Chapter

A Review of the Effect of Hydrocarbon Contamination on Soil Resistance Parameters

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Abstract

Oil contamination and derivatives are some of the types of pollution that can lead to irreparable damage to the environment. Oil pollution affects the mechanical, chemical, and dynamic properties of the soil. Petroleum contaminants alter the structure of cohesive and granular soil. The double-layer thickness of clay will change, causing the structure of the clay soil to become similar to granular soil. The results of adding oil contaminants to the soil showed decreases in the internal friction angle and increase in the cohesion of the soil. The shear strength of the contaminated soil showed no definite or constant trend of change. When contaminated with acidic sludge (burned-oil waste derivatives), despite an increase in the cohesion of the soil, a decrease in the internal friction angle caused a decrease in the shear strength. The dilatancy angle decreased as the dirt filter contaminant content increased. In more compact samples, the soil dilatancy angle remained constant after the addition of 3% dirt filter contaminants at high and low vertical stresses and did not affect the declining trend for shear strength.

Keywords: hydrocarbon contamination, soil resistance, geotechnical properties, soil dilatancy angle, direct shear test

1. Introduction

About 83.6 million barrels of crude oil are produced in the world daily and a significant portion of it penetrates to the soil due to different reasons. This infiltration can occur by leaking of the transmission pipes or overturning of the crude oil transmission tankers. The soil of refineries is contaminated with oil materials for various reasons [1]. Biological, Washing, physical, and chemical methods have been introduced to clean contaminated soil, but they are costly and have limitations [2]. In some cases, due to the large volume of the operation of moving contaminated soil and the difficulty and uneconomicality of cleaning contaminated soil, the same contaminated soil can be used, and the shear strength parameters were considered as a criterion for subsequent designs [3, 4].

Soil contamination with hydrocarbon substances can change the physical, chemical, and resistance parameters of the soil. So far, there have been many

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studies on the impact of various types of oil pollution on fine- and coarse-grained soils, and sometimes different results have been obtained. These differences are mainly due to the different reactions that different types of soil show against different types of pollution [5]. The poorly graded sandy soil contaminated with crude oil was examined, and it was found that, as the percentage of oil contaminants increased, the shear strength decreased. Crude oil and its derivatives are mainly composed of hydrocarbons, nitrogen compounds, sulfur, organic metal compounds, and mineral salts [6]. The duration of contamination, the type of pollutant, and the type of soil will affect the geotechnical properties of the polluted soil [7]. Any change in the shear resistance and other engineering characteristics of contaminated soil layers can cause a decrease in the stability of slopes, decrease the bearing capacity, and increase the total and relative settlement of structural foundations [8].

Nasehi et al. [9], by performing a direct shear test on the ML, CL, and SP soil contaminated with gas oil, showed a decrease in the optimum moisture content, soil friction angle, and relative soil density and an increase in soil cohesion with an increase in the contaminant content. Also, Saberian and Khabiri [10] stated that with sand pollution to 8% of gas oil, the optimum moisture content decreased by 4 percent and increased the maximum dry unit weight from 18.25 to 19.27 kN/m^3.

Karkush and Kareem [11] stated that by performing a direct shear test on clayey soil contaminated with 20% crude oil, the internal friction angle of the soil decreases by 12 degrees. They also discovered a 28.5% reduction in undrained soil cohesion. Kermani and Ebadi [12] tested clay soil contaminated with oil and reported that increased oil contamination decreased soil cohesion.

The soil investigated in this chapter has been exposed to pollutants and waste from a petroleum factory. This included the waste from burned oil from a refinery. Different studies have been conducted on the impact of hydrocarbons and petroleum pollutants, including crude oil, gasoline, diesel, motor oil, and burned motor oil in fine and coarse soils, but little study has been done on soil contamination by waste from burned oil from refineries. Burned oil refining factories bury this substance, which causes soil pollution. A literature review showed that the contamination of different types of soil by hydrocarbons would cause different changes in the soil geotechnical parameters. The results of these studies should be compared and analyzed; therefore, a complete and accurate study of the mechanisms of hydrocarbon contamination and its derivatives on the characteristics of the soil is required. This chapter was conducted to investigate differences in the process of change in the geotechnical parameters of all types of soil contaminated with hydrocarbons, especially acidic sludge and dirt filter residue, both waste products from a burned oil refinery.

2. Data and method

In previous studies, different types of soil with different weight percentages were mixed with crude oil and its derivatives and then tested to determine the impact of the pollutant on the resistance soil, compaction, soil settlement, etc. of the soil. In this chapter, the results of changes in the parameters of the contaminated soil were extracted using the data available from other research with the help of appropriate software (Get Data Graph Digitizer) and evaluated and analyzed. And secondly, in order to identify the contamination effect of materials obtained from the burning oil treatment on the compaction parameters of the soil, a modified proctor test was performed according to standard ASTM D698 [13] as well as a 100 × 100 mm sample box direct shear test to check the trend of soil resistance parameters according to standard ASTM D3080 [14] with contamination percentages of 0, 3, 6, and 9.

The choice of these pollutant values is to investigate the effect of low pollution on the geotechnical properties of the soil because when the contamination is high, it is taken into consideration and cleaned, while it may be ignored in low pollution percentages. Shroff [15] also showed that the maximum percentage of oil contamination in soils is about 10%.

The shear test was performed with a vertical stress of 10, 30, and 50 kPa with dry unit weight 1.7 and 1.9 g/cm^3 to investigate the effect of the depth of contaminated soil according to **Table 1**.

2.1 Soil properties and study area

The studied soil was collected from the landfill site of the waste from the burned oil refining factories located in the industrial city of Salafchegan. As shown in **Figure 1**, the city of Salafchegan is located 35 kilometers west of Qom. This city is located on the Qom- Arak road. The geological setting of the Saveh-qom basin is also presented in **Figure 2** [17]. The soil gradation (SC) test was performed according to the standard of ASTM D422 [18], and the characteristics of the studied soil are shown in **Table 2** (**Figure 3**).

