran 2011). Contaminants from oil pollution pose serious threat to public health and eco-systems. Oil spills are well known from natural seeps of oil which regularly occur in the Gulf of Mexico. It mainly occurs at production sites (drilling sites and refineries), storage sites due to leakage of container, and at transportation sites like pipelines, truck, and ships (Erdogan and Karaca 2011; Thapa, Kumar, and Ghimire 2012). The paradigm shift in the economic base of coal to crude oil and its distillates/by-products greatly increased the volume of these commodities being transported across the high seas, especially after the World War II Sea, land, and ground water are adversely affected by oil spills and resulted in land and sea water pollution (Ezeji *et al*., 2007). The marine and onshore lives are endangered because of these oil spills. The difference between oil spill in water and soil is the degree of spread. Small amounts of soluble ingredients in crude oil spills have rare effects on contamination, whereas refined hydrocarbon products having larger amounts of soluble components like BTX (benzene, toluene, and xylene) are the real danger to the environment (Chen *et al*. 2015). Transformation of oil due to the action of waves and sunlight which includes dispersion, evaporation, dissolution, photolysis, biodegradation, and formation of water oil emulsions has caused significant changes in oil viscosity, density and interfacial tension. Contamination of groundwater by oil spillage is a major environmental issue throughout the world (Ezeokpube *et al.*, 2022). Spillages from tankers have contributed 5% of the total oil pollution in ocean. Currently, about 80% of lands are contaminated/polluted by products of petroleum origin (hydrocarbons, solvents, etc.) used as an energy source in the oil industry, as well as chemicals. There are a variety of pollutants affecting soil and subsoil, such as fuel and oil products, hydrocarbon residues, crude oil, other products resulting from saturated and unsaturated aliphatic hydrocarbons, and monocyclic and polycyclic aromatics (Mariana *et al*. 2010).

Hydrocarbons have unacceptable risk affecting the quality of groundwater, making it unfit for use for drinking and other domestic uses; irrigation and different industrial uses.

It is also harmful to human health and other fauna. Aromatic compounds give a strong feature of mutagenic and carcinogenic effects, as well as affecting the environment security, presenting risks of explosion and fire. It also affects buildings and other structural foundations (Singh and Chandra 2014).

Hydrocarbon pollutants affects physical, structural properties, physiological and biochemical properties of soil (Head *et al*. 2006; Margesin *et al*. 2003). Plants are affected by oil pollution due to phytotoxic form of hydrocarbons, and deactivation of nutrients in the soil (Haghollahi *et al*. 2016). Consequently, on land, crude oil spills have caused a great negative impact on food productivity (Das and Kumar 2016). Treatment of oil polluted soils would make more land available for agricultural purposes, especially this period that economists and agriculturalist are predicting eminent food scarcity due to climate change and coupled with the post economic effect of covid-19 pandemic. The study is aimed at assessing crude oil pollution on soil and its effect on engineering properties of soil.

Materials and methods

Soil

In achieving the aim and objectives of this study, two major materials were sourced and used (crude oil contaminated soil and uncontaminated soil). The contaminated soil samples were sourced from the premises of Sterling Global Limited, located at Iko in Eastern Obolo LGA, while the uncontaminated soil were sourced from Ikot-enin in Mkpat-enin LGA, all in Akwa Ibom State, Nigeria. Although the contaminated soil was sourced from one location, contaminated soil samples were collected at different points around the area and mixed to give representative sampling for the location.

Methodology

Laboratory tests were performed to determine the engineering properties of both soil samples (contaminated and uncontaminated), with the uncontaminated sample serving as a control. Tests were carried out in accordance with BS 1377(1990) and AASHTO T-89 (Method B) respectively.

Particle size distribution

Particle size fraction of both soil samples was determined via BS 1377(1990) guidelines.

Compaction

Tests involving moisture-density relationship and CBR were carried out using the British Standard Light (BSL) compactive effort, in accordance with specifications outlined in BS 1377 (BSI, 1990). Tests were carried out on the uncontaminated and contaminated soils at using a predetermined moisture contents of 8 %, 10 %, 12 %, 14 % and 16 % by dry weight of soil respectively.

Strength

Strength tests were performed on both soils to determine the California bearing ratio (CBR) values. Specimens were prepared at their respective optimum moisture content as obtained from predetermined moisture content variations. Specimen were cured for 7days and immersed in water for 24hrs before testing in accordance with the BS 1377 Part 2, (1990).

