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Effects of crude oil contamination on the index properties, strength and permeability of lateritic clay

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Abstract: Crude oil spills have become regular in some communities where oil exploration activities are being carried out. This has impacted negatively on the environment, such as soil contamination. The aim of this experimental investigation is to contaminate a lateritic clay soil with crude oil and determine the effects of such contamination on the plasticity, strength and permeability of the soil. The soil was contaminated by adding varying percentages of crude oil to the soil. Specific gravity, Atterberg limits, compaction, California bearing ratio (CBR) and permeability tests were conducted on the uncontaminated and contaminated soil samples. The liquid limit, plastic limit and plasticity index of the soil increased as its crude oil content increased. The specific gravity, optimum moisture content, maximum dry unit weight, CBR and permeability of the soil decreased as its crude oil content increased. The crude oil contaminated soil requires stabilization or remediation before using it as a construction material.

Key words: Crude oil, geotechnical properties, lateritic soil, oil-contaminated soil, oil-producing areas.

1. Introduction

Hydrocarbon leaks and spills have become of great concern in most of the oil-producing countries of the world. The impact of these leaks and spills on the environment cannot be overlooked or disregarded. One of such impacts is that they cause a change in the engineering properties and behavior of soils. This change has a far-reaching implication on existing and proposed structures to be supported by the contaminated soil. It can result in structural or functional failure of existing structures, especially when the contamination causes a significant increase in the soil's plasticity; loss of its bearing capacity; increase its settlement, and/or prevent drainage of water or other liquid. For proposed structures, it can cause an abandonment of the site having the contaminated soil, a reduction in the scope of the project or an increase in its project cost. Increased project cost may result from geotechnical and chemical analyses of the soil to determine the extent of its contamination, inevitable choice of a more stable but expensive structural foundation type or the cost of applying soil remediation or stabilization technologies. However, the use of some wastes, which have already been investigated as soil stabilizers – marble powder (Okagbue and Onyeobi 1999), steel slag (Akinwumi et al. 2012, Akinwumi 2012), reclaimed asphalt pavement (Akinwumi 2014) – may reduce the percentage increase in the project cost of proposed structures on contaminated soils.

Researchers have studied the effects of contamination of soils with crude oil and petroleum products on the engineering properties of the soil. Rahman et al. (2010) investigated the influence of contamination of a basaltic residual soil with engine oil on the geotechnical properties of the soil while Izdebska-Mucha and Trzcinski (2008) investigated the effect of diesel oil pollution on microstructural changes of clay soil. Olgun and Yildiz (2010) investigated the effects of contaminating a clay soil with methanol, ethanol, isopropyl alcohol and acetic acid on its plasticity, consolidation and shear strength. Oyegbile and

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Ayininuola (2013) carried out laboratory studies to determine the effect of crude oil contamination of a lateritic soil on its shear strength. Khamehchiyan et al. (2007) and Kermani and Ebadi (2012) both investigated the effect of crude oil contamination on the plasticity and compaction characteristics (among some other geotechnical properties) of fine-grained soils but their results were dissimilar, making it difficult to have a general description of the effect of crude oil contamination on clay soils. This research work aims at investigating the effect of crude oil contamination on the plasticity, strength and permeability of lateritic clay and providing additional literature for the comparison of the effect of crude oil contamination on the geotechnical properties of clayey soils.

2. Materials and methods

2.1 Materials and preparation

The soil used in this study was obtained from a borrow pit, having a deep lateritic soil profile, at Agbara, Ogun State, Southwestern Nigeria. It was collected from the sidewall of the soil profile at about 10 m depth below the top of the pit. Samples were collected in sacks while some were stored in a water-tight container for laboratory determination of their natural moisture content. Prior to the commencement of laboratory tests on the soil samples collected in sacks and transported to the laboratory, they were air-dried, passed through a 4.75 mm sieve and thoroughly mixed. The contamination of the soil with varying percentages of crude oil was done in the laboratory.