2.2 Contaminant properties

In this chapter, firstly, different types of soil with different weight percentages were mixed with crude oil and its derivatives. Secondly, the waste material from the burned oil refining factories (acidic sludge and dirt filter) was used as a pollutant. The primary components of these two contaminants, as determined from x-ray fluorescence tests, were zinc, ferrum, plumbum, cuprum, phosphorus, dust, glycols, carbon, phenols, polymers, asphaltene, polymethacrylates, sulfonates, amines and phosphonates. The results of XRF testing are shown in **Table 3**, respectively.

Number of tests	Type/Value	Parameter
2	Acidic sludge	Contaminant type
	Dirt filter	
2	17	Dry unit weight (kN/m^3)
	19	
2	0.1–0.3–0.5	Vertical load steps (kg/cm^3)
	0.5–1–1.5	
4	0	Contamination content
	3	
	6	
	9	

Table 1.
Test conditions.

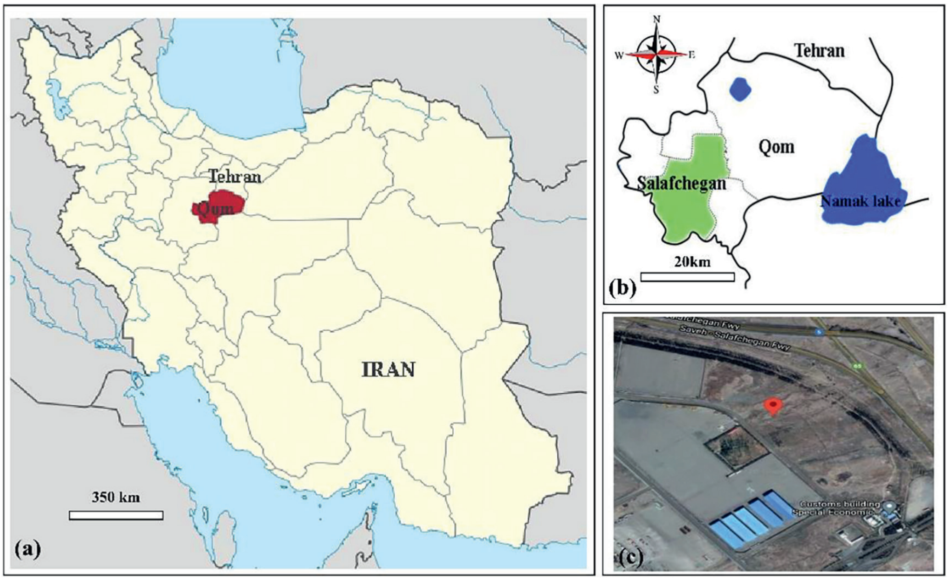

Figure 1.
(a) Position of the Qom city, (b) Position of the Salafchegan city, and (c) Satellite image of Salafchegan industrial region.

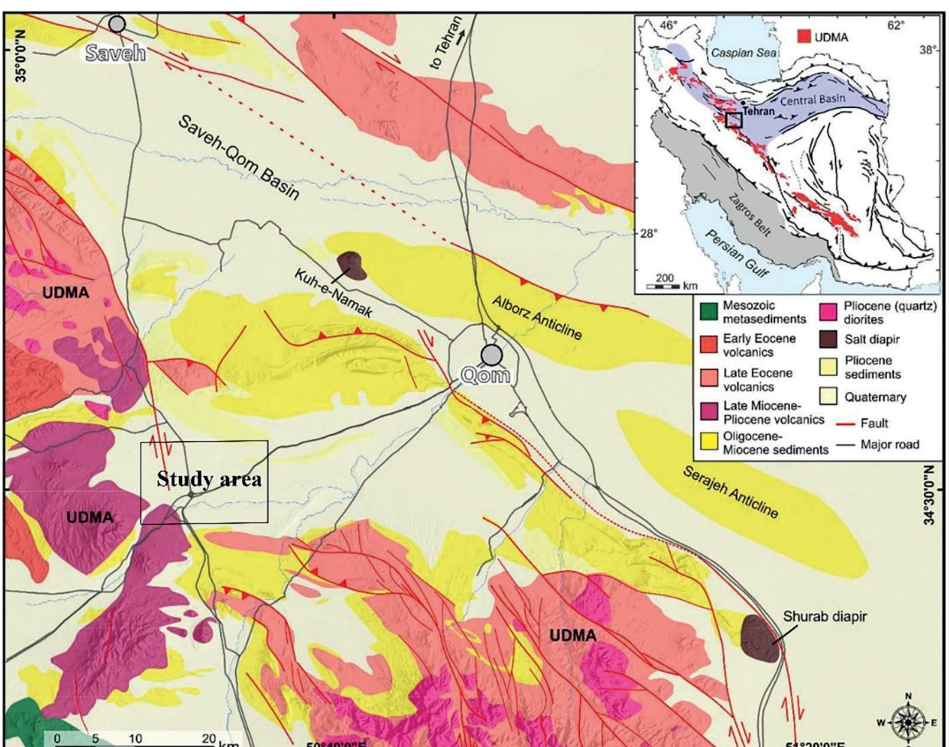

Figure 2.
Regional geology of a sector of Central Iran comprising the Salafchegan city [16].

NMC ω (%)	OMC ω	$\gamma_{d\,min}$ (kN/m^3)	$\gamma_{d\,max}$ (kN/m^3)	PL (%)	LL (%)	C_c	C_u	Parameter
3.51	8.9	14.72	20.48	15	30	4.52	331.92	Value

Table 2.
Soil properties.