Consistency limit

Consistency tests which includes; liquid limit (LL), plastic limit (PL) and plasticity index (PI) were performed on both soil samples in accordance with AASHTO (1986) T-89 (Method B). The liquid limit represents the minimum water content at which soil particles flow under their, own weight and theplastic limit is the minimum water content at which a soil is molded without breaking. These limits control the consistency of the soils as wetting conditions change. Atterberg or consistency limits have a very extensive use in geotechnical engineering for identification, description and classification of soils, and as a basis for the preliminary assessment of their mechanical properties.

Microanalysis

Microanalysis using scan electron microscope (SEM) was used to study the morphology of the soil and a comparison in the morphology between the contaminated and uncontaminated was presented.

Results and Discussion

Index properties

A summary of the geotechnical properties of the uncontaminated and contaminated soil samples are presented in Table 1. The uncontaminated and contaminated soil samples were classified as A-2-6 and A-2-4 respectively, using AASHTO classification system (AASHTO, 1986). The variation in particle size distribution curves of the uncontaminated and contaminated soil samples are shown in Fig.1.

Table1: Properties of the uncontaminated and contaminated soil

Property	Uncontaminated soil	Contaminated soil
Natural Moisture Content %	10.34	
% passed 75µm aperture	31	17
Liquid Limit (%)	34.98	32
Plastic Limit (%)	23.01	22.83
Plasticity Index (%)	11.97	9.17
AASHTO Classification	A-2-6	A-2-4
MDD (Mg/m^3)	2.059	2.042
OMC (%)	11.7	10.3
CBR (24 h soaking) (%)	12	0.27
Color	Rusty-red	Rusty-brown

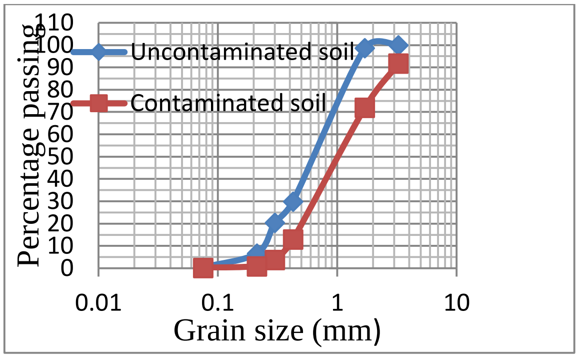


Fig.1. Variation of particle size distribution curves for contaminated and uncontaminated soil

Compaction characteristics

The variation of dry density and moisture content of the contaminated and uncontaminated soil samples are shown in Fig.2. The dry density increased with moisture content up to peak value of about 2.06 and 2.04g/cm^3 for uncontaminated and contaminated soil, respectively. Also, an optimum moisture content (OMC) of 11.5 and 10 % were recorded for uncontaminated and contaminated soil, respectively. The optimum water content is comparatively lower in oil-contaminated than the uncontaminated soil samples. The dry density in contaminated samples is very low compared to uncontaminated soil because the pore spaces are larger in these samples and oil canmove through the soil particles with the same rate as water and possibly act as lubricating effect. However, the results in this study is similar with those of previous researches (Alsanad *et al*., 1995; Meegoda *et al*., 1998; Ezeokpube *et al*., 2022).

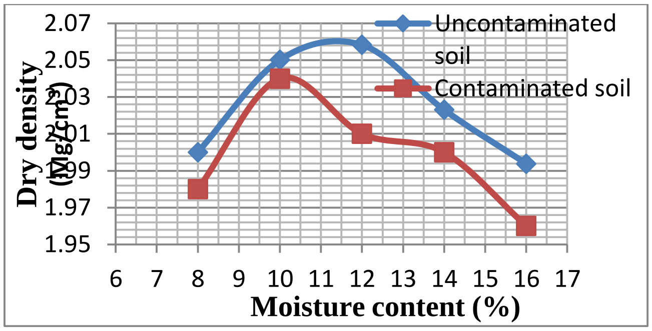


Fig.2. Variation of compaction curves for both contaminated and uncontaminated soil

California bearing ratio

The penetration versus load results for the California bearing ratio, CBR (soaked) values of uncontaminated and contaminated soil samples are shown in Fig.3 and 4. Generally the CBR (soaked) value for contaminated soil is lower compared to the uncontaminated soil. CBR test result for the uncontaminated fulfilled the requirement as an excellent subgrade material with a CBR value of 12% which is higher than the minimum value of 6% that is required for subgrade, but due to influence of crude oil contamination, this was not the case for the contaminated soil which has a CBR value of less than 1 % (i.e., 0.27%). The less than 1 % value of CBR of contaminated soil show that the strength properties has completely depreciated and thus render the material unsuitable and unusable for any engineering construction of earth fill or embankment.

