Polytechnic Journal
Polytechnic Journal

Volume 8 | Issue 2 Article 19

5-1-2018

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How to Cite This Article

GHAFFOORI, Farman Khalil and KARPUZCU, Mehmet (2018) "Influence of Oil Contamination on Geotechnical Properties of Sandy Soil," *Polytechnic Journal*: Vol. 8: Iss. 2, Article 19.
DOI: https://doi.org/10.25156/ptj.2018.8.2.215

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Abstract

Oil contamination due to accidental spill or leakage brings hefty damage to the environments. It percolates steadily into subsurface environments and contaminates the soil and water system. Every day, petrochemical activities, oil spills, and pipeline or reservoir leakage result in ground contamination. In addition to environmental concerns, such as groundwater pollution and the alteration of geotechnical properties of the contaminated soil. Contamination has been proven to alter the geotechnical properties of soil, and researchers have extensively studied the properties of contaminated granular soils. Hydrocarbon contamination has not just affected the quality of the soil but can also alter the physical properties of oil-contaminated soil. This study presented the geotechnical properties of oil-contaminated soils as well as uncontaminated soils for comparison. Testing programs performed on the studied soils included basic properties, compaction, and direct shear test. The soil samples were taken from the lands in the Lajan area and oil refinery site where there is a vast area subjected to this problem. Soil samples were artificially contaminated with crude oil in 4%, 8%, 12% and 16% by the dry weight of based soils. The results indicated a decrease in specific gravity from 2.619 to 2.58, also OMC decreased from 9.9 to 4.3 with increased crude oil from 0% to 16% respectively. Inversely cohesive was increased (0.26 to 48.1) with increase crude oil content at the same ratio. Knowledge of these effects of oil contamination is important in engineering and environmental remediation.

Polytechnic Journal: Vol.8 No. 2 (May 2018): Pp:129-141
http://epu.edu.krd/ojs/index.php/Journal

Influence of Oil Contamination on Geotechnical Properties of Sandy Soil

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ABSTRACT

Oil contamination due to accidental spill or leakage brings hefty damage to the environments. It percolates steadily into subsurface environments and contaminates the soil and water system. Every day, petrochemical activities, oil spills, and pipeline or reservoir leakage result in ground contamination. In addition to environmental concerns, such as groundwater pollution and the alteration of geotechnical properties of the contaminated soil. Contamination has been proven to alter the geotechnical properties of soil, and researchers have extensively studied the properties of contaminated granular soils. Hydrocarbon contamination has not just affected the quality of the soil but can also alter the physical properties of oil-contaminated soil. This study presented the geotechnical properties of oil-contaminated soils as well as uncontaminated soils for comparison. Testing programs performed on the studied soils included basic properties, compaction, and direct shear test. The soil samples were taken from the lands in the Lajan area and oil refinery site where there is a vast area subjected to this problem. Soil samples were artificially contaminated with crude oil in 4%, 8%, 12% and 16% by the dry weight of based soils. The results indicated a decrease in specific gravity from 2.619 to 2.58, also OMC decreased from 9.9 to 4.3 with increased crude oil from 0% to 16% respectively. Inversely cohesive was increased (0.26 to 48.1) with increase crude oil content at the same ratio. Knowledge of these effects of oil contamination is important in engineering and environmental remediation.

Key words: ***Oil contaminated soils; geotechnical tests; sandy soil; maximum dry density; optimum moisture content.***

INTRODUCTION

Land, air, and water are being contaminated for short-term benefits by industrial, petrochemical, construction, and sanitary activities. Considering land contaminations, environmentalists are concerned about subsurface water aquifer contaminations, plant growth in contaminated soil, and environmental and health hazards. On the other hand, geotechnical experts should consider the effects of soil contamination on the geotechnical properties of the soil. The soil-bearing capacity, foundation settlement, shear resistance, compressibility, and plasticity are the factors that must be taken into consideration.

Crude oil is one of the most common soil contaminants. Over two million tons of oil is produced all over the world every day, and about 10 percent is entering the environment due to pipeline breaks, leakage from reservoir tanks, tanker accidents, discharge from coastal facilities, and offshore petroleum productions. For instance, the destruction of Kuwait's oil production facilities at the end of the Gulf War resulted in a massive ground pollution (Al-Sanad et al., 1995). As another example, the southern coastal plain of Iran encounters pollution due to oil as a result of the historical oil exploitation and related tanker navigations, accidents, and petrochemical sewage (Kermani and Ebadi, 2012).

