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GEOTECHNICAL CHARACTERISTICS OF CONTAMINATED SOIL BY WASTE ENGINE OIL

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ABSTRACT

Soil is exposed to pollution as oil in most countries around the world due to leakage or spillage of petroleum materials. Also, increase in vehicles and equipment usage due to the increase in life civilization causes large quantities of waste engine oil that are disposed into the surrounding soil. Previous study on sandy soil by carried out by the authors [1] indicated that . The optimum waste engine oil content is found to be 12% by dry wieght of sand. The present study, laboratory testing program was carriedd out to find the optimum value of waste engine oil that affects the geotechnical properties of clayey soils. On the other hand, waste oils contain different components that may interact soil particles, and change its geotechnical properties. The present study focused on the effect of wate engine oil contamination on the geotechnical properties of both sandy and clayey soils in terms of its engineering and mechanical properties. The clay samples are prepared using kaolin clay and were artificially contaminated by mixing with waste engine oil with ratios in the range of 0% to 20% by dry weight. The results of the non-contaminated kaolin were taken as references for comparison. The results indicated that waste engine oil reduces the optimum moisture content and increases the maximum dry density of the contaminated samples. Also, the relative density decreases with the increasing of waste engine oil content. On the other land, increase of waste engine oil content in the sandy soil has no effect on the angle of internal friction. The optimum percentage is found to be around 8% of waste engine oil content. Finally, a comparison is made between the results obtained for both sandy and clayey soils in terms of the optimum waste engine oil content.

KEYWORDS: Engine oil, Contaminated Clay, Contaminated Sand, Shear Strength, Friction Angle, Compaction, Relative Density, Atterberg Limits.

الخصائص الجيوتقنية للتربة الملوثة بنفايات زيوت الماكينات

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الملخص

تتعرض التربة للتلوث البترولي في معظم دول العالم بسبب تسرب او انسكاب المواد البترولية. وكذلك نتيجة زيادة استخدام المركبات والماكينات يؤدي الى التخلص من كميات كبيرة من نفايات زيوت الماكينات الى التربة المحيطة. ومن دراسة سابقة اجراها الباحثون على تربة رملية [1]، وجد ان المحتوي الأمثل لنفايات زيوت الماكينات هو 12%. وتهدف الدراسة الحالية الى إيجاد القيمة المثلي لمحتوي نفايات زيوت الماكينات الذي يؤثر على الخواص الجيوتقنية للتربة الطينية. ونتيجة لذلك تحتوي نفايات الزيوت على مكونات مختلفة قد تتفاعل مع حبيبات التربة وتغير في خواصها الجيوتقنية. وركزت الدراسة الحالية على تأثير التلوث النفطي على الخواص الجيوتقنية للتربة الرملية والطينية من حيث خواصها الهندسية والميكانيكية. وقد تم اختيار عينات الطين على انها طين الكاولنيت وتم تلويثها اصطناعيا عن طريق خلطها مع زيوت الماكينات بنسب تتراوح من 0الي 20% من الوزن الجاف. وتم اخذ نتائج الاختبارات على الكاولنيت غير الملوث كمرجع للمقارنة مع الكاولنيت الملوث. هذا وقد اشارت النتائج الى ان نفايات زيوت الماكينات تقلل من محتوي الرطوبة الأمثل وتزيد من قيم الكثافة الجافة القصوى للعينات، أيضا تؤدي الى تناقص الكثافة النسبية. ونتيجة لذلك لم يظهر لنفايات زيوت الماكينات أي تأثير على معاملات القص بدلالة زاوية الاحتكاك الداخلي عند زيادة محتواه في التربة. وتبين ان النسبة المحتوي الأمثل لنفايات زيوت الماكينات للتربة الطينية هي 8%. وأخيرا تم اجراء مقارنة بين النتائج التي تم الحصول عليها من الاختبارات لكل من التربة الرملية والطينية من حيث المحتوى الأمثل لنفايات زيوت الماكينات.

الكلمات المفتاحية : نفايات زيت الماكينات، الطين الملوث، الرمل الملوث، مقاومة القص، زاوية الاحتكاك، الدمك، الكثافة النسبية، حدود اتربرج.

1 INTRODUCTION

Soil pollution is one of the common problems in most countries around the world, as there are many sources of pollution resulting from population growth and industrial progress or from human activities. Pollution may change soil components due to their interaction with pollutants or lead to a defect with these components. Among the pollutants most spread around the world and to which soil is exposed directly recently is petroleum products leaked into the soil. Petroleum products contain hydrocarbon materials or mineral substances that may interact with soil or cause slippage in the soil particles, and this leads to a change in the mechanical and engineering behavior of soil [2].

Several studies have conducted investigations to evaluation the effect of oil on the soil [3-7]. These studies showed that crude oil affects the properties of clay as Atterberg limits, plasticity index, specific gravity, maximum dry density, optimum water content, shear strength parameters and permeability. A few studies have inspected the influence of gasoline on the soil properties [8, 9]. The study showed that diesel causes an increase in maximum dry unit weight [10], and shear strength parameters will be adversely affected by diesel-oil contamination. Also, an increase in compressibility in one-dimensional compression tests was observed.

