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Stabilization of sandy soil contaminated with crude-oil utilizing Portland cement

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Keywords: soil pollution, sandy soil, geotechnical stabilizer, Portland cement, crude-oil, effective cohesion, shear stress

Abstract. The issue of soil pollution has lately gotten worse because of the increase in industrial wastes like heavy metals, liquid hydrocarbons, and petroleum hydrocarbons. Oil is one of the most important sources of industrial pollution, which deteriorates large parts of surface areas and water bodies, and oil or its derivatives spill into surface areas or water bodies, either spontaneously or forcibly. Petroleum-polluted soil has an ordinarily adverse impact on its geotechnical features making it inadequate substance for construction projects. Therefore, there is an urgent need to find suitable techniques for improving such polluted soils. This paper is prepared to show two matters: the first deals with a comparison between the natural sandy soil and sandy soil polluted with 11.8 % of crude oil, while the second deals with an estimation of the mechanical features of polluted soil after being treated with five different proportions of ordinary Portland cement as stabilizer agents. Many experimental tests have been applied depending on the ASTM standards to evaluate several geotechnical features like the consistency limits, compaction parameters, UCS, and direct shear characteristics. The results showed that the existence of crude-oil in sandy soil minimizes the dry density, moisture content, shear stress, friction angle, and effective cohesion. Otherwise, the utilization of Portland cement in polluted sandy soil increases such mechanical features.

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1. *Introduction*

Because of an increase in industrial wastes like heavy metals, liquid hydrocarbons, and petroleum hydrocarbons, the issue of soil pollution has lately gotten worse [1, 2]. Oil is one of the most important reasons of industrial pollution, which have deteriorated huge parts of surface areas and water bodies, and oil or its derivatives spill into surface areas or water bodies, either spontaneously or forcibly [3]. Oil tankers play a major role in polluting the soil and water, which usually spills from oil during loading and unloading operations, cleaning oil tanks, or oil tanker collisions or explosions, which negatively affects the environmental elements [4–10]. Several investigations were implemented to evaluate the impact of crude-oil (C-oil) pollution on soils. Effective stress tests were carried out by Evgin & Das [11] on polluted and unpolluted sands. According to their findings, both loose and dense samples' friction angles were significantly lowering for the oil-saturated samples. However, they noted an increment in the volumetric strain. They came to the conclusion that oil pollution would cause foundation settlement to increase. Moreover, Al-Sanad et al. [12] demonstrated that the addition of two percent of C-oil makes an insignificant increment in the maximum peak point of the soil compaction curve, but the addition of C-oil more than two percent causes a minimization in the maximum peak point of the soil compaction curve. At the same time, the maximum water content (MWC) and the strength of soil determined by California Bearing Ratio (CBR) test were demonstrated a reduction with increase the C-oil percent. Kham et al. [13] performed experimental tests on C-oil with clay and sandy soils in Iran. The studied soil specimens have been mixed with four different percent's of C-oil (0–16 % by weight of the soils), and the tests have carried out according to ASTM standards. They observed a minimization in the optimum peak point of the soil compaction curve with raise the percent of C-oil. In terms of strength parameter of soils, they observed a decrement in cohesion of clay soil and an increment in angle of friction of clay soil as the percent of oil raised. Moreover, the authors demonstrated a minimization in angle of friction of sand specimens as the percent of oil raised. Many authors, like Wang et al. [14], Akinwumi et al. [15], and Oluremi & Osuolale [16], studied the geotechnical characteristics of oil-polluted soil, reporting reduced soil resistance and raised Atterberg limits due to oil-pollution. The ability of soil to allow the flow of water through also reduced notably. Moreover, Alfach & Wilkinson [17] concluded that the pollution of soil by C-oil had a reverse impact on the piles' bases relating to geotechnical performance degradation. Very few researchers indicated the possibility of using Portland cement as a stabilizer for C-oil polluted clay or sandy soils. Yu et al. [18] discovered that the utilization of Portland cement with C-oil-polluted soil could improve the resistance of soil and decrease permeability. likewise, Abdulhamid et al. [19] conducted a laboratory study to minimize the pollution resulting from oil industries in the soils of Iraqi Region Kurdistan. They tried to treat the soil polluted with 14 % C-oil by using 8.7 % Portland cement. They reported that the presence of Portland cement could minimize the impact of C-oil pollution by increasing the values of compaction parameters. Based on the above literature, we find that there is an urgent need to prepare a study whose main objective is to understand the mechanical behavior of soil polluted with C-oil when treated with ordinary Portland cement (OPC). The current investigation concentrates on evaluating the mechanical properties of sandy soil polluted with 11.8 % of C-oil and treated with five different proportions of OPC.

