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Effect of Waste Engine Oil Contamination on the Geotechnical Properties of Cohesive Soils in Sulaimani City, Iraq

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Abstract— The effect of waste engine oil (WEO) contamination on the geotechnical properties of cohesive soils was investigated. Three cohesive soils were collected from three locations in Sulaimani City. Geotechnical laboratory tests were carried out included consistency properties, unconfined compression strength, swelling pressure, and compressibility properties for both of intact and contaminated soil samples. Various percentages (0%, 1%, 2%, 4% and 6%) of WEO were mixed with the selected cohesive soil as a simulation of the field contamination issue. The results showed that the liquid limit (LL), plastic limit (PL), plasticity index (PI) increased as the content of WEO increased, however, experienced a decrease at 1% WEO content, thereafter an increase commenced again. The values of linear shrinkage limit, unconfined compressive strength (UCS), swelling pressure (SP) and Recompression index (Cr) decreased as the content of the WEO increased. The values of compression index (Cc) also increased at 0%, 1% and 2% WEO content, after that a little increase commenced again. WEO contaminated soil requires stabilization before using it as a construction material and/or for construction projects foundations.

Keywords—Waste Engine Oil, Cohesive Soils, Sulaimani City.

1. Introduction

Oil spills and oil leakage from oil storage tanks. WEO is one of the main problems facing the oil producing countries of the world. The effect of these leaks and spills creates problems to the environment. Waste engine oil has been implicated as a major source of contamination resulting in building failures due to loss in strength, which results to differential settlement and cracks in the foundation of structures. The oil contamination in soil leads to a significant increase in the soil consistency characteristics, also loss in bearing capacity of contaminated soils and increases its settlement [2, 16]. This type of contaminated soil needs to be stabilized before using for any project. In the present study, the major purpose is to investigate the effect of WEO contamination on the geotechnical properties of some cohesive soils in Sulaimani City, northern part of Iraq.

The increasing of motor oil content [16] found to be decreasing consistency characteristics and unconfined compressive strength of an over consolidated clay. The effects of WEO were investigated by other researchers [17, 25]. The latter showed that the increasing of WEO content, which mixed with the soil, can result in decreasing both of liquid and plastic limits. Also, decreasing optimum moisture content (OMC), maximum dry density (MDD) and permeability of basaltic residual soil .

The effect of engine oil in the soil was studied by [20]. Their results showed that the OMC, MDD, UCS, and California bearing ratio (CBR) of a lateritic soil were reduced with the increasing of engine oil content in the soil. The work of [21] focused on the effect of WEO contamination on poorly-graded sands and clays. The effective angle of internal friction for the poorly-graded sands decreased thereby reducing its bearing capacity. However, hydraulic conductivity decreased with a maximum decrease at 3% contamination level. The influences of contaminating on a lateritic clay soil with WEO were also considered by [1]. It is found that the specific gravity, plastic limit, optimum moisture content, maximum dry unit weight, and permeability of the soil decreased with increasing of WEO content in the soil. On the other hand, the liquid limit, plasticity index of the soil increased as its WEO content increased. Impacts of crude oil contamination on soils specific gravity, liquid limit, plastic limit, and shrinkage limit was examined by [13]. In the same study, engineering properties (free swelling index) for kaolinite clay and fine-grained sand studied. The percentage variation for each property (specific gravity, liquid limit) shown by fine-grained sand for each percentage of contamination was concluded to be higher than that in clays. Then, the plastic limit, shrinkage limit and free swell index for kaolinite clay decreased with the increase of contamination percent in the soil. The use and improvement of lateritic soils, which is abundant in tropical and subtropical regions of the world, have been considered in recent research work such as [1, 2]. This paper consists of a batch of experimental investigations on natural and contaminated cohesive soil by WEO.

2. Materials and Methods

2.1 *Materials*

2.1.1 Soil samples

In the present study, cohesive soils were used. Three soil samples were collected from three different locations in Sulaimani City, northern Iraq namely: Qlyasan, Barika, and Arbat (Figure 1). The samples were extracted from a shallow depth of 0.5-1.0 m. Figure 2 illustrates graphically the grain size distribution for all soil samples.

