The effects of crude oil contamination on geotechnical properties of Bushehr coastal soils in Iran

MASHALAH KHAMEHCHIYAN[1], AMIR HOSSEIN CHARKHABI[2] & MAJID TAJIK[3]

[1] *Tarbiat Modarres University. (e-mail: khamechm1@modares.ac.ir)*
[2] *Soil and water conservation and research centre.*
[3] *Tarbiat Modarres University.*

Abstract: The southern coasts of Iran adjacent to the Persian golf are encountering oil pollution due to increases in exploitation activities, the loading of and leakage from tankers and marine accidents. This paper describes a study of oil pollution affects on Bushehr province coast.

Determination of the type and distribution pattern of pollution and their relationships to coastal sediment characteristics were the aim of the site investigations. Fourteen hypothetical transects were selected for the design of a regular sampling system. The distance between the transects was at least three kilometre. The transects were orientated perpendicular to the coast line on the tidal limit.

There were a maximum of three sampling points in each transect. Each sampling point consisted of a thirty centimetre diameter borehole from which were taken three samples for chemical analyses.

In the investigation the affect of petroleum pollution on the density, grain size distribution, pH and electrical conductivity was evaluated.

The geotechnical influence of crude oil on coastal sediments was studied by use of a series of soil mechanics tests, such as, grain size distribution, Atterberg limits, compressibility, direct shear test, uniaxial compression strength and permeability.

Three classes of sediment (CL, SM and SP) were selected in the transects. The different parameters measuring for each class of sediment are shown in the diagrams.

Résumé: Les côtes méridionales d'Iran adjacent au golf persan rencontrent de la pollution de pétrole en raison des augmentations dans les activités d'exploitation, le chargement de et la fuite des navire-citernes et des accidents marins. Ce papier décrit une étude de pollution de pétrole affecte sur la côte de province de Bushehr. La détermination du modèle de type et distribution de pollution et leurs relations aux caractéristiques de sédiment côtières était le dessein des investigations de site. Quatorze transects hypothétique a été choisi pour la conception d'un régulier essaie le système. La distance entre le transects était au moins trois kilomètre. Le transects a été orienté la perpendiculaire au littoral sur la limite de marée. Il y avait au maximum trois essaient des points dans chaque transect. Chaque essayer le point a consisté en un trente borehole de diamètre de centimètre de qui a été pris trois échantillons pour chimique analysent. Dans l'investigation l'affecte de pollution de pétrole sur la densité, la distribution de taille de grain, pH et la conductivité électrique a été évalué. L'influence de geotechnical de pétrole brut sur les sédiments côtiers a été étudiée par l'usage d'un feuilleton de tests de mécanique de sol, tels que, la distribution de taille de grain, les limites de Atterberg, la compressibilité, dirigent des cisailles essaient, la force de compression uniaxes et la perméabilité. Trois classes de sédiment (CL, SM et SP) ont été choisi dans le transects. Les paramètres différents mesurant pour chaque classe de sédiment sont montré dans les diagrammes.

Keywords: contaminated land, geotechnical engineering, laboratory tests, soils, properties.

INTRODUCTION

An oil spill in most cases is accidental – during transportation both on land and sea, as leakage from storage tanks, or during the oil drilling process. Also, there are some cases where oil was spilled purposely as in the Gulf War in 1991. When an oil spill or leakage occurs, soils around the sources of leakage are contaminated. Some major tasks need to be performed for remediation and reclamation of the contaminated area.

Several proposals were made by companies for remediation of heavily polluted soils after the oil lakes are drained of liquid crude. These included conversion of oily soil to road base material or a topping layer for car parks and roads after mixing with aggregate or consolidation agent. Other methods include containment in large burial sites, incineration, biological methods, absorption methods, soil washing methods, and vacuum extraction and separation by centrifuge and screen systems. The latter method is attractive in treating the oil sludge remaining in the areas presently covered by standing oil.