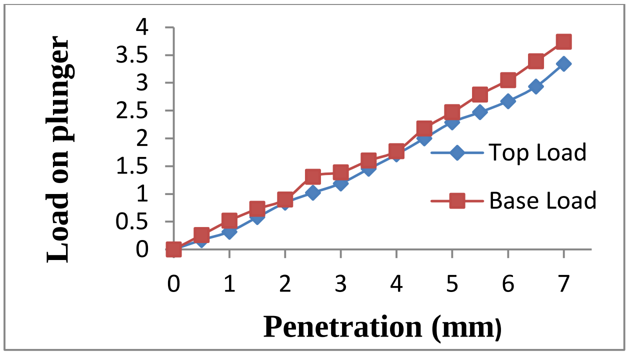


Fig.3. CBR chart for uncontaminated soil

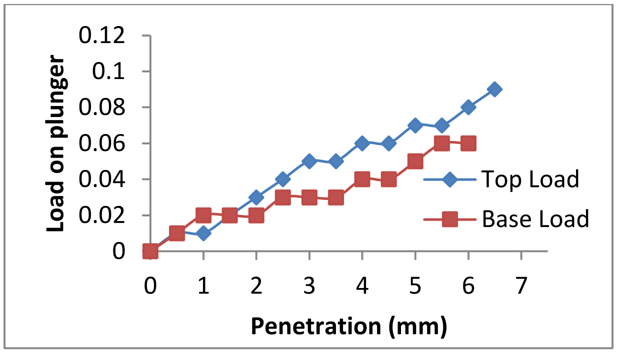


Fig.4. CBR chart for contaminated soil

Consistency limits

Although these limits are easily determined and their qualitative correlations with soil composition and physical properties have quite well established the fundamental interpretations of the limits and quantitative relationships between their values and compositional factors are more complex (Mitchell, 1993).

Liquid limit

Table 2 and 3, presents the results of liquid limit (LL) test of the uncontaminated soil and contaminated soil. The result shows that, the contaminated soil has a smaller LL value as compared to the uncontaminated soil. This is due to reduction in diffuse double layer due to valence ion changes and changes due to mineralogy variation caused by contamination. Similar trend was reported in pas researches ((Moses *et al*., 2018; Sani *et al*., 2019a,b; Moses *et al*., 2019a,b; Attah and Etim 2020; Yohanna *et al*., 2020, 2021).

Table 2: Liquid limit result for uncontaminated soil

Designation	Number of Blows	Mass of empty container (g)	Mass of empty container + wet soil (g)	Mass of empty container + dry soil (g)	Moisture content (%)
8_A	18	9.46	26.2	21.78	35.88
D_{2b}	23	10.19	22.42	19.26	34.84
C_{3b}	27	10.52	23.18	19.92	34.68
L_{3t}	32	7.76	20.91	17.54	34.46

Table 3: Liquid limit result for contaminated soil

Designation	Number of Blows	Mass of empty container (g)	Mass of empty container + wet soil (g)	Mass of empty container + dry soil (g)	Moisture content (%)
A	16	11.01	20.07	17.7	35.43
B	25	10.8	20.04	17.8	32.00
C	30	11.95	20.16	18.02	35.26
D	34	12.25	22.52	19.89	34.42

Plastic limit

The plastic limit tests results that were performed on the soil samples is presented in Table 4 and 5. The results show a decrease in plastic limits with increasing oil contamination. This reduction in Atterberg limits can be explained by the nature of water in the clay minerals structure (Moses *et al*., 2018; Sani *et al*., 2019a,b; Moses *et al*., 2019a,b; Attah and Etim 2020; Yohanna *et al*., 2020, 2021; Osinubi *et al*., 2016; Etim *et al*., 2017; Sani *et al*., 2017).

