Effect of Diesel-Oil Contamination on Shear Strength and Compressibility Behavior of Sandy Soil

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ABSTRACT

An experimental study was conducted to evaluate the effect of degree of diesel-oil contamination on deformation and strength of well-graded sandy soil with silt. The effects of contamination on shear strength and compressibility, in particular, have been thoroughly investigated in this study. The test results indicated that the shear strength parameters could be adversely affected by diesel-oil contamination. The compressibility of soil, as revealed by the compaction test and the one-dimensional compression test, was significantly influenced by the addition of diesel-oil as pore fluid. However, this ongoing study has yet to concentrate more on some other variables, such as the degree of saturation, relative density and rate of applying strain energy to the varying degree of diesel-oil contamination, which were not sufficiently addressed. Recommendations for extending these parameters and others are suggested.

KEYWORDS: Shear strength, Contamination, Compressibility, Sandy soil, Diesel-oil.

INTRODUCTION

Soil contamination by hydrocarbons is a pervasive problem that has adverse effects on the environment and on the physical and mechanical properties of soil. Sources of contamination include industrial and agricultural operations, leakage from pipelines, gasoline service stations, chemical and petrochemical storage tanks, refineries, pesticides and by-products of oil processing industry. During the past twenty years, several studies related to physical properties and behavior of oil-contaminated soil were published (Rahman et al., 2010; Srivastava et al., 2009; Ghaly, 2001; Al-Sanad and Ismael, 1997; Fan et al., 1994; Evgin and Das, 1992; Shin and Das, 1992). Most of the studies addressed the effect of contamination on strength and deformation properties of soil using crude oil (Ijimdiya et al., 2012) and spent engine oil (Achuba and Peretiemo-Clark, 2008) as chemical contaminant media to fill the pores of soil. Others studied the effects of other hydrocarbon contaminants on parameters other than strength and deformation of soil (Abu-Ashour and Shahlam, 2002; Lyman et al., 1990; Rizzo et al., 2002). Majority of soils tested in those studies were poorly graded sandy to silty soils, while few others studied the effect of contamination on other types of soil (Ojuri and Ogundipe, 2012; Ratnaweera and Meegoda, 2006).

In this study, a well-graded sandy silt soil, that was manufactured from designed percentages of grain sizes to bring this soil to the well-graded state while giving the soil some plasticity to conduct the targeted tests, was used .This soil was contaminated with diesel-oil and the geotechnical properties of this diesel-oil-contaminated soil were measured through intensive laboratory tests. The tested properties included shear strength

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parameters, compaction characteristics, compressibility and permeability.

In previous studies, it was reported that some geotechnical properties, such as compressibility of soil, depend on whether the soil is fine-grained or coarse-grained. For fine-grained soil, compressibility was attributed to both physical and environmental factors (physico-chemical factors). For medium-to coarse-grained soil, the mechanical behavior is governed by mechanical factors, such as deformation and rotational and translational displacements, rather than physico-chemical factors (Bolt, 1956; Terzaghi, 1957). Therefore, by using this type of soil, the physic-chemical factor, as a variable, was excluded from the tests.

LABORATORY STUDIES

The manufactured soil used in this study was brought from nearby creek. This soil was classified as (SW-SM) well-graded sand with silt, according to the Unified Soil Classification System. The following index properties were measured:

a. Specific Gravity, Gs = 2.63.
b. Effective Size, D_{10} = 0.119 mm.
c. Coefficient of Uniformity, C_u = 8.175.
d. Coefficient of Curvature, C_c = 1.122.
e. Maximum Void Ratio, e_{max} = 0.692.
f. Minimum Void Ratio, e_{min} = 0.403.
g. Unified Soil Classification: SW-SM.
h. Max. Dry Unit Weight, γ_{dmax} = 18.37 kN/m^3.
i. Min.Dry Unit Weight, γ_{dmin} = 15.29 kN/m^3.

Diesel-oil was used as soil contaminant in this study. The measured properties of diesel-oil are shown in Table 1.

