RESEARCH Vol. 15, 2018

ISSN 2319–7757 EISSN 2319–7765

Indian Journal of Engineering

Impacts of petroleum fuel oil contamination on the geotechnical properties of fine-grained soils

Karkush MO[1], Abdul Kareem MS[2]

1.Department of Civil Engineering, University of Baghdad, Iraq, Email: mahdi_karkush@coeng.uobaghdad.edu.iq
2.Department of Civil Engineering, University of Baghdad, Iraq, Email: mahmoudshakir7992@yahoo.com

Article History
Received: 08 June 2018
Accepted: 14 July 2018
Published: July 2018

Citation
Karkush MO, Abdul Kareem MS. Impacts of petroleum fuel oil contamination on the geotechnical properties of fine-grained soils. *Indian Journal of Engineering*, 2018, 15, 228-237

ABSTRACT

The effects of light fuel oil on the chemical, physical, and mechanical properties of silty clay soil have been investigated in the present work. The contaminant is light fuel oil (incidental product) disposed from a thermal electric power plantand the intact soil sample was collected from the countryside of Alexandria city in the central region of Iraq. The clayey soil samples were artificially contaminated by two types of contaminants P1which consists of (49% industrial wastewater, 21% kerosene, and 30% water) and P2 which consists of (70% industrial wastewater, and 30% kerosene). The soil specimens were covered by contaminants for a period of 30 days in separate tightens closed plastic containers. The results detected that light fuel oil have significant effects on the chemical and engineering characteristics of silty clay soil samples with different types of contaminants. Moreover, static and cyclic plate loading tests are carried out to investigate the static and cyclic modulus of subgrade reaction (Ks) of contaminated soil samples. The static modulus of subgrade reaction reduced with increasing the concentration of contaminant by 28 to 42%in contrast with that of intact soil samples. In addition, cyclic modulus of subgrade reaction decreased by 32 to 47%.

Keywords: Light fuel oil, contamination, engineering properties, silty clay, and cyclic subgrade reaction

1. INTRODUCTION

Soil can be contaminated with crude oil or petroleum products from many sources which range from onshore and offshore crude oil exploration, pipeline leakages, tanker accidents, discharge from coastal facilities, underground storage facilities leakage and onsite oil spillage. Ali [1] studied the actions of four percentages of kerosene on the behavior of clayey silt soil. The results of tests proved that kerosene causes large values of void ratio, compression index, and volumetric stain. In addition, the contaminated soil samples obtained a considerable reduction in the cohesion and slight increase in the friction angle depending upon kerosene content. Kermani and Ebadi[3] discussed the impacts of oil contaminants on the engineering properties of fine-grained soils. The plastic limit tends to increase rapidly with increasing the oil content, while the liquid limits increase slightly. Karkush et al. [4] discussed in details the impacts of four different types of contamination (heavy metals and hydrocarbons) on the chemical, physical, and mechanical properties of clayey soil samples. The results of tests proved that the contaminants have diverse effects on the geotechnical properties of soil depending on the type and content of contaminant.

Akinwumi et al.[5] detected the crude oil effectuation on the notable increasing in Atterberg's limits and slightly decreasing in specific gravity. In addition, the optimum moisture content and maximum dry unit weight increased highly depending on the content of crude oil. Karkush and Abdul Kareem[7] demonstrated that Atterberg's limits, clay fraction, the compressibility characteristics, shear strength parameters, and stiffness parameters are decreased with increasing the concentration of industrial wastewater. Abousnina et al.[8]investigated the effects of light fuel oil on the physical and mechanical properties of fine sand. This study showed increasing the crude oil content causes increasing the cohesion between soil particles and reduction in the permeability and angle of internal friction.

Estabragh et al.[9] conducted series of mechanical tests on soil specimens which are contaminated with organic materials of different concentration ratios10, 25, and 40%.The results detected that a reduction in the soil compressibility depends on the type of organic fluid and its concentration. Whereas, the cohesion and angle of internal friction increased obviously with increasing of contaminant content. Nasehi et al.[10] detected that a decrease in an angle of friction and an increasing of the strength of the sandy soil samples because of increasing of gas oil content. In addition, the plasticity of clay and silt soils increased significantly as a function of gas oil content. Gadyani et al.[11] observed an improvement in compaction characteristics of kaolinite and bentonite specimens contaminated with kerosene. Also, the shear strength undergoes a significant decrease with increasing of kerosene content.

Karkush and AL-Taher[12] discussed a reduction in specific gravity, soil plasticity, clay fraction, soil compressibility, shear strength, and soil stiffness due to increasing of the content of total petroleum hydrocarbons(TPH) through a series of laboratory experiments implemented to investigated the influence of TPH content on the geotechnical behavior of cohesive soil.