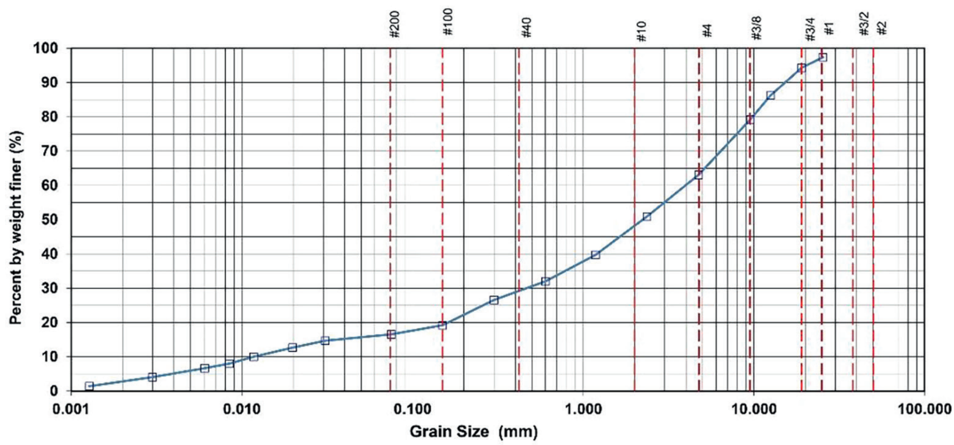

Figure 3.
Grain-size distribution curve of soil.

3. The effect of contamination on soil geotechnical parameters

The effect of pollution on granular soils is physical, and on cohesive soils, it is a change in soil texture. Generally, cohesive soil is more affected by oil contamination. Past research shows that soil compaction and resistance parameters decrease when hydrocarbon substances contaminate soil.

3.1 Compaction parameters

The modified compaction test was carried out on contaminated soil with zero moisture percentage in order to identify the effect of the contamination of materials resulting from the treatment of burned oil on the compaction parameters of the soil. **Figure 4** shows that with the increase of acid sludge contaminations up to 4.2% due to the reduction of void soil and easier sliding of grains soil, the maximum dry soil unit weight increases. But with increasing contamination due to the separation of grains of soil from each other, the maximum dry soil unit weight decreases.

With 5.1% contamination of the dirt filter, first, the specific weight of the soil increased, then due to the filling of the spaces between the soil grains, the specific weight decreased.

The results of other researchers are shown in **Table 4**, as it is clear that the specific dry weight of the soil decreased with the increase of contamination.

Figures 5 and **6** show that the addition of 12% crude oil to the soil caused a 2.5% decrease in the maximum dry weight and a 50% decrease in the optimum moisture content [25]. Karkush and Jihad [27] and Ghadyani et al. [24] stated that soil

	L.O.I	**Na2O**	**MgO**	**Al_2O_3**	**SiO2**	**P2O5**	**SO3**	**Cl**	**K2O**	**CaO**	**Cr**	**TiO2**
Acidic Sludge	86.87	0.425	0.09	0.079	0.322	1.207	6.683	0.008	0.099	2.941	0.01	
Dirt Filter	37.25	0.073	1.44	6.67	47.734	0.04	2.418	0.073	0.358	3.041		0.067
	Mn	*Fe2O3*	*Ni*	*Cu*	*Zn*	*Rb*	*Sr*	*Zr*	*Ba*	*Mo*	*Pb*	
Acidic Sludge	0.007	0.428	00.04	0.018	0.784		0.002	0.001		0.019	0.004	
Dirt Filter	0.028	0.736	0.004		0.007	0.002	0.016	0.005	0.04			

Table 3.
X-ray fluorescence test results on contaminants.

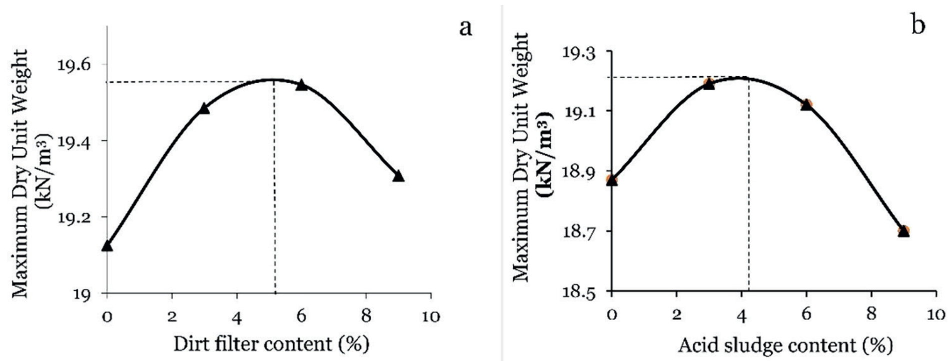

Figure 4.
Maximum dry unit weight of soil by percentage of (a) dirt filter, and (b) acidic sludge contaminants.

References	Soil type	Type of contamination	Content (%)	Curing period	MDD	OMC
Sarmadi et al. [19]	SP Iran	Kerosene	0–3–6–9–12–15	Two weeks	D	D
Fazeli et al. [20]	SC, Iran	Gas oil	0–2–4–6	One month	D	D
		Crude oil			D	D
George et al. [21]	SM India	Gas oil	0–4–8–12	A week	FID	
Khamehchiyan et al. [22]	SP, Iran	Crude oil	0–4–8–12–16	One month	D	D
	SM				D	D
	CL				D	D
Nasehi et al. [9]	SP, Iran	Gas oil	0–3–6–9	One month	D	D
	CL				D	D
	ML				D	D
Roshanqhiyas and Bagheripour [23]	CL Iran	Crude oil	0–2–4–6–8–10	One month	I	D
Ghadyani et al. [24]	CH Iran	Kerosene Gas oil	0–3–6–9	One month	I	D
					I	D
Karpuzcu et al. [25]	SC, Turkey	Crude oil	0–6–12	Two weeks	D	D
	CL				D	D
Choura et al. [26]	SP	Crude oil	0–5–10		D	D
Al-Sanad et al. [5]	SP Kuwait	Crude oil	0–2–4–6		I	D

Note: MDD: Maximum dry density, OMC: Optimum moisture content, FID: First increased and then decreased, I: Increased, D: Decreased.