The following laboratory tests were conducted as part of this ongoing study:

a. Standard Proctor Compaction Test (ASTM-D698-00).
b. Direct Shear Test under consolidated drained conditions (ASTM-D3080-04).
c. One-dimensional Compression Test.

Table 1. Physical properties of diesel-oil used in this study

Item	Quantity
Specific Gravity	0.836
Flash Point	58 ºC
Viscosity (Centipoises)	3.80
Heating Value (MJ/kg)	43.9

Compaction Test

The standard Proctor Compaction Test (ASTM- D-698) was performed on raw as well as on diesel-contaminated soil samples. For technical accuracy and for the sake of providing a basis for assessing the effect of diesel-oil on the compaction characteristics of soil, 14 batches of soil were tested. Each batch was made of two identical samples. One sample was tested using water as pore fluid and the other sample was mixed with a given proportion of diesel-oil and left to attain equilibrium prior to compaction. The mixing proportions were 2%, 3%, 4%, 5%, 6%, 7% and 8%. Test results were fed to a computer program that computes the optimum moisture content and the maximum dry unit weight (kN/m^3) (Bradet, 1999).

The program also predicts the dry unit weight at varying water (fluid) content. Table 2 lists the optimum moisture (fluid) content and the maximum dry unit weight (kN/m^3) with varying diesel-oil mixing proportions.

Direct Shear Test

Direct shear test (ASTM-D- 3080-04) was conducted to examine the effects of relative density and degree of saturation on shear strength parameters of diesel-oil-contaminated, well-graded soil. Cylindrical specimens of 63.5 mm diameter and 24 mm length were tested on a Geotechnical Consulting and Testing System (GCTS) direct shear apparatus. In this apparatus, the normal and shear loads were applied using servo-controlled hydraulic actuators, while the shear test was monitored using a built-in computer program (CATS

1.5). This program allows the user to easily setup and conduct direct shear test. It allows for real time determination and control of various test inputs, such as the corrected shear area of the specimen, as well as normal stress and shear stress.

To prepare a specimen , a predetermined weight of oven-dried soil was mixed with corresponding weight of diesel-oil, mixed thoroughly in a mixer, then preserved tightly to prevent any evaporation of diesel-oil out of the specimen and left to attain equilibrium prior to the test for 48 hours. The specimen was added to the shear box mold in three predetermined weighed layers and compacted enough to bring the specimen to the required relative density. Shear strength test was conducted on dry specimens of oven-dried sand and also on specimens having diesel-oil content of 2%, 3%, 4% , 5%, 6%, 7% and 8%, respectively.

The contaminant oil content is defined as:

$$w_o = \frac{W_o}{W_s} \tag{1}$$

where,

W_o = weight of diesel-oil occupying the void space.

W_s = weight of oven-dried specimen.

Table 2. Optimum moisture content and dry unit weight of the tested samples

Mixing Proportion (by weight)	Optimum Moisture Content (%)	Max. Dry Unit Weight (kN/m^3)
0%	10.88	17.91
2%	10.27	18.03
0%	10.76	17.73
3%	11.42	17.8
0%	10.32	18.01
4%	10.88	18.03
0%	10.75	17.69
5%	10.87	18.04
0%	10.34	17.05
6%	10.49	18.12
0%	11.4	17.69
7%	12.49	17.91
0%	12.23	17.72
8%	10.28	18.15

The degree of saturation, *S*, is defined as (Shin and Das, 2001):

$$S = \frac{V_o}{V_v} = \frac{w_0 G_s}{e G_0} \tag{2}$$

where,

V_o = volume of diesel-oil occupying the void space.

V_v = volume of void space in the soil solids.

G_s = specific gravity of the soil solids.

G_o = specific gravity of diesel-oil used to fill the void spaces.

e = void ratio of the soil.

