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Effects of Contamination with Gasoline and Diesel Oil on the Value of the Oedometric Compressibility Modulus of Fine Sand

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Abstract: The following publication presents the results of a study on the effect of contamination by engine fuels, such as petrol and diesel, on the oedometric compressibility modulus of fine sand - FSa according to EN ISO 14668-1. Sand samples were contaminated with fuels at percentages of 1, 3, 5, and 10% relative to the dry mass of the soil skeleton. The results demonstrated that for the same amounts of contamination, a higher deformability was observed when diesel was the contaminant, regardless of the compressive stress range. The differences in oedometric deformation decrease with increasing impurity content in the sample. For 10% impurities, the oedometric compressibility modulus values are comparable to those of soil with a natural moisture content of 10%.

Keywords: motor fuels, fine sand, soil contamination, oedometric compressibility modulus

1. Introduction

Land contamination by petroleum fuels is a serious environmental problem, arising from a variety of contamination sources and taking a variety of forms (Chmielewski et al. 2020, Gierak 1995). Soil sorption is referred to as the retention of ions, liquid, and solid particles, as well as microorganisms, by the solid phase of the soil (Surygała 2000). The soil is a sorbent for petroleum-based pollutants. Transported hydrocarbons contained in fuels form a thin film around the soil grains. This phenomenon is called adsorption, which can affect basic geotechnical parameters. Petroleum contamination accounts for almost 40 per cent of all events that may pose an environmental emergency (Warchałowska 1999). These products can significantly alter the properties of the soil in terms of the foundation of structures, as well as environmentally by changing biological and chemical properties (Izdebska-Mucha 2005, Korzeniowska-Rejmer & Izdebska-Mucha, 2006, Czado et al. 2010, Marinescu et al. 2011, Tumanyan et al. 2017, Arbili & Karpuzcu 2018, Azam et al. 2022, Podlasek & Gmur 2024). Contaminants in the soil can occur in the form of a point, a sequence of points, or larger areas (Karkush & Kareem 2017, Brzeziński & Olchawa 2023). The distribution of contaminants in soil depends on the type of soil, the grain size, and the presence of clay minerals characterized by electrostatic properties (Guo & Yu 2017) as well as the filter properties of the soil. Contamination is mostly the result of human industrial activities during the production of fuels, their transport, and the operation of the various types of equipment that run on them (Sari et al. 2018, Al-Obaidy & Shaia 2019, Abu-Khasan & Makarov 2021, Adeniran et al. 2023, Sutormin et al. 2024). We are therefore faced with a large area of potential for ground contamination. Particularly the areas around refineries, transmission facilities, as well as green spaces and farmland. All of these instances can lead to serious environmental problems, adversely affecting the environment.

Previous studies in the literature (Mikołajków 2006) have shown that the coefficient of permeability k is higher when the filter medium is petrol compared to the medium being diesel oil. These differences are probably brought about by the different viscosity of the fluid and the different surface tension, which can affect the effective porosity of the soil and, therefore, the size of the pores through which the fluid can flow. Analyses show that the filtration coefficient of petrol is two to three times higher than that of diesel. The greatest differences were observed in fine-grained soils, where the filtration coefficient of diesel can be two to five times lower compared to coarse-grained sands. It has also been shown that the sorption of benzene and paraffin by organic matter in the soil can differ by up to 10-500 times from reference values obtained under controlled laboratory conditions (Van Leeuwen 1995). It is therefore advisable to test the sorption of hydrocarbons for each soil individually (Surygała 2000). Petroleum-based contaminants can affect the structure of the soil, changing the way water moves through its porous spaces. The effect of petroleum-based contaminants on the compressibility of soils may result from the electrostatic attraction of their particles across the soil surface, resulting in a "slip" effect.

This study aims to evaluate the effect of soil contamination, with petroleum-based contaminants, on the value of the oedometric compressibility modulus of fine sand (FSa). In the experimental work, the sand was contaminated with diesel and petrol at 1, 3, 5, and 10% relative to the dry weight of the soil skeleton. The work is a continuation of previous research on the effects of propellant contamination on selected properties of coarse-grained soils (Brzeziński &Olchawa 2023).

2. Materials and Methods

2.1. The soil

Soil samples were taken from the Nowina gravel pit near the city of Elbląg. Based on the granulometric composition tests carried out following PN-EN ISO14688-1:2018-05P and classification according to PN-EN ISO 14688-1:2006, the soil on which the experimental tests were carried out is fine sand (FSa).