2. *Materials and Methods*

Unpolluted sandy soil samples have been brought from a site nearby Dhi Qar Refinery – Dhi Qar government – Iraq. Moreover, sandy soil samples polluted with 11.8 % C-oil. The chemical features of natural sandy soil, and the features of pollutant are demonstrated in Tables 1 and 2, consecutively. The distribution curves of soil particles is demonstrated in Fig. 1.

Type I OPC locally manufactured was utilized in this investigation as stabilizer substance, its chemical and physical characteristics are demonstrated in Table 3.

Table 1. Chemical test results of unpolluted soil.

Silicon dioxide percent	Aluminium oxide percent	Iron (III) oxide percent	Calcium oxide percent	Carbon dioxide percent	Sodium oxide percent	Potassiu m oxide percent	PH
71.3	4.5	7.9	1.3	0.87	0.33	0.41	7.4

Table 2. Pollutant characteristics (C-oil).

Physical characteristics		Chemical characteristics	
Dynamic viscosity at 60°, mm^2/s	6.75	Paraffin, %	35
Kinematic viscosity at 40°, mm^2/s	43.9	Naphthenic, %	30
Viscosity index, minute	98	Aromatic, %	15
Density	0.805	Asphaltic, %	5
Flash point	73		
Pour point	–37		
Total acid content	0.1		
PH	8.1		
Specific gravity, API	28.5		
Moisture content, mg/kg	83		

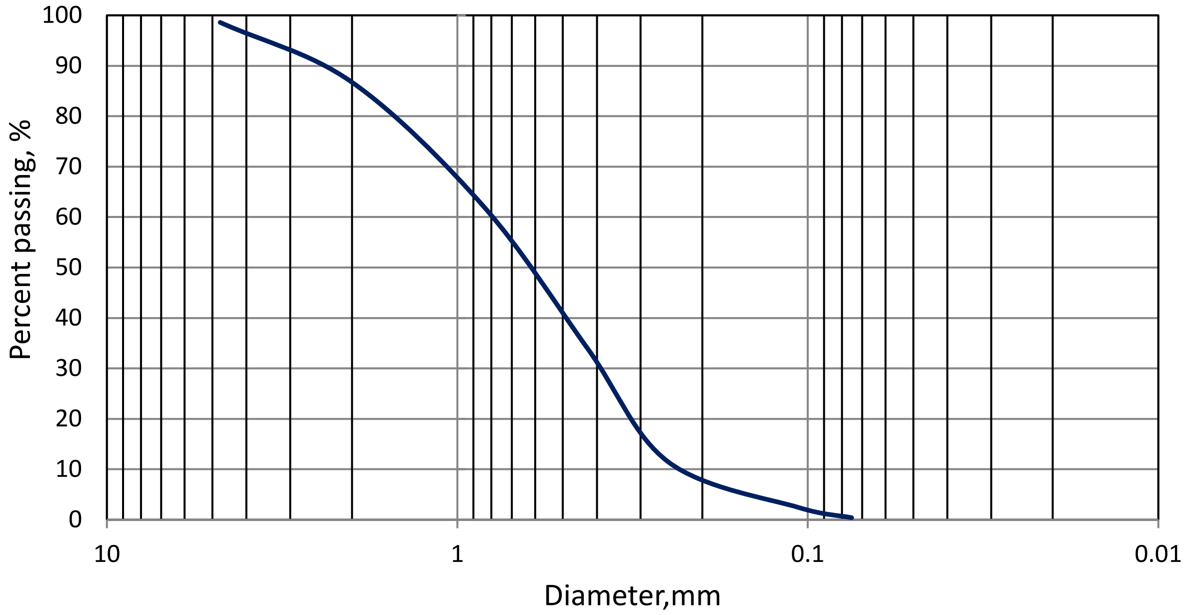


Figure 1. Size distribution curve of sandy soil according to D-6913/D6913M-17 [20].

Table 3. Features of cement utilized.

Chemical Features		Physical Features	
Compositions	**% by Wt.**	**Features**	**Values**
Calcium oxide Silicon dioxide	60.89 22.74	Specific surface area (m^2/kg)	326
Aluminum oxide Iron (III) oxide	4.51 3.45	Setting time (min)	Initial: 185 Final: 225
Sulfur trioxide Magnesium oxide	2.1 3.05	Compressibility (MPa)	After 3 days: 21 After 1 week: 34
Loss on ignition Insoluble residue Lime saturated factor	2.06 0.5 0.7	Soundness %	0.23

2.1. Preparation of Samples

The sandy soil samples have been kept in plastic bags to keep their water content from evaporating when transporting them to the soil engineering laboratory in Thi Qar University. The samples have been laboratory oven dried at one hundred and ten degrees Celsius, then grind by using Loss Angeles device and obtaining suitable samples ready for the experimental program. The compaction tests have been implemented according to ASTM-D698-12E-21 [21] standards. According to ASTM-D3080-04 [22], cubic soil samples have been prepared by utilizing 60 × 60 mm standard shear box to evaluate the direct shear parameters of for unpolluted sandy soil, C-oil polluted sandy soil, and polluted sandy soil treated with 6, 12, 18, 24, 30 % Portland cement. The experimental program, which adopted in the current investigation, are demonstrated in Plate 1, and all outcomes have been obtained as an average from three samples for each type of test and for each case studied.

