Geosciences and Engineering, Vol. 12, No. 2 (2024), pp. 37–44.
https://doi.org/10.33030/geosciences.2024.02.003

ON THE IMPACT OF HYDROCARBON CONTAMINATION ON COMPACTION AND PLASTICITY BEHAVIOR OF SANDY CLAY SOIL CASE STUDY: NORTHEAST HUNGARY

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Abstract: This study investigates the behavior of hydrocarbon-contaminated soils, using Atterberg tests and Modified Proctor Tests (MPT) conducted on sandy clay soil samples. By exposing the soil to higher artificial contamination percentages than has been reported in the literature, our approach gives a further comprehensive analysis and provides a complex interpretation of the contamination process and its impact on compaction. The oil contamination led to an increase in the plastic limit and a decrease in the plasticity index. It also influenced the compaction behavior, resulting in a decrease in the maximum dry density. The analysis emphasizes the significance of considering higher contamination levels for a more robust understanding with implications for diverse engineering applications.

Keywords: *Atterberg tests, compaction, contamination, hydrocarbon, MPT, soil*

1. INTRODUCTION

Industrialization and increased reliance on hydrocarbon-based fuels have brought forth significant environmental concerns. As hydrocarbons, the primary constituents of crude oil, infiltrate the soil matrix, they trigger a cascade of transformations in its physical and chemical properties. Under the force of gravity, the oil that had spilled or was rushing down to the groundwater. The oil on its route has partially saturated the soil. The liquid migrated within the capillary zone and spread horizontally after it reached the groundwater (Shroff, 1997). As a result, they have the potential to cause irreversible harm to the environment.

Although oil spills have decreased in recent years, the long-term impact of the previously recorded oil spill still affects some productive and vulnerable compartments of the ecosystem (Chen et al., 2012).

When the environment is contaminated by a fluid substance, clay soil, which is electrochemically active, is most impacted (Rehman et al., 2017). An oil spill could cause pollution on land or in water. Crude oil pollution on land is influenced by several variables, such as the soil's permeability, adsorption capacity, and partition coefficient (Nudelman et al., 2002).

This matter been a long-standing concern in Western countries for 30-40 years, while Hungary began addressing it only after the end of the Soviet era in 1989. The Soviet occupation from 1945-1989 left behind numerous barracks and military bases, serving as significant sources of pollution. After the withdrawal of Russian military troops, these areas, such as old Soviet barracks in Szentendre turned factory sites, continued to exhibit contamination, particularly with chlorinated hydrocarbons. This can be investigated with geophysical surveys such as engineering geophysical soundings (EGS) and direct-push geophysical measurements (Háromkő Bt., 2018).

In addition, contaminated soils exhibit a distinctive profile of lower maximum dry density and higher optimal moisture content, indicative of a compromised compaction effectiveness (Adejumo, 2012). When compared to uncontaminated soils, contaminated soils typically exhibit decreased maximum dry density and higher optimal moisture content, which indicates less effective compaction (Safehian et al., 2018). By increasing oil contamination in clayey soil, oil pollution usually decreases the permeability, strength, and Atterberg limits (Khamehchiyan et al., 2007).

The objective of this study is to perform a series of laboratory tests such as Modified Proctor Test (MPT) and Atterberg Limits tests to determine the impact of high percentages of hydrocarbon contamination on geotechnical properties of artificially sandy clay soil. These properties include Atterberg limits and compaction curves provide valuable insights into the compaction and the plasticity behavior.

2. MATERIALS AND METHODS

The materials used in this study are soil samples and a synthetic brake fluid. Disturbed soil sample was collected from Mályi quarry located in the northeast of Hungary. Particle size distribution analysis, Atterberg limit and compaction properties were determined. The soils are then classified as medium plasticity, lean clay according to European standard (Eurocode7) and Hungarian standard (MSZ) classification. Table 1 shows the summary of basic properties.

Table 1

Summary of basic properties of the investigated soil

Natural water content [%]	**Plasticity index (IP) [%]**	**Organic matter content [%]**
12.79	17.69	2.70

On the other hand, X-Ray Diffraction (XRD) analysis is a potent method used to examine the mineralogical composition of soil samples. By identifying and measuring the mineral phases that are present in soil, XRD techniques offer important insights about the soil's origin. The dominating minerals can be identified by researchers by examining the X-ray diffractograms. Table 2 provides a summary of the outcomes.

Table 2

XRD results for the investigated soil.
(The values are expressed in percentages (%)).

Quartz	**Muscovite 2M1**	**Chlorite IIb**	**Kaolinite**	**Calcite magnesian**	**Dolomite**	**Albite**
35.171	13.761	1.989	3.836	2.277	1.911	6.304
Illite 2M1	**i/sm 11A**	**Smect 14A**	**Microcline**	**Biotite 1M**	**Goethite**	**Vermiculite**
22.311	5.729	1.299	0.869	0.099	2.904	1.540

The following sample preparation procedure was followed. After particle size classification, each sample was dried in oven at 105 °C. Then the clay samples were mixed with clean sand in a ratio of 80:20 (80% clay and 20% sand) by weight. This mixing strategy was chosen to facilitate laboratory testing methods and enhance the workability of the clay soil samples during the Proctor compaction tests resulting in more accurate and effective testing. The testing program includes Atterberg limits and the compaction tests. The tests were performed on clean samples and then repeated for contaminated ones.