Table 1. Grain-size content of the soil as percentage

Si	Sa	Gr
$d < 0.063$	$0.063 < d < 2$	$2 < d < 63$
8%	87%	5%

2.2. Contaminants

The soil samples were contaminated with two types of contaminants, i.e., diesel oil and petrol with an octane number of 95. The density of the motor fuels measured in the soil mechanics laboratory of the State University of Applied Sciences of Elbląg was $0.797 \cdot 10^3$ kg/m^3 for petrol and $0.845 \cdot 10^3$ kg/m^3 for diesel oil, respectively.

2.3. Sample preparation

Three types of samples were prepared for the study, which were contaminated with diesel oil, petrol, and a clean control sample containing only water with a moisture content close to the natural moisture content of 10%. Contamination of the samples was carried out under laboratory conditions by manually mixing the sand with the contaminants. To redistribute the contaminant in the samples and homogenize the test material, the samples were stored for 10 days in sealed containers. While preparing the samples, the method used to prepare the samples for shear strength tests was repeated (Olchawa 2023). The samples prepared in this manner were placed in oedometer rings according to the procedure described in section 6 of PN-88/B-04481. Additionally, to reduce evaporation of contaminants from the samples, a rubber gasket with a diameter equal to the inner diameter of the ring was placed on the filter paper. The gasket deformation was included in the calculation of the oedometric compressibility modulus. The sequence in which the samples were prepared for testing is illustrated in Figure 1. Oedometric tests were then carried out to determine the compressibility moduli.

Fig. 1. Procedure for preparing the test sample

2.4. Oedometric Compressibility Modulus Test

An EL-1 mechanical edometer was used to carry out the oedometric tests. A linear digital gauge with an accuracy of up to one-thousandth of a millimeter was employed for precise measurement of soil volume changes. According to the procedure described in the standard (PN-88/B-04481), loads in the range of 0-400 kPa were applied, and the applied loads satisfied the condition $\sigma_{(i+1)}/\sigma_i = 2$. Deformation of the sample from the applied load was considered complete if the deformation in the time interval of successive measurements was less than 0.03 mm. Readings were taken at intervals of 8, 15, 30 minutes, and after 1, 2, 3, 24 hours, and at 24-hour intervals until the settlement process was completed. Compressibility modulus values were calculated according to the following formula:

$$M_0 = \frac{\Delta\sigma \cdot H_{i-1}}{H_{i-1} - H_i} \tag{1}$$

where:
M_0 – soil compressibility modulus [kPa],
$\Delta\sigma$ – increase in effective stress [kPa],
H_{i-1} – is the height of the sample before applying the next load σ_i [mm],
H_i – the height of the sample after completion of settlement from a given load σ_i [mm].

3. Results

The calculated values of the compressibility oedometric moduli of contaminated soils for varying compressive stress ranges are shown in Figures 2-7. The values of the compressibility oedometric modulus decrease with increasing engine fuel content, irrespective of fuel type and compressive stress range.

Figures 8-10 show the values of the compressibility moduli of sand contaminated with diesel oil and petrol. As can be seen in the figures for the same contaminant content, higher modulus values can be observed when the contaminant is petrol. This relationship is observed regardless of the size of the contaminant and the range of compressive stresses. Comparing the values of the oedometric compressibility moduli of soil containing 10% water, diesel oil, and petrol, it can be seen that samples contaminated with diesel oil, petrol, and water, respectively, have the highest values. The modulus values are shown in Table 2.

The moduli of contaminated soils are 6 to 18% higher compared to those with water content.