Karkush and Resol[6] investigated the impacts of industrial wastewater on behavior of sandy soil samples contaminated with four percentages of industrial wastewater. The results of tests revealed that the particle size, specific gravity and maximum dry unit weight are decreased with increasing the content of industrial wastewater. Karkush and Abdul Kareem [13] implemented several geotechnical tests on clayey soil specimens which are artificially contaminated with industrial wastewater. The obtained results detected that a reduction in clay fraction, soil plasticity, optimum water content and maximum dry density due to increasing of contaminant content with increasing of industrial wastewater content. In the present study, the impacts of two types of light fuel oil as contaminants on the chemical, physical, and mechanical properties of silty clay soil have been investigated through conducting a series of laboratory experiments.

2. PETROLEUM OIL CONTAMINATION

Petroleum is a mixture of paraffin and hydrocarbons in some areas and cyclo-paraffin and aromatics. The common petroleum oil is containing approximately 80 % of carbon compounds, 11% of hydrogen and approximately 1 to 2% of nitrogen, oxygen and sulfur. Generally, in most oil fields, oil and natural gas are exist together, gas being the upper layer on crude oil that may lie above or under water table depending on its density. Petroleum oil is a mixture of hydrocarbons (gaseous, liquid, and solid) that occurred naturally beneath the earth's crust. The petroleum oil can be separated into fractions gas, gasoline, naphtha, kerosene, fuel oil, lubricating oil, pin wax, and asphalt. Toxicity, ignitability, corrosivity, or reactivity indicates to the riskiness of industrial waste. This contaminant can be risk on the health and environmental, if erroneous managed [14,15]. Therefore, it is necessary to investigate the oil contaminant impacts on the soil behavior, due to a huge volume of petroleum oil disposing into soil and aquifer and a large deteriorate soil in its properties resulting from disposing these products.

3. FIELD WORK

3.1. Materials and Field Tests

The obtained soil samples which are gained from the north of the Babylon governorate in centre of Iraq (countryside of Alexander city) (UTM: 33N515276, 44E28102). The field unit weight was 19.3 kN/m³ (ASTM D2937-00) and the natural water content was 32% (ASTM D2216).The contaminant is an industrial wastewater which is a by-product from fuel used in a thermal electricity power plant at the same area where the soil samples are brought up. The industrial wastewater is classified as light fuel oil (LFO) according to the American Petroleum Institute gravity (API gravity) (ASTM, D278) [14,15]. The chemical composition of contaminant and soil samples is considerable indicator to investigate the behaviour of contaminated soil samples. Moreover, chemical, physical and mechanical tests were performed on intact and contaminated soil samples. The obtained results of chemical analysis and physical properties analysis of contaminants used in the present work are given in Table 1.Where, the contaminant P1 is composed of 49% LFO, 21% kerosene and 30% free water and P2 is composed of 70% LFO and 30% kerosene. The contaminants P1 and P2 are classified as LFO according to the API gravity.

Table 1 Physical-chemical properties of LFO, P_1, and P_2.

Property	Unit	LFO	P_1	P_2
Density at 22°C	kg/m³	925	938	891.5
Viscosity at 50°C	mm²/sec	45	30	37
pH	value	5.75	6.16	5.89
Flash point	°C	64	33	45
Carbon Residues	%	18	13	16
Sulphur	%	3.87	1.9	2.6
Aluminum and Silica	mg/kg	25	19	25
Water	%	0.1	0.5	0.22
Calcium	mg/kg	3	2.3	2.7
Magnesium	mg/kg	1	0.8	1
Iron	mg/kg	15	12	15
Ash	%	0.15	0.9	0.13
TSS	mg/L	20460	9220	13650

3.2. Drilling and Sampling

The disturbed and undisturbed intact soil specimens are obtained from a depth of 4 meter below the natural ground surface. The water table encountered 2.5 to 3 m below the existing ground surface. An open pit of 10m length and 5m width was drilled in the site to get soil samples. Then, the disturbed soil samples were placed in tight plastic containers and labeled, and then transferred to the laboratory for use in physical and chemical tests of the soil. The undisturbed soil samples extracted in Shelby tubes covered with wax and labeled to be used in testing the mechanical properties of soil samples.

4. LABORATORY WORK

In a present study, the impacts of two types of contaminants (P1 and P2) on the geotechnical properties of silty clay soil specimens were investigated. The designations of tested soil samples are: intact soil sample (C_0), soil sample contaminated with P_1 (C1) and soil sample contaminated with P_2 (C_2). The disturbed soil samples were covered with contaminants (soaking process) for 30 days in tighten closed plastic containers.

4.1. Chemical Tests

In the present study, the chemical properties of soil samples designated SO_3(ASTM D516), SO_4(ASTM D516), gypsum, Ca^{+2}(ASTM D511), Cl^{-1}(ASTM D512 A), pH value (ASTM D4972), TPH (atomic absorption spectrometer, AAS), TDS ASTM (D5907), Ec (ASTM D1125), $CaCO_3$(ASTM D4373),and Mg^{+1}(ASTM D511)are tested to measure the impacts of contaminants P1 and P2 on the chemical composition of soil samples [16].

4.2. Physical Tests

In order to determine the required soil parameters and investigate the changes that may occur as a result of contamination the soil samples with industrial wastewater. The tested physical properties of soil samples are: specific gravity (BS: 1377, 1975, Test 6B), liquid and plastic limits (ASTM D4318), particle size distribution (ASTM D422), and the maximum dry unit weight and corresponding optimum water content (ASTM D698) [16,17].