Figure 1: Qylyasan, Arbat, and Barika Locations on Iraqi and Sulaimani City maps, which used for soil samples collection.

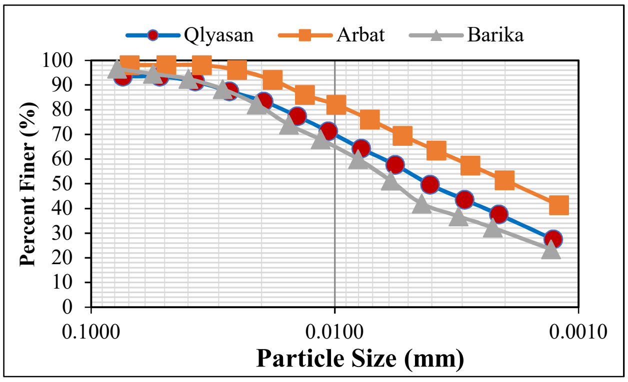

Figure 2: Particle size distribution (Hydrometer Analysis) of the non-contaminated natural soil samples.

2.1.2 Waste Engine Oil

Waste Engine Oil (WEO) was collected from local changing automobile oil companies. The selected WEO was for small cars. **Table 1** gives a summary of the basic properties of the used WEO used in this study, including: specific gravity, density, and color. The tests on WEO have been conducted by the researches in the geotechnical laboratory, college of engineering at the University of Sulaimani, Iraq.

Table 1: Some of the physical properties of the used Waste Engine Oil (WEO).

Color	Density (gm/cm^3)	Specific Gravity (S_G)
Black	0.723	0.9064

2.2 *Testing specimens' preparation*

Soil samples were collected and saved in jute bags, then brought to the geotechnical laboratory in the University of Sulaimani, Sulaimani City. All samples used to pass 4.75 mm sieve opening. For each geotechnical tests, soil samples were divided into five proportions. The WEO sample has been prepared in order to add it to the prepared soil samples and water according to the previous determination of soil samples wet and dry densities and field moisture contents. The WEO sample was added to the soil proportions in the dry state, then, all the proportions were mixed and then each testing specimen was prepared. Each testing specimen was left for 24 hours before testing in order to get homogenous distribution of the added water and the prepared sample be matured. The addition of WEO was conducted to replicate in-situ condition in most possible manner at 0%, 1%, 2%, 4% and 6% of the total mass of the collected cohesive soil samples.

2.3 *Methods*

In this study, the index properties, classification, shear strength and compressibility tests namely, natural moisture content, specific gravity, field density and particle size analysis (Hydrometer analysis), Atterberg's limits, swelling pressure, compressibility and unconfined compression test were performed on the intact and contaminated soil samples with various percentages of WEO. Geotechnical laboratory experiments were conducted according to ASTM standards as follows; moisture content [7], specific gravity [11], hydrometer analysis [4], density (unit weight) [5], Atterberg limits [8], linear shrinkage limit [6], unconfined compression strength [12], one-dimensional consolidation [9] and swelling pressure [10].

3. Results and Discussion

3.1 *Basic properties of intact soil samples*

Table 2 shows the natural cohesive soil samples (non-contaminated samples) index and some other geotechnical engineering properties. It can be seen in the table that, the listed properties for the given soil samples are variable.

Table 2: Geotechnical properties of the selected intact soil samples.

Soil properties	Qlyasan Soil	Arbat Soil	Barika Soil
Natural moisture content (%)	14.13	13.63	14.50
Specific gravity	2.64	2.65	2.55
Dry Density (gm/cm^3)	1.66	1.66	1.57
Liquid limit (%)	44	52	48
Plastic limit (%)	24	30	25
Plasticity index (%)	20	22	23
Shrinkage limit (%)	14	17	12
Unconfined compressive strength (kN/m^2)	485.81	335.34	223.77
Swelling Pressure (kN/m^2)	131.9	91.6	100
Compression Index (C_c)	0.16	0.16	0.154
Recompression Index (C_r)	0.007	0.018	0.013
Soil Type (USCS)	CL	CL	CL