2.2 Methods

The thoroughly mixed soil sample was divided into six parts. Crude oil was added to each of the parts in 0%, 2%, 4%, 6%, 8% and 10% proportions by dry weight of the soil sample, respectively. The soil-crude oil mixtures were thoroughly mixed and stored in containers for 24 hours to allow for homogeneity of the mixtures. Sieve and hydrometer analyses were carried out on the uncontaminated soil sample. Specific gravity, Atterberg limits, compaction, unsoaked and soaked CBR and permeability tests were conducted on the uncontaminated (0% crude oil content) and contaminated (2%, 4%, 6%, 8% and 10% crude oil contents) soil samples, respectively. The procedures for these laboratory tests were in accordance with those outlined in BSI (1990a, 1990b).

3. Results and discussion

3.1 Properties of the crude oil and chemical composition of the soil

The crude oil used has its specific gravity at 15.55°C to be 0.841 and its American Petroleum Institute (API) gravity at 15.55°C to be 36.8 degree API. The soil sample used for this study consists predominantly of silica (SiO_2) and Alumina (Al_2O_3). Its silica-sesquioxides ratio is 1.66, which is an indication that the soil is lateritic. A tri-plot or ternary of the silica and sesquioxides (Al_2O_3 and Fe_2O_3) of the soil incorporating Schellmann (1986) scheme of classification of weathering product is shown in Figure 1. The silica and sesquioxides plot falls within the kaolinization part of the Schellmann classification chart, which indicates that the soil sample was taken from a kaolinized profile.

3.2 Properties of uncontaminated soil

The results of the index properties, strength and permeability tests on the uncontaminated soil are presented in Table 1. The soil is predominantly fine-grained. According to the American Association of State Highway and Transportation Officials (AASHTO) and Unified soil classification (USC) systems, it is classified as A-7-6(7) and sandy lean clay (CL), respectively. It is of low plasticity, low unsoaked CBR value, soaked CBR value and permeability. Figure 2 graphically illustrates its particle size distribution.