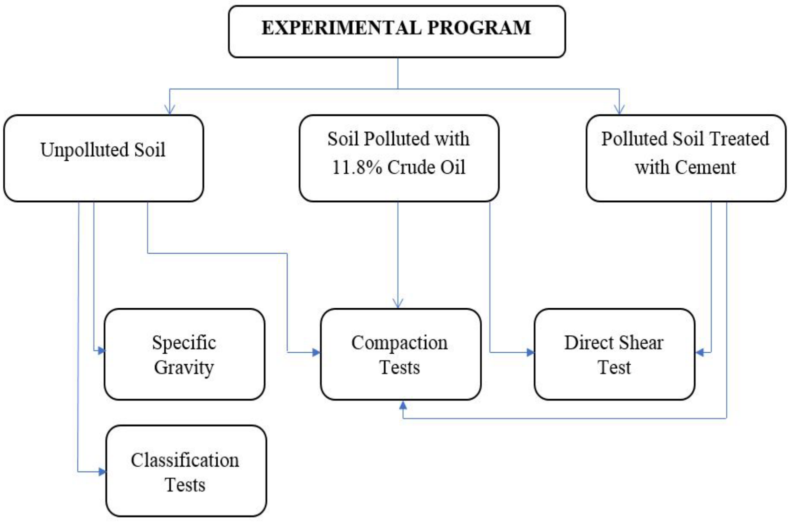


Plate 1. Experimental program.

3. Results and Discussion

3.1. Geotechnical Features of Unpolluted Sandy Soil

The general geotechnical outcomes got from the experimental program of unpolluted sandy soil are demonstrated in Table 4. The features values were 2.65 for specific gravity (Gs), 1.884 Kg/m^3 for optimum dry density (ODD), 9.5 % for optimum moisture content (OMC), 3.115 ratio for coefficient uniformity (Cu), and 0.758 ratio coefficient for curvature (Cc). From Table 4, it could be noted that the collected sandy soil classified as SP according to unified classification system [23], and as A-2-6 according to AASHTO classification system [24].

Table 4. Geotechnical features of unpolluted sandy soil.

Gs	ODD (kg/m^3)	OMC (%)	Cu	Cc	Classification	
					USCS	AASHTO
2.65	1.884	9.5	3.115	0.758	SP	A-2-6

3.2. Impact of Cement Additive on Compaction Parameters

The compaction parameters outcomes for sandy soil, represented as OMC and ODD, which got from the Proctor compaction tests for natural sandy soil, oil-polluted soil, and oil-polluted soil contained 6, 12, 18, 24, or 30 % cement are demonstrated in Table 5 and Fig. 2.

Compared with unpolluted sandy soil, the outputs demonstrated that the presence of C-oil decreased the dry unit weight and the moisture content by about 3.93 and 21.05 %, consecutively. This variation was due to the fact that oil has partially occupied the inter-particles spaces and the occurrence of oil has changed the soil to a state of looser material than an unpolluted sandy soil.

Table 5. Results of compaction test.

Samples	Descriptions	ODD (kg/m^3)		OMC (%)	
		Test value	Change (%)	Test value	Change (%)
NS	Natural soil	1.884	/	9.5	/
CS	Polluted soil	1.840	–3.93	7.5	–21.05
$CS+C_{6\%}$	Polluted soil treated with 6% cement	1.842	1.77	7.7	2.67
$CS+C_{12\%}$	Polluted soil treated with 12% cement	1.856	2.54	7.9	5.33
$CS+C_{18\%}$	Polluted soil treated with 18% cement	1.896	4.75	9.2	22.67
$CS+C_{24\%}$	Polluted soil treated with 24% cement	1.901	5.03	8.7	16.00
$CS+C_{30\%}$	Polluted soil treated with 30% cement	1.911	5.58	8.5	13.33