Effect of motor oil contamination on clay was also studied [11], the results showed that, motor oil caused decreases in liquid and plastic limits. Also, the coefficient of permeability is increased significantly three times its control value with increasing the contamination. Increasing the contamination duration up to 24 months causes minor effect on the coefficient of permeability at high stress range. Oil contamination causes a significant reduction in the unconfined compressive stress which reaches 38%. Compression index and swelling index are increased with increasing duration of contamination up to 6 months.

On other land, effects waste engine oil contamination on the plasticity, strength and permeability of lateritic clay were studied [12]. The results showed that the waste engine oil causes an increase in plasticity index of the soil. By increasing waste engine oil, the optimum moisture content, maximum dry unit weight, permeability decreased. Also, the unsoaked and soaked California Bearing Ratio values of the contaminated soil were greater than those of the uncontaminated soil. The results showed that compaction characteristics improve with the presence of waste engine oil. Unsoaked and soaked CBR values soil increase significantly with the presence of the waste engine oil to 8%. After that, a decrease in these values occurs at 12% and 16%.

Recently, the influence of waste engine oil on geotechnical properties of clayey and sand soil was studied [13]. The results showed that compaction characteristics improve with the presence of waste engine oil.

A previous study on sandy soil by the authors[1] showed that , the optimum waste engine oil content is found to be 12%. laboratory testing program was carried out to find the optimum value of waste engine oil content that affects the geotechnical properties of clayey soils. The present study focused on the effect of oil contamination on the geotechnical properties of both sandy and clayey soils in terms of its engineering and mechanical properties. Then, a comparison is made between the obtained results for both sandy and clayey soils in terms of the optimum waste engine oil content. This study was necessary to understand the mechanical behavior of contaminated soil.

2 MATERIALS AND METHOD

2.1 Soil Materials

2.1.1 Sand

The sand samples used in this study were collected from a site under construction for a building located in Giza Governorate – Egypt. The sand samples were taken from a depth of approximately 4.00 m below the existing ground elevation. The groundwater was not found until the depth of the boreholes that were taken to explore the site before construction. The grain-size distribution of soil was determined according to Egyptian geotechnical code of practices, (ECP). The sand samples are poorly graded (SP). Figure 1 graphically illustrates its particle size distribution. Physical and engineering properties of sand are summarized in Table 1.

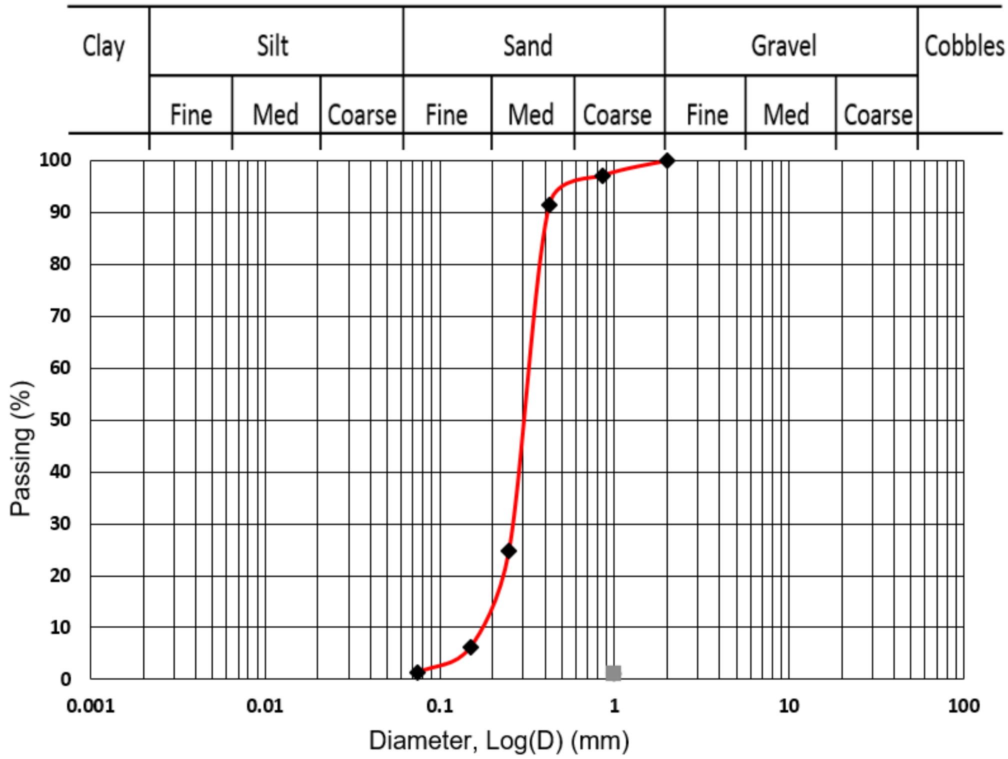

Figure 1. Grain-size distribution curve of the used sand.