Five levels of relative density were tested in this study: 35%, 45%, 60%, 75% and 90%. These levels should, to some degree, represent the consistency (stiffness) classification of loose, low dense, medium dense, dense and very dense states, respectively (Lamb and Whitman). For each level of relative density and oil content, three levels of normal pressure were applied: 55, 85 and 110 kPa. For each of these levels, the effects of the addition of diesel-oil in the pore spaces on the angle of friction and strength deformation were investigated. All tests were conducted in an undrained condition and at a constant horizontal shear displacement of 1.00 mm/minute. Table 3 summarizes all the test parameters that were involved in the direct shear test.

One-Dimensional Compression Test

One-dimensional test was performed to determine the effect of diesel-oil contamination on the strength and deformation properties of soil. This test was conducted on a hollow cylindrical steel mold (similar to the one used in compaction test) having an internal diameter of (104) mm and a height of (190) mm, with a steel plate below the base.

The test samples were prepared in batches, at variable degrees of diesel-oil saturation and five relative densities. A loading plate of (100) mm was placed in the "Master Loader HM-3000 Humboldt" Machine. The sample was loaded from the top using a constant rate of axial strain of (25mm/s). The applied load and the corresponding deformation of the sand specimen were measured. The tests were conducted under drained conditions only.

TEST RESULTS AND DISCUSSION

A computer program was used to plot and present the compaction behavior with water, as pore fluid, as well as with diesel-oil as pore fluid. The results of optimum moisture content *versus* maximum dry density were presented for each of the samples tested. Figure 1 presents an example of two plots, one for a non-contaminated sample and another for a sample that was mixed with diesel-oil as pore fluid (diesel-oil content, w_o, was 5%).

Table 3. Calculated values of degree of saturation (S) of the tested contaminated soils under varying levels of relative density and percentages of diesel-oil contents

		Diesel-Oil Content %							
		0	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Relative Density	35	0	10.6	15.97	21.30	26.62	31.95	37.27	42.6
	45	0	0 11.20	16.79	22.93	27.99	33.60	39.19	44.79
	60	0	12.13	18.20	24.26	30.33	36.39	42.46	48.53
	75	0	13.24	19.86	26.48	33.10	39.72	46.34	52.96
	90	0	14.57	21.85	29.14	36.42	43.70	50.99	58.27

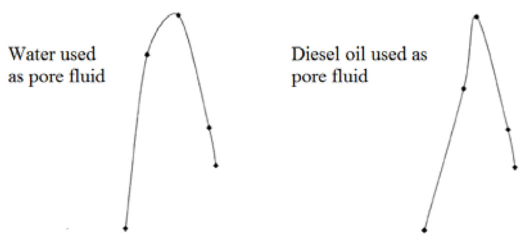

Figure (1): Compaction behavior of the two samples

For this batch, the maximum dry density obtained with water used as pore fluid was 17.69 kN/m^3, while the maximum dry unit weight achieved under the same compactive energy was 18.14 kN/m^3 (which is 2.5% higher when diesel-oil was used for compaction as compared to water).

This could probably be attributed to the higher viscosity of diesel-oil over water, which resulted in a better lubrication effect on sand particles, which in turn responded by rearranging themselves in tighter packing, thus resulting in higher dry unit weight.

To further investigate the effect of compaction, a plot of degree of saturation *versus* dry unit weight of all the batches tested was made. An example of these plots is shown in Figure 2, which represents the data extracted from compaction curves of the 6% diesel-oil content used as pore fluid in compaction. In general, for all the curves where the degree of saturation exceeds 50%, the maximum dry unit weight achieved when diesel-oil was used as pore fluid was significantly higher than that achieved when water was used as pore fluid.

Shear Strength

Based on the test results, it is believed that the shear strength parameters (namely angle of internal friction, ф, and cohesion, c) are adversely affected by diesel-oil contamination. Unfortunately, other variables have to be considered to support such conclusion. These variables include relative density of the tested soil, total normal stress and degree of saturation of the contaminated samples. Three levels of normal stress, eight percentages of degree of saturation and five levels of relative density will be considered in the experimental design. The acquired data through the data acquisition system will include peak shear stress and magnitude of horizontal displacement, while the measured data will include both angle of internal friction, ф, and cohesion, c. An example of the plot of shear stress is shown in Figure 3.