Table 4.
Optimal moisture percentage and maximum specific dry weight of soil types contaminated with hydrocarbon and non-carbon materials.

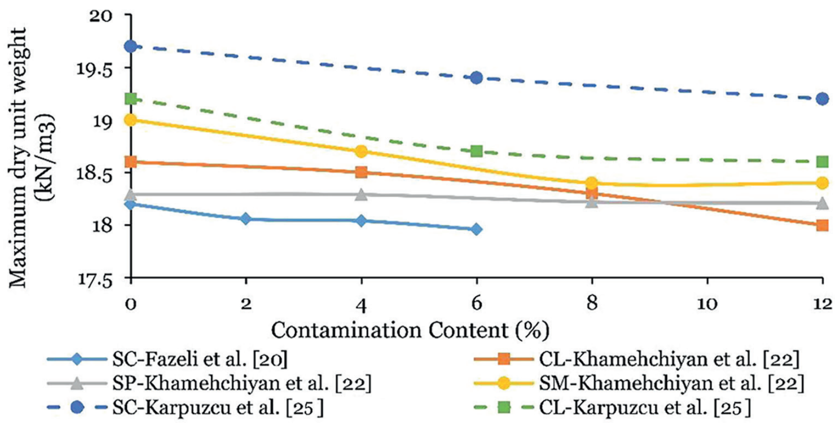

Figure 5.
Maximum specific dry weight of soil contaminated with crude oil.

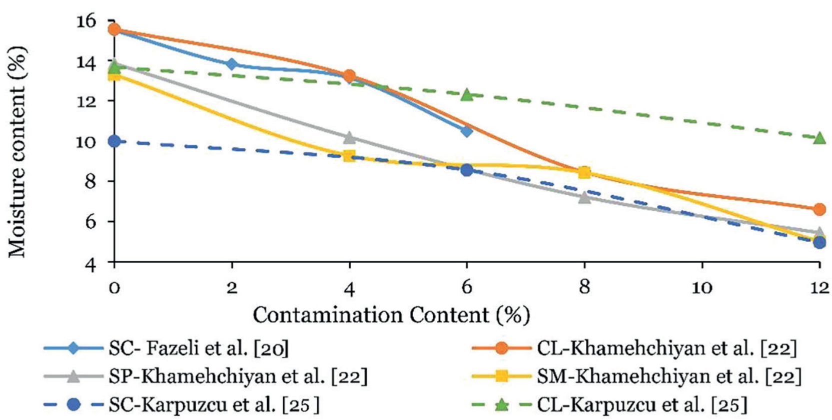

Figure 6.
Optimum moisture percentage of soil contaminated with crude oil.

contaminated by hydrocarbon substances would reach the maximum dry weight of the soil at a lower optimum moisture percentage.

3.2 Soil resistance parameters

3.2.1 The effect of contamination on the internal friction angle of the soil

Mohr-Columb rupture cover is generally curved, but it is linear in low vertical stresses, and the results presented by the researchers are also assumed to be linear. Usually, with the addition of hydrocarbon materials to the soil, these materials are placed between the soil grains and cause a decrease in the firm connection between the soil particles and the easier sliding of the soil grains on each other, and finally, the internal friction angle of the soil is reduced.

As it is clear in **Table 5**, with the increase of soil contamination, the friction angle of the soil decreases.

As shown in **Figure 7**, with an increase in vertical stress, the process of reducing the internal friction angle of the soil has increased. As the soil particles became

Dry unit weight (kN/m^3)	Vertical stress (kg/cm^2)	Contaminant content			
		0	3	6	9
(a)					
17	0.1–0.3–0.5	44	43	42	38
	0.5–1–1.5	42	41	40	34
19	0.1–0.3–0.5	49	48	44	43
	0.5–1–1.5	47	35	34	34
(b)					
17	0.1–0.3–0.5	44	42	41	41
	0.5–1–1.5	42	35	34	34
19	0.1–0.3–0.5	49	41	39	38
	0.5–1–1.5	47	41	37	33

Table 5.
Soil friction angle according to percentage of (a) dirt filter, and (b) acidic sludge contaminants.

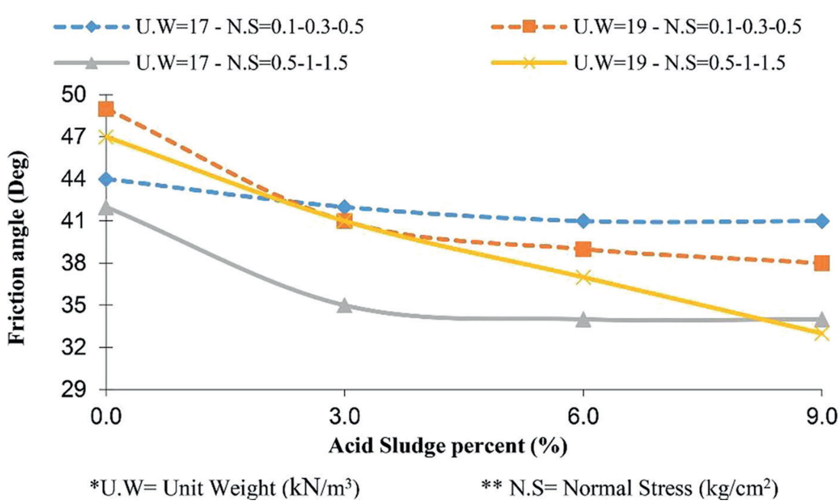

Figure 7.
Variation of internal friction angle of soil contaminated with different percentages of acidic sludge.

more compacted, acidic sludge had the function of a lubricant that reduced friction between soil particles. The internal friction angle of the soil sample with higher vertical stress with a dry unit weight 17 kN/m^3 has decreased by about 8 degrees, and the sample with a dry unit weight 19 kN/m^3 has decreased by about 14 degrees.