2.1.2 Clay

The clay samples were obtained from Osheem ceramic in Fustat - Cairo Governorate – Egypt and that used in this study. Properties of kaolin were determined by SAFCO laboratory. Physical and engineering properties of kaolin were determined according to Egyptian geotechnical code of practices, (ECP) and summarizes in Table 1. Kaolin is white in color and in powder form.

Table 1. Properties of uncontaminated of the natural soil

Properties	Clay	Sand
Sand, (0.075-4.75mm) (%)	0	98.69
Silt and Clay, (<0.075mm) (%)	100	1.31
Color	White	Yellow
Effective diameter, D10 (mm)	-------	0.20
Uniformity coefficient, Cu	-------	1.62
Curvature coefficient, Cc	-------	0.55
Unified soil classification system	-------	SP- poorly graded sand
Specific gravity, Gs	2.66	2.60
Bulk density, γ_b (kN/m^3)	13.70	15.80
Maximum dry unit weight, γ_{dmax} (kN/m^3)	18.32	16.83
Optimum moisture content, O.M.C (%)	14.35	15.20
Void ratio, (e)	-------	0.67
Maximum void ratio, (e_{max})	0.94	0.87
Minimum void ratio, (e_{min})	0.45	0.56
Angle of internal friction, ϕ°	34.86	33°
Apparent Cohesion (kN/m^2)	5.00	-------
Liquid Limit, L.L (%)	32.2	-------
Plastic Limit, PL (%)	18.43	-------
Plastic Index, PI (%)	13.77	-------

2.2 Waste Engine Oil

The pollutant used in this study is waste engine oil collected from a petrol station nearby collected sand samples. A sample of waste engine oil was taken and transported to Egyptian

Petroleum Research Institute to determine the properties of the pollutant as shows in Table 2.

Table 2. Properties of engine oil

Properties	Standard	Value/Description
Density@ 15.56°C (kN/m3)	ASTM D-4052	8.884
Specific gravity, Gs	ASTM D-4052	0.8893
API gravity @ 60 °F	ASTM D-4052	27.62
Kinematic viscosity, cSt,@40o C	ASTM D-445	112.79
Dynamic viscosity, Cp,@40o C	ASTM D-445	98.45
Flash point, °C	ASTM D-92	215

Where :

API, (American Petroleum Institute) : The most commonly found classification standard on engine oil labels.

centiStocks, (cSt) : A unit expressing the measure of kinematic viscosity for motor oil at high temperatures.

centipoise, (Cp) : A unit expressing the measure of dynamic viscosity for motor oil at colder temperatures.

2.3 Sample Preparation

The clayey samples were divided into six parts. Waste engine oil added to each of the portions at 0%, 4%, 8%, 12%, 16% and 20% for clayey samples by dry weight of soil sample. Soil-Waste engine oil mixture was mixed and put into closed containers for 15 days for aging curing and equilibrium, allowing possible reactions between soil and waste engine oil. There are some limitations for addition of more waste engine oil more than 20%, because it will be on the moist side of compaction curve without increasing water. Moreover, the excess waste engine oil during compaction tests will drain out of the samples.

2.4 Experimental Work

Atterberg limits, compaction, relative density, and direct shear tests were conducted to study the contaminated sand and clay. The test procedures were carried out following ASTM standard. In some cases, the test has been repeated on other samples to check the results.

3 RESULTS AND DISCUSSION

3.1 Atterberg limits

The liquid limit, plastic limit, and plasticity index of uncontaminated clay were 32.205, 18.43% and 13.77% respectively. then the waste engine oil was added with 4%, 8%, 12%, 16% and 20% by dry wight of clay samples. The results showed that the liquid limit, plastic limit, and plasticity index of clay at 4% and 8% of waste engine oil content decrease progressively, then to increase at 12%, 16% and 20. Table 2 summarizes the results of these tests.

Table 3. Atterberg limits for uncontaminated and contaminated clay with waste engine oil

Waste Engine Oil Content (%)	0	4	8	12	16	20
Liquid Limit, L.L (%)	32.20	28.10	26.10	27.30	28.95	30.60
Plastic Limit, PL (%)	18.43	17.53	15.59	16.18	17.26	18.33
Plastic Index, PI (%)	13.77	10.57	10.51	11.12	11.69	12.27

