Geotechnical Properties of Cement Stabilized Oil-Contaminated Soils

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Summary

This paper investigates the effect of cement on the geotechnical properties of two types of oil-contaminated soils and a natural soil from northern Oman. The soils were mixed with cement at 0, 5, 10, 15 and 20% by dry weight of the soil, and cured for 7, 14 and 28 days. Compaction, compressive strength, direct shear, permeability and leaching tests were carried out on the mixtures. The results indicate that cement improves the properties of oil-contaminated soils.

Introduction

Oil-contaminated soils result from leaking underground storage tanks, or soils surrounding petroleum refineries and crude oil wells. The stabilization of petroleum-contaminated soils were accomplished by pozzolanic reactions, which include both chemical and physical interactions between the wastes and additives [1]. Cement increases the strength of soil which also increases with curing time. Cement improves the interparticle binding and mechanical properties of wastes. It reacts with water and binds the materials within a short time. This reaction occurs between the Portland cement and silica, alumina and iron oxide from pozzolan to produce strength and durability [2]. It was found that petroleum-contaminated soil stabilized with 5% cement, 10% fly ash and 20% lime showed the best strength results [3]. The stabilization process produced physically, mechanically and chemically new soil mixtures.

This study was undertaken to investigate the effect of cement on the geotechnical properties of oil-contamineted soils. Cement was mixed at 5, 10, 15 and 20%, by dry weight of the soils, and the compaction characterisitics, unconfined compressive strength, cohesion, angle of internal friction, and permability of the mixtures after curing for 7, 14 and 28 days were determined. In addition, the leaching characteristics of the stabilized soils were evaluated.

Materials and Basic Properties

Untreated soil, treated soil and natural soil collected from Petroleum Development Oman (PDO) oil prodcution sites in northern Oman (Fahud area) were used in this study. The untreated soil is a soil that contains approximately

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10-15% oil and has not been subjected to any treatment, whereas the treated soil has been subjected to biological treatment at the site. The natural soil is a non-contaminated soil used as a control soil for comparative purposes.

The geotechnical properties of the three soils are presented in Table 1. All basic physical tests were conducted according to the British Standard: BS1377 [4]. The results show that the untreated soil has the lowest specific gravity of 2.05 due to its high oil content as compared with the treated and natural soils which have values of 2.58 and 2.67, respectivly. The grain size distribution showed that the soils were poorly graded sands according to the Unified Soil Classification system. The standard Proctor compaction test results (Table 1) indicate that the treated soil has the highest maximum dry density of 2070 kg/m^3 at an optimum moisture content of 9.7%, whereas the maximum dry density and the optimum moisture content for the natural sand were 1810 kg/m^3 and 18.8 % respectively. The untreated soil has the lowest maximum dry density (1790 kg/m^3) at an optimum water content of 10.8%.

Table 1. Geotechnical properties of the samples

Properties	Untreated Soil	Treated Soil	Natural Soil
Specific gravity	2.05	2.58	2.67
Maximum dry density (kg/m^3)	1790	2070	1810
Optimum moisture content (%)	10.8	9.7	18.80
Unified Soil Classification	SP	SP	SP

SP = poorly graded sand

Compaction Characteristics

The compaction curves for the stabilized soils are presented in Fig. 1 to 3. For the untreated soil, the increase in cement content from 5 to 20% resulted in an increase in maximum dry density (Fig. 1). The maximum dry density (1915 kg/m^3) was achieved at the addition of 20% cement. The treated samples results (Fig. 2) indicate that the control mix (0% cement) of the treated soil has the highest maximum dry density of 2070 kg/m^3 at an optimum water content of 9.7%. The cement stabilized treated samples showed lower maximum dry density values as compared with the control mix. Figure 3 shows the same trend for the natural soil; the highest maximum dry density for the natural soil was obtianed with zero cement content.