As can be seen in **Figure 8**, the dirt filter grains are placed around the soil grains, causing the soil grains to move away from each other and lose them—roughness and friction of the soil.

Figure 9 shows the process of reducing the internal friction angle of soil contaminated with dirt filters on heavy and light vertical stresses. The reason for this reduction is because the polluting substance is placed between the soil grains, causing the grains to move away from each other. As a result, the internal friction angle of the soil decreases.

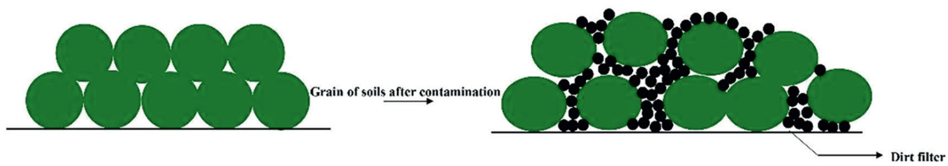

Figure 8.
Behavior of soil contaminated with dirt filter.

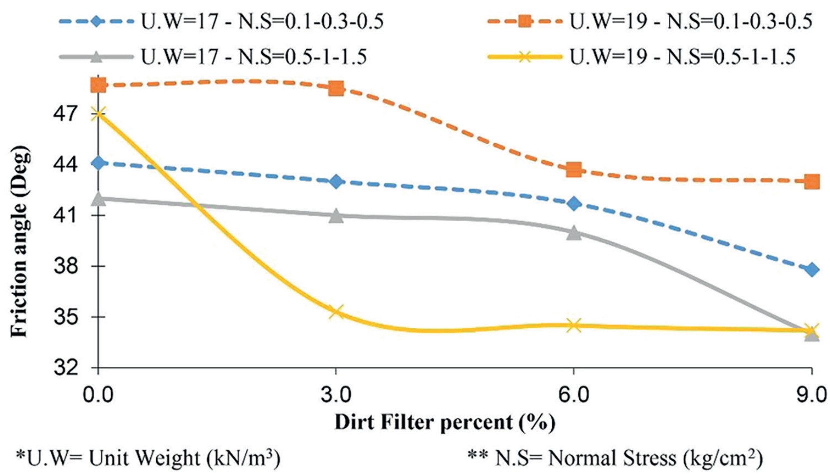

Figure 9.
Variation of internal friction angle of soil contaminated with different percentages of dirt filter.

3.2.2 The effect of contamination on the soil cohesion

By adding the polluting substance to the soil particles, the particles of this polluting substance are placed between the soil grains, and its surface active agents create a van der Waals bond with silica and other soil elements due to the non-polarity of the acidic sludge. The pollution of these bonds has increased, and the soil particles around the acid sludge particles begin to bond and finally stick to the particles, which results in an increase in soil cohesion.

By adding a dirt filter to the soil, the cohesion of the soil increases, which is due to the change in the nature of the soil. With increasing pollution, granular soil behaves like cohesion soil. This process of increasing cohesion is shown in **Table 6**.

Figures 10 and **11**, respectively, show the increase in cohesion of soil contaminated with acidic sludge and dirt filters under light and heavy stresses.

Table 7 shows the results for other contamination soils. The changes in the internal friction angle and cohesion of the contaminated soil generally decreased, depending on the type of soil and the pollutant. For granular soil, lubrication between the grains caused grain sliding and a decrease in the internal friction angle.

3.2.3 The effect of contamination on the shear strength of soil

Figure 12 shows that the shear strength of soil contaminated with acidic sludge, which is dependent on the combined effects of the internal friction angle and soil cohesion, had no clear and constant trend of change. In general, except at a vertical

Dry unit weight (kN/m^3)	Vertical stress (kg/cm^2)	Contaminant content			
		0	3	6	9
(a)					
17	0.1–0.3–0.5	0.051	0.166	0.119	0.12
	0.5–1–1.5	0.107	0.265	0.267	0.169
19	0.1–0.3–0.5	0.129	0.16	0.182	0.342
	0.5–1–1.5	0.06	0.393	0.364	0.5
(b)					
17	0.1–0.3–0.5	0.05	0.074	0.076	0.13
	0.5–1–1.5	0.11	0.135	0.21	0.263
19	0.1–0.3–0.5	0.13	0.225	0.167	0.192
	0.5–1–1.5	0.06	0.207	0.229	0.258

Table 6.
Soil cohesion resulting from (a) dirt filter contaminants, and (b) acidic sludge.

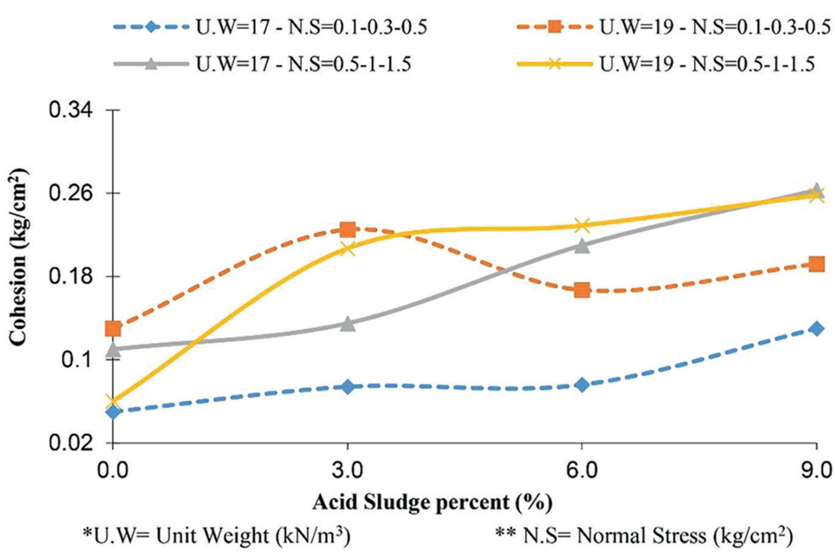

Figure 10.
Variation of cohesion of soil contaminated with different percentages of acidic sludge.

stress of 0.1 kg/cm^2, the shear resistance of the soil decreased. It is evident that, with an increase in the vertical stress of the soil, its shear resistance increased as the soil grains grew close together and the grains locked.