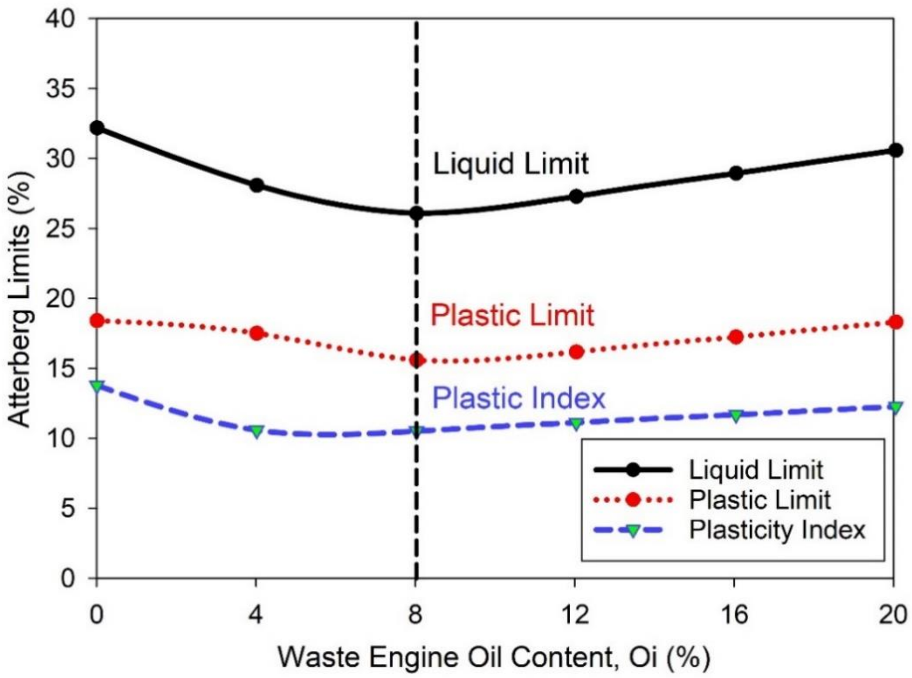

Figure 2. Atterberg limits - waste engine oil content

Figure 2 shows relationship between Atterberg limits and waste engine oil content and indicate that, Atterberg limits reach the lowest value at 8% of waste engine oil content, then to gradually increase with the increase of waste engine oil content.

Addition of waste engine oil to the soil caused micro-structural transformation of the soil. It is thought to have caused an inner layer expansion within the clay minerals. The waste engine oil may have enveloped both the clay minerals of the soil and the adsorbed water bonded to its surfaces (diffuse double layer).

Moreover, the waste engine oil led to lubricate the particles, which leads to a decrease in the amount of water content present in soil, by adding the waste engine oil content up to 8%. While, by increasing the waste engine oil by more than 8%, the waste engine oil begins to separate from the water content, which leads to an increase in the Atterberg limits. In general contamination by the waste oil has little effect on the Atterberg limits of the tested clay samples.

3.2 Relative Density

The clay samples were prepared at its natural relative density of 99.84% and then, the waste engine oil was mixed with 4%, 8%, 12%, 16% and 20% by dry wight of clay samples. The results as illustrated in Figure 3 indicates that the relative density of clay soil at 4% and 8% of waste oil content slightly decreased to 97.16% and 94.37% respectively, after which the relative density significantly decreased. Table 4 summarizes the results of the test to determine relative density of clay compared with sand samples at various waste engine oil content.

Table 4. Relative density for uncontaminated and contaminated samples by waste engine oil

Waste Engine Oil Content (%)		0	4	8	12	16	20
Relative Density, Dr (%)	Sand	69.55	78.96	89.80	90.56	82.24	------
	Clay	99.84	97.16	94.37	84.25	73.13	62.92

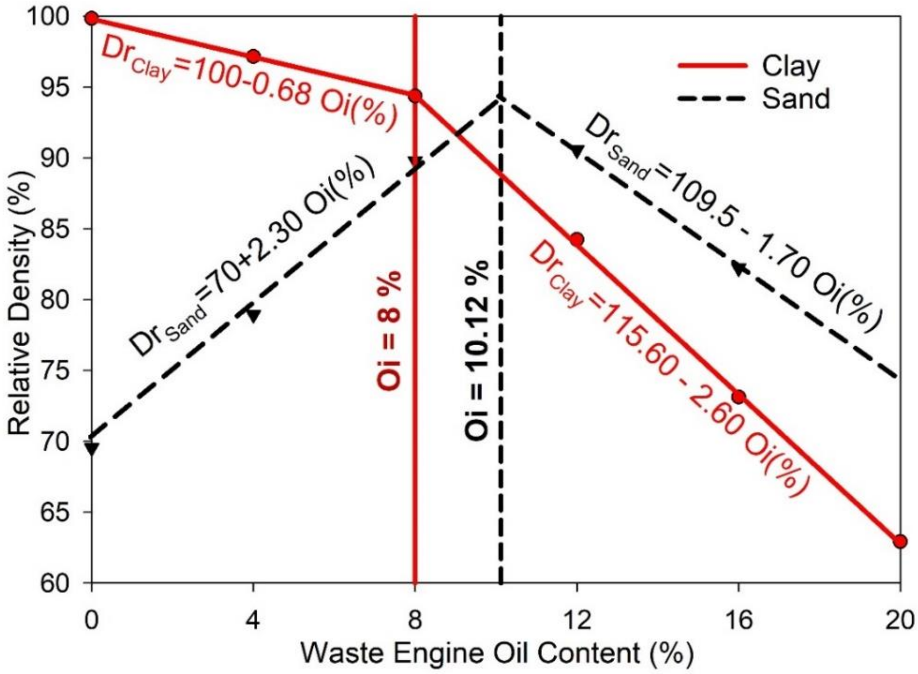

Figure 3. Relative density- waste engine oil content curve

The results reveal that the relative density improved for sand with adding the waste engine oil content up to 10.12%. While the relative density for clay significantly decreases with adding the waste engine oil content.