4.3. Mechanical Tests Results

Mechanical tests were performed for undisturbed and remolded soil; and contaminated soil samples. The tests included determining the shear strength parameters, modulus of elasticity, coefficient of consolidation, and the coefficient of subgrade reaction.

4.3.1. Consolidation Tests

Oedometer tests were implemented to determine the compressibility characteristic of soil samples. The compression of soil caused by the application of loads onto soil is resulting from the deformation of soil particles, relocations and squeezing of pore water. Two types of soil samples, undisturbed and remolded, are used to investigate the compressibility characteristics of intact soil, while remolded soil samples used to measure these characteristics of contaminated soil samples, ASTM (D2435) [16].

4.3.2. Shear Strength Tests

The shear strength test is one of the most important tests used for determining the mechanical properties of soils. The shear strength of soil mass, may be attributed to cohesion between fine particles and friction between coarse particles, will resist failure and sliding along any plane inside it. The shear strength of silty clay soil was measured by conducting unconfined compression test (UCT, ASTM D2166) and direct shear test (DST, ASTM D3080) [16].

4.3.3. Plate Loading Tests

A comparison between static and cyclic modulus of subgrade reaction (Ks) due to contamination impacts are investigated by conducting static and cyclic plate loading tests. The tests were performed in a steel cube box of side 700mm. The rigidity of steel box has been guaranteed by using rigid steel plates of 4 mm thickness in the sides and bottom. The tests are carried out on a square steel plate of dimensions 125x125x10mm. In the present study, $Ks_{,(static)}$ is determined according to ASTM (D1196). The cyclic modulus $Ks_{,(dynamic)}$is determined by conducting cyclic plate loading tests at 500 cycles. For verification the modulus of subgrade soil reaction under repeated loading test conditions (loading, unloading, reloading schedule) as per standard practice [18, 26]. Repeated loads are induced on plates with two cycles per second and number of cycles that applied at each load are equal to five hundred cycles to investigate the behavior of square footing constructed on the surface of homogeneous soil under static and cyclic loads. The model of cyclic plate loading test is shown in Figure 1.

Figure 1 Cyclic plate loading test.

5. RESULTS AND DISCUSSION

The chemical results obtained according to the ASTM standards and atomic absorption spectrometer (AAS) instrument are given in Table 2. The reduction in pH value of soil samples with increasing the concentration of contaminants is attributed to the low value of the hydrogen power in contaminant solution which is considered as acidic medium. The three sulfate ions (SO_3), gypsum, four sulfate ions (SO_4) and chloride content are increased rapidly as a function of increasing the contaminant concentration in the soil samples due to the high content of these compounds in contaminants itself in comparison with the intact soil sample which have small percentages of these compounds. Total hydrocarbon content increased rapidly with the increase of contaminant concentration due to the high hydrocarbon content in residues oil contaminant; calcium carbonate ($CaCO_3$), calcium ion (Ca^{+2}) and Magnesium ion (Mg^{+1}) are increased with increasing of contaminant concentration, because contaminant has high concentrates of calcium carbonate. Finally, electrical conductivity (Ec) and total dissolved salts (TDS) are highly increased in contaminated soil samples, due to the low value of salts in intact soil while the high content of salts such as sulfate compounds, chloride ions (Cl^{-1}), calcium ion (Ca^{+2}) and Magnesium ion (Mg^{+1}) in LFO.

Table 2 Chemical analysis of soil samples

Soil Sample	SO_3 %	SO_4 %	Gypsum %	Ca^{+2} ppm	Cl^{-1} %	pH value	TPH %	TDS ppm	Ec mS/m	$CaCO_3$ ppm	Mg^{+1} ppm
C0	0.1015	0.065	0.21	680	0.07	7.20	0.095	3742	0.0873	1700	413
C1	1.71	0.71	3.67	1000	0.14	6.30	2.35	300000	12.00	2500	607
C2	2.30	0.802	4.94	1020	0.18	6.10	3.44	600000	14.00	2550	619

The effectuations of contaminants (P_1 and P_2) on the physical properties of soil arepresented in terms of different physical indexes of soil. The results of particle size distribution tests showed that the percentage of finer less than 0.005 mm in intact soil is 55%, but in contaminated soil sample (C_1 and C_2) is 20% and 10% respectively, because crude oil covers the clay particles with a thin film and gives it more volume than that of particles in intact soil sample. Also, the particles size of an insoluble salts found within contaminant are greater than the clayey particles, Therefore the soil condenses more quickly in a hydrometer during testing period. Consequently, the percentage of particles of diameter less than 0.005 mm decreases with increasing of these salts in the contaminants. The specific gravity of soil decreased in significant value as a function of the contaminant concentration increasing in the soil, because the density of LFO which covers clay particles within a thin film is less than the soil density. The results of particle size distribution, specific gravity, plasticity characteristics, and standard proctor tests are given in Table 3. In addition, the particle-size distribution curves are given in Figure 2.