3.2 *Effect of WEO on consistency properties of the soils*

3.2.1 Liquid Limit, plastic limit and plasticity index relationships with WEO content

From Figures 3, 4, and 5, it can be noticed that the liquid limit (LL), plastic limit (PL) and plasticity index (PI) for all the soil samples decreased within a range of 0-1% of the added percent of WEO. So, hence, when the WEO content increased, contaminated soils become less workable within a range of 0-1%. Also, with increasing of the WEO percent thereafter, the value of LL, PL and PI started to increase as the WEO increased. This shows that the contaminated soils become more workable. An interlayer expansion within the clay minerals thought to be caused within the addition of WEO to the soil, which may be responsible for the change in its plasticity [2]. The obtained results are in contrast with the results of Khamehchiyan et al., 2007 [15]. The study showed that a reduction in the Atterberg's limits happens as oil contamination raises in CL soil samples. In addition, they are also compatible with the results of Rehman et al., 2007 [18].

Qlyasan soil showed the highest increase in the consistency properties as shown in **Figure 5**, and Barika soil showed the lowest increase in LL and PL percent's. These differences were obtained may be due to various chemical and physical factors such as particles shapes and sizes, mineral content, impurities content, clay mineral types and percent's. In the same time, the used WEO can be responsible for some of the changes happened with consistency properties. Due to the low physical properties (**Table 1**) of WEO and when replace by parts of the soil samples, it causes notably changes because of low interaction with water and decrease the activity of soil particles for water absorption issue.

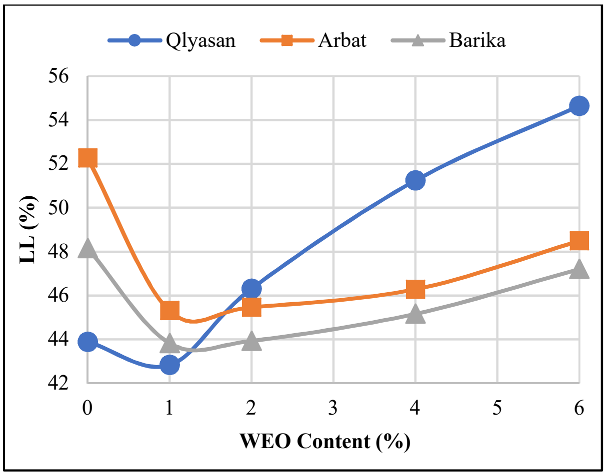

Figure 3: Variation of liquid limit with WEO content.

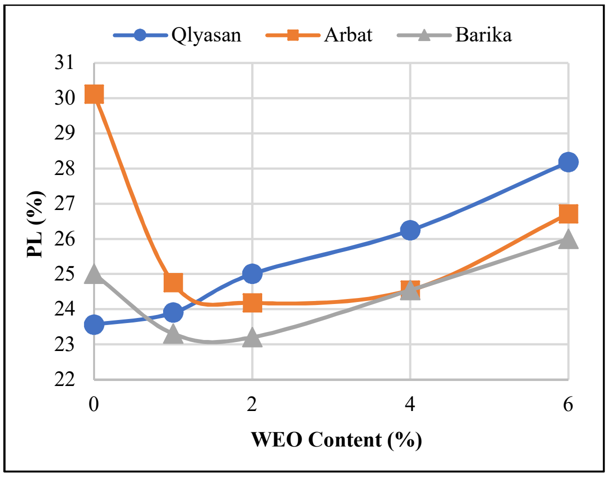

Figure 4: Variation of plastic limit with WEO content.