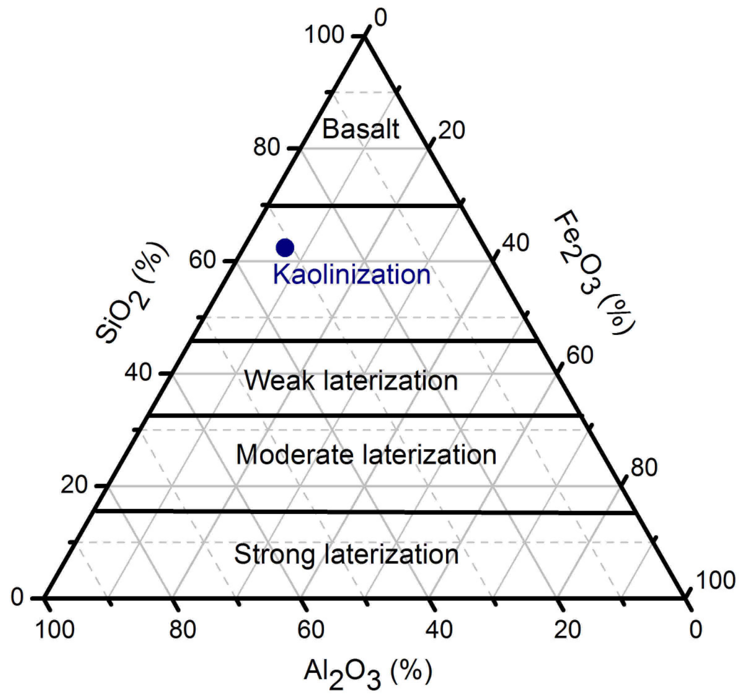

Figure 1: Al_2O_3-SiO_2-Fe_2O_3 ternary plot for the soil

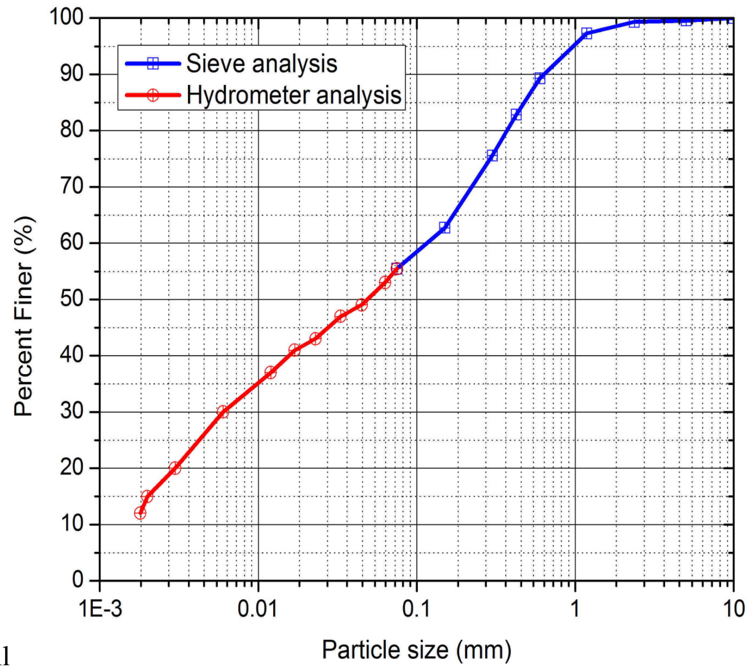

Figure 2: Particle size distribution of natural soil

Table 1: Properties of the uncontaminated soil

Properties		Value / Description
Gradation / Classification	Gravel (>4.75 mm), %	0.5
	Sand (0.075 - 4.75 mm), %	44.0
	Silt and Clay (<0.075 mm), %	55.5
	AASHTO Soil Classification System	A-7-6 (7)
	Unified Soil Classification System	CL - Sandy clay
Physical	Colour	Brown
	Natural Moisture Content (%)	15.6
	Specific Gravity	2.51
	Liquid Limit (%)	41.0
	Plastic Limit (%)	23.0
	Plasticity Index (%)	18.0
	Maximum Dry Unit weight (kN/m^3)	18.2
	Optimum Moisture Content (%)	15.3
	Coefficient of Permeability (cm/s)	8.24×10^{-6}
Strength	Unsoaked CBR (%)	18
	Soaked CBR (%)	10

3.3 Effects of contamination of soil with crude oil

The soil has a specific gravity of 2.51. A graphical illustration of the results of specific gravity tests on the soil admixed with varying percentages of crude oil content is presented in Figure 3. The specific gravities of the contaminated soil samples were found to be lower than that of the uncontaminated soil sample. As the crude oil content in the soil increased, the specific gravity of the contaminated soil progressively decreased. This is attributed to the lower specific gravity of the crude oil.

The results of liquid and plastic limits test are graphically presented in Figure 4. The liquid and plastic limits and plasticity index of the uncontaminated soil progressively increased with higher crude oil content. The addition of crude oil to the soil caused micro-structural transformation of the soil. It is thought to have caused an inter layer expansion within the clay minerals. The crude oil may have enveloped both the clay minerals of the soil and the adsorbed water bonded to its surfaces (diffuse double layer). Consequently, this creates a false increase in the thickness of the diffuse double layer. This may be responsible for the increase in the liquid and plastic limits. The plasticity index also increased with progressive addition of crude oil; indicating that the contaminated soil becomes less workable.