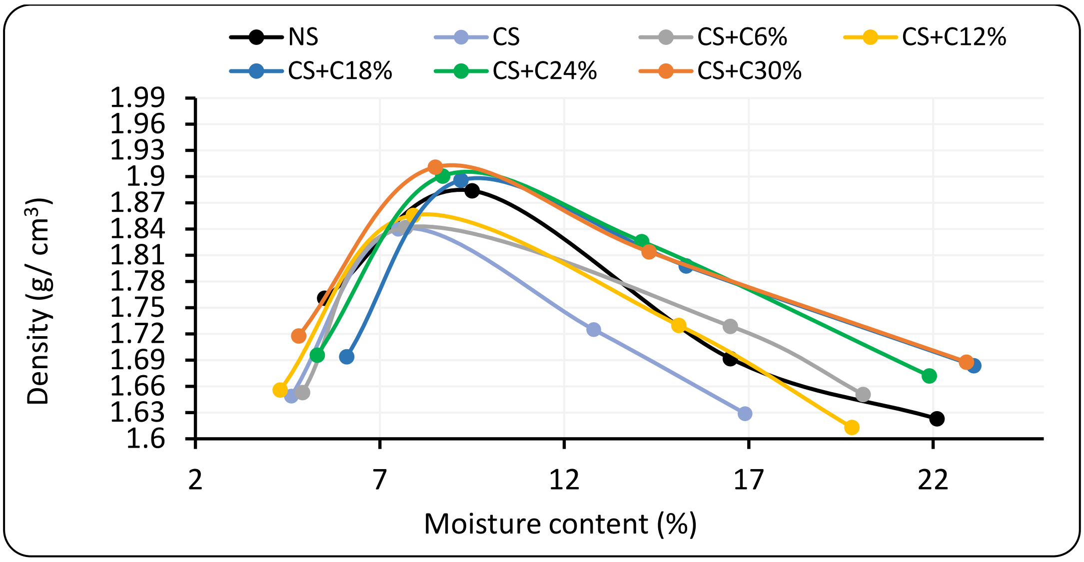


Figure 2. Compaction curves.

Comparing with polluted soil, it could be noted that the presence of cement helped to increase the ODD by about 1.77, 2.54, 4.75, 5.03, and 5.58 % for soil treated with 6, 12, 18, 24, and 30 % of cement, consecutively. The increment in ODD is primarily due to the difference in Gs because the OPC has a Gs of about 3.15, which is higher than that of the soil. The impact of cement content on the ODD of polluted sandy soil is demonstrated in Fig. 3. Moreover, it could be noted that the presence of 6, 12, 18, 24, and 30 % cement helped to increase the OMC by about 2.67, 5.33, 22.67, 16, and 13.33 %, consecutively, comparing with polluted soil. This behavior could be ascribed to the fact that the C-oil is considered a dense nonaqueous phase liquid that will prevent both the cement and soil from interacting with water, and thus the cement will require more water. The impact of cement content on the OMC of polluted sandy soil is demonstrated in Fig. 4.

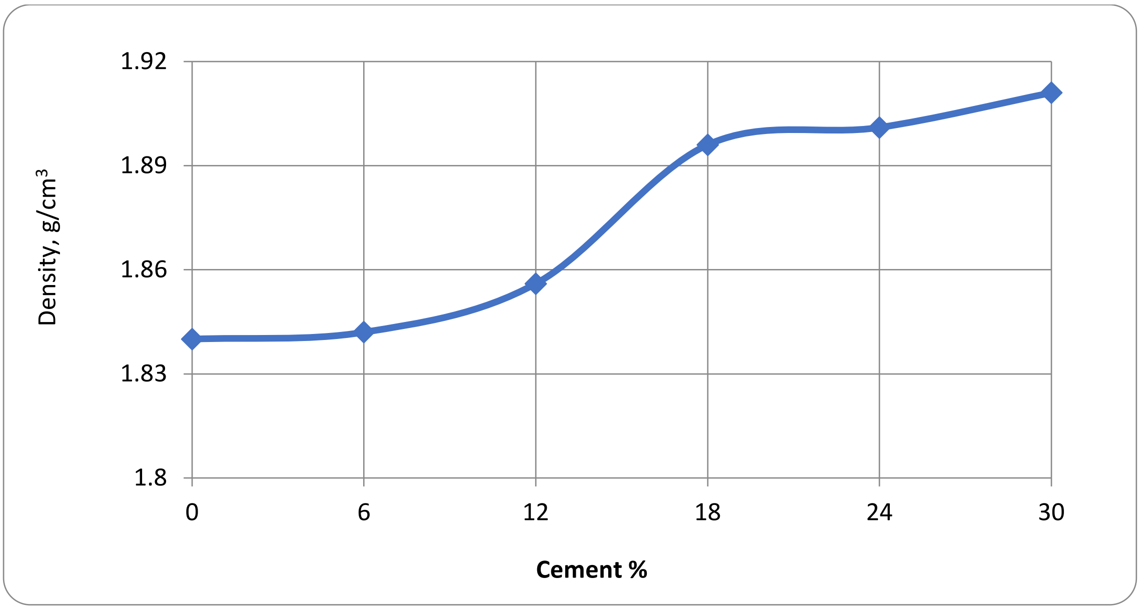


Figure 3. Impact of Portland cement additive on optimum dry density of oil-contaminated coarse soil.