Table 3 Results of physical tests

Soil Sample	Gs	Sand (%)	Silt (%)	Clay (%)	LL (%)	PL (%)	PI (%)	$\gamma_{d,max}$(kN/m^3)	ω_{opt} (%)
C0	2.72	4	41	55	53	23	30	17.0	20
C1	2.65	4	66	30	57	29	28	15.9	17
C2	2.58	6	84	10	59	34	25	15.2	16

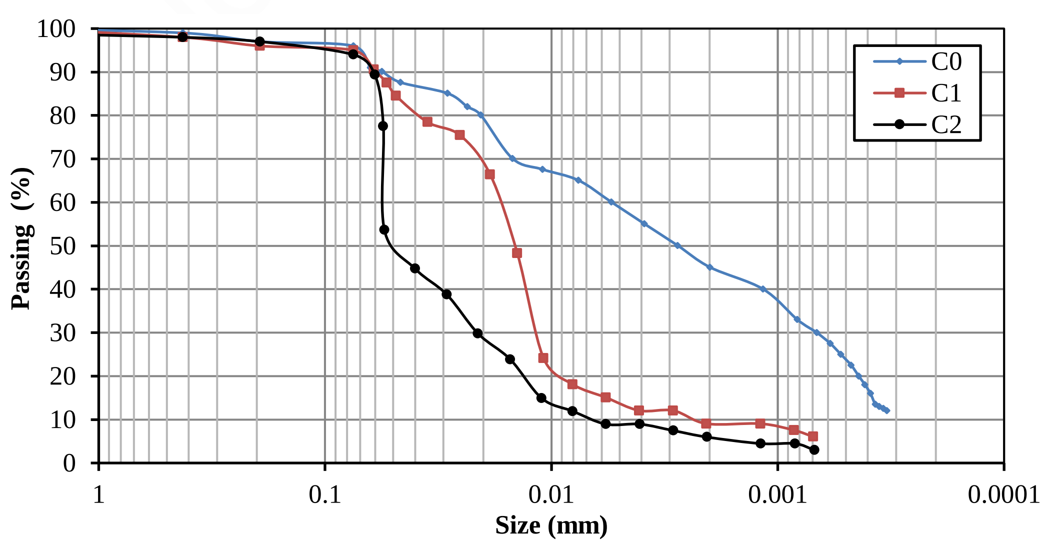

Figure 2 Analysis of particle-size distribution of natural and contaminated soil specimens.

The plasticity characteristics of contaminated soil samples are increased with increasing the percentage of (LFO) contamination. The reason of significant increasing in plasticity (plastic limit) is that crude oil covers the clay particles with a thin coated film and does not permit water molecules to reach the double diffusive layer of water, so more water is needed for the soil to obtain plastic properties. Whereas the slightly increase in flow properties (liquid limit) is occurred, because the water in pore spaces that is not absorbed by clay particles due to the thin film which is coated the clay particles and that moves easily in a soil as free water. Therefore, no significant increase in liquid limit occurs. The results of compaction tests of intact and contaminated soil samples, which are obtained by standard Procter test as illustrated in Figure 3.Finally, the maximum dry density and optimum water content are decreased due to increasing the oil contamination. The oil coated the individual clay particles and reduces the water required to reach the optimum water content and make low dry density.

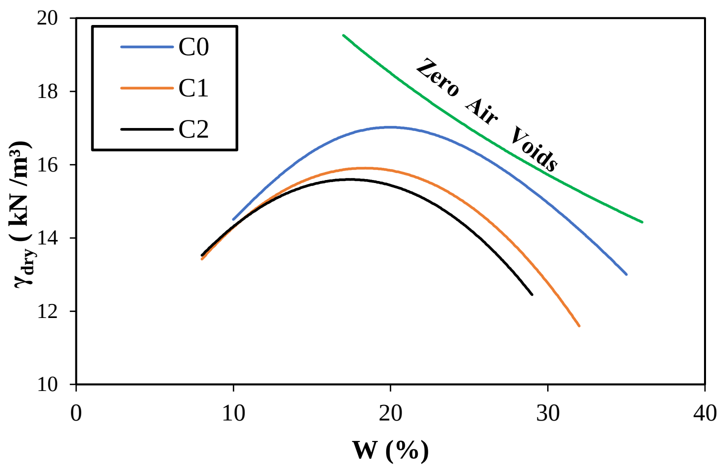

Figure 3 Results of standard Proctor tests of intact and contaminated soil samples.