The extent of contamination depends on the chemical composition of the contaminant and the properties of the soil (Fine et al., 1997). Also, in connection with the cleanup works, and for any possible applications of contaminated soils, a knowledge of the geotechnical properties and behaviour of contaminated soil is required. This information is also required when oil leakage from storage tanks and processing plants cause oil contamination in the surrounding soils. In this case it is necessary to determine the effect of oil contamination on existing structures. Very few studies that deal with geotechnical properties of contaminated soils are available in the literature (Al-Sanad et al., 1995 &1997; Aiban, 1998; Meegoda and Rotnaweera, 1994).

This paper presents the results of a laboratory testing program carried out to determine of crude oil contamination on geotechnical properties on three soil type (CL, SP, and SM) of Bushehr beaches, south of Iran. These properties include permeability and strength parameters (uniaxial compressive strength and direct shear tests), and compaction characteristics.

SCOPE OF THE PROBLEM

A joint research work between Tarbiat Modares University and Soil Conservation and Watershed Management Research Centre has been done to monitor oil contamination of soils in the beaches of Bushehr Province, south of Iran. This research was performed by sampling from 14 points through beaches and analyzing the samples. The results showed that the oil contamination is very low in this area, in the range of ppb, part per billion (Tajik, 2004). Therefore, it was decided to select some samples for making artificially oil contaminated soils. The sampling was done in a manner that satisfies two criteria: a) different soil type, b) from the area with higher oil contamination. Finally, three soil types from three locations in the area were selected for this research.

BASIC PROPERTIES OF SOIL SAMPLES

Sieve analysis was conducted on the soil samples (ASTM D422-63, D4318-84, and D854-92). They are classified as SM, or silty sand, Sp, or poorly graded sand, and CL, or lean clay, according the Unified Soil Classification System. Table 1 shows the summary of basic properties for soil samples.

Table 1. Summary of basic properties of soil samples.

	Soil Type	SP	SM	CL
Identification	**GS**	*2.42*	*2.57*	*2.71*
	Class	SP	SM	CL
Particle size (% passing)	**4 #**	*99.71*	*99.69*	*100*
	40 #	*79.28*	*86.61*	*99.16*
	75 µ	*0.05*	*32.30*	*78.8*
	2 µ	*0.00*	*3.44*	*20.70*
Atterberg Limit	**LL**	*NONE*	*NONE*	35.30
	PL	*NONE*	*NONE*	17.09
	PI	*NONE*	*NONE*	18.21

SAMPLE PREPARATION

After classification, each soil sample was divided to five parts and dried by oven. Then they were mixed with crude oil in the amount of 0%, 4%, 8%, 12%, and 16% by weight of the dry soil samples. The samples were put in closed containers for one month for aging and allowing for the possible reaction between soil and oil. Therefore, 15 samples were prepared (Table 2). There are some limitations for addition of more crude oil to the soil samples. The peak value in compaction tests on soils with more than 16%oil cannot be reached it will be on the wet side of compaction cure without increasing water. Additionally, the excess crude oil will drain out of sample during tests. Also, sampling from SP and SM soils will be too difficult.

Table 2. The names of artificially oil contaminated soil samples.

Sample Name			
CL	**SP**	**SM**	**Oil Content (%)**
CL0	SP0	SM0	0
CL4	SP4	SM4	4
CL8	SP8	SM8	8
CL12	SP12	SM12	12
CL16	SP16	SM16	16

PROGRAM OF LABORATORY TESTING

At present, design and construction of most geotechnical projects are based on test results following ASTM and AASHTO standards. These standards are based on controlled conditions at room temperature with distilled water as the pore fluid. But, the condition and composition of water is different in the environment due to infiltration of various contaminants. Since field situation and standard control conditions are significantly different, premature or progressive failures frequently occur (Fang, 1997). The analysis of a soil pollution problem depends upon information gained in the field and the laboratory and fed into risk analysis models of one sort or another to determine the need, if any, and the time scales for remedial or corrective actions (Loxham et al., 1997). The main engineering properties of relevance to soil contamination problems can be broken down into principal groups: (a) those dealing with contaminant transport processes, e.g., permeability, porosity, density, soil structure, and water saturation; and (b) those dealing with the strength and compatibility of the soils, i.e., those physical/mechanical properties pertinent to establishment of stability of soil materials used as engineered barriers and those properties involved in the "dig and dump" method of contaminated site remediation (Yong, 2001).