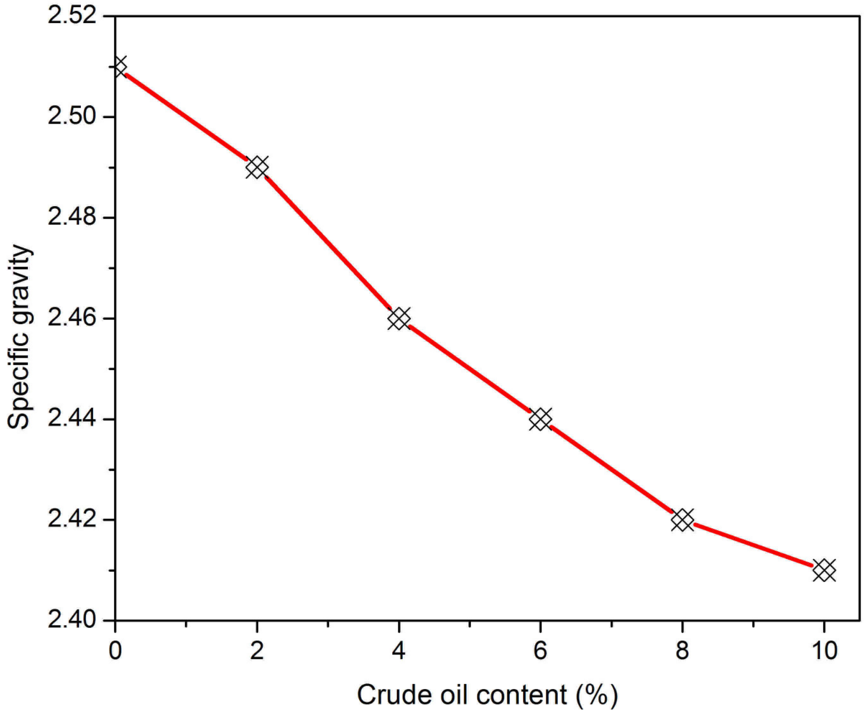

Figure 3: Variation of specific gravity with oil content

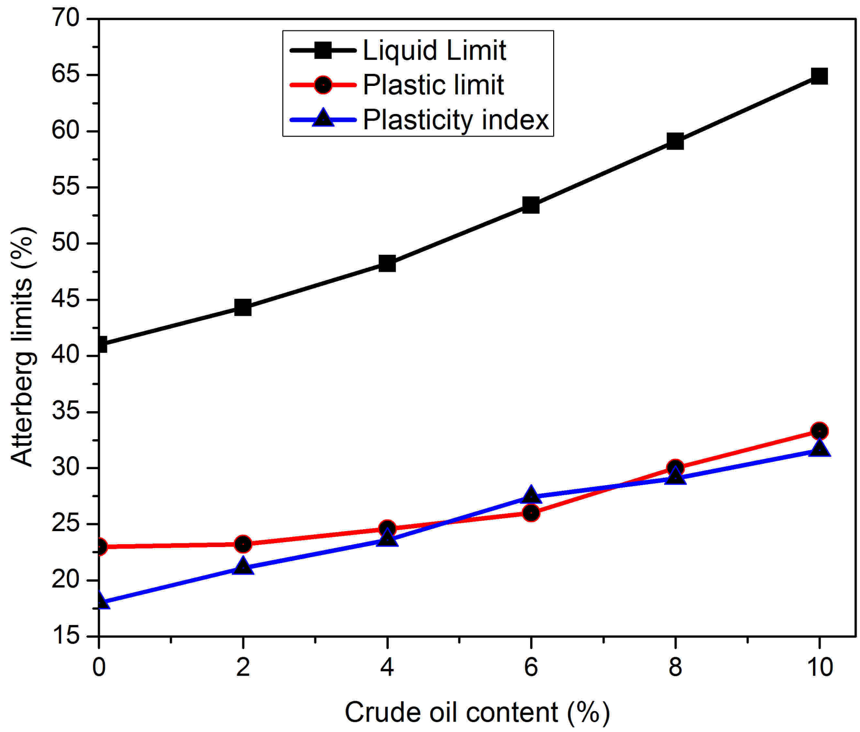

Figure 4: Variation of Atterberg limits with oil content

The results of the compaction test on the soil sample are presented in Figure 5. As crude oil content in the contaminated soil increased, both the optimum moisture content (OMC) and the maximum dry unit weight of the soil decreased. Crude oil is hydrophobic and as it coats itself around individual clay particles, it disallows free water (water other than the adsorbed water) from interacting with the clay particles. This may be accountable for the reduction in the amount of water needed by the soil to reach its maximum unit weight, as the crude oil content increased. Crude oil in the pore fluid increased the thickness of the diffusedouble layer. Therefore using the same compaction energy as that used for the compaction of the uncontaminated soil, the soil particles get less packed together and consequently resulting in a decrease in the dry unit weight of the contaminated soil.