Unconfined Compressive Strength

The unconfined compressive strength results of the stabilized soils are given

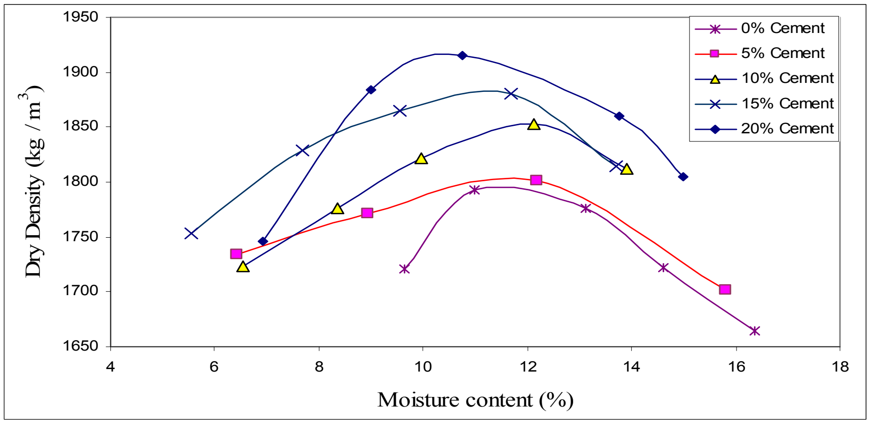

Fig. 1 Compaction characteristics for the stabilized untreated soil.

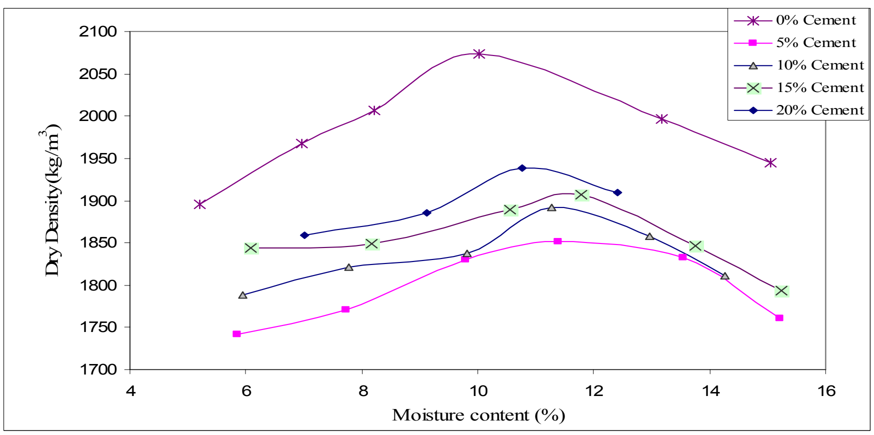

Fig. 2 Compaction characteristics for the stabilized treated soil.

in Table 2. This test was conducted according to ASTM D2166 [5]. Specimens were tested after 7, 14 and 28 days of curing. The results indicated that the unconfined compressive strength increases with the increase in cement content for all these soils, and different curing periods. The highest strength of 4.8122 N/mm^2 was acehived after 28 days for the natural soil stabilized with 20% cement. The relatively high presence of oil in the untreated soil clearly reduces the strength compared with both the treated and natural soil.