From oedometer tests results are given in Table 4, it’s observed that the coefficient of vertical consolidation, compressibility characteristics and the permeability increase due to increasing of contaminant concentration in soil specimens. The coefficient of consolidation (c_v) increased by 5%, the coefficient of permeability (k) increased by 13%, the compression index increased by 3%, but the constrained modulus (D) decreased by 6% for remolded soil samples (C0R) in comparison with these of intact soil sample. This behavior of increasing the indexes of compressibility can be simulated to the loss of strength resulting from the destruction of molecular attraction forces between clay particles which depends on the sensitivity of clay. The coefficient of consolidation (c_v) increased by 22 and 36% of contaminated soil samples C_1 andC_2 respectively compared with that of intact soil (C_0). On the other hand, the coefficient of permeability (k) was increased by 81 and 149%, but the constrained modulus (D) decreased by 32 and 45 % of contaminated soil samples C_1 and C_2 respectively. The compressibility increases significantly as the oil content increases. The obtained results are well agreed with the findings out of references [2,19, 27]. This behavior can be attributed to the oil lubrication action and the reduction of cohesion between the soil particles. Therefore, a contaminated soil sample will more easily be compressed into denser configurations [6]. In addition, clay particles being coated with oil, so clay particles cannot absorb water easily. Therefore, abandoned water molecules do not tend to come back to the surface of clay minerals. Consequently, the contamination of soil will increase the swelling index of the soil slightly and for this reason the swelling coefficient is not distinctively changed as the oil content increases. The relations between void ratio and pressure are shown in Figure 4.

Table 4 Results of consolidation tests

Soil Sample	e_o	e_f	Cc	Cs	$m_v \times 10^{-5}$ (m^2/kN)	$c_v \times 10^{-2}$ (cm^2/sec)	$k \times 10^{-9}$ (cm/sec)	D (MPa)
C0	0.80	0.608	0.145	0.034	4.76	1.31	6.08	21.02
C0R	0.80	0.600	0.149	0.035	5.11	1.38	6.92	19.54
C1	0.83	0.588	0.158	0.036	6.98	1.61	11.03	14.32
C2	0.86	0.515	0.165	0.038	8.65	1.78	15.11	11.55

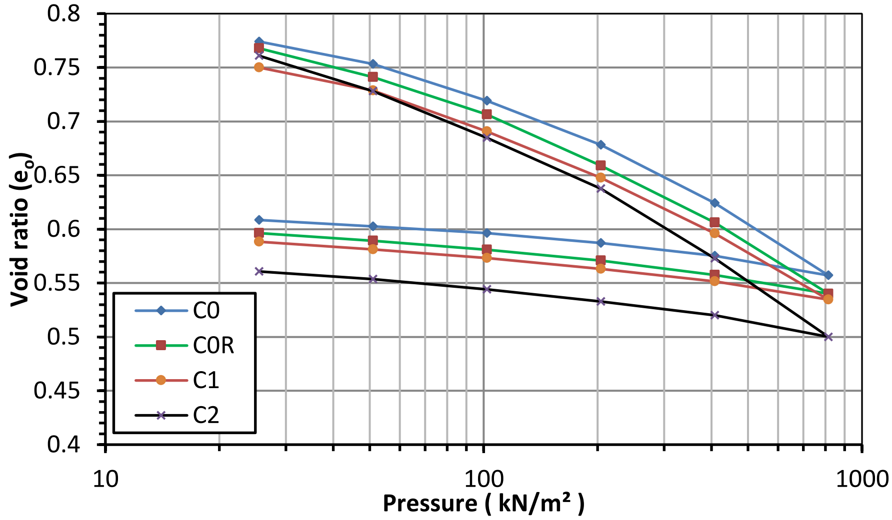

Figure 4 Void ratio-pressure relations of soil samples tested by oedometer

The unconfined compression strength showed the undrained shear strength at remolded soil sample (C0R) decreased by 7%, and also the modulus of elasticity decreased by 8% than undisturbed soil specimen because of the soil disturbance that lead to destruction of soil structure. The sensitivity of soil is about 1.05 and the soil sample can be classified as slightly or low sensitive clays[20,21]. The undrained shear strength decreased considerably because the disturbance of the soil, but the significant regain of strength occurs with elapsed time in long-term phenomena of strength regain in the soil depended on sensitivity of clay. Consequently, the strength will usually increase because of the thexotropic regain of undrained shear strength as structural bonds destroy by remolding. The undrained shear strength parameters determined by unconfined compression test and direct shear test are given in Table 5. Also, the variations of stress with axial strain of tested soil samples are given in Figure 4.

Moreover, the undrained shear strength of contaminated soil samples (C1 and C2) decreased by 33-45% and also the modulus of elasticity decreased by 37-50% than the undisturbed intact soil sample (C0). The reduction in undrained shear strength is attributed to the soil particles are coated by oil and the specific surface area of contact is decreased. So, this reduction in specific area led to a reduction in the adsorption of water molecules with clay particles and a reduction in the contact of clay particles, which consequently leads to a reduction in cohesion and constrained modulus of elasticity. From the results of direct shear tests, it's observed that the undrained shear strength and the angle of internal friction of soil samples will be varied in their behavior. The undrained shear strength at remolded soil sample (C0R) decreased by 6% and the angle of internal friction decreased by 9% than undisturbed intact soil sample due to soil disturbance, so the strength decreases due to the remolding of soil sample.