Oil contamination can adversely affect the soil microbes and plant as well as contaminate groundwater resources for drinking or agriculture (Hong et al., 2005). Hydrocarbon itself can separate into solid, liquid and gaseous phases which either remain close to the leaking places or migrate within the groundwater system or absorbed on grains as immobile residual fluid. The properties of soils and migration substances control the rate of migration, changes of composition and properties of migration substance.

Al-Sanad et al (1995) studied the compaction, CBR and permeability characteristics of oil-contaminated sand. Four different types of petroleum products were used in his study. Their study revealed that the compaction characteristics and CBR values improved up to 4 % oil by weight in sand. They further reported that the permeability value decreased with the increase in the content of oil in the sand but the changes were not significant. A laboratory testing program was performed to determine the effects of crude oil contamination on some of the geotechnical properties of clayey and sandy soils from the coastal soils from Persian Gulf beaches by Khamehchiyan et al. (2007). Their testing program examined basic properties, Atterberg limits, compaction, direct shear, uniaxial compression, and permeability of clean and contaminated soil samples that had the same density. Their study reveals that the optimum water content, maximum dry density and permeability decreases with the increase in crude oil content in the sand.

Cleaning of oil-contaminated soil commonly depends on excavating the material followed by subsequent treatment, incinerator or disposal in a landfill. This usually involves a complicated task especially located under storage facilities by virtue of high cost and limited disposal facilities of excavated soil (Shah et al., 2003). The hydrocarbon contamination will not just affect the quality of the soil but will also alter the physical properties of oil-contaminated soil. This will lead to geotechnical problems related to construction or foundation structure on this oil-contaminated site. Most associated impacts of oil contaminant are an excessive settlement of tanks and breakage of the pipeline (Mackenzie, 1970). The utilization of highly weathered soil for road base led to causes of damage from rainwater erosion and traffic (Millogo et al., 2008). An attempt has been made to use oil-contaminated sand in asphalt concrete for secondary road material (Al-Mutairi and Eid, 1997). Jamrah et al. (2007) investigated the geotechnical properties of untreated contaminated soils of Oman and comparison had been made with the treated soils. A microscopic study on oil-contaminated clay was also presented by (Habib-ur-Rahman et al. 2007) in order to understand the fabric and interaction between oil and clay mineral under Scanning Electron Microscope (SEM).Meegoda and Ratnaweera (1994) studied the compressibility behavior of contaminated fine-grained soils of low plasticity and high plasticity clays (CL and CH). The results showed that compressibility is controlled by the mechanical and physicochemical factors; they proposed correction factors to account for the change in the compression index caused by the viscosity of pore fluid.

Professional engineers and scientists have suggested several remedial methods for oil-contaminated lands. These included the conversion of oily soil to road base material or topping layers for car parks and roads after mixing with aggregate or consolidation agents. Other methods include containment in large burial sites, incineration, biological methods, absorption methods, soil washing methods, and vacuum extraction and separation by centrifuge and screen systems (Al-Sanad et al., 1995).

Aiban (1998) studied the effect of temperature on the strength, permeability, and compressibility of oil-contaminated sand obtained from eastern Saudi Arabia. He found that the compressibility and permanent deformation of the oil-contaminated sand increased as the temperature increased above room temperature and that the shear strength parameters were not sensitive to the testing temperature.

Puri (2000) evaluated the geotechnical aspects of oil-contaminated soils through laboratory testing on sand samples. The test results indicated that the compaction characteristics are influenced by oil contamination. The angle of internal friction of the sand based on the total stress condition was found to decrease with the presence of oil in the pores. One-dimensional compression characteristics of sand are significantly influenced by oil contamination, which results in a decrease in the value of the constrained modulus as the degree of oil saturation increases. Hydraulic conductivity was observed to be a function of the initial viscosity and the degree of oil saturation.

Shin and Das (2001) studied the bearing capacity of unsaturated oil-contaminated sand. Based on their test results, oil contamination drastically reduced the bearing capacity of sand.

This paper presents the results of a comprehensive laboratory testing program that was designed to determine the effects of crude oil contamination on sandy soils in the Lajan site at Erbil governorate, Kurdistan region-Iraq. The tested properties include shear strength parameters and compaction characteristics.