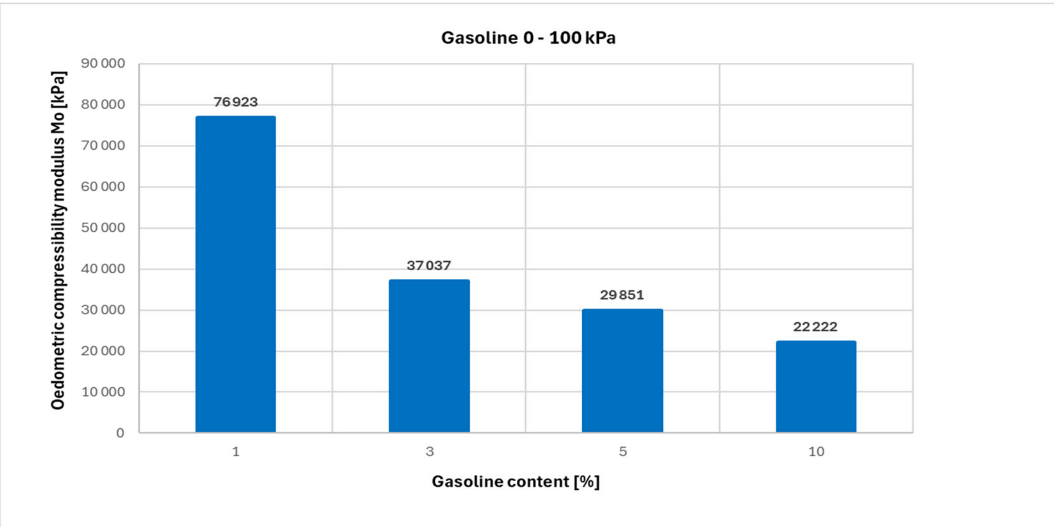

Fig. 2. Experimental oedometric compressibility moduli for gasoline-contaminated soil in the stress range of 0-100 kPa

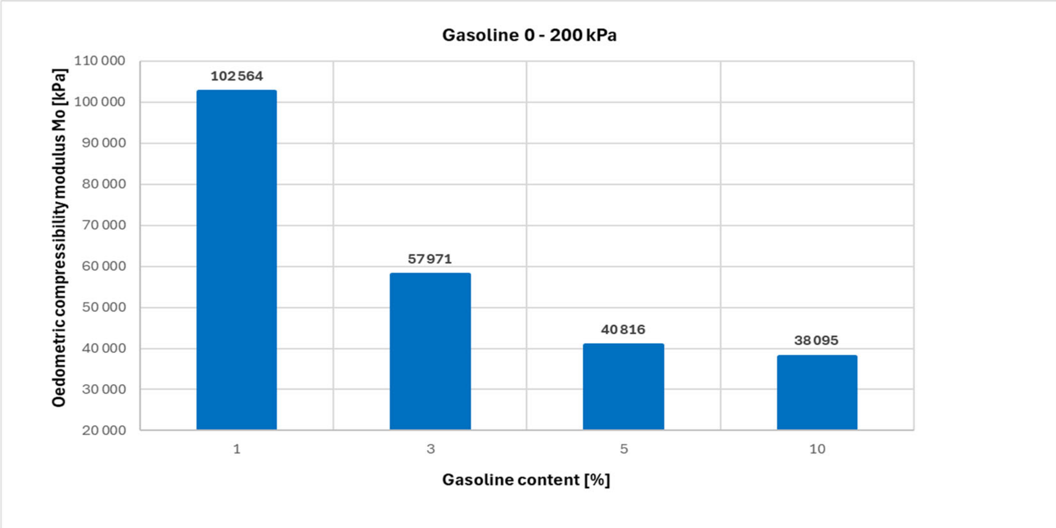

Fig. 3. Experimental oedometric compressibility moduli for gasoline-contaminated soil in the stress range 0-200 kPa

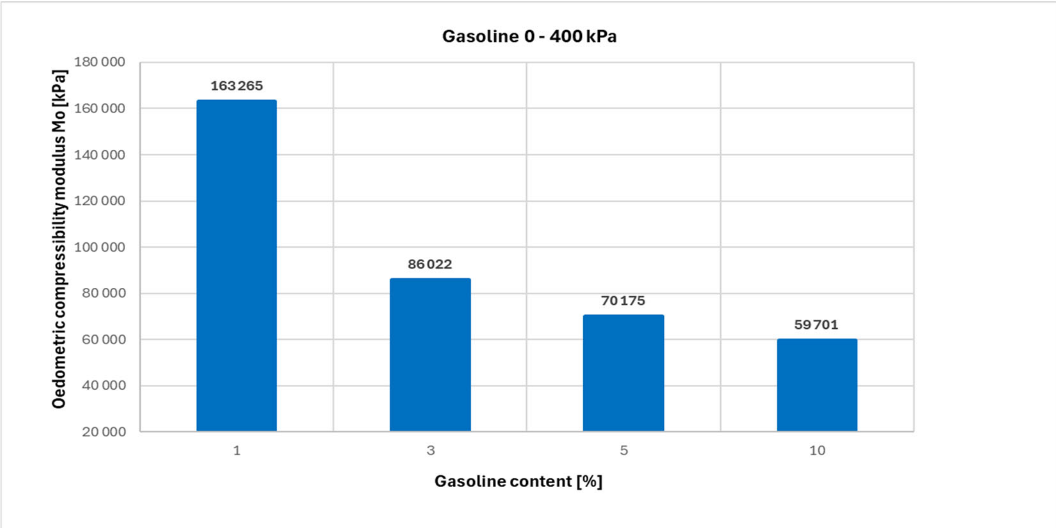

Fig. 4. Experimental oedometric compressibility moduli for gasoline-contaminated soil in the stress range 0-400 kPa