In this research, the testing program included, compaction tests, direct shear tests, uniaxial compressive tests, and permeability tests for understanding the effects of crude oil contamination on geotechnical properties of study soil samples. At first, the compaction tests were done to find a base density for preparation of samples for other tests. The maximum dry densities and optimum moisture contents of CL16, SP16m, and SM16 samples were selected as the base. With this assumption, all of the samples will be on the dry side of compaction curve and the difference between the samples will be the difference in the amount of crude oil contaminant. Also, equation 1 has been used to determine water content of oil contaminated soil samples in all tests:

$$\omega\% = (1+mn)\frac{W_t}{W_d} - (1+n) \qquad (1)$$

Where:

W_t = wet weight of contaminated soil
W_d = dry weight of contaminated soil
m = remained oil content after drying
n = oil content before drying

COMPACTION TESTS

Standard Proctor compaction tests (ASTM-D698, method A) were carried out on the artificially oil contaminated soils samples. The results are plotted in Figures 1 to 3 in the form of dry density versus water content. They generally show a reduction in maximum dry density with increasing oil content. This reduction is faster in SM and CL samples (Figs. 1 and 2). This reflects the lubricating effect caused by the presence of oil, which facilitates compaction and reduces the amount of water needed to reach maximum density (Fig. 4). The reduction of dry density in SP samples is very low, because the pore spaces are larger and oil can move through the soil the same as water and has similar lubricating effect.

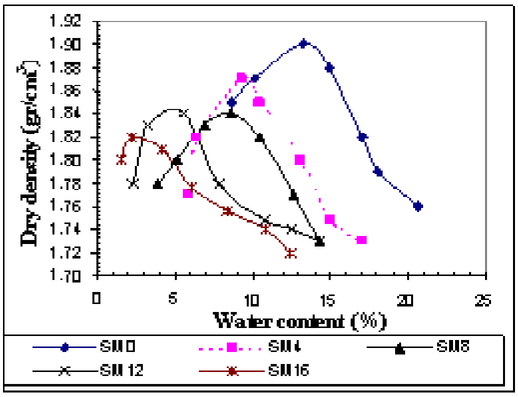

Figure 1. Compaction curves for SM samples.

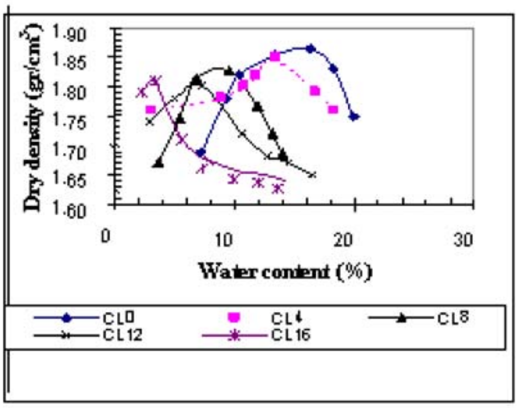

Figure 2. Compaction curves for CL samples.

However, with increase of the oil content the shape of compaction curves changes. This shape is usually bell shaped for clayey soils (ASTM-D-698; Dos, 1994; Lee and Suedkamp, 1972). The shape of compaction curves become odd shape at oil content more than 8 percent (Figs. 1 to 3), which indicates that too much oil is already present to reach effective compaction.