MATERIALS AND METHODS

Sample preparation

The soil used in this study was obtained from Lajan area, having a sandy soil profile, at Erbil governorate, Kurdistan region-Iraq. It was collected from the site of the soil profile at about 50 cm depth below the ground surface to prevent upper organic soil layers from entering the sample soils. Prior to the commencement of laboratory tests on the soil samples collected in sacks and transported to the laboratory, they were passed through a 4.75 mm sieve and oven dried, then the samples were mixed with crude oil in the amount of 0%, 4%, 8%, 12% and 16% by weight of the dry soil samples. The mixed samples were put into closed containers for 2 weeks for aging and equilibrium, allowing possible reactions between soil and crude oil. The contamination of the soil with varying percentages of crude oil was done in the laboratory.

PROPERTIES OF UNCONTAMINATED SOIL AND OIL

Sandy soil

The grain-size distribution of the sand is determined from hydrometer tests according to ASTM Standard Test Method D 422-63. As shown in Figure 1.

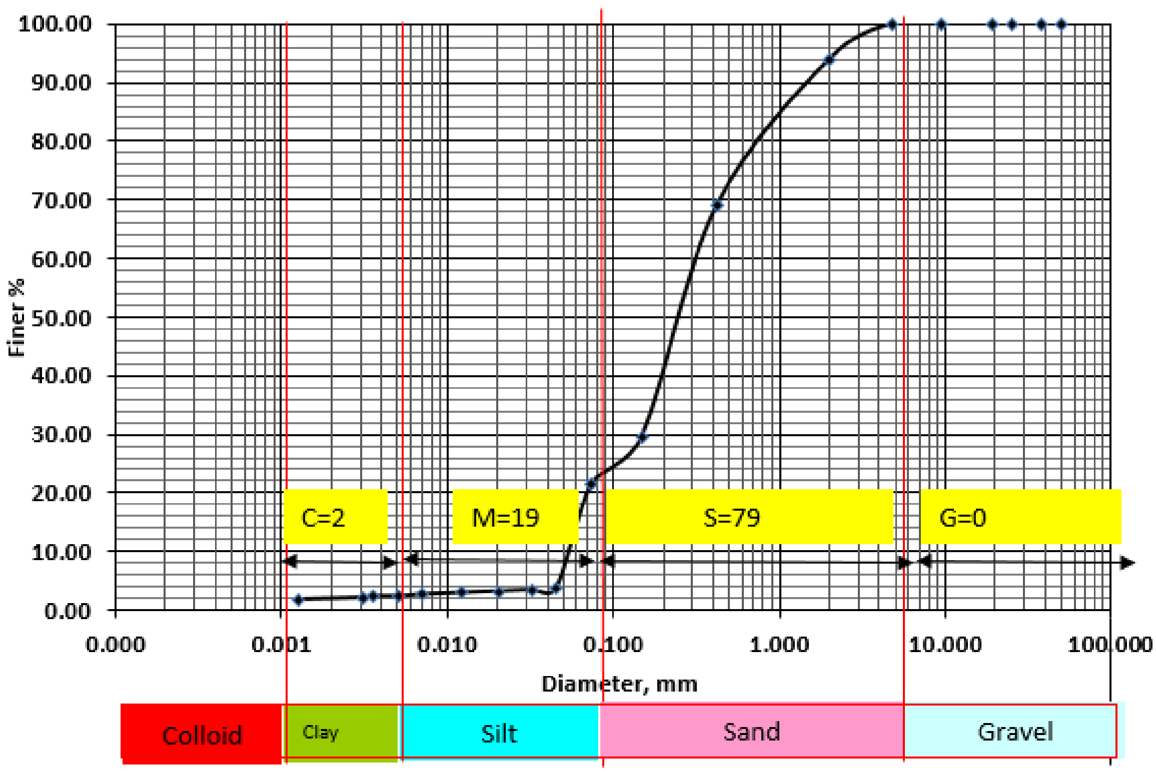

Figure 1: Particle Size distribution curve for soil samples.

Chemical composition of contaminated and uncontaminated sample by (XRF) test according to B.S. 1377/ 1990.

Table 1, Chemical composition of contaminated and uncontaminated sandy soil.