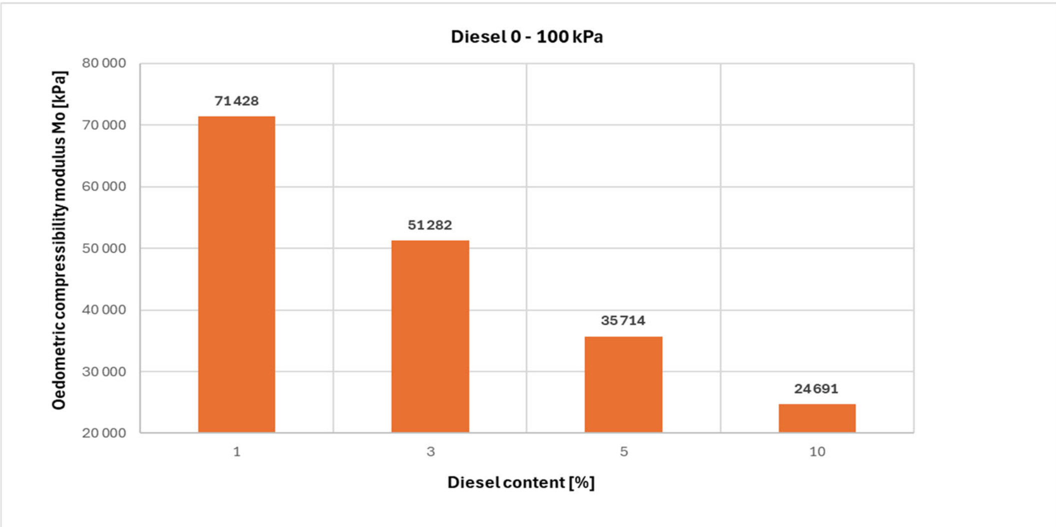

Fig. 5. Experimental oedometric compressibility moduli for diesel oil contaminated soil in the stress range 0-100 kPa

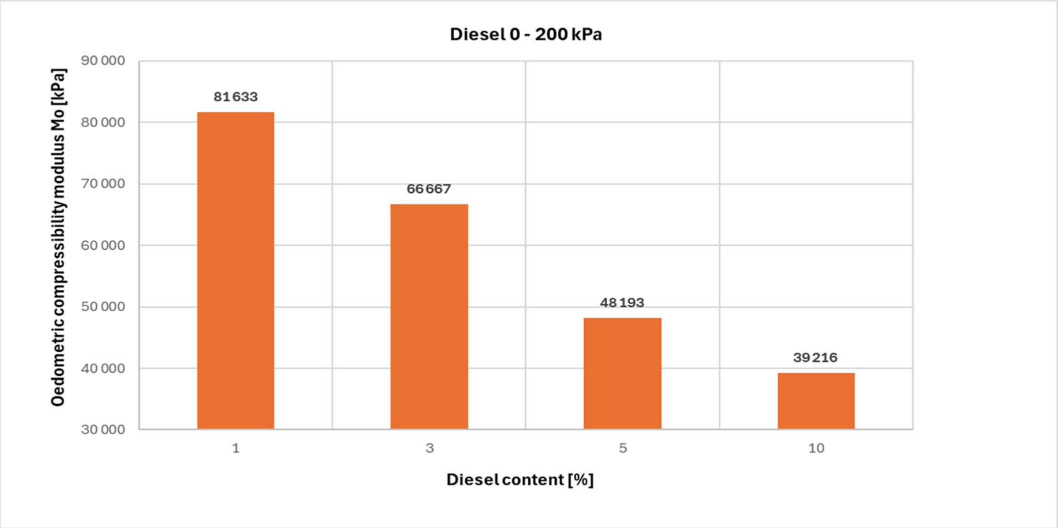

Fig. 6. Experimental oedometric compressibility moduli for diesel oil contaminated soil in the stress range 0-200 kPa