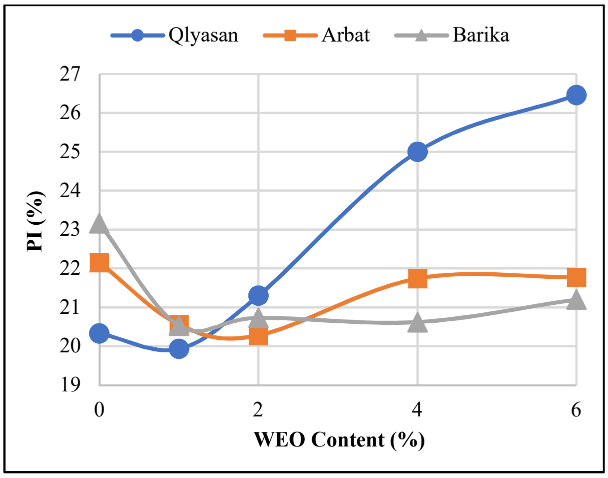

Figure 5: Variation of plasticity index with WEO content.

3.2.2 Linear shrinkage limit relationships with WEO content

Figure 6 shows a decrease in the samples linear shrinkage limit as the WEO content in the soils increases. The initial decrease in the linear shrinkage limit of the soils is referred to the fact that the pore spaces are occupied by water and used WEO. With the increasing of the WEO content, the ratio of the WEO to that of water in the pore spaces also decreased, therefore the rate of evaporation during drying also decreased, and less shrinkage obtained. These result compiled with the results of Swaroop & Rani, 2015 [22].

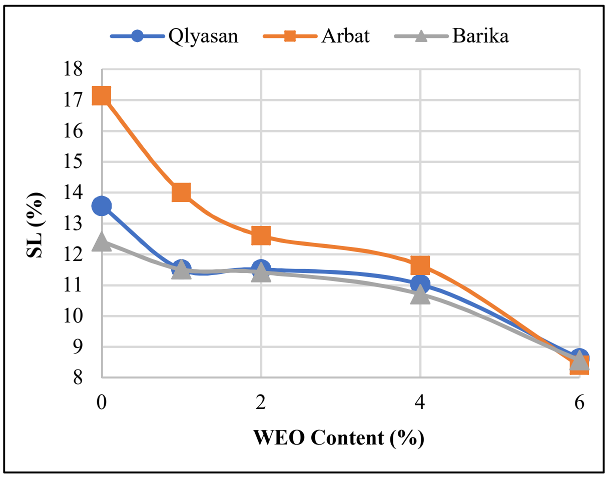

Figure 6: Variation of Linear Shrinkage Limit with WEO content.

3.2.3 Effect of WEO on unconfined compressive strength of the soil

Variation of unconfined compressive strength (UCS) with added WEO is shown in the following Figure 7. In contaminated clay soils with engine oil causes substantial microstructure change in the contaminated soils: relatively loose packing between particles of clay and their detachment of cohesion from grain surface while the WEO content increased. So, the UCS value decreased with increasing of WEO content in the soils. Generally, as a result of WEO contamination, there is a trend of reduction in the strength characteristics of the soils samples of current study as shown in Figure 7. Similarly, some researchers [14, 15, 20, and 24] also obtained similar results for oil contaminated residual soils.

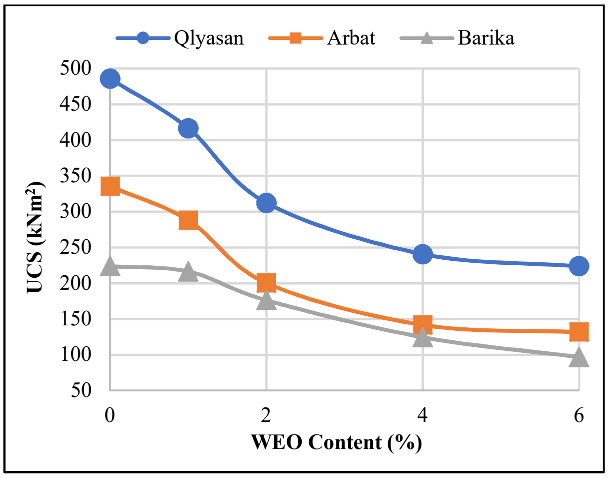

Figure 7: Variation of UCS with WEO content.