Elements	0% Oil	4% Oil	8% Oil	12% Oil	16% Oil
Na_2O %	0.026	0.022	0.026	0.028	0.043

MgO %	0.793	1.222	0.776	0.658	0.612
Al_2O_3 %	7.804	8.266	7.159	6.241	5.088
SiO_2 %	23.773	24.415	23.555	21.594	19.049
P_2O_5 %	0.709	0.625	0.681	0.656	0.688
SO_3 %	0.094	0.167	0.251	0.417	0.707
K_2O %	0.366	0.357	0.321	0.261	0.157
CaO %	18.507	16.625	16.953	15.504	15.308
MnO %	0.175	0.136	0.145	0.122	0.106
Fe_2O_3 %	4.598	4.548	4.279	3.9	3.703
pH	7.21	7.83	7.73	8.28	7.97

Crude oil

The crude oil used has its specific gravity at 25.0°C to be 0.851 and its American Petroleum Institute (API) gravity at 25.0°C to be 23.261 degree API.

Table 1, Properties of crude oil

Sample	Flash Point ^{0}C	Density @ 25^{0}C(g/cm3)	Specific Gravity @ 25^{0}C	^{0}API	Dynamic Viscosity (Cp)
Kar refinery	53	0.849	0.851	23.261	18.20

METHODS

In this investigation, the samples were prepared by mixing dry sand with different percentages of crude oil (0%, 4%, 8%, 12% and 16%) by the weight of the dry sand. The soil-crude oil mixtures were thoroughly mixed and stored in containers for 2 weeks to allow for homogeneity of the mixtures. Sieve and hydrometer analyses were carried out on the uncontaminated soil sample. Specific gravity (according to ASTM D854-10), compaction (according to ASTM D1557), and direct shear tests (according to ASTM D3080-72) were conducted on the contaminated and uncontaminated sandy soil.

RESULTS AND DISCUSSION

Specific gravity

The soil has a specific gravity of 2.619. 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 2. The specific gravities of the contaminated soil samples were found to be increased in 4% and 8% of crude oil content. It was higher than that of the uncontaminated soil sample after that, the specific gravity of the contaminated soil decreased with 12% and 16% of crude oil. Variability in specific gravity due to lubrication in particle contact is caused by the viscous nature of the pore fluid.

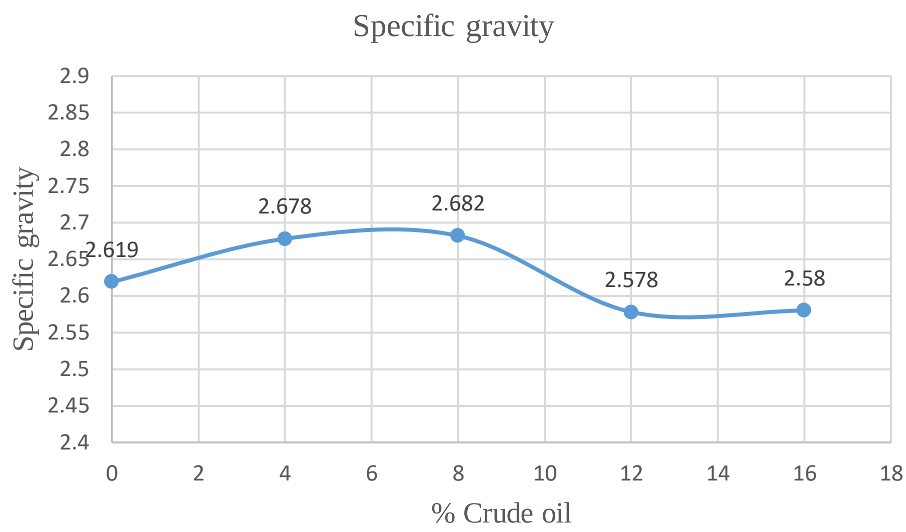

Figure 2. Illustrates the effecting crude oil on specific gravity of sandy soil.

Compactions

Standard Proctor tests (ASTM-D698) were performed on the artificially prepared samples with 0%, 4%, 8%, 12% and 16% oil content. The compaction characteristics were presented in graphical plots as shown in Figure 3. The compaction curves for contaminated soils clearly moved to the left the uncontaminated soils' curve as oil content increased. The effect of oil contamination on the maximum dry density and optimum moisture content can be seen from Figure 4a and 4b.