Based on the test results shown in Figure 3 and statistical analyses, linear equations were proposed between the relative density and waste engine oil content in the soil representing the first portion and second portion of the curve. The proposed equations are as follows:

1st portion $Dr_{Clay} = 100 + 0.68\ Oi(\%)\ < Oi = 8\ \%$ Eq (1)

$Dr_{Sand} = 70 + 2.30\ Oi(\%)\ < Oi = 10.12\ \%$ Eq (2)

2nd portion $Dr_{Clay} = 115.60 - 2.60\ Oi(\%)\ > Oi = 8\ \%$ Eq (3)

$Dr_{Sand} = 109.50 - 1.70\ Oi(\%)\ > Oi = 10.12\ \%$ Eq (4)

where:

$\boldsymbol{Dr}$: Relative density, (%)

Oi : Waste engine oil content in the sand samples by dry weight, (%)

3.3 Compaction test

Considering the non-effect of oven temperature(105 °C) on the waste oil within the soil matrix, the effect of heat will transfer directly to the water within the voids. Table 5 shows summary of the test results, in the form of maximum dry density and optimum moisture content for soil samples.

Table 5. Modified proctor compaction test results.

Waste Engine Oil content (%)		0	4	8	12	16	20
Sand	Maximum Dry Density, γ_{dmax} (kN/m^3)	16.83	17.78	18.17	18.62	18.52	-----
	Optimum Moisture Content, O.M.C (%)	15.20	9.60	5.60	2.52	0.75	-----
Clay	Maximum Dry Density, γ_{dmax} (kN/m^3)	18.54	18.85	19.00	18.95	18.88	18.82
	Optimum Moisture Content, O.M.C (%)	14.35	11.25	8.40	6.20	2.88	1.10

The results showed that, for the clay the maximum dry density of the uncontaminated samples is 18.54 kN/m3 with optimum moisture content of 14.35%. By increasing the waste engine oil to 8%, the maximum dry density increased to 19 kN/m3 with optimum moisture content decreased to 8.4%. Increasing the amount of waste engine oil to 20%, the maximum dry density value decreased to 18.82 kN/m3 and optimum moisture content to 1.1%. After 20% waste engine oil content, the reduction becomes negligible due to the increase of total value of soil matrix. Also, maximum dry density do not change by adding more water. The relationship between the maximum dry density and waste engine oil content for clay compared with sand is shown in Figure 4.

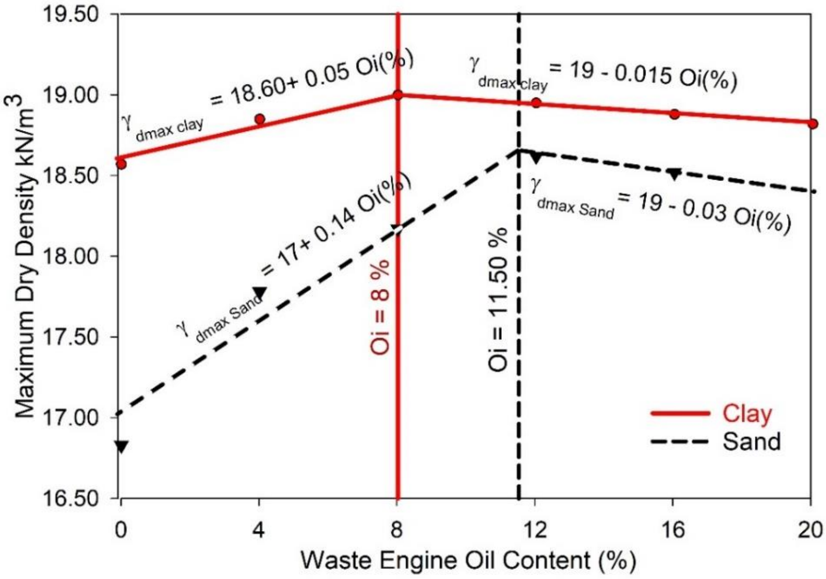

Figure 4. Maximum dry density-waste engine oil content curve

The effect of waste engine oil on compaction for sand and clay led to an improvement in the compaction for both soils, with more effect on sandy soil. On the other hand, the effect of waste engine oil on the maximum dry density of clay showed slightly improved.