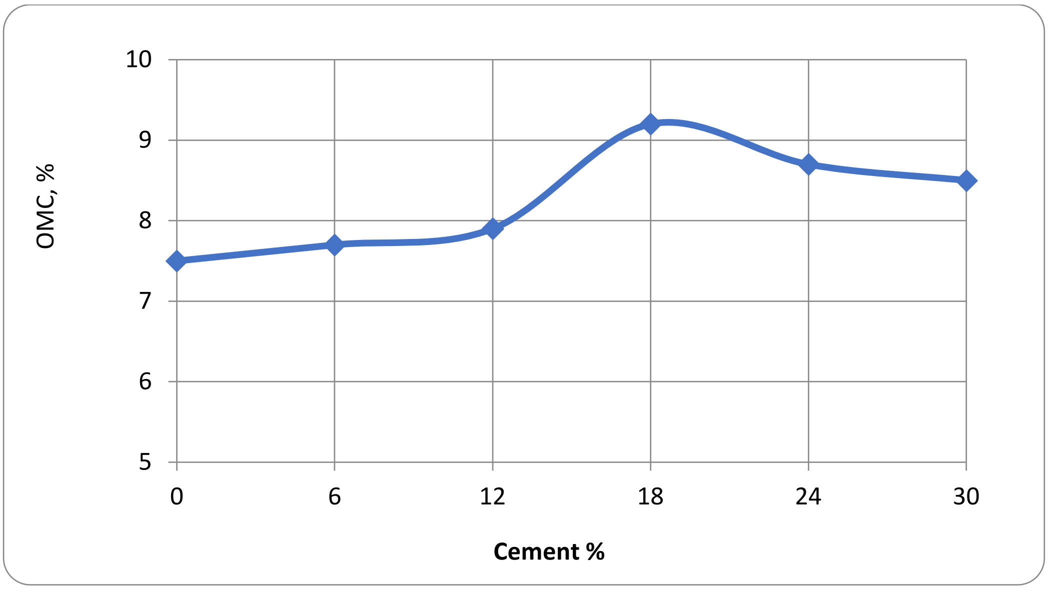


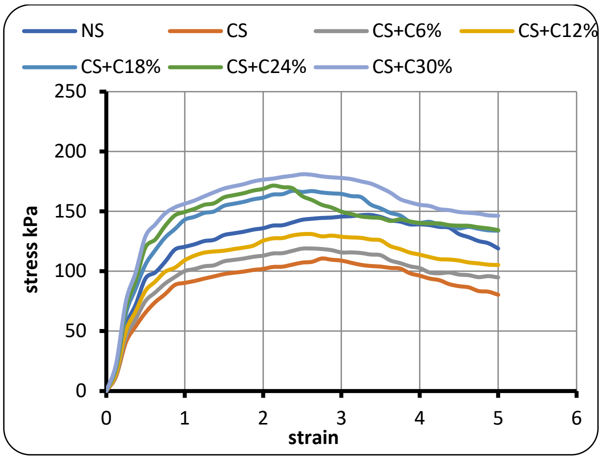
Figure 4. Impact of Portland cement additive on optimum moisture content of oil-contaminated coarse soil.

3.3. Impact of Cement Additive on Direct Shear Parameters

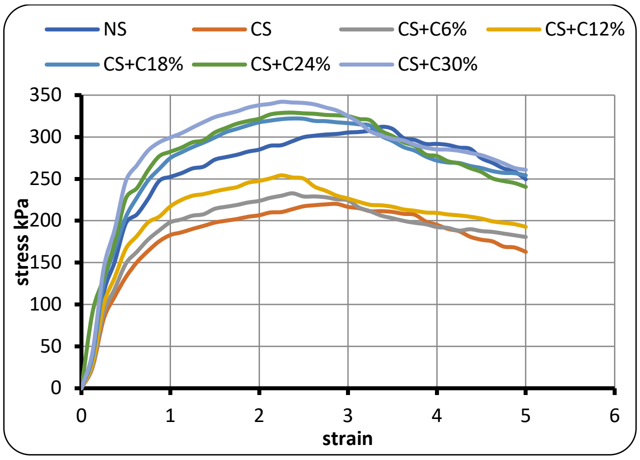
The direct shear parameters outcomes, represented as effective cohesion (C) and friction angle (φ), which got from the direct shear tests for natural sandy soil, oil-polluted soil, and polluted soil contained 6, 12, 18, 24, or 30 % cement are demonstrated in Table 6. The behavior of stress vs. strain for three normal applied stresses 136.202, 272.405, and 408.608 kPa are demonstrated in Fig. 5.

Table 6. Impact of cement on direct shear parameters.