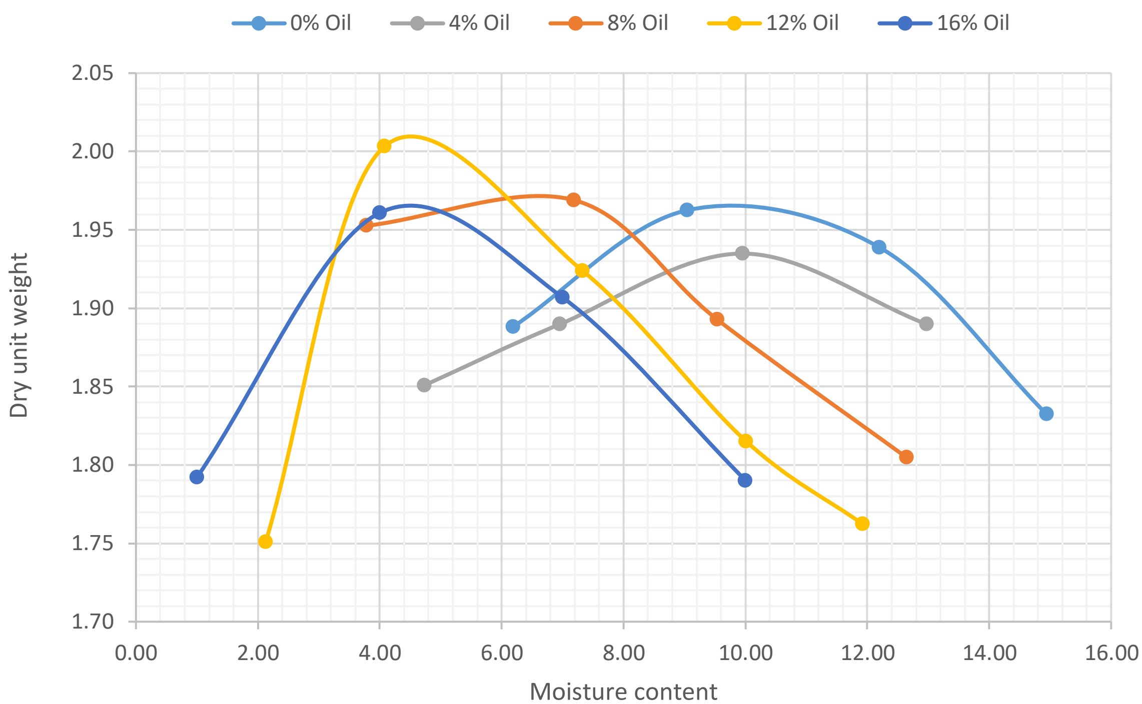

Figure 3. Compaction curves for samples with different oil contents.

Test results in figure 4a show a reduction in maximum dry density with increasing oil content up to about 4% and then increase in maximum dry density with increasing oil content. The reduction of dry density in sandy samples is very low because the pore spaces are larger in these samples and oil can move through the soil particles with the same rate as water and it has the similar lubricating effect. Al Sanad et al. (1995) observed effect oil contamination on Kuwaiti sand showed that maximum dry density decreased with increasing oil content.

However, with an increase of the oil content the shape of compaction curves changes. This indicates that too much oil is already present to reach effective compaction. For sands, the dry unit weight has a general tendency first to decrease as water content increases, and then to increase to a maximum value with the further increase of water content. The initial decrease of dry unit weight with an increase of oil content can be attributed to the capillary tension effect. At lower water content, the capillary tension in the water inhibits the tendency of the soil particles to move around and be densely compacted (Das, 1994). Capillary tension is extremely depending on the surface tension of electrolytes and angle of contact. As oil has hydrophobia property, it prevents contact of water with soil particles. As a result, the capillary tension force decreases with increasing oil content of soil samples.