Low vertical stresses such as 0.1 kg/cm^2, contamination caused an increase in the shear resistance of the soil. At a higher vertical stress, the soil shear resistance decreased when contaminated with pollutants. The reason for this could be that, under a vertical stress of 0.1 kg/cm^2, the addition of a pollutant to the soil caused the filling of the space between the grains and eventually caused them to lock. This increased the shear resistance of the soil. Under vertical stresses, with the closeness of the grains, the addition of a pollutant increased the distance between the grains and

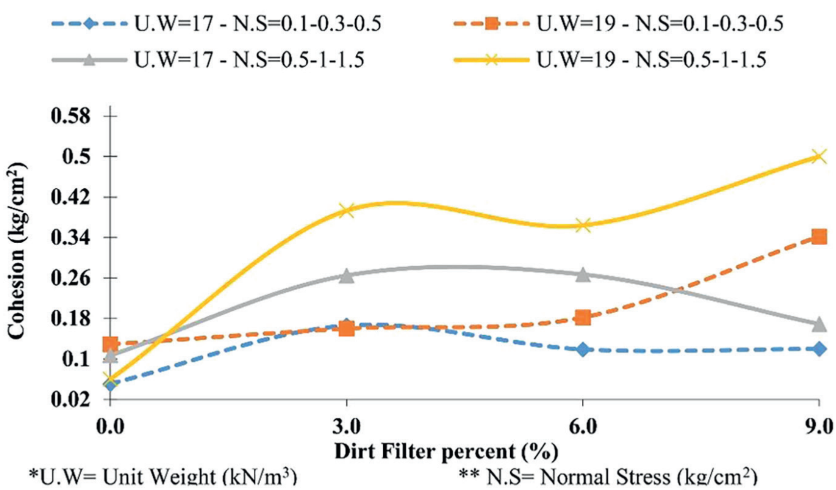

Figure 11.
Variation of cohesion of soil contaminated with different percentages of dirt filter.

References	Curing period	Vertical stress (kPa)	Content (%)	Type of contamination	Soil type	Soil friction angle (°)	Soil cohesion (kPa)
Safehian et al. [28]	A week	50–100–150	0	Gas oil	CH	39	52
			4			37	41.3
			8			36	34.5
			12			36	32.5
			16			35	31
			20			34	30.6
Khamehchiyan et al. [22]	One Month	55–110–160	0	Crude oil	SP	35	0
			4			32	3.3
			8			32	8
			12			29	7.6
			16			27	6.2
			0		SM	33	27.4
			4			33	19.9
			8			32	22.7
			12			26	20.8
			16			26	34
			0		CL	26	74.8
			4			27	28.4
			8			28	19.4
			12			29	19.4
			16			34	18

References	Curing period	Vertical stress (kPa)	Content (%)	Type of contamination	Soil type	Soil friction angle (°)	Soil cohesion (kPa)
Saberian and Khabiri [10]		55–111–222	0	Gas oil	SP	39	0
			3			35	10.2
			5.25			32	17.4
			8			31	26.7
Nasehi et al. [9]	One Month	24–44–64	0	Gas oil	CL	19	12.1
			3			14	11.4
			6			6	14.3
			9			6	14.6
			0		ML	21	9.9
			3			18	9.8
			6			14	11.3
			9			11	12.4
			0		SP	20	7.4
			3			19	8.4
			6			15	12.4
			9			14	12.2
Askarbioki et al. [29]	48 Hours	50–100–150	0	Gasoline	SC	28	14.9
			1			25	13.7
			3			23	13.5
			5			23	13
Rasheed et al. [30]	One Day		0	Gas oil	SPSM	12	18
			3			17	11
			5			26	4
			7.5			32	1.1
			0	Gasoline		12	18
			3			14	16.5
			5			15	14.2
			7.5			20	12.3
Karkush and Kareem [11]	Four Days	50–110–220	0	Crude oil	CL	37	66
			10			30	37
			20			25	22
Choura et al. [26]			0	Crude oil	SP	31	
			5			52	
			10			40	
Karpuzcu et al. [25]	Two Weeks	100–200–300	0	Crude oil	CL	26	0
			6			31	42.9
			12			23	67.3
			0		SC	39	24.4
			6			30	102.4
			12			36	139.5

References	Curing period	Vertical stress (kPa)	Content (%)	Type of contamination	Soil type	Soil friction angle (°)	Soil cohesion (kPa)
Sarmadi et al. [19]	Two Weeks	50–100–150–200–250	0	Kerosene	SW	38	0
			3			35	5.6
			6			33	6.4
			9			32	6.8
			12			31	7.1
			15			30	7.3
			10			20	41
			20			18	36
			30			18	32

Table 7.
Cohesion and internal friction angles of soil contaminated with hydrocarbons by maximum specific dry weight density.

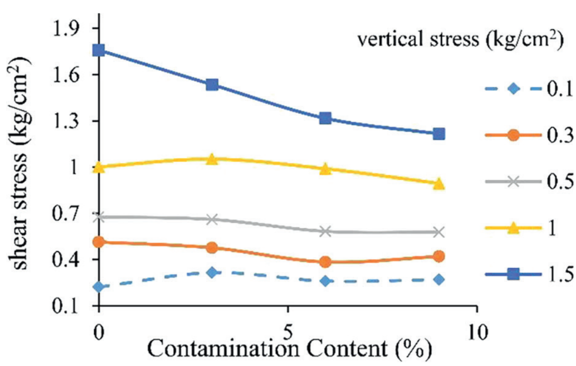

Figure 12.
Shear strength of soil contaminated with acidic sludge under vertical stress (0.1, 0.3, 0.5, 1, 1.5 kg/cm^2) at a specific dry weight of 1.9 g/cm^3.

made it easier for the soil grains to slide relative to one another. As a result, the shear resistance of the soil decreased.