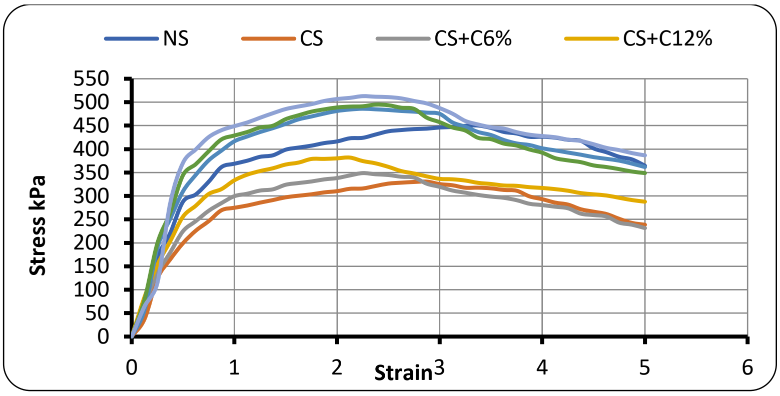
Samples	φ (°)		C (kPa)	
	Test value	Change (%)	Test value	Change (%)
NS	36	___	0.04	___
CS	24	–33.33	0.53	1225
CS+$C_{6\%}$	24.8	3.33	2.34	341.51
CS+$C_{12\%}$	26.2	9.17	3.84	624.53
CS+$C_{18\%}$	27.5	14.58	6.24	1077.36
CS+$C_{24\%}$	30.7	27.92	8.51	1505.66
CS+$C_{30\%}$	33.8	40.83	13.45	2437.74



Normal stress 136.202 kPa



Normal stress 272.405 kPa



Normal stress 408.608 kPa

Figure 5. Stress-strain behavior of oil- polluted soil contained cement.

Compared with unpolluted soil, the outputs demonstrated that the presence of C-oil decreased the friction angle value by about 33.33 % and increased the effective cohesion value by about 1225 %, consecutively. Moreover, in terms of shear stress, compared with unpolluted sandy soil, the stresses have been decreased when soil polluted with C-oil as demonstrated in Fig. 6. It could be deduced that the shear stress of sandy soil reduces with polluting sandy soil by C-oil due to upon pollution sandy soil particles tend to be more lubricated and easy to slide.

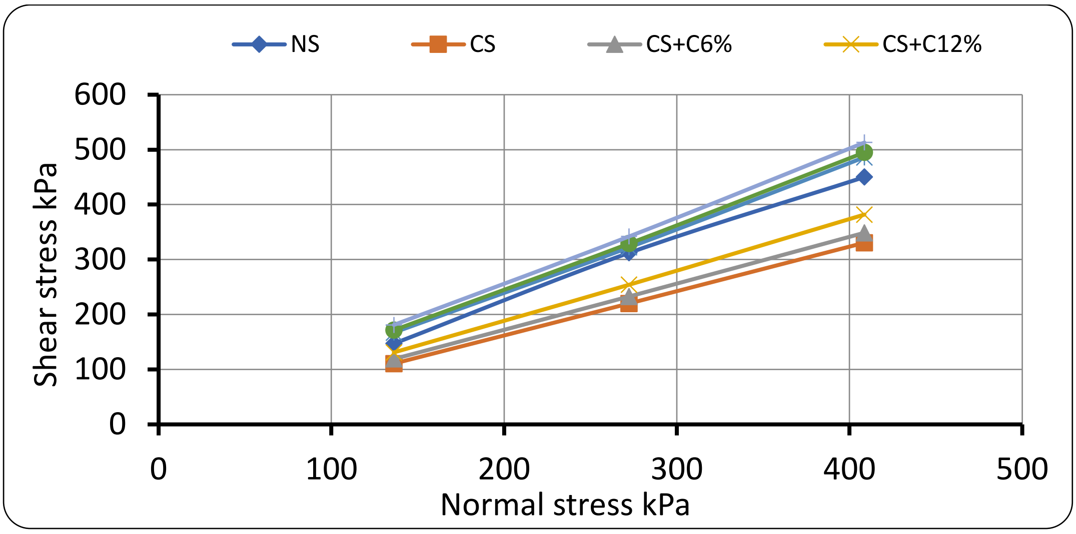


Figure 6. Shear stress – normal stress relations of oil- polluted sandy soil contained cement.

It could be found the impact of cement content on oil-polluted soil by compared the results of oil-polluted soil sample with cement treated soil samples. The relation between cement content and angle of friction values, which is demonstrated in Fig. 7, shown a significant increment in angle of friction values by about 3.33, 9.17, 14.58, 27.92, and 40.83 % for cement content 6, 12, 18, 24, and 30 %, consecutively, compared with contaminated sand. This increase can be attributed to the action of the cement, which increases the agglomeration between the grains and reduces lubrication, which increases the contact strength between the particles. Likewise, it could be noted a significant improvement in effective cohesion values by about 615.09, 813.20, 1077.35, 1505.66, and 2437.73 % for cement content 6, 12, 18, 24, and 30 %, consecutively, see Fig. 8. This is due to the cementing action, resulting from the hydration process, increasing the cohesion of the material. This impact could be clearly seen in Figs. 9 and 10. Moreover, in terms of shear stress, compared with polluted sandy soil, the stresses have been improved when cement content increased as demonstrated in Fig. 6.