Based on the test results as shown Figure 4 and statistical analyses, linear equations are proposed between the maximum dry density and waste engine oil content in the soil are equations in first and second portion. The proposed equations are as follows:

1st portion $\gamma_{dmax\ clay} = 18.60 + 0.50\ Oi\ (\%) < Oi = 8\ \%$ Eq.(5)

$\gamma_{dmax\ sand} = 17 + 0.14\ Oi\ (\%) < Oi = 11.50\ \%$ Eq. (6)

2nd portion $\gamma_{dmax\ clay} = 19 - 0.015\ Oi\ (\%) > Oi = 8\ \%$ Eq. (7)

$\gamma_{dmax\ sand} = 19 - 0.03\ Oi\ (\%) > Oi = 11.50\ \%$ Eq. (8)

where:

γ_{dmax} : Maximum dry density, (kN/m^3)

Oi : Waste engine oil content in the soil, (%)

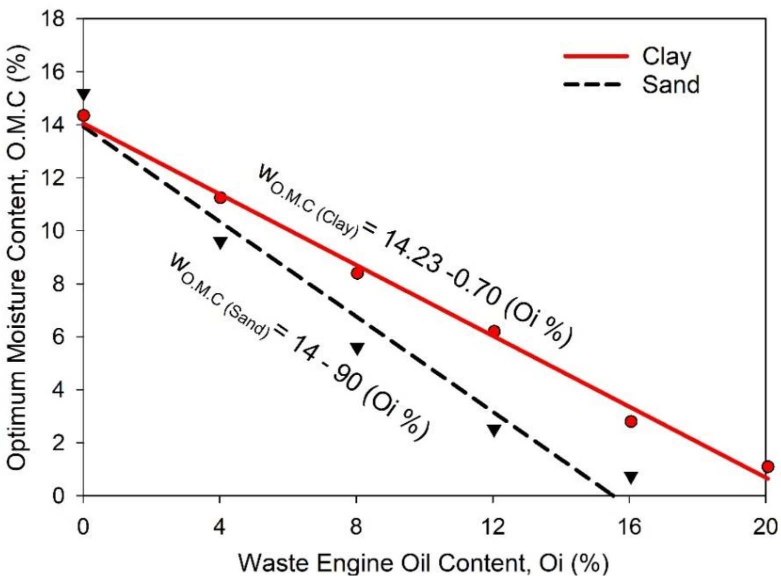

Figure 5. Optimum moisture content-waste engine oil content curve

Figure 5 shows the relationship between the optimum moisture content and waste engine oil for sand and clay. The results indicate that the optimum moisture content decreases with the increase of waste engine oil content. The optimum moisture content of sand decreases at a higher rate more than that for clay. This is due to the ability of clay to absorb waste engine oil and water together before the liquidity of the clay occurs, at 20% waste engine oil content, compared to sand, which reaches liquidity 16% waste engine oil content.

These results are consistent with the results of other studies which investigated effects of a similar waste engine oil-contaminated material on soil [3, 13-15]. Based on the test results shown in Figure 5 and statistical analyses, linear equations were proposed between the optimum moisture content and waste engine oil content in the soil are Equation 9 for clay and Equation 10 for sand.

wo.m.c (clay) = 14.23 - .0.70 Oi(%) Eq. (9)

wo.m.c (sand) = 14 - 90 Oi(%) Eq. (10)

where:

wo.m.c : Optimum moisture content, (%)

Oi : Waste engine oil content, (%)

3.4 Shear Strength

The procedures adopted for preparing samples for testing direct shear box were the same as those followed for studying the effect on relative density. The effect of the waste engine oil content on the angle of internal friction of clay and sand samples is listed in Table 6 and plotted in Figure 6. The angle of internal friction of clay increases from 34.86° to 42.90° with increasing of waste engine oil content from 0% to 4% of waste engine oil content then the angle of friction decreases to 34.9° at 8% of waste engine oil then the angle of friction increases and decreases up to 20% of waste engine oil. This means that the waste engine oil no effect on the angle of friction for clay. Where the angle of friction for sand decreases from 33° to 28.60° with increasing of waste engine oil content from 0% to 16% with neglecting cohesion. The angle of friction decreased about 13.33% with 16% of waste engine oil compared to its value at 0% waste engine oil, (uncontaminated sand).

Table 6. Results of shear strength tests

Waste Engine Oil content (%)		0	4	8	12	16	20
Sand	Angle of Internal friction, ϕ°	33	31.10	30.10	29.10	28.6	-----
	Apparent Cohesion, c' (N/mm^2)	Almost Zero					
Clay	Angle of Internal friction, ϕ°	34.86	42.90	34.90	39.90	41.80	41.40
	Apparent Cohesion, c' (N/mm^2)	-4.23	-40.70	4.90	-19.40	-16.40	-19.40