Figure 13 shows that the shear strength of soil contaminated with dirt filter residue increased at all vertical stresses except 1.5 kg/cm^2. Under a vertical stress of 0.1 kg/cm^2, with the addition of 9% dirt filter residue to the soil, its shear strength increased from 0.221 to 0.479 kg/cm^2.

3.3 Soil vertical deformation

As shown in **Figures 12** and **13**, when the soil is contaminated, the vertical deformation does not show very different behavior in different percentages of contamination. In fact, in soil samples, there is a lot of conflict between the grains and the locking between them, and the grains cause expansion and expansion of the soil by moving on each other. In general, in most of the stresses, soil contamination has reduced the expansion of the soil (**Figures 14** and **15**).

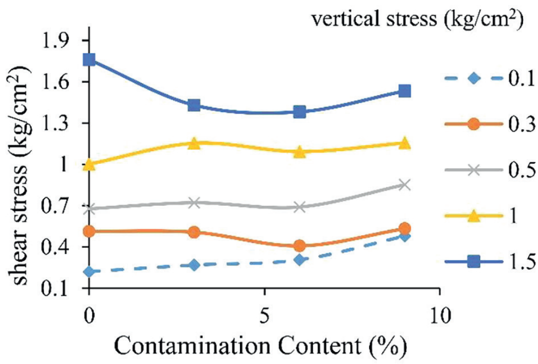

Figure 13.
Shear strength of soil contaminated with dirt filter under vertical stress (0.1, 0.3, 0.5, 1 and 1.5 kg/cm²) at specific dry weight of 1.9 g/cm³.

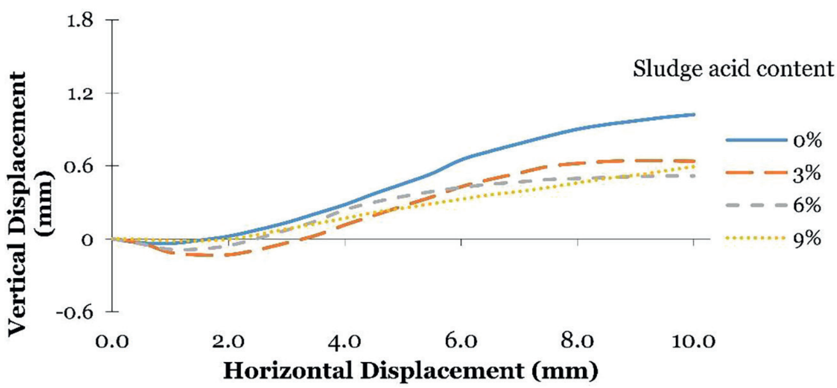

Figure 14.
Horizontal displacement-vertical displacement diagram of acid sludge samples with different contamination percentages under vertical stress of 1 kg/cm² and dry specific gravity of 1.7 g/cm³.

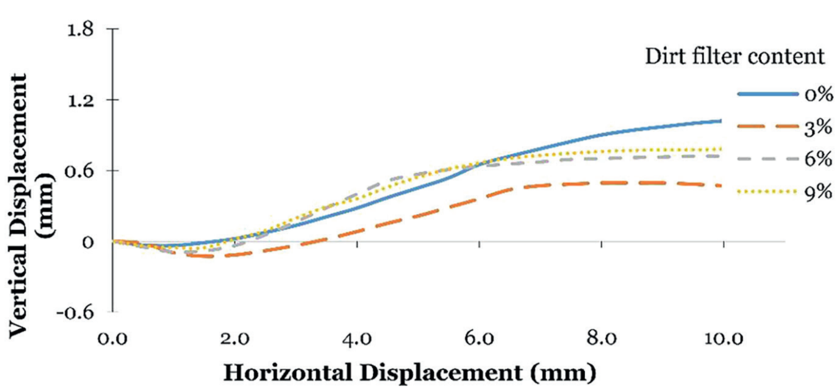

Figure 15.
Horizontal displacement-vertical displacement diagram of dirt filter samples with different contamination percentages under vertical stress of 1 kg/cm² and dry specific gravity of 1.7 g/cm³.

3.4 Effect of oil on soil structure

Clay particle placement can be categorized as mass or complex, coagulated or non-coagulated [31–33]. Therefore, the particles tend to be oriented face-to-face in a dispersed or divergent structure. If the forces are attractive, the particles tend to be oriented corner-to-face or corner-to-corner depending on the complex structure of the particles [34–36].

Considering that the structure of soil particles depends on the charge capacity of the electrostatic field, when clay is contaminated by hydrocarbons, their low dielectric constant and non-polarity will reduce the absorption capacity and force between the particles. This has a function similar to insulation; thus, it will affect the overall structure of the clay particles. As a result, the electrostatic field between the particles will push them toward repulsion and the degree of flocculation of the structure will decrease, giving it a scattered appearance [20].

Figure 16 shows that, with the addition of crude oil contamination to clay soil, the stickiness and low dielectric constant of the crude oil will cause a decrease in the double layer thickness that will cause edge-to-edge or edge-to-side formation of the soil particles. This means that, practically, the soil will become coagulated or flocculated.

Figure 17 shows that the addition of crude oil pollutants to a mixture of sandy and clay soil caused it to become flocculated with a scattered structure. The specific surface area of the soil decreased. This decreased the specific surface area of the soil and indicated a decrease in the resistance of the soil affected by the crude oil contamination [39].

In granular soil, unlike fine-grained soil, where the structure of the soil changes, the contaminant will surround the soil grains. The high viscosity of the hydrocarbon materials will cause lubrication between the soil grains and ultimately lead to a decrease in the surface tension between soil grains.