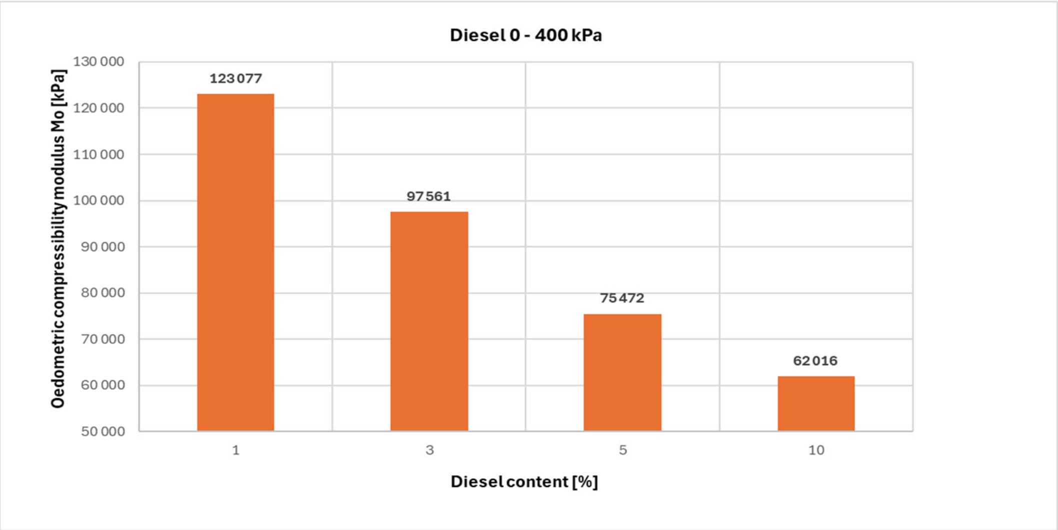

Fig. 7. Experimental oedometric compressibility moduli for diesel oil contaminated soil in the stress range 0-400 kPa

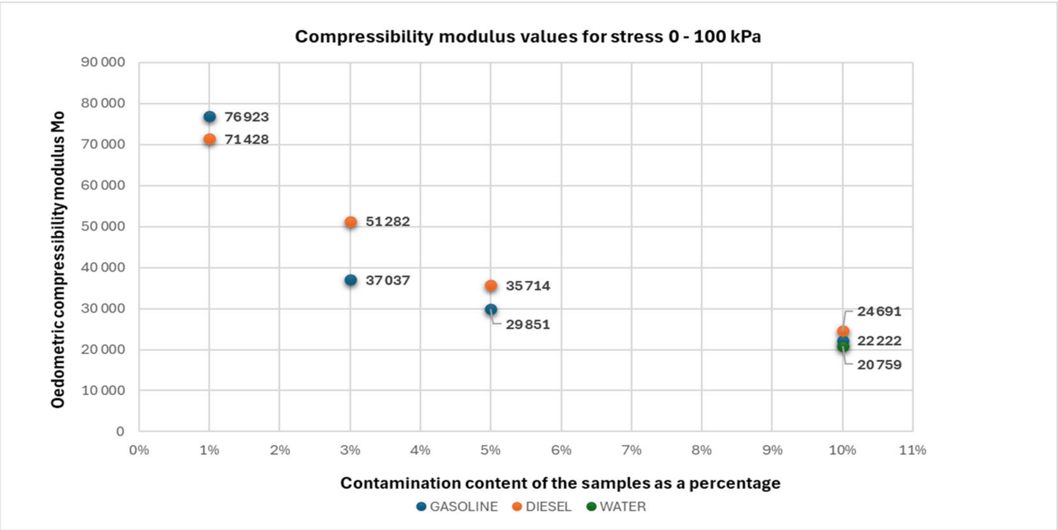

Fig. 8. Compressibility moduli of the tested samples with various contamination content for the stress range of 0-100 kPa