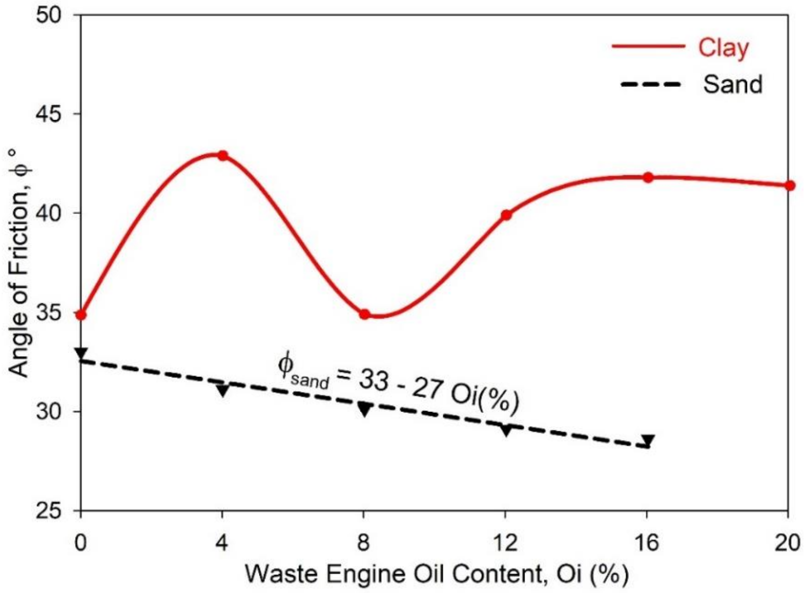

Figure 6. Relationship between angle of friction and waste engine oil content

The waste engine oil makes the sand particles slide, which reduces the angle of internal friction. As for kaolin, with the addition of waste engine oil, the angle of internal friction begins to increase and then decreases and increases. It can be considered that the waste engine oil does not have a noticeable effect on the angle of friction in clay. Based on the test results as shown in Figure 6 and statistical analyses, a linear equation was proposed between the internal friction angle and waste engine oil content for the sandy soil is Equation 11.

□ = 33 - 27 Oi(%) Eq. (11)

where:

□: The internal friction angle.

Oi : Waste engine oil content in the soil, (%)

Figure 7 shows that the apparent cohesion for clay increases and decreases with adding waste engine oil to clay sample from 0% up to 20% waste engine oil content by dry weight samples. This means that the waste engine oil no effect on the apparent cohesion for clay. Too, the apparent cohesion for sand was neglected.

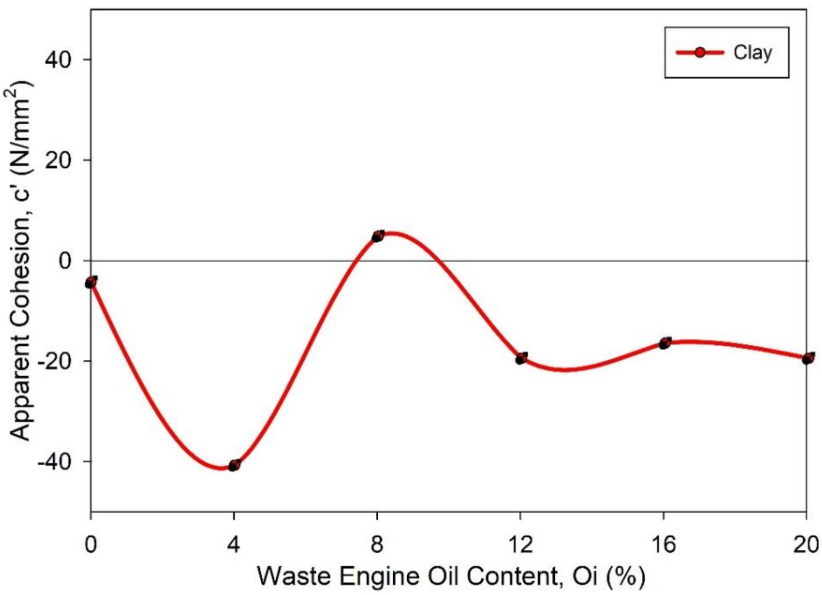

Figure 7. Relationship between apparent cohesion and waste engine oil content

From the results of previous tests, it was considered that the optimum waste engine oil content for clay and sand are 8% and 12%, respectively. For clay and sand, a comparison of the shear stress and specimen height variation with shear displacement at different applied stress, (σn) of (a) 100kN/m2, (b) 200kN/m2 and (c) 300kN/m2 and the change in height of the specimen increases during the application of the shear force at same level of waste engine oil content as shown in Figure 8. This can be shown as the presence of waste engine oil content with higher viscosity than water may be covering the soil particles. Also, with increasing of waste engine oil content in particular soil, the inter-particle slippage will increase, this led to decrease the shear strength.