Table 4: Result of plastic limit test for uncontaminated soil

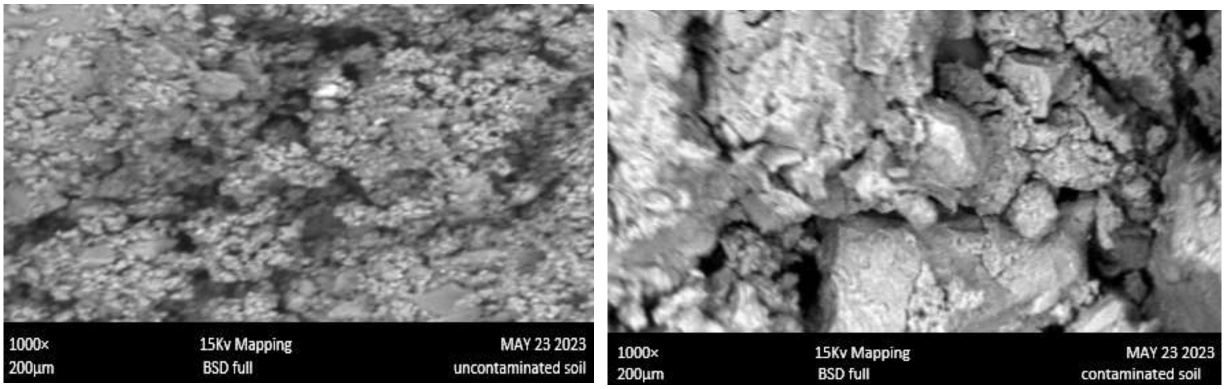
	Observation And Calculation	Determination Number		
S/N	Observation	1	2	3
1	Container Designation	A	B	C
2	Mass of empty container (M_1) g	7.84	10.25	10.24
3	Mass of container + wet soil (M_2) g	13.03	15.4	15.25
4	Mass of container + dry soil (M_3) g	12.06	14.46	14.29
5	Mass of water (M_2-M_3) g	0.97	0.94	0.96
6	Mass of dry soil (M_3-M_1) g	4.22	4.21	4.05
7	Water content $W=(M_2-M_3)/(M_3-M_1)*100$ (%)	22.99	22.33	23.70
	Plastic Limit = Average of water content	23.01		

Table 5: Result of plastic limit test for contaminated soil

	Observation And Calculation	Determination Number		
S/N	Observation	1	2	3
1	Container Designation	A	B	C
2	Mass of empty container (M_1) g	10.24	11.18	11.28
3	Mass of container + wet soil (M_2) g	16.56	18.25	17.89
4	Mass of container + dry soil (M_3) g	16	17.02	16.08
5	Mass of water (M_2-M_3) g	0.56	1.23	1.81
6	Mass of dry soil (M_3-M_1) g	5.76	5.84	4.8
7	Water content $W=(M_2-M_3)/(M_3-M_1)*100$ (%)	9.72	21.06	37.71
	Plastic Limit = Average of water content	22.83		

Microanalysis

A number of studies used scan electron microscope (SEM) to explain physical appearance of soil materials due to chemical or mechanical changes at micro scale level (Attah *et al*., 2021; Ekpo *et al*., 2021; Etim *et al*., 2022; 2023). The morphological variation that occurred between the uncontaminated and naturally uncontaminated soil specimen (See Plate I) could be due to the changes in: particle gradation, mineralogy, chemical composition, charged ions induced by diffuse double layer reduction and internal fabric of the soil. Similar observation was reported in some researches (Ezeokpube *et al*., 2022; Attah *et al*., 2022; Etim *et al*., 2021).



(a) (b)

Plate 1: SEM of: (a) uncontaminated and (b) contaminated soil

Conclusion

The comparative assessment on the engineering properties of crude oil contaminated soil and an uncontaminated soil were studied experimentally in the laboratory. The results from sieve analysis and Atterberg limits tests classifies both soil samples (contaminated and uncontaminated) as silty soils. The contaminated and uncontaminated soils were classified as A-2-4 and A-2-6 using the AASHTO classification scheme. The compaction characteristics for the contaminated soil has MDD and OMC values of 2.042 Mg/cm^3 and 10.3%, while the uncontaminated soil has MDD and OMC values of 2.059 Mg/cm^3 and 11.7% respectively. The CBR test result for the contaminated soil was 0.27%, while that of the uncontaminated soil was 12%. The results indicated a decrease in strength in terms of CBR, maximum dry density, optimum water content and Atterberg limits of the contaminated soil, renders the soil unsuitable for some Civil Engineering construction works. The variation in morphology of the contaminated soil in contrast to the uncontanminated is evidenced by the presence of droplet of organic compounds from crude oil. Further study in terms of unconfined compressive strength, deep investigation from several boring long, durability evaluation and other several other microanalysis such as X-ray diffraction (XRD) is recommended in future for extensive geotechnical clarity and presentations.

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Conflict of Interest: The authors declare that they have no conflict of interest.

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