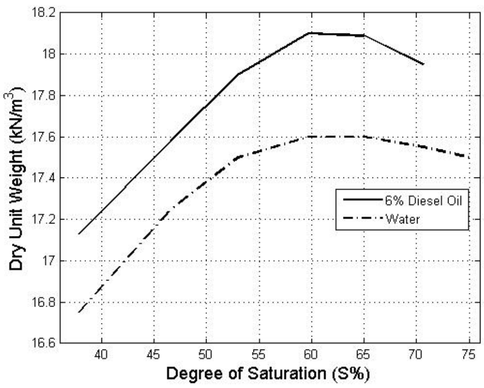

Figure (2): Variation of dry unit weight with degree of saturation of diesel-oil

One-Dimensional Compression Test

Based on the results of one-dimensional compression test, an increase in compressibility of soil samples contaminated with diesel-oil was observed. However, other variables have to be considered in the test in addition to relative density and degree of saturation. Among these, are the rate of strain level, the magnitude of the applied load and the duration. In general, it was evident that settlement will increase as a result of contamination of soil with diesel-oil.

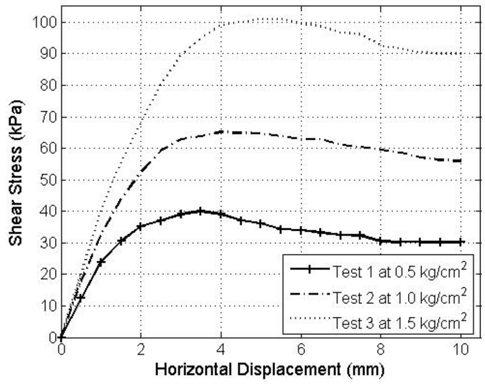

Figure (3): Shear stress plot of a contaminated soil sample

CONCLUSIONS AND FUTURE WORK

Contamination of soil by hydrocarbons is a serious problem that affects the safety and durability of civil engineering structures, such as highways, buildings, dams, among others. A soil that is contaminated with hydrocarbons may lose some of its shear strength and compressibility, which may result in excessive settlement and shear failure. Diesel-oil contamination is no exception. It may also affect other soil properties, such as hydraulic conductivity and ability to transmit and retain water in soil (Jamal and Shahlam, 2002).

This ongoing research is very important both to geotechnical and geoenvironmental engineering. Although the effect of crude oil, as contaminant, on the geotechnical engineering properties of poorly graded sandy soil was tackled by other investigators, this study is the first to investigate the effect of diesel oil, as contaminant, on strength and deformation of soil. Also, this research focused on a well-graded soil, which represents a considerable part of soils contaminated by man-made chemicals. The most important conclusions reached by this work are as follows:

a. Maximum dry unit weight under fixed compactive energy was higher when diesel-oil was used for compaction as compared to water.
b. It is believed that shear strength parameters will be adversely affected by diesel-oil contamination. However, further tests are needed to confirm this conclusion.
c. An increase in compressibility in one-dimensional compression test was observed. This conclusion could be very important in predicting settlement under a structure overlying formations that are prone to contamination by diesel-oil. However, other variables need to be included in this test (soil type, expansive soil, dispersive soil or other problematic ones).

To enrich this work further, work needs to be accomplished. This includes:

a. Continuing the direct shear test under varying percentages of relative density and percentages of contamination.
b. Studying the effect of other contaminants on the same type of soil.
c. Studying the effect of diesel-oil contamination on hydraulic conductivity (permeability) of soil under general loading conditions.
d. Studying the compression index of soil under contamination.
e. Conducting California Bearing Ratio (CBR) test on contaminated soil to investigate the possibility of utilizing contaminated soil in road construction.

There have been few methods to improve soil in contaminated areas. Soil stabilization by adding some additives, such as lime cement, bituminous fly ash and fiber seems to be the most practical and economic method to rehabilitate such contaminated areas.

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