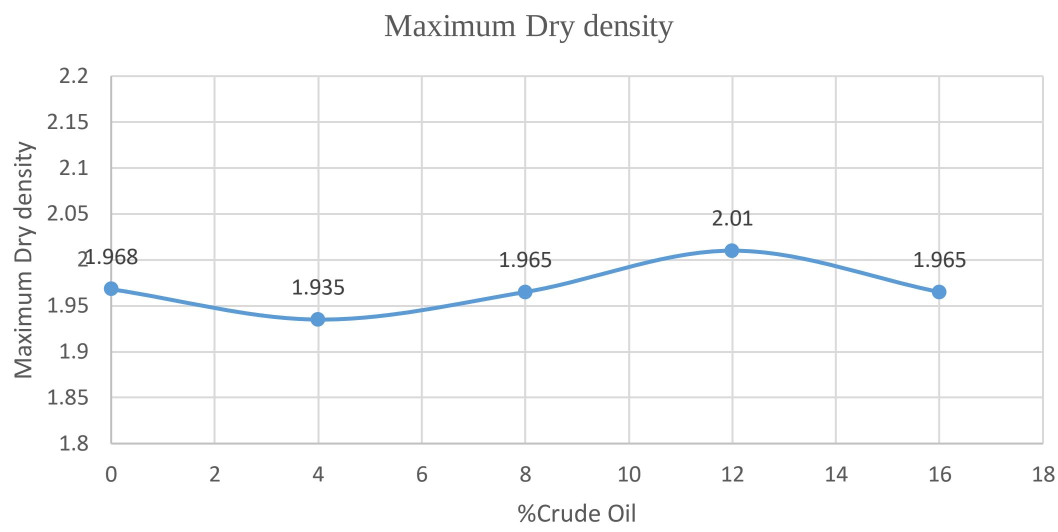

Figure 4a: Maximum dry density with crude oil.

Figure 4b shows the relationship between the moisture content and crude oil content from which it clearly indicated that drawdown trend of optimum moisture content with the increase in oil content. It clearly suggests that the moisture content required to achieve maximum dry density has decreased when crude oil content increased in contaminated soil. This is probably due to the fact that oil has partially occupied the inter-particles spaces and the occurrence of oil has changed the soil to a state of looser material than an uncontaminated soil.

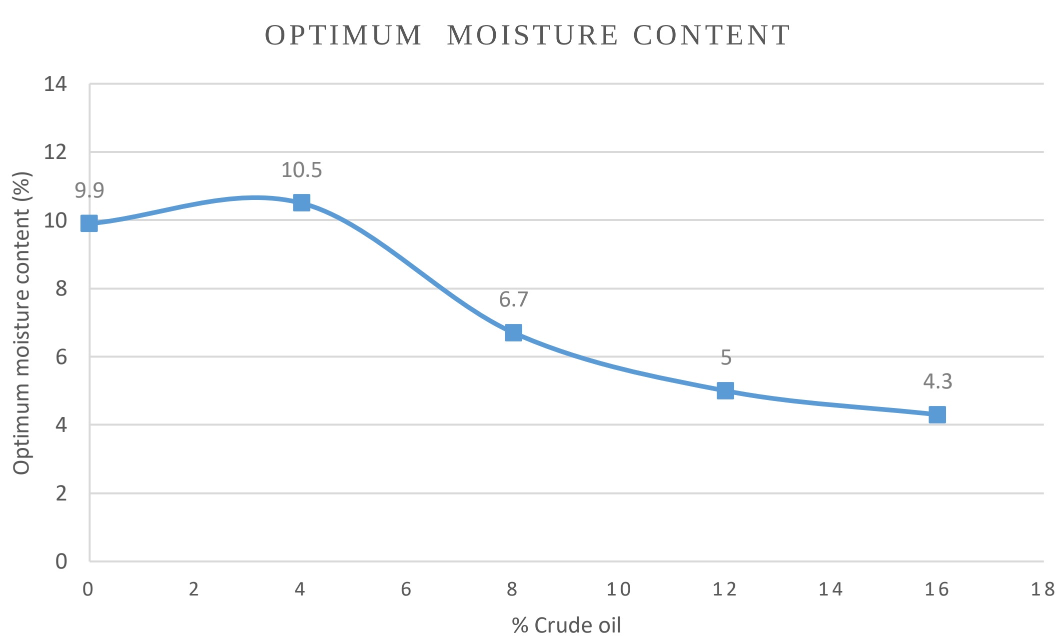

Figure 4b: Optimum moisture content with crude oil.

Direct shear test

The shear resistance of soil is an important parameter because it controls the bearing capacity as well as the slope stability and foundation design of a civil engineering structure. Direct shear tests (ASTM-D3080-72) were carried out to find the effect of oil contamination on strength parameters of soils. The present results show an inverse correlation between oil content and angle of internal friction Φ in sandy soils (Fig. 5). This correlation does not have any distinct path in samples show a low cohesion due to oil contamination that it can be the result of viscosity and inherent cohesion of oil (Fig. 6). It must be noted that wet sands show a little apparent cohesion due to the surface tension force of existing water in the soil. The cohesion increased significantly with oil contamination of up to 8% and then decreased with increasing percentage of crude oil. This increment in cohesion was due to the wetness of the sand by crude oil and hence the peak value of cohesion was obtained at 8%.