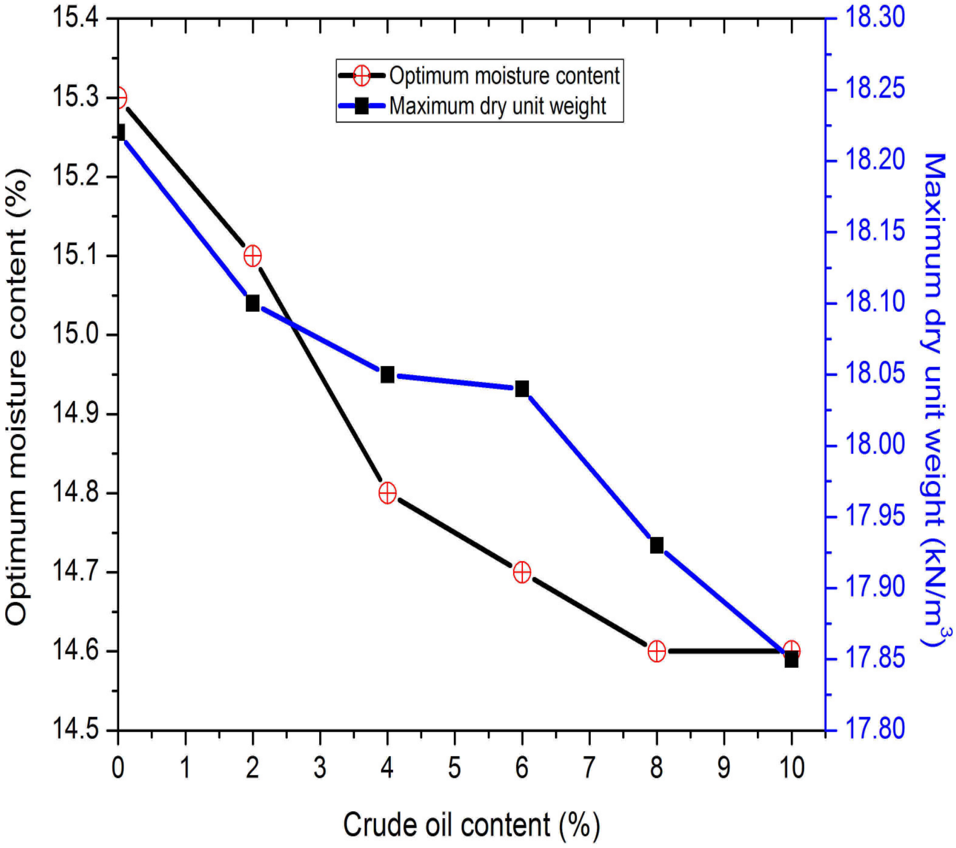

Figure 5: Variation of CBR with oil content

Figures 6(a) and 6(b) show plasticity charts with the incorporation of AASHTO and USC systems, respectively. The uncontaminated soil (classified as A-7-6 and CL) got transformed after the addition of 10% crude oil to a soil classified as A-7-5 and an organic soil of high plasticity (OH), according to AASHTO and USC systems respectively.

The variations of the unsoaked and soaked CBR values of the soil with addition of varying percentages of crude oil are graphically illustrated in Figure 7. It shows that as the percentage of crude oil in the soil increased, the unsoaked CBR slightly increased and later decreased while the soaked CBR decreased. The slight increase in the unsoaked CBR of the contaminated soil is thought to have resulted from the clumping together of clay particles facilitated by the crude oil, which may have caused an increase in the inter-particle shearing resistance of the soil. The decrease in unsoaked CBR after adding 4% crude oil suggests that addition of 4% crude oil is the limit to the increase in inter-particle shearing resistance. Beyond addition of 4% crude oil, lubrication effect of the oil is believed to cause the soil particles to easily slide over each other, accounting for the decrease in the unsoaked CBR.

