Compressibility of contaminated sand with petroleum oil

Compressibilité du sable contaminé par le pétrole

A.A. Ahmed, M.T. Abdelrahman & G.M. Iskander
Faculty of Engineering, Ain Shams University, Egypt

E.M. Hassan
Co-operation Petroleum Company, Egypt

ABSTRACT
Leakage of oil into the soil may occur due to several reasons. This leakage will result in the formation of soil layer mixed with oil. The mechanical soil properties may be influenced by the leaked oil. To investigate the compressibility parameters for oil contaminated sandy soil, an extensive testing program was carried out in the Geotechnical Engineering Laboratory at Ain Shams University in Egypt. The oil by-products used in the testing program were kerosene, solar, and used oil. Sand samples with different relative densities were mixed with the oil by-products, using 2 % to 15 % oil contents. Consolidation tests were carried out on the prepared oil contaminated sand samples. The results obtained from the testing program are Analyzed and discussed. The effects of oil viscosity, together with its percentage on the sloughing and the modulus of deformation are studied and presented. Finally, the general conclusions of the research are pointed out.

RÉSUMÉ
La fuite de pétrole dans le sol peut se produire due à plusieurs raisons. Cette fuite provoquera la formation d'une couche de sol mélangée avec le pétrole. Les propriétés mécaniques des sols peuvent être influencées par cette fuite. Pour examiner les paramètres de compression du sable contaminé par le pétrole, un vaste programme des essais a été effectué au Laboratoire géotechnique de l'Université Ain Shams en Égypte. Les sous-produits du pétrole utilisés dans le programme d'essais ont été le kérosène, le diesel et l'huile usée. Les échantillons du sable de différentes densités relatives ont été mélangés avec des teneurs en sous-produits du pétrole, qui varient entre 2% et 15%. Les essais de consolidation ont été effectués par la suite sur les échantillons du sable contaminé. Les résultats obtenus par le programme d'essais sont analysés et examinés. Les effets de la viscosité du pétrole, ainsi que son pourcentage sur l'éboulement et le module de déformation ont été étudiés et présentés. Enfin, les conclusions générales de la recherche étaient montrées.

Keywords : contamination, petroleum, oil, sand, viscosity, compressibility

1 INTRODUCTION

Oil spills occur around the world every now and then. For example; oil spills in Kuwait during the Gulf war in 1991 (Al-Sanad et al. 1995), historical oil exploitation in the southern coastal plain of Iran at the Persian Gulf (Khamehchiyan et al. 2007), and polluted sites of Isikwuato, Abia State in Nigeria (Onweremadu & Duruigbo 2007). These oil spills ultimately contaminate the soil.

Oil contamination of soils may occur through a variety of sources such as leakage from ground and underground storage tanks, leakage from damaged pipelines, tanker accidents, discharge from coastal facilities, offshore petroleum production facilities, processing plants, and petrochemical industries. Extraction and refining processes of the crude oil may also contaminate the soil, and it is required to reduce the impact of oil sand tailings disposal (Beier & Sego 2007). Treatment cost of oil contaminated soil is expensive and was found to be in the range 40–100 US$/yd (Benyahia, 2005).

Land contamination with oil affects engineering properties and behavior of the soil. The fuel oil contaminated soil samples of foundation soil from the petrochemical complex near Vadodara City in Gujarat State, India exhibited drastic changes in their geotechnical parameters (Shah et al. 2003). Micro-structural changes of clay soil are caused by pollution with oil (Izdebska-Mucha & Trzciński 2008). Bearing capacity (Shin et al. 1999) and settlements of the structures may be changed. Consequently, it is necessary to determine the effect of oil contamination on the soil.