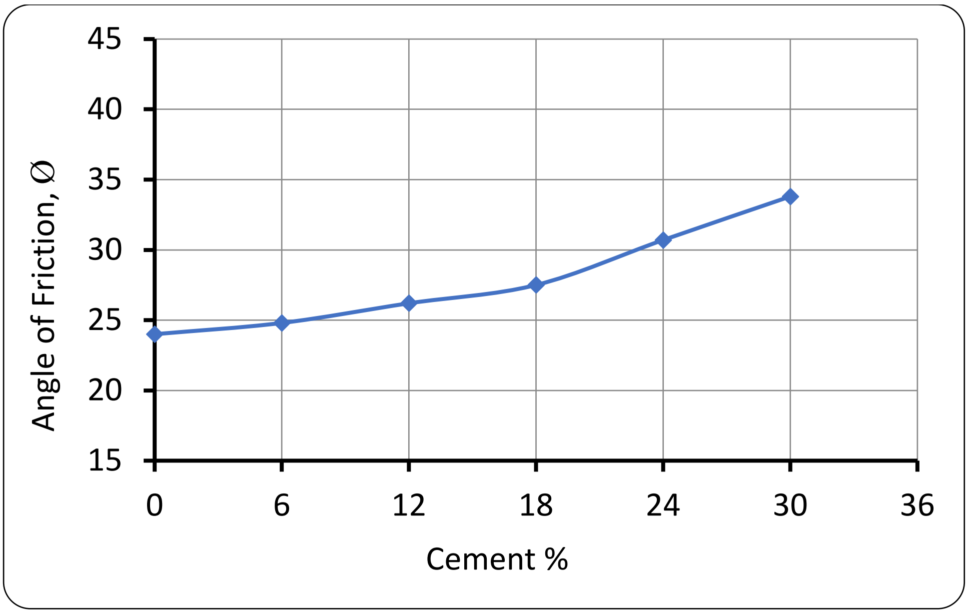


Figure 7. Impact behavior of cement content on angle of friction.

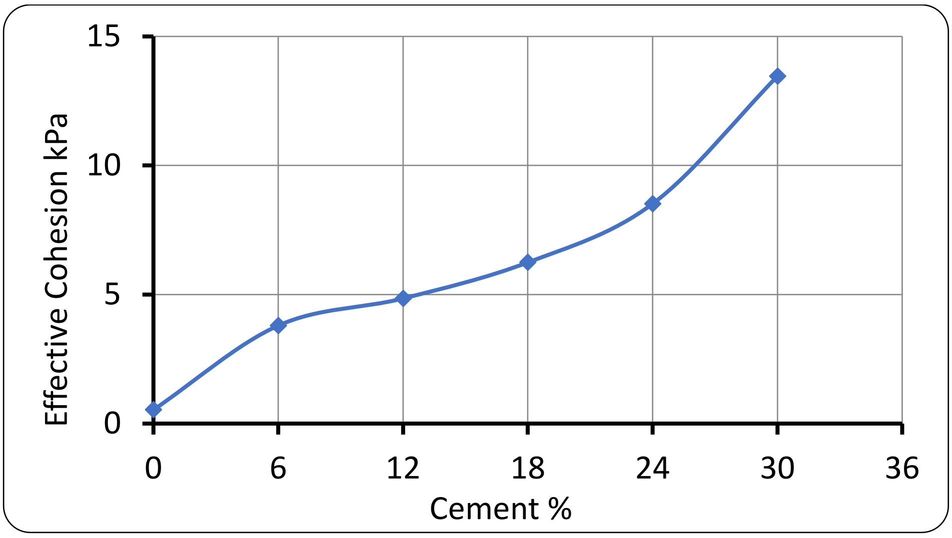


Figure 8. Impact behavior of cement content on effective cohesion.