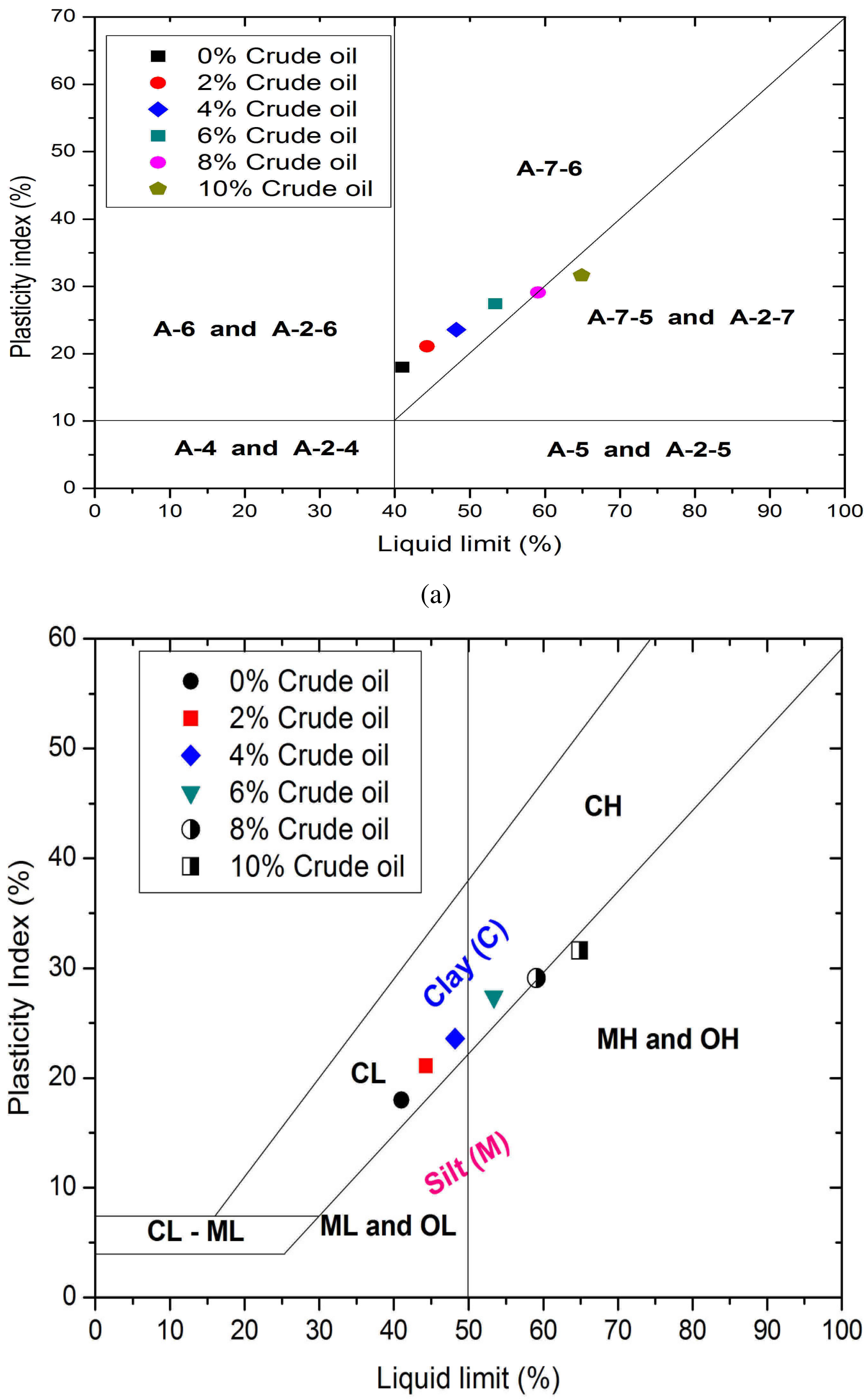

Figure 6: Plasticity (a) AASHTO (b) USC charts showing the plots of the soil and soil-crude oil mixtures

A graphical illustration of the results of the permeability tests on the soil admixed with varying percentages of crude oil content is presented in Figure 8. As the crude oil content increased, the permeability of the contaminated soil decreased. Crude oil becomes entrapped in the pore spaces that forms the pathway for water within the contaminated soil and consequently, reduced the pore sizes. The decrease in the permeability of the contaminated soil is attributed to the reduction in the pore space.