3.2.4 Effect of WEO on the swelling properties of the soil

The relationship between swelling pressure of the contaminated cohesive soil samples and the WEO content is shown in **Figure 8**. It shows that when the contamination degree of the soil samples by WEO increases, the swelling pressure of the soil samples decreases. Furthermore, the swelling pressure decrease for small percent of WEO (0% - 2%) is a slightly greater than the higher percent (2% - 6%), which indicates again the transition process of contamination influence. It indicates that the influence of pore fluid property on swelling potential of clay specimens will be gradually changed due to the depression of electrical double layer by engine oil contamination. All of the soil samples showed similar behavior as the WEO contamination percent increase and notably swelling pressure decreased as shown in Figure 8.

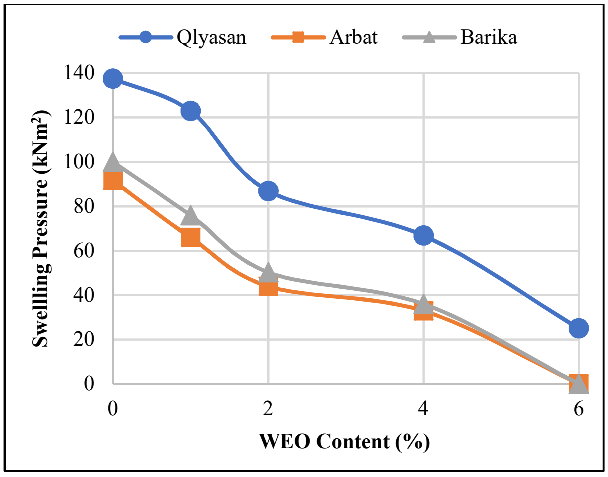

Figure 8: Variation of swelling pressure with WEO content.

3.2.5 Effect of WEO on compressibility properties of the soil

The results of consolidation tests are plotted in Figures 9 to 11 in the form of *e*-log *p* curves and in Figures 12 and 13 for three selected soil samples. The compressibility increases distinctively as the WEO content increases. These results are in agreement with the findings of Rehman et al., 2007, and Meegoda & Ratnaweera, 1994 [18, 19]. This behavior can be attributed to the lubrication effects of the oil and the friction reduction among the soil particles. Also, the soil particles being coated with oil and having reduced specific surface area, clay particles cannot easily absorb water. Therefore, uncontrolled water molecules do not tend to come back to the clay minerals surface. As a result, carrying out a pre-consolidation will significantly decrease the porosity of the soil and improve its properties before civil engineering structures are constructed over the contaminated soil.

In focus on Figures 9 to 10, contaminated Qlyasan soil sample showed increases in the values of both of compression and swelling indexes. However, Arbat and Barika contaminated soil samples showed decreases in the values of both of compression and swelling indexes. This may be due to the differences in the microscopic composition of each sample. Clay mineral type and percent, voids distribution and quantity, solid particles shapes and sizes can be as important factors to cause such responses to contamination and cumulative loading of consolidation process.

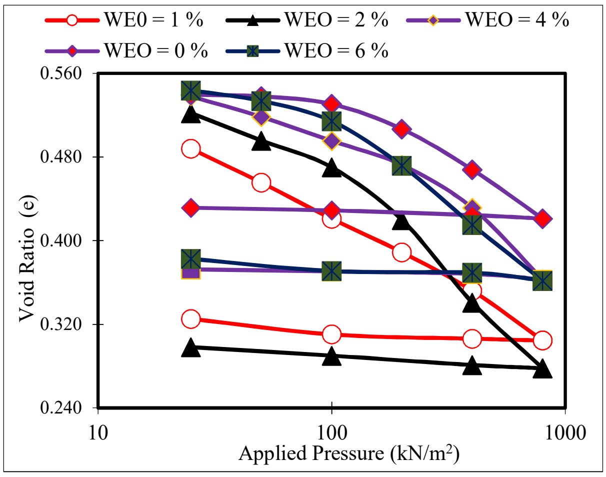

Figure 9: e-log p curves for soil samples with various percentages of WEO (Qlyasan soil sample).