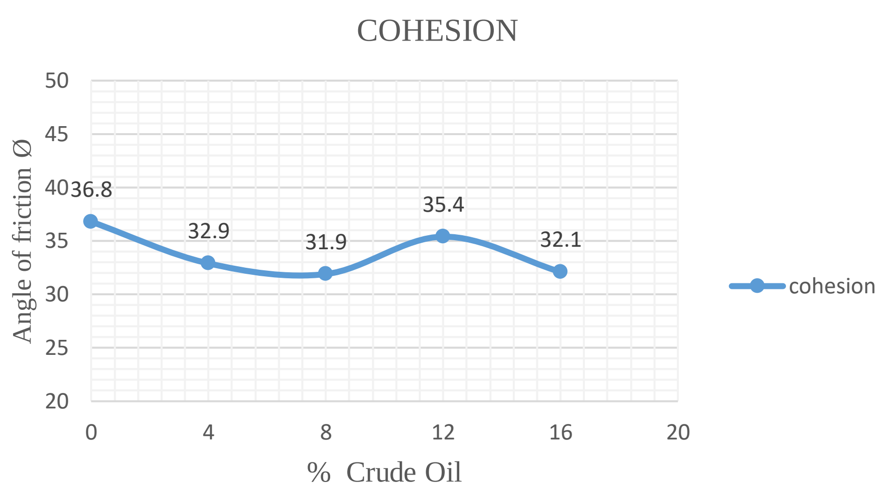

Figure 5: Angle of friction with crude oil

Lubrication at particle contact is caused by the viscous nature of the pore fluid. An increase in pore fluid viscosity changes the properties of mineral-to-pore fluid contacts, thereby displaying softening of stress-strain behavior (Ratnaweera and Meegoda, 2006). Direct shear tests performed on oil-contaminated sands (Ghaly, 2001) showed a reduction in Φ with the increase in oil percentage. Shin et al. (2002) report a significant reduction in Φ with oil contamination. The shear strength of granular soil decreases with an increase in pore fluid viscosity (Ratnaweera and Meegoda, 2006).

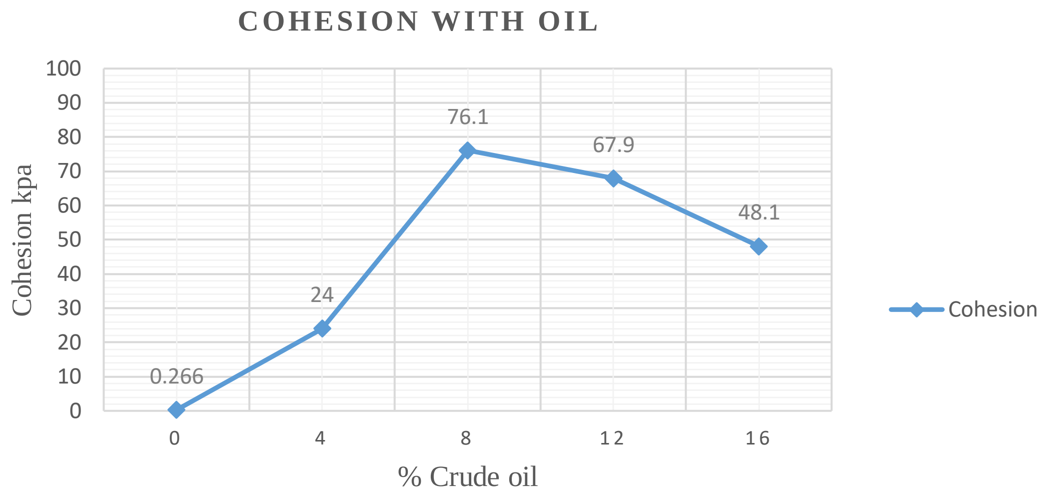

Figure 6: Cohesion with crude oil.

CONCLUSIONS

In this study, the effects of oil contamination on specific gravity, compaction and shear strength parameters properties are clearly observed on sandy soil.

- The specific gravity decreased as the crude oil content in the soil increased.
- The maximum dry density and maximum dry unit weight decreased as the crude oil content in the soil increased. Similar behavior was also observed on the shear strength of sandy soils.
- A slight reduction in frictional angle was observed for contaminated sand due to the inter-grain lubrication of the sand particles by the crude oil.
- The cohesion increased significantly with increased crude oil content.

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