2 SOIL CONTAMINATED WITH OIL

During the last years, the results of a number of studies related to the physical properties and behavior of oil-contaminated soil have been published. Abdel-Aziz (1986) carried out a series of direct shear tests on sand-oil mixes. Al-Sanad et al. (1995) and Al-Sanad & Ismael (1997) carried out permeability tests, consolidation tests, and direct shear tests on Kuwaiti sands having 60% relative density, contaminated with 6% of heavy crude oil and 6% of light crude oil. Wong (2003) carried out drained triaxial tests on dense oil sand samples. Habib-ur-Rehman et al. (2007) carried out a laboratory testing program on crude oil-contaminated clay. Wong et al. (2008) proposed a mechanistic model to predict consolidation behavior of non-segregating oil sands fine tailings.

The researches in literature pointed out that the mechanical as well as the physical soil properties are influenced by the oil. Among the mechanical properties, the compressibility is a main property that affects the structures founded on the soil. The aim of this research is to investigate experimentally the compressibility parameters for oil contaminated sandy soil.

3 MATERIALS USED

The tested soil in this study is siliceous sand which was brought from the Egyptian deserts. The grading curve was obtained using the standard sieves according to ASTM. The percents of gravel, sand, and fines are 0.05%, 95.30%, and 4.65 %

Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-44

respectively. The index properties are shown in Table 1. Maximum and minimum dry densities of the sand were determine experimentally and found to be 1.95 gm/cm^3 and 1.56 gm/cm^3, respectively, corresponding to minimum and maximum voids ratio of 0.354 and 0.667, respectively.

Table 1. The index properties of the used sand

D_{10}	D_{30}	D_{60}	C_u	C_c	Gs
0.1630	0.3006	0.5775	3.5436	0.9601	2.61

Three types of petroleum products (I, II, and III) which are Kerosene, solar, and used oil respectively are used in the study. The physical properties of the oils are given in Table 2.

Table 2. Physical properties of oils used.

Type of oil	Density (gm/cm^3)		Kinematic viscosity (centistokes)	
	At 25°C	At 30°C	At 25°C	At 30°C
Oil (I)	0.813	0.810	3.00	2.50
Oil (II)	0.842	0.840	6.89	5.73
Oil (III)	0.896	0.893	377.00	261.00

4 EXPERIMENTAL WORK

A laboratory testing program was conducted at Ain Shams University in Egypt, to examine the effect of oil contamination on sand deformation properties.

4.1 *Sand-oil mixture*

For each oil type, the tested samples were prepared by mixing clean sand with four different oil percentages by weight of the dry sand; 2%, 5%, 10% and 15%. This range represents the different cases of contaminated soil with petroleum oil. To achieve the required relative density, the samples were placed and compacted in three layers in the mould using a rubber rod. Sand was tested for three different relative densities (20, 50, and 80%). Thus, for each oil type, 12 samples were prepared.

4.2 *Consolidation tests program*

Consolidation tests were conducted on the contaminated sand samples, in addition to testing the clean sand to be used as a reference for results. Stresses of 0.173 and 0.347 kg/cm² were applied at dry condition. At stress 0.347 kg/cm² the specimens were inundated for 24 hours, then, the stress was increased gradually to 11.114 kg/cm².

5 RESULTS AND DISCUSSION

Figure 1 shows sample of results for sand-oil (II) mixture.

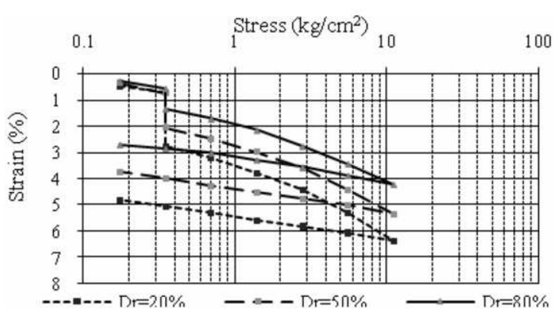

Figure 1. Oedometer results for 10% oil (II) content.

Figures 2 to 5 show the effect oil percentages of the different oils used on the stress-strain relationship of the tested samples.