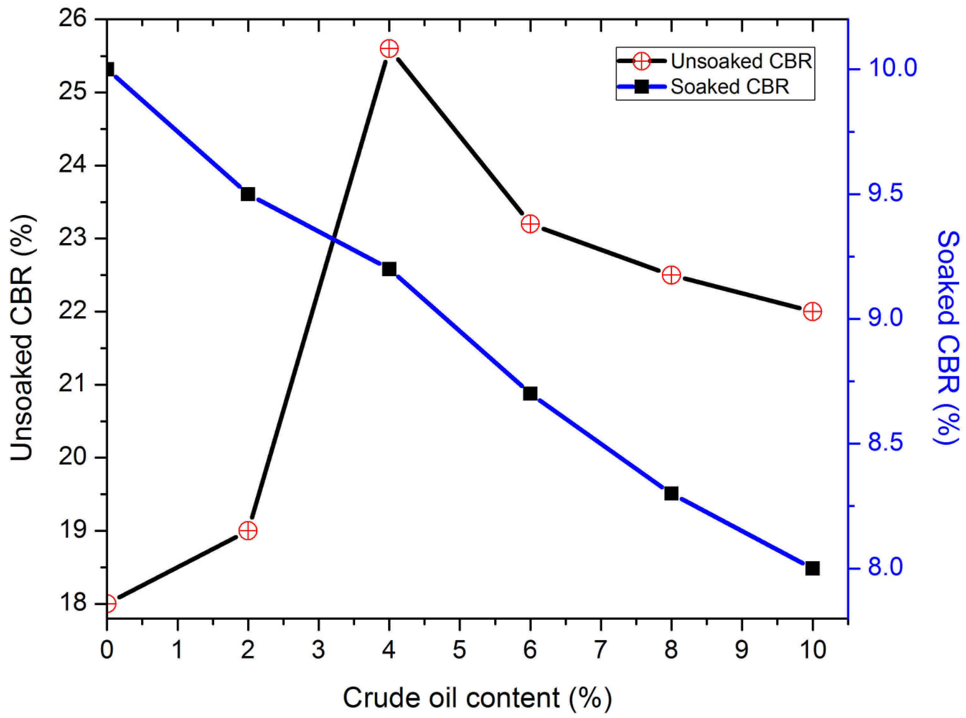

Figure 7: Variation of CBR with oil content

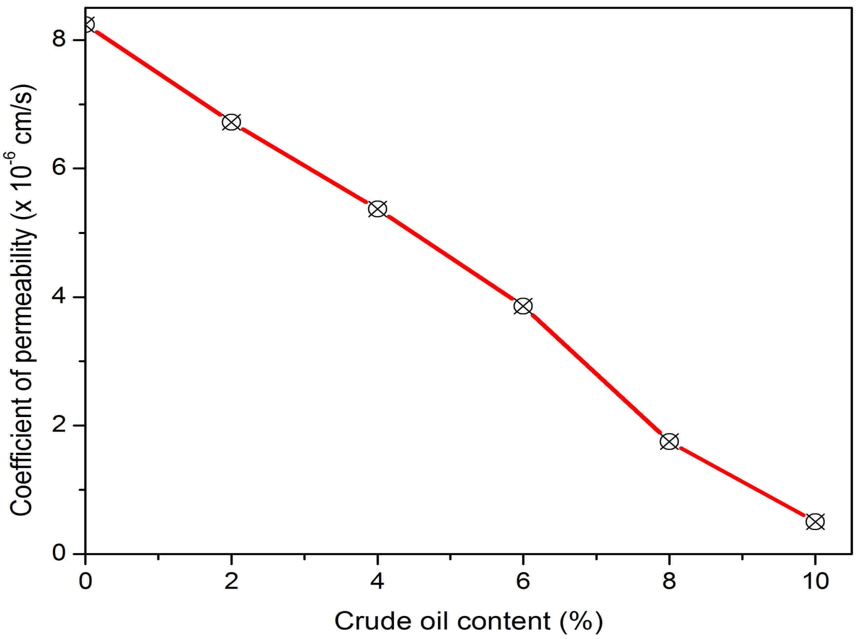

Figure 8: Variation of permeability with oil content

4. Conclusions

From the results of this study, the main conclusions are as follows:

1. Addition of crude oil to the soil resulted in an increase in the liquid limit, plastic limit and plasticity index of the contaminated soil. This was attributed to the increase in the thickness of the diffuse double layer. Increased plasticity indicates that contamination of the soil made it less workable.

2. The specific gravity, OMC and maximum dry unit weight decreased as the crude oil content in the soil increased.
3. The unsoaked CBR of the soil initially increased before it decreased while its soaked CBR decreased with increasing percentages of the crude oil in the soil.
4. Addition of crude oil to the soil reduced its permeability. This was attributed to the entrapment of the crude oil within the pore spaces of the soil.
5. Use of the contaminated soil, without its stabilization or remediation, as a construction material is not recommended.

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