3. RESULTS AND DISCUSSION

The following section provides an analysis of the data collected from compaction tests and the Atterberg limits test.

3.1. Compaction test results

The standard Proctor test: the soil mass is put and compacted in three layers inside a 944 cm^3 volume cylindrical mold and a diameter of 101.6 mm. A hammer 2.5 kg weight is dropped 25 times from a height of 30 cm to compress each layer. (Knappett et al., 2012). In the Modified Proctor Test (Figure 1) according to MSZ-EN 13286-2, the procedure involves meticulous steps, it's the modified version of the Standard Proctor Test that uses a heavier compaction effort and a larger mold.

This laboratory test typically includes compacting soil with a known moisture content into a cylindrical mold while applying a controlled amount of compaction force. It was developed to better simulate the compaction effort of heavy machinery used in the field. The soil mass is put and compacted into five layers inside a 944 cm^3 volume cylindrical mold and a diameter of 101.6 mm. A hammer of 4.54 kg is dropped 25 times from a height of 457 mm to compress each layer.

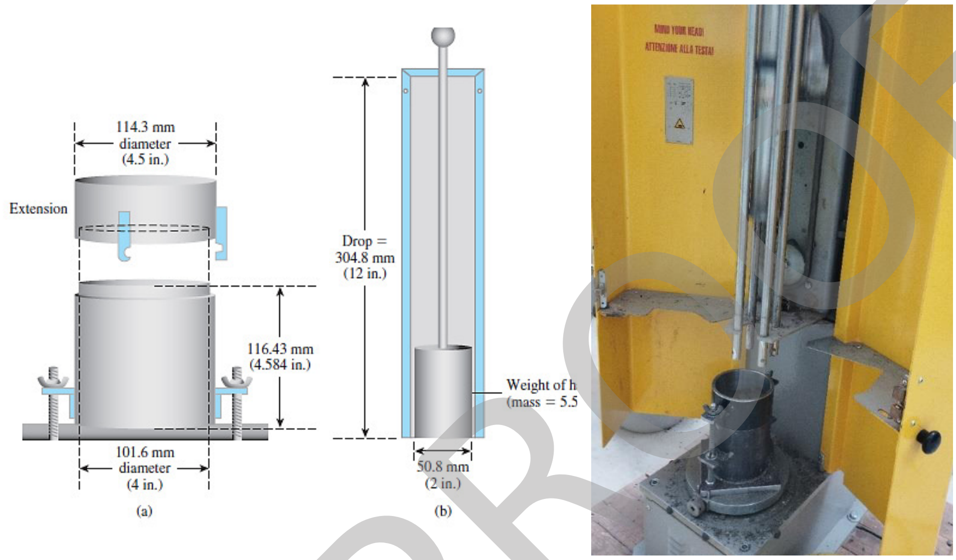

Figure 1

Schematic picture of the standard proctor test (Das and Sobhan, (2013)) (left) and compacting the samples under laboratory conditions (right)

The water content is determined by the test, and the dry density of the compacted sample is calculated according to Equation 1:

$$\rho_d = \frac{1}{1+\frac{\omega\%}{100}} * \rho_n \tag{1}$$

where ρ_n bulk density [g/cm^3], $\omega\%$ water content of the sample [%], ρ_d dry density in [g/cm^3].

Moisture content and dry density are recorded for each compaction effort, enabling the establishment of a compaction curve (Proctor, 1933). This section of the study compares the compaction behavior of samples of clean soil with those that were previously contaminated with oil brake fluid. In addition, two levels of contamination were applied to the soil samples, with 30% and 50% (by volume) of brake oil added to the water used to moisten the soil.

These levels of contamination represent the typical moderate to extremely high contamination levels found in contaminated environments to approximate extreme real-world scenarios, such as industrial spills or prolonged exposure to hydrocarbons. By testing these elevated levels, the study aims to expand scientific understanding of the impact of substantial oil pollution on soil behavior.