Direct Shear Test

Samples were prepared at their optimum moisture content and tested after 7,

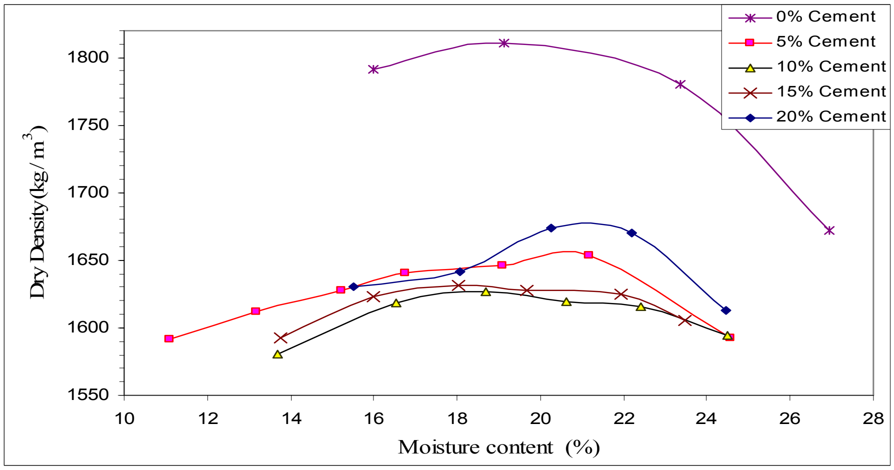

Fig. 3 Compaction characteristics for the stabilized natural soil

Table 2. Unconfined compressive strength of the three soils

Soil Type	Curing Time (days)	Unconfined Compressive Strength (N/mm^2)				
		Amount of cement added (%)				
		0	5	10	15	20
Untreated Soil	7	0.04	0.36	1.10	1.24	1.77
	14	0.04	0.32	1.10	1.64	1.88
	28	0.04	0.80	1.59	1.91	2.04
Treated Soil	7	0.08	0.91	1.88	2.65	2.87
	14	0.09	1.15	2.19	3.04	3.57
	28	0.10	1.42	2.48	3.29	4.22
Natural Soil	7	0.19	0.67	1.19	2.76	2.87
	14	0.16	0.90	1.43	3.68	3.62
	28	0.23	1.47	2.65	4.17	4.81

14 and 28 days of curing. The cohesion and friction angle results are given in Table 3. The untreated soil showed no clear trend but generally cohesion increases with the increase in cement content except for the 20% cement addition. For the treated soil, there was an increase in cohesion and friction angle with the increase in cement content and curing time. In the case of natural soil, the cohesion increases with the increase in cement content and curing time. However, an opposite trend was observed for the friction angle.

Table 3. Direct shear test results of the three soils

Soil Type	Cement, %	Curing time					
		7 days		14 days		28 days	
		c, kN/m^2	Φ, deg.	c, kN/m^2	Φ, deg.	c, kN/m^2	Φ, deg.
Untreated soil	5	64	46.1	55	56.3	74	45.4
	10	87	43.2	94	41.6	76	55.2
	15	212	24.1	158	53.7	[a]	[a]
	20	95	68.7	105	66.6	[a]	[a]
Treated soil	0	15	45.0	15	45.7	15	51.3
	5	128	51.3	147	68.2	[a]	[a]
	10	185	54.0	190	75.3	235	68.2
	15	192	78.5	288	82.3	[a]	[a]
	20	213	80.9	430	64.5	[a]	[a]
Natural soil	0	6	61.9	35	42.4	28	49.0
	5	28	52.4	100	43.9	[a]	[a]
	10	174	40.8	226	38.7	[a]	[a]

[a] Not available

Permeability

The falling head test was used to obtain the permeability of the stabilized treated specimens (Table 4). The specimens were prepared in the compaction mould. Tests were performed after 7, 14 and 28 days of curing. The permeability varied in the order 10^{-3} to 10^{-6} m/day. It has to be noted that at such low permeability values the exponent is more significant. Therefore, the results generally indicate the decrease in permeability with the increase in cement content and curing period.

Leaching

A leaching test was performed on the stabilized soils. The water leached due to gravity through semi-compacted soils was analyzed to determine the heavy metals present and whether the soils were hazardous. Metals were analyzed using Inductivity Coupled Plasma (ICP) spectroscopy. The results indicated that arsenic, barium, cadmium, chromium and lead were present in the leachate but none exceeded the US Environmental Protection Agency (EPA) limits for land disposal of solid waste [6].

Table 4. Permeability of the treated soil

Cement (%)	Permeability k (m/day)		
	7 days	14 days	28 days
0	1.28E-03	1.75E-03	2.06E-03
5	1.63E-04	1.42E-04	9.33E-05
10	2.47E-05	3.12E-06	2.95E-06
15	1.28E-05	5.88E-06	5.53E-06

Conclusions

All the oil-contaminated soils were poorly graded soils. The control soil samples have the highest maximum dry density except for the treated soil. The compressive strength of the stabilized soils increases with the increase in cement content and curing time. Permeability decreases with the increase in cement content. Arsenic, barium, cadmium, chromium and lead were present in the soils but none of them exceeded the EPA limits.

Reference

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