For poorly graded sands (SP) the dry unit weight has a general tendency first to decrease as water content increases, and then to increase to a maximum value with further increase of water content. The initial decrease of dry unit weight with increase of water content can be attributed to the capillary tension effect. At lower water content, the capillary tension in the water inhibits the tendency of the soil particles to move around and be densely compacted (Dos, 1994). In this research, the shape of compaction curves of SP samples are nearly double peak at 0% or low oil content and becomes bell shaped at more oil content (Fig. 3). Capillary tension is extremely dependant on the surface tension of electrolytes and angle of contact. As oil has a hydrophobic property, it prevents the contact of water with soil particles. As the result, the capillary tension force decreases with increasing oil content of soil samples. Therefore, the shape of compaction curves change from double peak to bell shaped in SP samples with increase of oil content up to 8 percent.

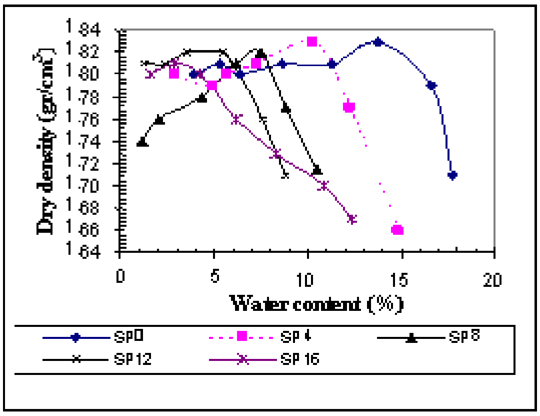

Figure 3. Compaction curves for SP samples.

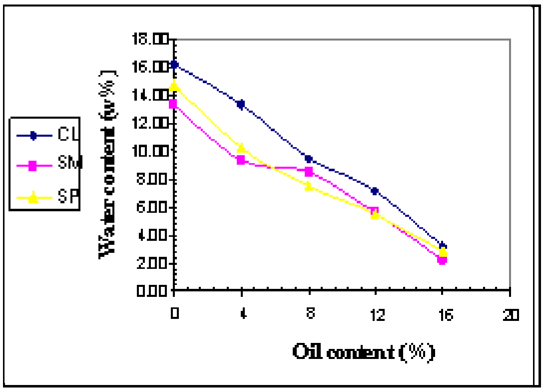

Figure 4. Relationship between compaction parameters and oil content in soil samples.

DIRECT SHEAR TESTS

Direct shear test (ASTM-D3080-72) were carried out to find the effect of oil contamination on strength parameters of soils. The tests were performed in a circular shear box (6cm × 2cm) with a rate of shear equal to 0.5 mm/min at normal loads of 20, 40, and 60 kilograms. The tests were done in dry condition to prevent drainage of oil from the samples.

The present results show direct correlation between oil content and internal friction angle (Φ) in CL soils and inverse correlation between oil content and Φ in SP and SM soils (Fig. 5). There is extreme reduction in cohesion (C) with increasing of oil content in CL, while this correlation does not have any distinct path in SM. SP samples show a low cohesion due to oil contamination that it can be the result of viscosity and inherent cohesion of oil (Fig. 6). It must be noted that wet sands show a little apparent cohesion due to surface tension force of existing water in soil.

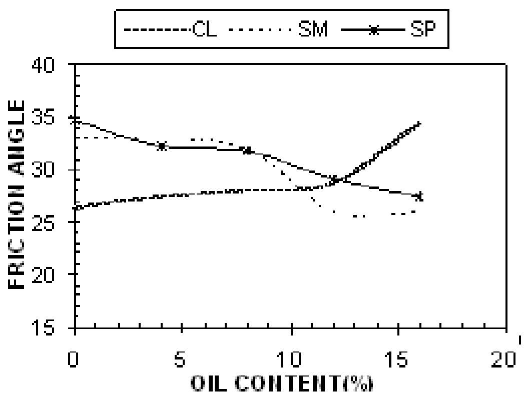

Figure 5. Influence of oil content on shear strength parameters of soil samples.