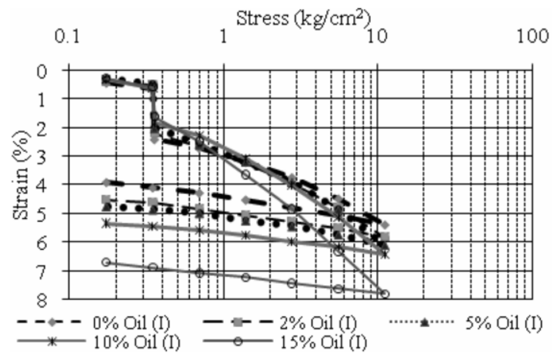

Figure 2. Stress-strain relationships at Dr = 20% for pure sand and sand-oil mixtures with different oil (I) contents.

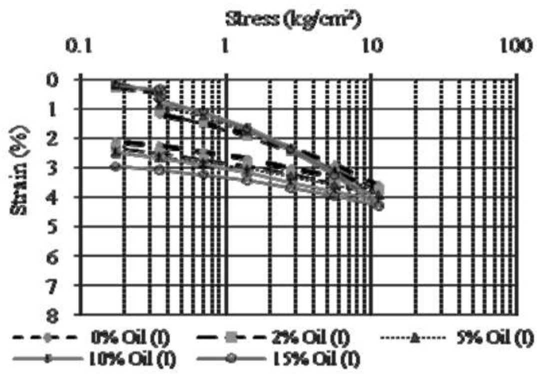

Figure 3. Stress-strain relationships at Dr = 80% for pure sand and sand-oil mixtures with different oil (I) contents.

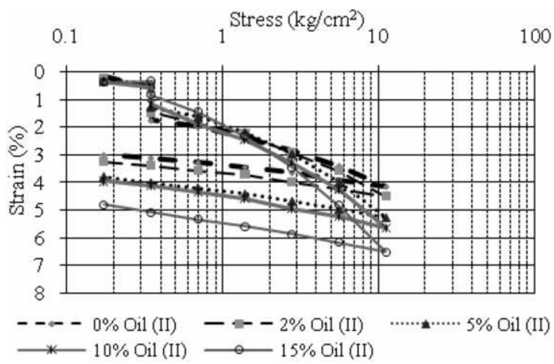

Figure 4. Stress-strain relationships at Dr = 50% for pure sand and sand-oil mixtures with different oil (II) contents.

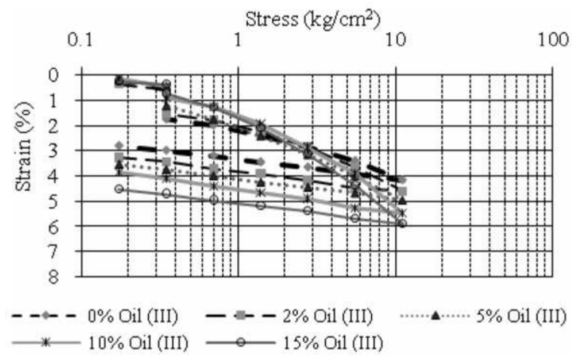

Figure 5. Stress-strain relationships at Dr = 50% for pure sand and sand-oil mixtures with different oil (III) contents.

5.1 *Effect of oil on sloughing*

As shown in the previous figures, after flooding at applied stress of 0.347 kg/cm^2, all samples showed sloughing (sudden collapse settlement). Sloughing is caused under the imposed loads and water flow through the soil due to rearrangement of soil particles. For both pure sand and sand-oil mixtures, sloughing decreases with the increase of sand relative densities as shown in Table 3.

Table 3. Values of sloughing (%) at applied stress = 0.347 kg/cm^2 for different cases.

Type of oil	D_r (%)	Oil percentage (%) 0	2	5	10	15
Oil (I)	20	1.742	1.688	1.528	1.178	1.015
	50	1.183	1.046	0.907	0.701	0.612
	80	0.736	0.651	0.509	0.403	0.359
Oil (II)	20	1.742	1.669	1.463	1.071	0.914
	50	1.183	0.995	0.837	0.605	0.491
	80	0.736	0.612	0.455	0.313	0.233
Oil (III)	20	1.742	1.641	1.398	0.991	0.819
	50	1.183	0.951	0.768	0.451	0.372
	80	0.736	0.551	0.364	0.163	0.112

For small oil percentages, the oil covers the surfaces of sand particles with very thin layers. These thin layers of oil resist percolating water to voids during compressibility leading to a reduction in sloughing with respect to pure sand. As the percentages of the same oil gets higher, the oil starts to fill the voids between particles. The particles will be covered with thick layers of oil which decreases the value of sloughing. The effect of the oil content on the sloughing for oil (II) is illustrated in Fig. 6.