The undrained shear strength of contaminated soil samples C1 and C2 decreased by 31-42%, while the internal friction angle increased by 9-22% than undisturbed intact soil sample (C0) with increasing of contaminant content. This situation is coincided with "*the large increase in clay strength is considered to be a result of an increase in inter particle contact area*" [22]. Also, the results of DST indicated increasing the angle of internal friction with increasing the oil content in soil samples. The reason for the improvement of the friction is due to improvement of compaction characteristics. The fluid in the pores and a thin layer of fluid exists between minerals of soil. The free water acts as a lubricant agent making particles attain a closer packing and then increasing the soil friction.

Table 5 Summary of shear strength tests results

Soil Sample	UCT		DST	
	c_u kN/m²	E MN/m²	c_u kN/m²	φ degree
C0	85	12	74	22
C0R	79	11	70	20
C1	57	7.5	51	24
C2	47	6	43	27

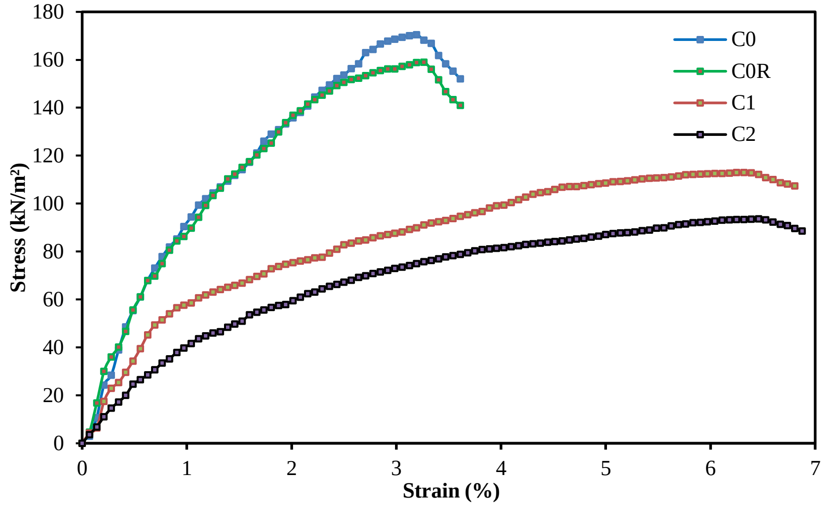

Figure 5 Stress versus strain of unconfined compression tests

The subgrade reaction resulted from plate loading tests are decreased by 28 and 42%of contaminated soil samplesC1 and C2 respectively due to increasing of petroleum contaminant concentration. The reduction in Ks is attributed to increasing of compressibility and settlement; and decreasing the strength of soil. The cyclic plate loading tests proved that dynamic modulus of subgrade reaction decreased by 32 and 47% of contaminated soil samplesC1 and C2 respectively due to increasing of petroleum contaminant concentration. The cyclic modulus of subgrade reaction is less than the static modulus due to the response of soil to the cyclic loading. The ratio of ($Ks_{,(dunamic)}$/$Ks_{,(static)}$) is varied from 73 to 67% depending on the soil conditions which are represented with the compressibility, strength and the subgrade reaction of the soil. The results of laboratory-model tests on 125mm square plate are illustrated in Figure 5 and Table 6.

Table 6 Results of plate loading tests

Soil Sample	C_0	C1	C2
$Ks_{,(static)}$ (MN/m^3)	34.4	24.8	20
$Ks_{,(dynamic)}$ (MN/m^3)	25.25	17.2	13.4

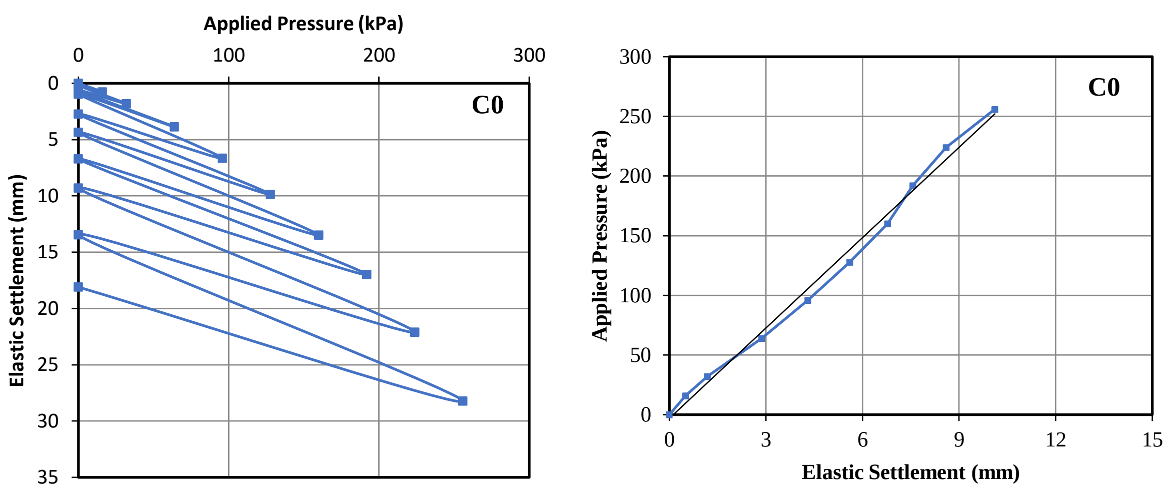

Figure 6 Results of cyclic plate loading tests of soil samples.