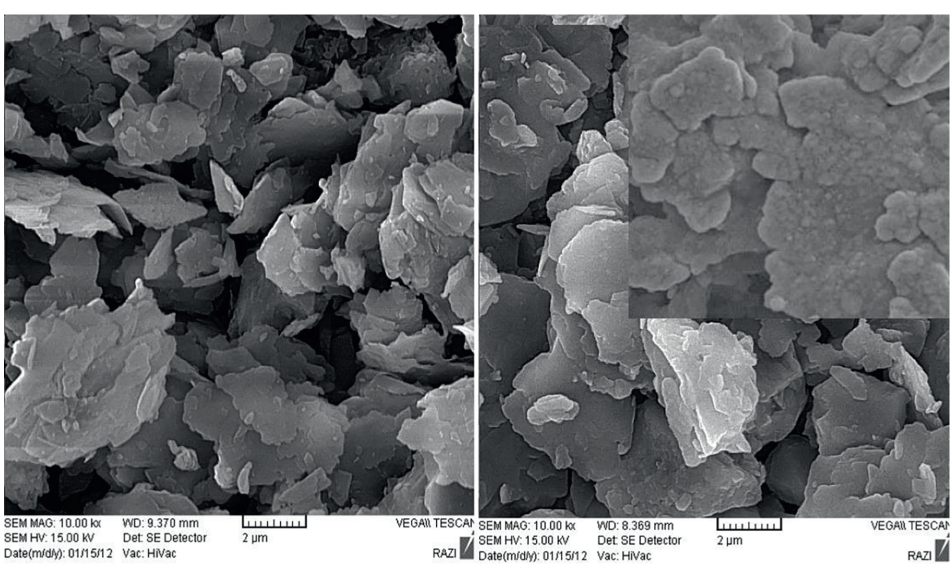

Figure 16.
SEM images of soil texture at 10,000× for uncontaminated samples and 20% crude oil contamination [37].

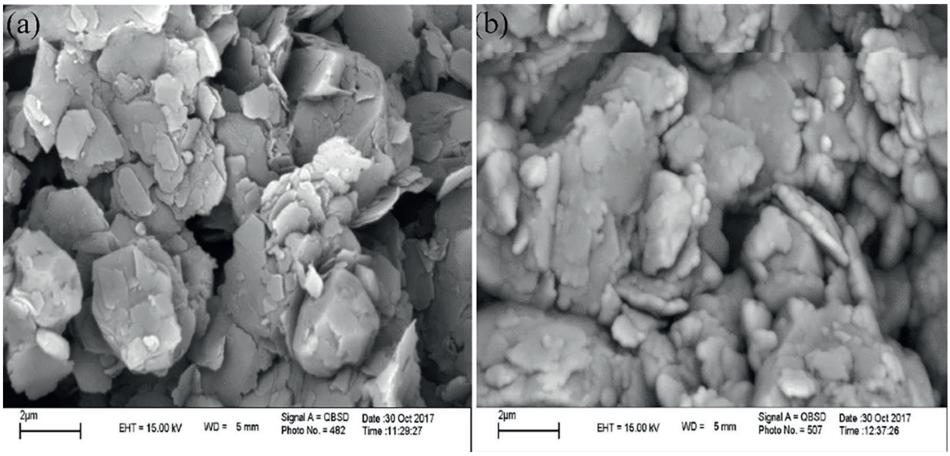

Figure 17.
SEM images of soil texture at 20000× of samples of: (a) 60% kaolinite +40% sand; (b) 60% kaolinite +40% sand +16% crude oil [38].

4. Discussion

Nowadays, the change of geotechnical characteristics of soil as a result of pollution by petroleum materials is considered as one of the challenges of geotechnical engineers. In this chapter, the effect of this pollution on the parameters of shear strength and shear behavior was investigated by performing direct shear tests and compression tests.

The results of the compaction test showed that soil contamination with hydrocarbon materials increases the compressibility of the soil. In fact, the high viscosity of hydrocarbon materials compared to water makes it easier for grains to move and slide more easily, which makes it possible to achieve higher densities.

The shear strength of the soil contaminated with hydrocarbon materials does not have a clear trend, but generally the internal friction angle of the soil decreases due to the easier sliding of the soil grains and the cohesion of the soil increases.

5. Conclusion

The following are the results of the present study

- the increase of acid sludge contaminations up to 4.2% due to the reduction of void soil and easier sliding of grains soil, the maximum dry soil unit weight increases.

- the dirt filter grains are placed around the soil grains, causing the soil grains to move away from each other and lose them—roughness and friction of the soil.

- with the addition of hydrocarbon materials to the soil, these materials are placed between the soil grains and cause a decrease in the firm connection between the soil particles and the easier sliding of the soil grains on each other, and finally, the internal friction angle of the soil is reduced.

- Under similar experimental and loading conditions, an increase in the contaminant content decreased the soil dilatancy angle. Under general conditions, the shear strength of soil will decrease with a decrease in the soil friction angle, which will decrease the dilatancy angle, except where the contaminant acts as a lubricant between soil particles.

- Dirt filter contamination at a dry unit weight of 1.7 g/cm^3 under high and low vertical strengths caused the contaminants to act as lubricants and boosted the shear strength of the soil. Further contamination filled the void spaces between the soil particles and caused a decreasing trend in soil shear strength.

6. Proposals for future research

In order to better analyze, suggestions for future research are presented as follows:

- Investigation of Shear Modulus variations of crude oil contaminated clay on small-strain range.

- The influence of hydrocarbon materials on the geotechnical properties of soil with Bending element, reinforcement column test.

- Designing a neural network in order to predict changes in geotechnical parameters of different soils using the results and data provided by other researchers.

- Investigating the effect of oil contamination on other geotechnical soil parameters including consolidation, Bearing capacity, settlement, permeability coefficient, liquefaction potential, and slope stability.

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