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

Nihad Bahhaaldeen Salih1*, Tavga Aram Abdalla 2, and Sundus Abbas Ali 3

1Irrigation Engineering Department, College of Engineering, University of Sulaimani, Iraq, nihad.salih@univsul.edu.iq
2Civil Engineering Department, College of Engineering, University of Sulaimani, Iraq, tavga.abdalla@univsul.edu.iq
3Civil Engineering Department, College of Engineering, University of Sulaimani, sundusabasali@yahoo.com

*Nihad Bahhaaldeen Salih, and email: nihad.salih@univsul.edu.iq

Published online: 31 March 2020

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 including 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: Qlyasan, 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/cm³) | 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].

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/cm³) | 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/m²) | 485.81 | 335.34 | 223.77 |
| Swelling Pressure (kN/m²) | 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. 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.

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.

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].

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.
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.

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 7: Variation of UCS with WEO content.](image1)

![Figure 8: Variation of swelling pressure with WEO content.](image2)

![Figure 9: e-log p curves for soil samples with various percentages of WEO (Qlyasan soil sample).](image3)
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 increased. 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.

- 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 |

Acknowledgements

The authors are grateful to the geotechnical laboratory of Civil Engineering, College of Engineering, University of Sulaimani, Northern of Iraq for the constant motivation and guidance to perform the laboratory tests.

References

[1] Akinwumi I. I, “Utilization of Steel Slag for the Stabilization of a Lateritic Soil,” LAP Lambert Academic Publishing, GmbH & Co. KG, Saarbrücken, 2013.
[2] Akinwumi I. I., Maiyaki U. R., Adubi S. A., Daramola S. O., and Ekanem B. B, “Effects of Waste Engine Oil Contamination on the Plasticity, Strength and Permeability of Lateritic Clay,” International Journal of Scientific & Technology Research, Vol. 3, no.9, 2014.
[3] Akinwumi I I, “Earth Building Construction Processes in Benin City, Nigeria and Engineering Classification of Earth Materials Used,” Indian Journal of Traditional Knowledge, Vol. 13, no.4, 2014.
[4] ASTM (2007). Standard Test Method for Particle-Size Analysis of Soils. ASTM Standards D 422 – 63, (Reapproved 2007).
[5] ASTM (2010). Standard Test Method for Density of Soil in Place by the Drive - Cylinder Method. ASTM Standards D 2937 – 10.
[6] ASTM (2010). Standard Test Method for Linear Shrinkage of Preformed High-Temperature Thermal Insulation Subjected to Soaking Heat. ASTM Standards C356 – 10.
[7] ASTM (2010). Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. ASTM Standards D 2216 – 10.
[8] ASTM (2010). Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. ASTM Standards D4318 – 10.
[9] ASTM (2011). Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading. ASTM Standards D 2435– 11.
[10] ASTM (2014). Standard Test Methods for One-Dimensional Swell or Collapse of Soils. ASTM Standards D 4546 – 14.
[11] ASTM (2014). Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer. ASTM Standards D 854 – 14.
[12] ASTM (2016). Standard Test Method for Unconfined Compressive Strength of Cohesive Soil. ASTM Standards D 2166 – 16.
[13] Harsh G., Patel A., Himanshu B., and Tiwari P, “Effect of Rate of Crude Oil Contamination on Index Properties and Engineering Properties of Clays and Sands,” Journal of Science and Technology, Vol. 9 no. 30, 2016.
[14] Ijimdiya T. S., and Igboro T, “Effect of Used Oil on the Strength and Compressibility Behaviour of Lateritic Soil,” in: Laryea, S., Agyepong, S.A., Leiringer, R. and Hughes, W. (Eds), Procs 4th West Africa Built Environment Research (WABER) Conference, 24-26 July, Abuja, Nigeria, pp. 709-717, 2012.
[15] Khamelchiyan M., Charkhabi A. H., and Tajik M, “Effects of Crude Oil Contamination on Geotechnical Properties of Clayey and Sandy Soils,” Engineering Geology, Vol. 89, no. 3, pp. 220-229, 2007.
[16] Nazir A. K, “Effect of Motor Oil Contamination on Geotechnical Properties of Over-Consolidated Clay,” Alexandria Engineering Journal, Vol. 50, pp. 331–335, 2011.
[17] Obeta I. N., and Eze-Uzomaka O. J, “Geotechnical Properties of Waste Engine Oil Contaminated Laterites!,” Nigerian Journal of Technology, Vol. 32. No. 2, pp. 203–210, 2013.
[18] Rehman H., Abduljauwad S. N., and Akram T, “Geotechnical Behavior of Oil-Contaminated Fine-Grained Soils,” E. J. Geotech. Eng., Vol. 12, no. A, pp.15–23, 2007.
[19] Meegoda N. J. and Ratnaweea P, “Compressibility of Contaminated Fine-Grained Soils,” Geotech. Test. J. Div. Vol. 17, no.1, pp. 101–112, 1994.
[20] Ojuri O. O. and Ogundipe O. O, “Modelling Used Engine Oil Impact on the Compaction and Strength Characteristics of a Lateritic Soil,” EJGE, Vol. 17, pp. 3491-3501, 2012
[21] Singh S. K., Srivastava R. K., and John S. (2008), “Settlement Characteristics of Clayey Soils Contaminated with Petroleum Hydrocarbons,” Soil and Sediment Contamination, Vol. 17, no. 3, pp. 290-300, 2008.
[22] Swaroop S. S. and Rani V, “Effect of Oil Contamination on Geotechnical Properties of Clayey Soil,” International Journal of Scientific & Technology Research (IJERT), Vol. 29, no. 3, pp. 1-5, 2015.
[23] Rehman H., Abduljauwad S.N., and Akram, T, “Geotechnical Behaviour of Oil Contaminated
The influence of oil contamination on the geotechnical properties of basaltic residual soils was studied in Sleman City, Iraq. Three samples of residual soil were collected from three different locations in Sleman City, Iraq. Laboratory tests were conducted on the residual soil samples, including moisture content, specific gravity, natural water content, liquid limit, plastic limit, consistency limit, unconfined compressive strength, and resilience index. The results showed that the liquid limit, plastic limit, and resilience index increased with an increase in oil content, while the unconfined compressive strength and consistency limit decreased. The contaminated soil samples were found to be suitable for use as a building material or in road construction projects.

Key words: Oil contamination, residual soil, Sleman City.