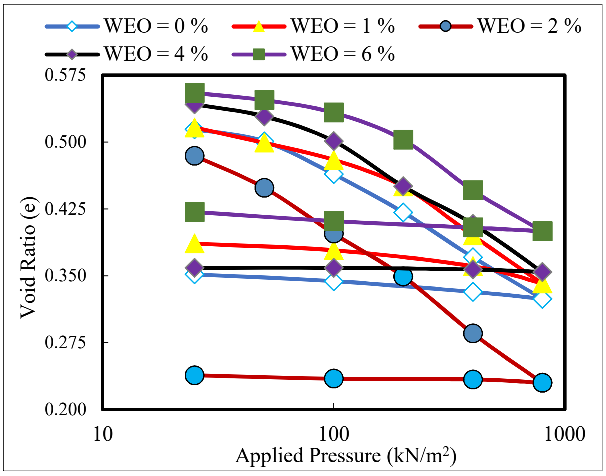

Figure 10: e-log p curves for soil samples with different percentages of WEO (Arbat soil sample).

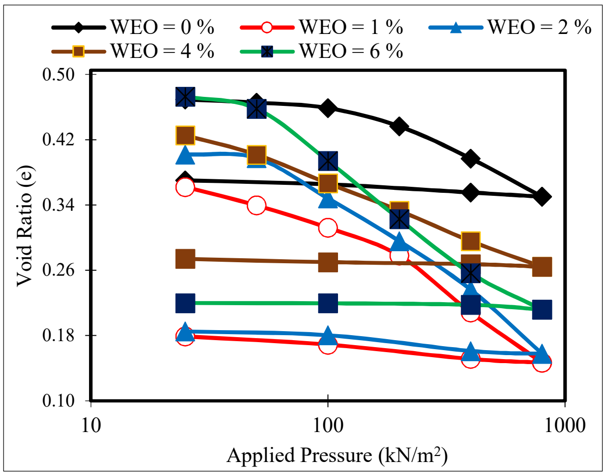

Figure 11: e-log p curves for soil samples with different percentages of WEO (Barika soil sample).

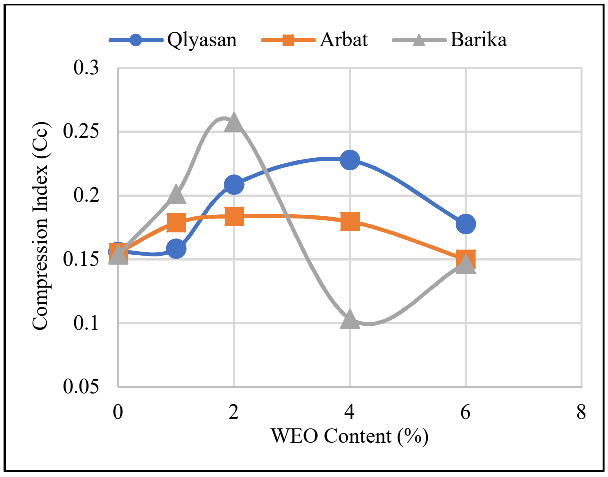

Figure 12: Variation of compression index with WEO content.

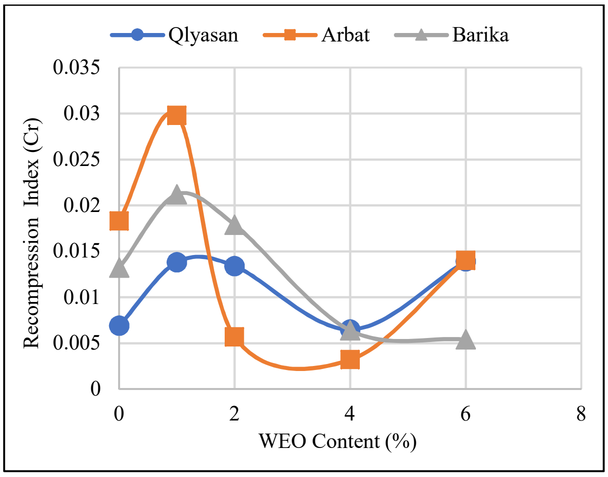

Figure 13: Variation of swelling index with WEO content.