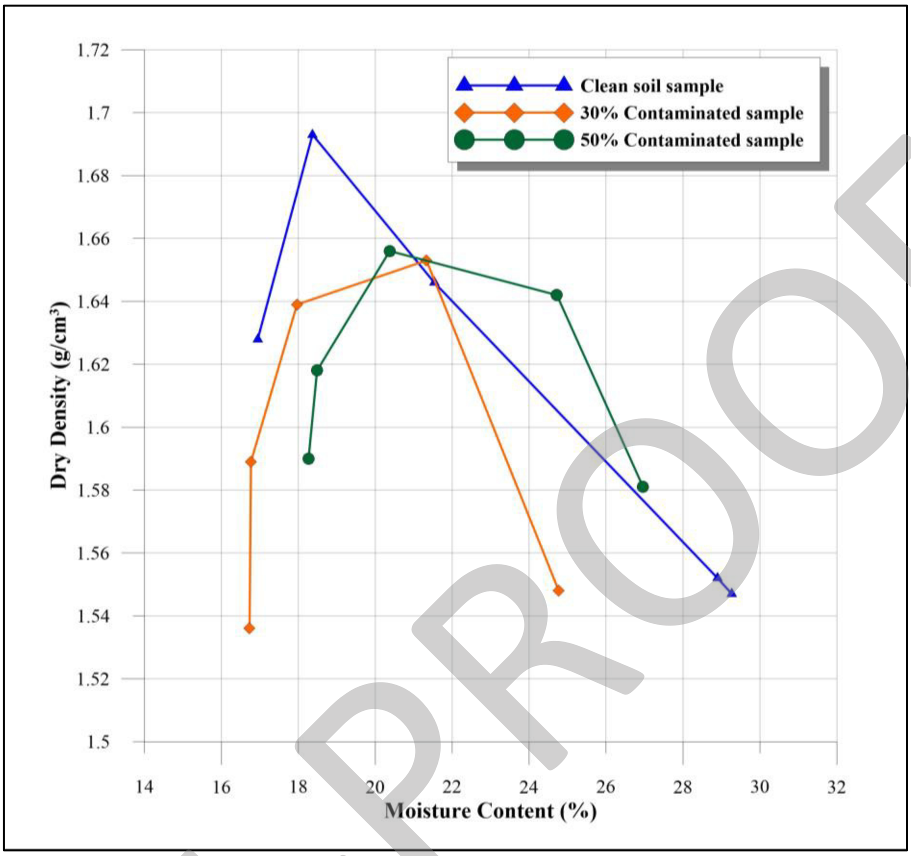

Figure 2
Compaction curves of the investigated soil sample

The maximum dry density and optimum water content of the contaminated and clean samples differ noticeably, according to study. When brake oil is added, the optimum water content increases by around 3%, suggesting that a larger moisture content is required to achieve optimal compaction. Simultaneously, data analysis reveals a marginal reduction in the maximum dry density in the presence the contamination. The maximum dry densities of the contaminated clay samples are slightly lower than those of the clean clay samples. These results shown in Figure 2 highlight the influence of brake oil on the compaction properties of the soil, highlighting the necessity of cautious thought and modifications in construction methods while working with contaminated soil.

3.2. Atterberg limit test

Atterberg limits provide critical information about the consistency and plasticity of soils. The limits are described as certain moisture levels at which the soil changes from one condition to another, such as from liquid to plastic to solid. The tests were conducted in accordance with MSZ EN ISO 14688-2 and MSZ 14043-2 standards, and the outcomes are shown in Table 3.

Table 3

Atterberg limits results of the investigated soil

	clean	**30 w/w% contamination**	**50 w/w% contamination**
plastic limit [%]	23.05	28	33.1
liquid limit [%]	47.7	43.9	43.7
plasticity index [%]	24.64	15.9	10.6
consistency index [-]	1.425	1.62	1.63

When brake oil is added, the Plastic Limit (WP) increases, as measured by looking at the 50% polluted soil sample, which is 33.1% compared to 23.05% for the clean sample. This 10% increase suggests that contamination reduces the soil's plasticity making it less prone to reach the semisolid state at lower moisture contents. Comparably, the 50% contaminated sample's Plasticity Index (PI) drops from 24.645% for the clean sample to 10.6%, suggesting a 14% decrease in the range of moisture content at which the soil exhibits plastic behavior. By comparing the 50% and 30% contaminated samples, the contaminated samples. Liquid Limit (WL) values are found to be marginally lower than those of the clean sample. This indicates that a larger brake oil concentration can increase the amount of moisture needed for the clay to become liquid.

4. CONCLUSIONS

The oil contamination has been found to affect the compaction behavior, leading to a decrease in the maximum dry density and an increase in the optimum moisture content in most cases. By combining plasticity characteristics and compaction behavior, we can understand how oil contamination impacts the overall engineering properties of sandy clay soil. The increased plasticity limits and reduced plasticity indexes, in conjunction with the decrease in maximum dry density and the increase in optimum moisture content, indicate that hydrocarbon contamination reduces the soil's compaction potential and alters its behavior.

The presence of hydrocarbons can interfere with the soil particles' ability to aggregate and rearrange, affecting the compaction process. This can be explained by disruption of Particle Arrangement. In other words, oil contamination tends to lubricate the soil particles, reducing inter-particle friction and making it more difficult for the particles to interlock during compaction. This results in a looser arrangement of soil particles, leading to a decrease in the maximum dry density.

To improve this study in general, several recommendations can be implemented. It is crucial to ensure an adequate sample size and replication for each treatment group to enhance statistical power and account for natural variability. Proper data analysis using appropriate statistical methods such analysis of variance (ANOVA), along with thorough interpretation and discussion of results, is necessary to derive meaningful conclusions.

ACKNOWLEDGMENT

The research presented in the article was carried out within the framework of the Széchenyi Plan Plus program with the support of the RRF-2.3.1-21-2022 00008 project.

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