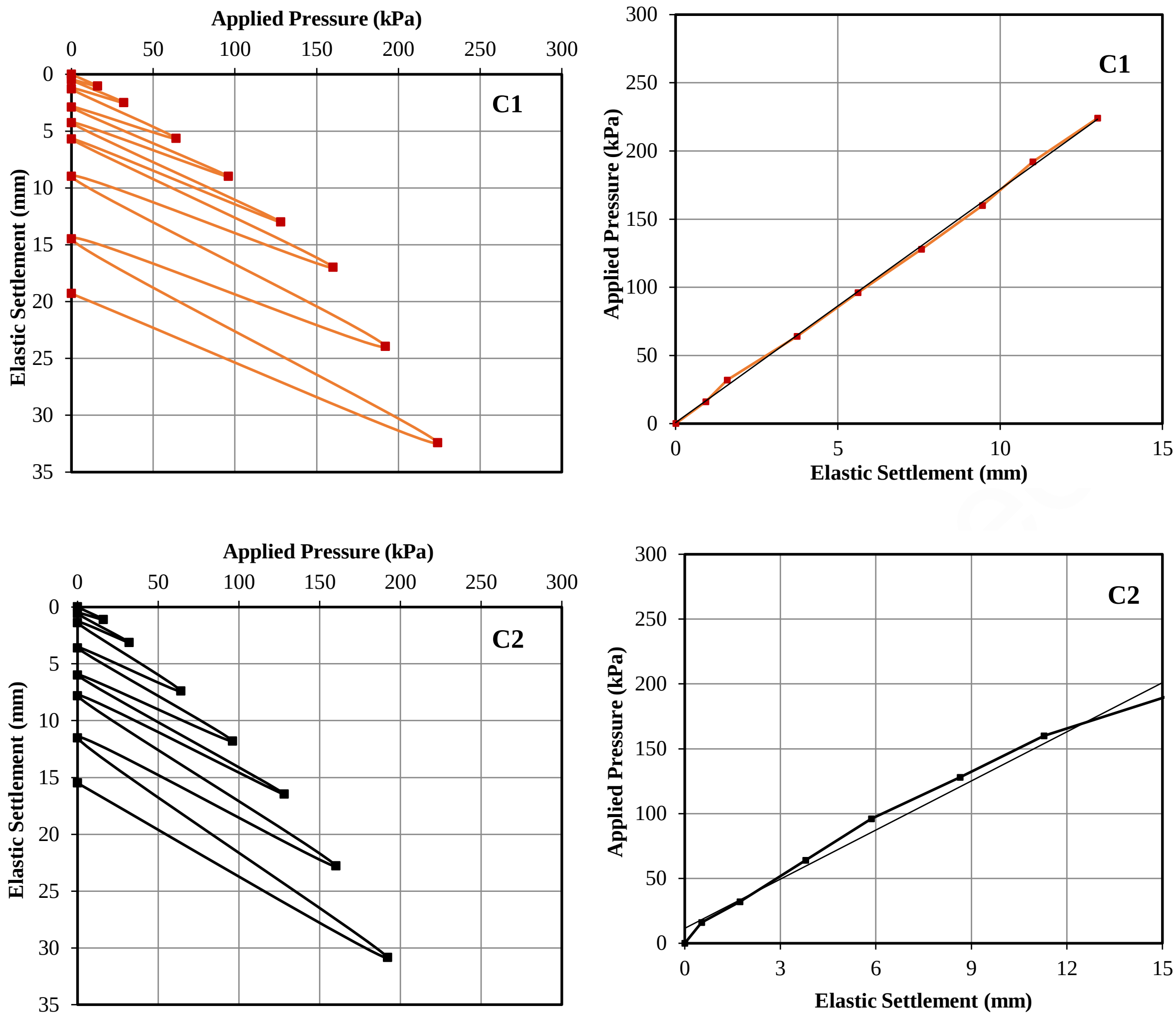

Figure 6 Continued

6. CONCLUSIONS

The fuel oil effluent from the electricity power plants had various impacts on the behaviour of silty clay soil sample brought up from the same region. This variety ranged from slight effect for some soil properties to significant influence for other soil properties. Moreover; strength, compressibility and modulus of subgrade reaction have been significantly affected by contaminant content. The conclusion drawn from this study can be summarized as follows:

a) The pH value, three sulfate ions (SO_3), gypsum, four sulfate ions (SO_4), chloride content; calcium carbonate ($CaCO_3$), calcium ion (Ca^{+2}) and TDS increased with increasing the contaminant percentage in soil samples.

b) Clay fraction, specific gravity, optimum water content and maximum dry density decreased with increasing contaminant concentration in soil samples.

c) The plastic limit increased significantly in comparison with increasing of liquid limit, so the plasticity index will be decreased.