UNIAXIAL COMPRESSIVE STRENGTH AND PERMEABILITY TESTS

According to the values of q_u measured in the uniaxial compressive strength (ASTM-D2166-85) on CL and SM samples, there is an inverse correlation between q_u and oil content (Figs 6). The only exception is for CL4 that shows a little increase in q_u. Based on relationship of consistency and compression strength of clays (Das, 1994), CL samples change from hard consistency (q_u equal to about 400KN/m^2 for CL0) to soft consistency at oil content of 16 percent.

Constant head permeability tests were carried out on the soil samples. The results show direct correlation between permeability and soil particles size and inverse correlation between permeability and oil content, but the reduction of coefficient of permeability with increase of oil content is not so much even at 16 percent oil content. Also, the changing path is not the same for different soil type. The slope of the CL curve is less that SM and SP curves (Fig. 7). It seems that the effect of oil content on permeability decreases with increase of soil porosity. However, the reduction of permeability is attributed to the reduction of pore volume contributing to hydraulic conductivity due to trapped oil. Since oil occupies some pore space, it is expected that the permeability will decrease with increasing the oil content.

Some researchers considered the effect of permeating fluid properties on the permeability and use especial equations where the permeating fluid is not water (Gillott, 1987; Mitchell, 1993; Sarsby, 2000; Yong, 2001). Hydrocarbons have very low solubility in water and do not change the properties of distilled water at short time of doing permeability tests. Therefore, the usual procedure was used to study the permeability of soil samples in this research.

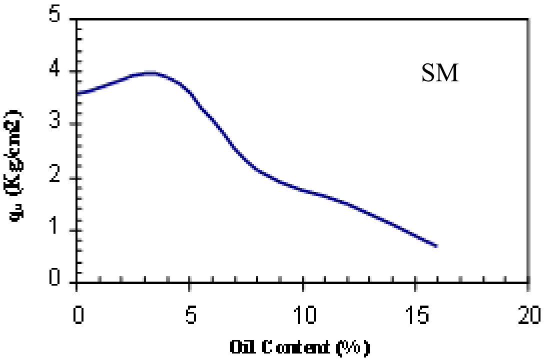

Figure 6. Influence of oil content on uniaxial compressive strength in SM and CL samples.

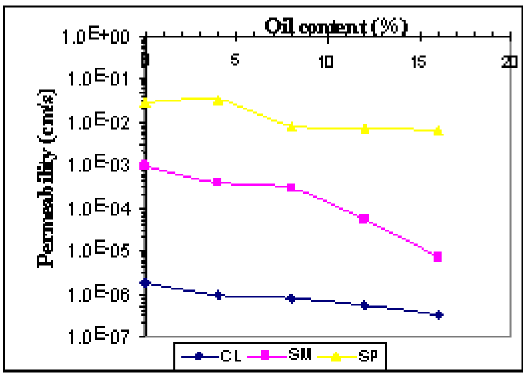

Figure 7. Influence of oil content on permeability coefficient of soil samples.

CONCLUSIONS

An extensive laboratory testing program was carried out to study the effect of crude oil contamination on the properties of three soil type (CL, SM, and SP) from Bushehr beaches in South of Iran. The amount of 0 to 16 percent by weight of dry soil samples selected as oil contamination. The following conclusions can be made based on this research:

Oil has a complex composition and evaporates even under room temperature but some parts of it remain as solid materials, therefore the usual equation can not be used to determine water content of oil contaminated soil. A proposed equation, considering the amount of remained oil after drying, were used to determine water content of oil contaminated soils.

Compactability of all soil samples increases with increasing oil content due to reduction of maximum dry density and optimum water content. The reduction in optimum water content is more, indicating excess oil in the soil, and rate of reduction in maximum dry density is faster for SM and CL samples.

In general, oil contamination induces a reduction in permeability and strength of all soil samples. However, effect of oil contamination on shear strength parameters is not uniform and it depends on the soil type but it leads to decreased peak shear strength in all studied samples.

The long-term effect (aging) of oil contamination on studied soils properties and behaviour should be determined and compared with the results of the present tests.

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