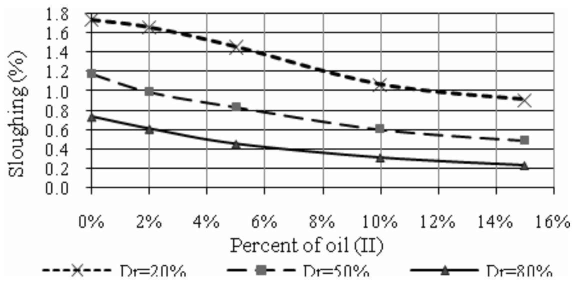

Figure 6. Relation between oil (II) content and sloughing.

By increasing the value of viscosity, pore pressure created during compressibility increases. Therefore, effective pressure between sand particles is reduced which reduces the sloughing. Generally as the oil viscosity increases the sloughing decreases. Figure 7 shows the reduction of the sloughing by increasing the oil viscosity for different relative densities and the different oils used.

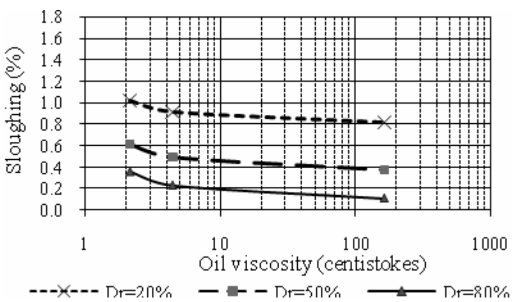

Figure 7. Effect of oil viscosity on sloughing at 15 % oil content.

5.2 *Effect of Oil on Modulus of Elasticity*

Increase of oil content from zero to 15%, for the different oils used causes reduction in the value of soil modulus of elasticity (Es), for different relative densities, as shown in Table 4. These results are compatible with those obtained by (Al-Sanad & Ismael 1997). The explanation is that oil facilitates the sliding of particles due to lubrication of soil particles, and compressibility decreases.

Table 4. Values of modulus of elasticity (kg/cm^2) for different cases

Type of oil	Dr (%)	Oil percentage (%) 0	2	5	10	15
Oil (I)	20	165.30	139.91	127.14	120.04	113.32
	50	206.24	177.58	161.62	152.99	148.46
	80	220.47	202.05	185.00	176.23	171.21
Oil (II)	20	165.30	130.12	116.23	108.22	104.20
	50	206.24	167.79	146.74	138.74	130.79
	80	220.47	191.11	170.23	160.89	154.45
Oil (III)	20	165.30	118.91	107.53	98.87	94.67
	50	206.24	149.65	137.38	127.96	119.44
	80	220.47	167.80	158.13	148.85	138.25

For small percent of oil content (2%), a high reduction occurs in the modulus of elasticity, and for higher percentage of the same oil between 2% up to 15%, a relatively gradual decrease of the modulus of elasticity, as shown in Figures 8 to 10.

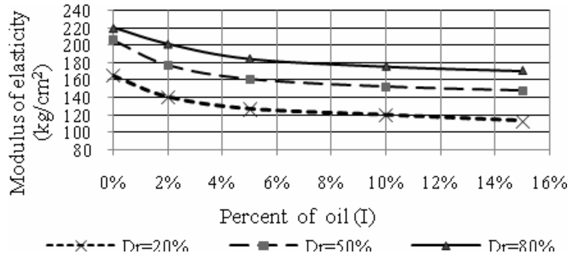

Figure 8. Relation between oil (I) content and modulus of elasticity.