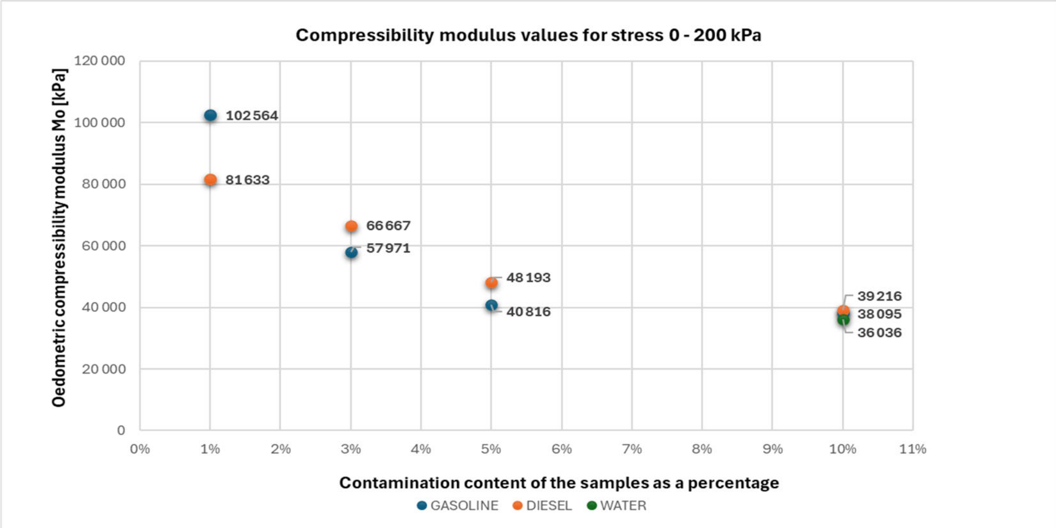

Fig. 9. Compressibility moduli of the tested samples with various contamination content for the stress range of 0-200 kPa

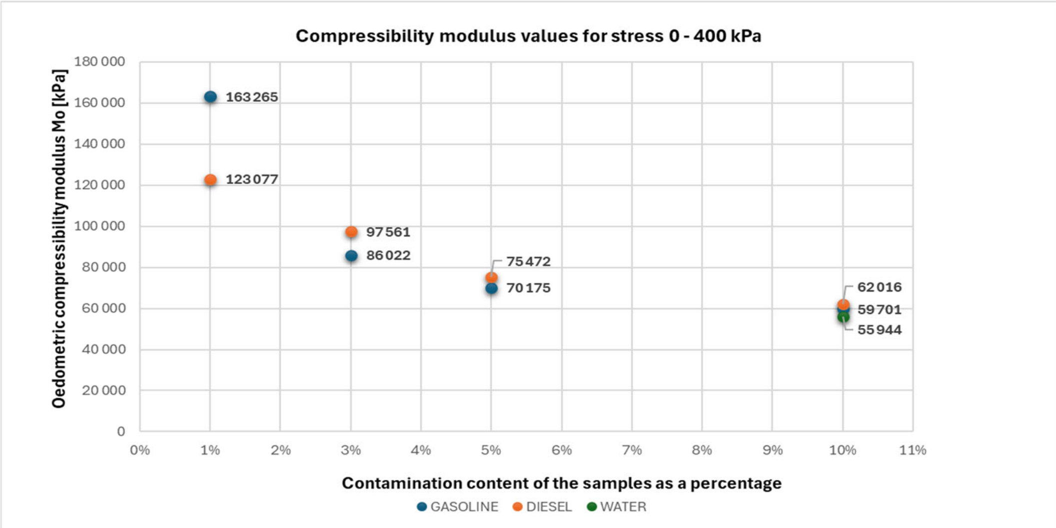

Fig. 10. Compressibility moduli of the tested samples with various contamination content for the stress range of 0-400 kPa

Table 2. Values of the oedometric compressibility modules for fine sand with 10% water content and petroleum impurities

Range of applied stress	0-100 [kPa]	0-200 [kPa]	0-400 [kPa]
Diesel oil	24691	39216	62016
Gasoline	22222	38095	59701
Water	20759	36036	55944

4. Conclusions

The following paper presents the results of an experimental laboratory study to investigate the effect of engine fuel contamination on the oedometric compressibility moduli of fine sand.
The results of the research and their analysis allow the following conclusions to be drawn:

1. Compressibility modulus values decrease with increasing petroleum contaminant content in the soil.
2. For the same pollutant content, a higher modulus value is observed when the pollutant is petrol, regardless of the range of compressive stresses. An inverse relationship was observed when the pollutant contamination was 1%.
3. The content of petroleum contaminants can be a predictor for estimating compressibility modulus values for a known contaminant value, expressed in terms of the ratio of contaminant mass to the soil skeleton mass.

4. For an impurity content of 10%, the compressibility moduli are greater compared to the moduli of the same soil with a moisture content of 10%. This phenomenon requires a detailed study to interpret it. This may be related to the propellant properties, such as viscosity. It may also indicate weaker electrostatic bonds of sand particles with petroleum substances compared to the dipole bonds of water molecules.
5. In engineering practice, contamination of the coarse-grained subsoil with petroleum substances will not bring about its increased settlement.

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