4. Conclusion

From the obtained results from the previous sections, the following conclusions can be drawn:

- Addition of WEO to cohesive soil samples resulted in an increase in the liquid limit, plastic limit and plasticity index by. The achieved increase is 19.9%, 7.5% and 2.25% for LL for Qlyasan, Arbat, and Barika soils respectively, 17%, 11.5% and 4% for PL for Qlyasan, Arbat, and Barika soils respectively, and 23.5, 2 and 8.5 for PI for Qlyasan, Arbat, and Barika soils respectively.
- A decrease in the linear shrinkage limit was obtained when the WEO content in the soils increase. The recorded decrease is 36.41%, 50.99%, and 31% for SL for Qlyasan, Arbat, and Barika soils respectively.
- Unconfined compressive strength of contaminated soil also decreases drastically with increase in the WEO in the soil samples. The obtained decrease is 54%, 61%, and 56.72% for UCS values for Qlyasan, Arbat, and Barika soils respectively.
- As the WEO content increase in the soil, also caused the swelling pressure of the contaminated soils to decrease. The recorded decrease is 81.81%, 72.71%, and 100% for SP values for Qlyasan, Arbat, and Barika soils respectively.
- As the WEO content increases, the compressibility increases distinctively. The achieved increase is 11.2%, 2%, and 2.5% for C_c values for Qlyasan, Arbat, and Barika soils respectively.
- WEO contaminated soils without proper stabilization or remediation can leads to differential settlement. So, require improvement before using it as construction material.

List of Symbols

Symbols	Description
ASTM	American Society for Testing and Materials
Cc	Compression Index
Cr	Swelling Index
LL	Liquid Limit
PL	Plastic Limit
PI	Plasticity Index
SL	Linear Shrinkage Limit
SSA	Specific Surface Area
SP	Swelling Pressure
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System
WEO	Waste Engine Oil

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تأثير التلوث بزيت المحرك على الخواص الجيوتقنية للتربة المتماسكة في مدينة السليمانية

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الخلاصة – ركزت هذه الدراسة على تأثير التلوث بنفايات زيت المحرك (WEO) في الخواص الجيوتقنية للتربة المتماسكة (الناعمة). وقد تم جمع ثلاث عينات من التربة المتماسكة من ثلاثة مواقع مختلفة في مدينة السليمانية، في العراق. و تم إجراء الفحوصات المختبرية الجيوتقنية بما في ذلك خصائص الاتساق وقوة الانضغاط غير المقيدة وضغط الانتفاخ وخصائص الانضغاط لكل من عينات التربة غير الملوثة والملوثة. و تم خلط النسب المئوية المختلفة (0٪ ، 1٪ ، 2٪ ، 4٪ ، 6٪) من نفايات زيت المحرك مع التربة المتماسكة المختارة لتمثيل حالة الحقل الملوث. و أظهرت النتائج أن كل من حد السائل (LL)، حد البلاستيك (PL)، مؤشر اللدونة (PI) زادوا مع زيادة محتوى نفايات زيت المحرك، و انخفضوا مع انخفاض محتوى نفايات زيت المحرك بنسبة 1 ٪، وبعد ذلك زادوا مرة أخرى. و انخفض كل من قيم حد الانكماش المستقيم (SL)، قوة الضغط غير المقيدة (UCS)، ضغط الانتفاخ (SP)، ومؤشر اعادة الضغط (Cr) مع زيادة محتوى نفايات زيت المحرك. و زادت قيم مؤشر الضغط (Cc) أيضًا عند زيادة نسبة محتوى نفايات زيت المحرك بالنسب التالية: 0٪ و 1٪ و 2٪، وبعد ذلك، بدأت زيادة طفيفة مرة أخرى فقط في عينة تربة قليسان. ان التربة الملوثة بنفايات زيت المحرك يجب تثبيتها وتحسين خواصها قبل استخدامها كمواد للبناء أو لأسس مشاريع البناء.

الكلمات الرئيسة: نفايات زيت المحرك، التربة المتماسكة، مدينة السليمانية.