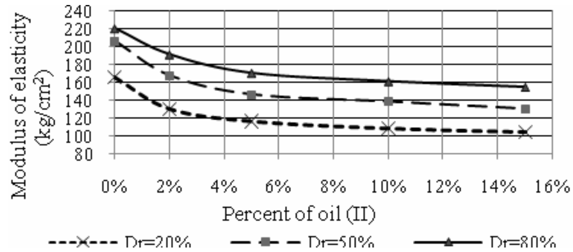

Figure 9. Relation between oil (II) content and modulus of elasticity.

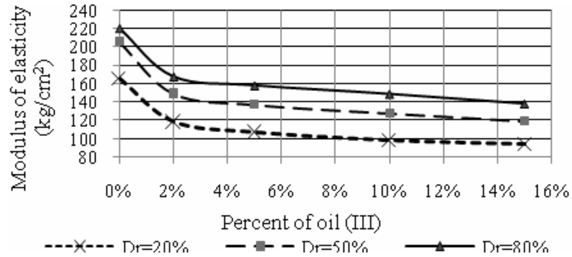

Figure 10. Relation between oil (III) content and modulus of elasticity.

As the viscosity of oil gets higher, oil covers the particles with thicker layer. This facilitates lubrication of particles and thus increases the compressibility. These results are compatible with those obtained by (Al-Sanad et al. 1995). Figures 11 and 12 show the reduction of soil modulus of elasticity by increasing the oil viscosity. This can be explained as follows:

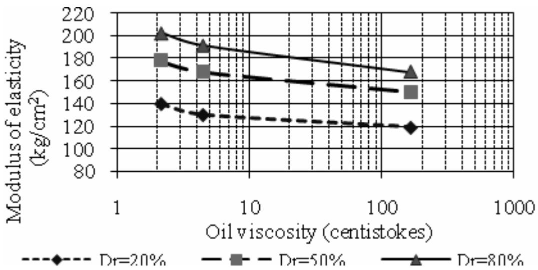

Figure 11. Relation between oil viscosity and E_s at 2% oil content.

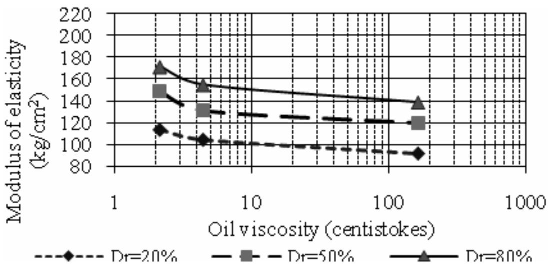

Figure 12. Relation between oil viscosity and E_s at 15% oil content.

Oil (I), which has small viscosity, covers parts of the particles surfaces of the tested sample with very thin layers causing reduction of soil modulus of elasticity ranging from 8% to 15% for 2% oil content, and ranging from 22% to 31% for 15% oil content, for different relative densities, as shown in Fig. 11. Oil (II) which has higher viscosity than Oil (I), reduces the soil modulus of elasticity by21% to 13% for 2% oil content, and by 30% to 37% for 15% oil content, for different relative densities. Oil (III) which has higher viscosity than Oil (II) covers the particles with thick layers causes higher reduction of soil modulus of elasticity ranging from 24% to 28% reduction for 2% oil content and ranging from 37% to 44% for 15% oil content), for different relative densities, as shown in Fig. 12.

6 CONCLUSIONS

An extensive consolidation testing program was carried out, in the Geotechnical Engineering Laboratory at Ain Shams University in Egypt, to study the effect of oil contamination on the compressibility of sand. The used sand was siliceous sand brought from the Egyptian deserts. Sand was tested for three different relative densities; 20, 50 and 80%. The oil by-products used in the testing program were kerosene, solar, and used oil, which have different viscosities. For each oil type, the tested samples were prepared by mixing clean sand with four different oil percentages by weight of the dry sand; 2%, 5%, 10% and 15%. Stresses of 0.173 and 0.347 kg/cm² were applied at dry condition. At stress 0.347 kg/cm² the specimens were inundated for 24 hours then the stress was increased gradually to 11.114 kg/cm².