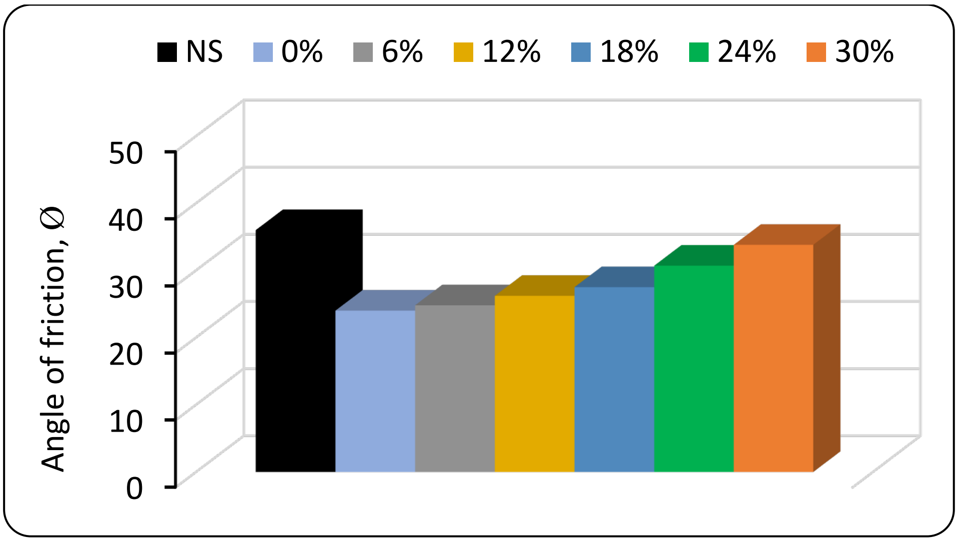


Figure 9. The impact of cement content on angle of friction.

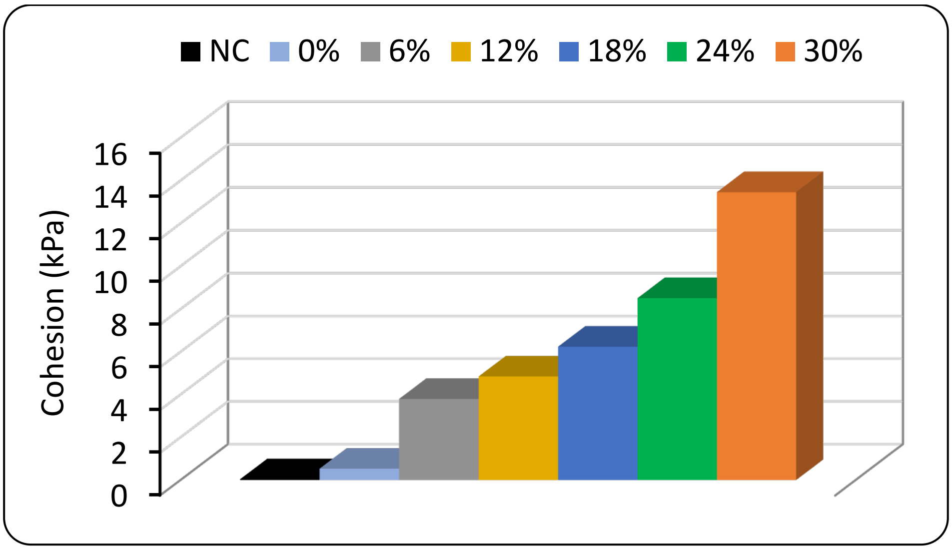


Figure 10. The impact of cement content on effective cohesion.

4. Conclusion and Recommendations

Experimental tests have been implemented to evaluate the difference in mechanical features between natural SP soil and such soil polluted with 11.8 % of C-oil. Moreover, Portland cement has been utilized in five different percentages 6, 12, 18, 24, and 30 % by weight of soil as stabilizer agents for polluted soil. Based on the experimental tests, the following points could be concluded:

1. The optimum unit weight and OMC of sandy soil minimize with the presence of C-oil.
2. The shear stress decrease when sandy soil is polluted with C-oil.
3. In terms of shear parameters, C-oil pollution in sandy soil reduce the friction angle and increase the effective cohesion.
4. The utilization of OPC in polluted soil increases the ODD, and this increment rises with increasing OPC content.
5. In general, the presence of 6, 12, 18, 24, or 30 % Portland cement in polluted soil increases the OMC, and it should be noted that 18 % of cement content record the highest moisture content.
6. OPC improves the shear stress of polluted soil, and this improvement is rise with increasing OPC content.
7. Both of friction angle and effective cohesion of polluted soil increase when Portland cement utilizes as a stabilizer agent, and it should be noted that this increment is rise with increasing cement content.

Finally, the following points are recommended for future work:

1. More investigation related with oil polluted soil must be implemented with another kinds of soil such as gypsum or silt soils.
2. Long-term impact of oil-pollution on soil geotechnical features must be evaluated and made a comparison with the outputs of the current experimental work.
3. Computer simulation programs must be utilized to study the impact of cement content in polluted soil and made a comparison with the outputs of the current experimental work.
4. Stabilization of oil-polluted soil considered a significant topic; therefore, it must be made another investigation deals with utilizing other economic or recycled materials as stabilizing agents for polluted soil.

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