d) The compressibility and permeability of soil samples C1 and C2 increased, but the constrained modulus of soil decreased.

e) The undrained shear strength and the modulus of elasticity of remolded soil sample (C0R) decreased by 7 %due to the disturbance of soil sample.

f) Direct shear test proved that the undrained shear strength decreases, but the internal friction angle increases with increasing of contamination concentration in the soil samples.

g) The increase of concentration of contaminant led to decrease of static and cyclic modulus of subgrade reaction by 28 to 43 % and 32 to 47 % of soil samples C1 and C2 respectively.

h) The cyclic modulus of subgrade reaction is ordinary less than static modulus due to the low response of soil to cyclic loading.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

REFERENCE

1. Ali, HA. Some geotechnical properties of oil contaminated soil. M.Sc. Thesis 1999, University of Baghdad.
2. Ur-Rehman, H., Abduljauwad, S. N., Akram, T. Geotechnical behavior of oil contaminated fine-grained soils. E. J. Geotechnical Engineering 2007; 12 A, 15–23.
3. Kermani, M., Ebadi, T. The effect of Oil Contamination on the Geotechnical Properties of Fine-Grained Soils. Int. Journal of Soil and Sediment Contamination. 21, 655-671; 2012.
4. Karkush MO., Zaboon AT., Hussien H.M. Studying the effects of contamination on the geotechnical properties of clayey soil. Proc. of Coupled Phenomena in Environmental Geotechnics, Taylor & Francis Group, London, 599–607; 2013.
5. Akinwumi I., Diwa D., Obianigwe N. Effects of crude oil contamination on the index properties, strength and permeability of lateritic clay, Int. Journal of Applied Sciences and Engineering Research, 3(4), 816-824; 2014.
6. Karkush MO., Abdul Kareem M S. Behavior of pile foundation subjected to lateral cyclic loading in contaminated soils. Journal of Civil Engineering Research, 5(6), 144-150; 2015.
7. Karkush MO., Resol DA. Geotechnical properties of sandy soil contaminated with industrial wastewater. Journal of Engineering Science and Technology, 12(12), 3136-3147; 2017.
8. Abousnina RM., Manolo A., Shaian J., Lokouge W. Effects of light crude oil contamination on the physical and mechanical properties of fine sand. Journal of European Journal of Environmental and Civil Engineering, 833-845; 2015.
9. Estabragh AR., Beytolaphour I., Moradi M., Javadi A. A. Mechanical behavior of a clay soil contaminated with glycerol and ethanol. Journal of European Journal of Environmental and Civil Engineering, 503-519; 2015.
10. Nasehi SA., Uromeihy A., Nikudel M R., Morsali A. Influence of gas oil contamination on geotechnical properties of fine and coarse-grained soils. Journal of Geotechnical and Geological Engineering, volume 34; 2016.
11. Gadyani M., Hamidi A., Hatambeigi M. Investigating of geotechnical behavior of oil-contaminated clays. European Journal of Environmental and Civil Engineering, p.p. 1-24; 2015.
12. Karkush MO., Al-Taher TAA. Geotechnical evaluation of clayey soil contaminated with industrial wastewater. Archives of Civil Engineering, 2017.
13. Karkush MO., Abdul Kareem Z. Investigation the impacts of fuel oil on the geotechnical properties of cohesive soil. Journal of Engineering, volume 21; 2017.
14. Sharma HD., Reddy KR. Geoenvironmental engineering: site remediation, waste containment, and emerging waste management technologies. John Wiley & Sons, Hoboken, New Jersey; 2004.
15. United Nations Environment Program Report “UNEP”. Assessment of environmental “hot spots” in Iraq, Report ISBN 92-807-2650-1; 2005.
16. Annual book of ASTM standards. Soil and Rock; Building; Stone; Peats, 2003.
17. British Standards, BS1377. Methods of testing for civil engineering purpose, British Standards Institution 1976, London.
18. Rowe RK. Geotechnical engineering handbook. Springer Science and Business Media, New York; 2001.
19. Meegoda, NJ., Ratnaweera P. Compressibility of contaminated fine grained soils. Geotechnical Test. J. Div. 17(1), 101–112; 1994.
20. Skempton, AW., Northey, RD. The sensitivity of clays. Geotechnique, 3(1), 30-53; 1952.
21. Rosenqvist, ITh. Considerations on the sensitivity of Norwegian quick –clays. Geotechnique, 3(5), 195-200; 1953.
22. TerzaghiK., Peck RB., Mesri G. Soil mechanics in engineering practice. 3rd Ed., John Wiley & Sons; 1996.
23. Das, B. M. Principles of geotechnical engineering, 3rd ed. Boston, MA: PWS Publishing Company, 1994; page 436.
24. Oluremi JR., Osuolale OM. Oil contaminated soil as potential applicable material in civil engineering construction, Journal of Environment and Earth Science, 2014.
25. Schifano V., Thurston N. Remediation of clay contaminated with petroleum hydrocarbons using soil reagent mixing, Proceedings of the Annual International Conference on Soils, Sediments, Water and Energy: Vol. 12, Article 27; 2007.