After flooding at applied stress of 0.347 kg/cm2, all samples showed sloughing (sudden collapse settlement). As the percentages of the same oil gets higher the value of sloughing decreases, and as the oil viscosity increases the sloughing decreases. For pure sand and sand-oil mixtures, sloughing decreases with the increase of sand relative densities.

Increase of oil content, for the different oils used causes reduction in the value of soil modulus of elasticity (Es) for different sand relative densities. For small percent of oil content 2 %, a high reduction occurs in the modulus of elasticity, and for higher percentage at the same oil between 2% up to 15 %, a gradual decrease of the modulus of elasticity. As the viscosity of oil gets higher, oil covers the particles with thicker layer and the compressibility increases. As the oil percentage increases from 2% to 15%, the soil modulus of elasticity is reduced by 8% to 31%, by 21% to 37%, and by 24% to 44%, for cases of contamination with kerosene, solar, and used oil respectively.

ACKNOWLEDGMENT

The authors would like to express their appreciation to the Geotechnical Engineering laboratory at Ain Shams University, for providing support and laboratory facilities for the successful execution of this research.

REFERENCES

Abdel-Aziz, H. 1986. Effect of oil on shear strength of sand, M.Sc., Cairo University, Egypt.

Al-Sanad, H.A., Eid, W.K., and Ismael, N.F. 1995. Geo-technical properties of oil-contaminated Kuwaiti sand, Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. 121, No.5, pp.407-412.

Al-Sanad, H.A., and Ismael, N.F. 1997. Aging effects on oil-contaminated Kuwaiti sand, Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol.123, No.3, pp.290-293.

Beier, N., and Sego, D. 2007. The oil sands tailings research facility. Proceedings of the 60th Canadian Geotechnical Conference and the 8th Joint CGS/IAH-CNC Groundwater Conference, Ottawa, Ontario, Canada, October 21-25, Vol.2, pp.1423-1430.

Benyahia, F., Abdulkarim, M., Zekri, A., Chaalal, O., and Hasanain, H. 2005. Bioremediation of crude oil contaminated soils: a black art or an engineering challenge?, Journal of Process Safety and Environmental Protection, Vol.83, Issue 4, July, pp.364-370.

Habib-ur-Rehman, Abduljauwad, S.N., and Akram, T. 2007. Geotechnical behavior of oil-contaminated fine-grained soils, The Electronic Journal of Geotechnical Engineering, April, <http://www.ejge.com>.

Izdebska-Mucha, D., and Trzciński, J. 2008. Effects of petroleum pollution on clay soil microstructure, Geologija magazine, Geological Survey of Slovenia, Vol.50, pp.S68–S74.

Khamehchiyan, M., Charkhabi, A.H., and Tajik, M. 2007. Effects of crude oil contamination on geotechnical properties of clayey and sandy soils, Engineering Geology Journal Vol.89, pp.220–229.

Onweremadu, E.U., and Duruigbo, C.I. 2007. Assessment of Cd concentration of crude oil polluted arable soils, International Journal of Environmental Science and Technology, Vol.4, No.3, pp.409-412.

Shah, S.J., Shroff, A.V., Patel, J.V., Tiwari, K.C., and Ramakrishnan, D. 2003. Stabilization of fuel oil contaminated soil-a case study, Geotechnical and Geological Engineering Journal, Vol.21, pp.415-427.

Shin, E.C., Lee, J.B., and Das, B.M. 1999. Bearing capacity of a model scale footing on crude oil-contaminated sand, Geotechnical and Geological Engineering Journal, Vol.17, pp.123–132.

Wong, R.C.K. 2003. Strain-induced anisotropy in fabric and hydraulic parameters of oil sand in triaxial compression, Canadian Geotechnical Journal, Vol.40, pp.489-500.

Wong, R.C.K., Mills, B.N., and Liu, Y.B. 2008. Mechanistic model for one-dimensional consolidation behavior of nonsegregating oil sands tailings. Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol.134, No.2, pp.195-202.