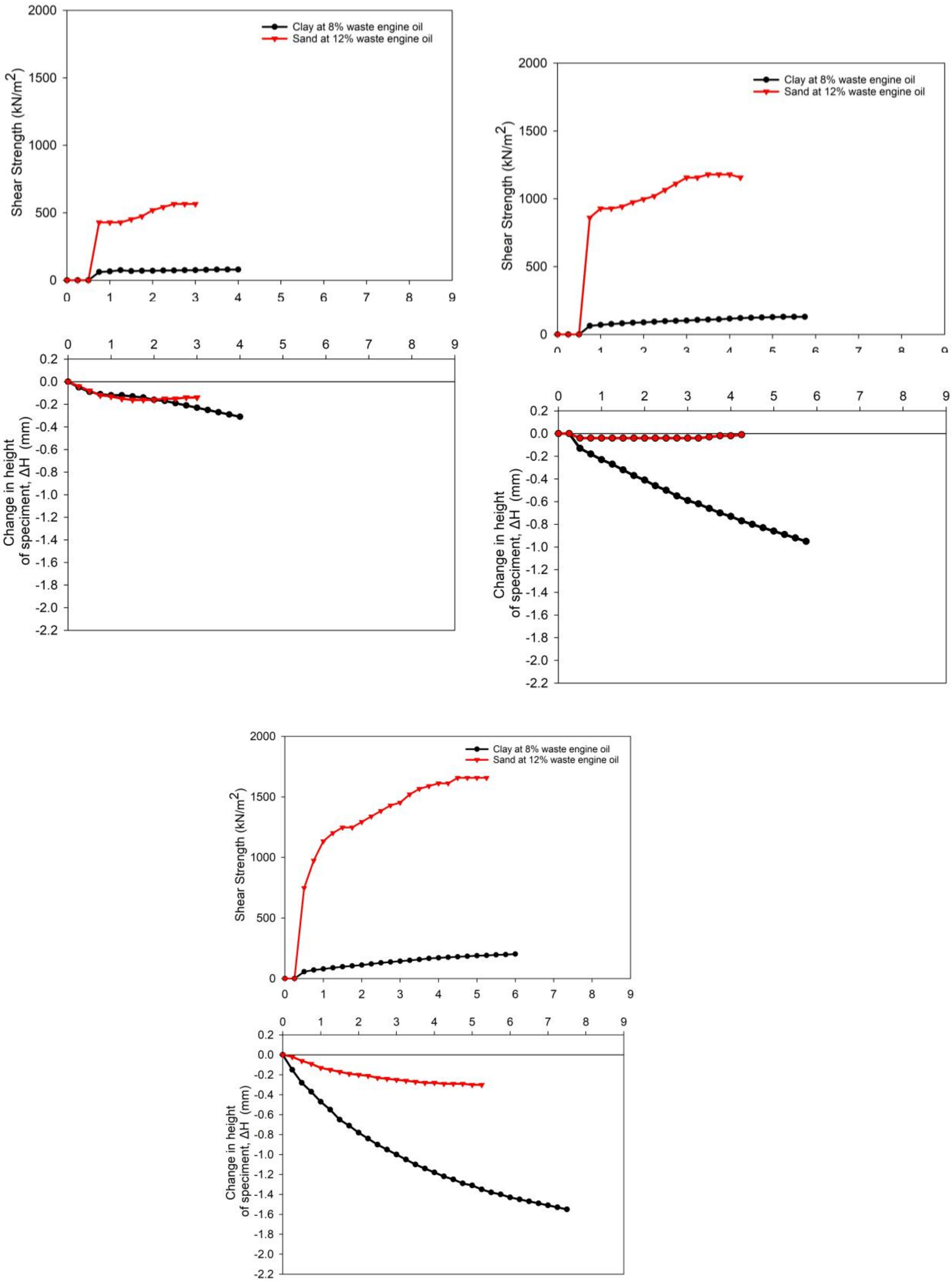

Figure 8. Shear stress and change in height of specimen against shear displacement at different applied stress, σn of (a) 100kN/m^2, (b) 200kN/m^2 and (c) 300kN/m^2

4 CONCLUSIONS

In the present study, the effect of waste engine oil on geotechnical, engineering and mechanical properties of clay and sand soils were studied, Atterberg limits, compaction, relative density. The results showed that, by adding the amount of waste engine oil in soil, highly viscous waste engine oil acts as a lubricant, facilitating the sliding of particles over each other and causing dunchin of particle voids. The following conclusions can be made from the obtained results:

Atterberg limits reach the minimum value at 8% waste engine oil content, then to gradually increase at 12%, 16% and 20% of waste engine oil contents.

The relative density increases with increasing waste engine oil content from 0% to 10.12% for sandy soil, then it decreases by increasing the waste engine oil content, while the relative density of clay decreases by adding the waste engine oil content.

The maximum dry density for sandy soil increases with increase of waste engine oil from 0% to12% and slightly decreases at 16%. For clayey soil, the maximum dry density increases by increasing waste engine oil from 0% to 8%, then slightly decreases at 20%. while the optimum moisture content decreases with increasing of waste engine oil until it is reaching negligible value.

Waste engine oil contamination decreased the peak shear strength in all ranges of oil content. The angle of internal friction of sand decreased about 13.33% with 16% of waste engine oil compared to its value at no waste engine oil, (uncontaminated sand).

Based on the statistical analyses linear equations were proposed relative density (Dr), maximum dry density (□dmax) and the angle of internal friction (□) with the percentage contents of waste engine oil.

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