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Effect of Oil Contamination on the Liquefaction Behavior of Sandy Soils

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***Abstract*—**Oil leakage from the pipelines and the tanks carrying them, or during oil extraction, could lead to the changes in the characteristics and properties of the soil. In this paper, conducting a series of experimental cyclic triaxial tests, the effects of oil contamination on the liquefaction potential of sandy soils is investigated. The studied specimens are prepared by mixing the Firoozkuh sand with crude oil in 4, 8 and 12 percent by soil dry weight. The results show that the oil contamination up to 8% causes an increase in the soil liquefaction resistance and then with increase in the contamination, the liquefaction resistance decreases.

***Keywords*—**Cyclic triaxial test, Liquefaction resistance, Oil contamination, Sandy soil.

I. Introduction

MASSIVE environmental and ecological problems are caused by oil spills during transportation on the land or during oil drilling processes. These problems also could have different effects on engineering properties of soil such as shear strength, compressibility, hydraulic conductivity, etc. Oil contamination has adverse effects on the engineering properties, including the reduction of bearing capacity of shallow foundations and exposing the structure stability into hazard of Asymmetric settlements, while by several researchers the useful effects of oil pollution on shear strength have been reported.

The major researches on soils contaminated by oil have been focused on studying the geotechnical properties. Hasan et al. (1995) [1] carried out CBR, compaction, permeability, and triaxial tests on clear and oil contaminated, varied up 6%, Kuwaiti sands to determine the influence of oil contamination on the geotechnical properties. The results revealed decreasing insignificant permeability and strength, increasing compressibility, and improving compaction characteristics and CBR values with the presence of oil up to 4% by weight. In order to complete the investigation, Hasan et al. (1997) [2] followed aging effects on the oil-contaminated Kuwaiti sand. The results indicated an increase of strength and stiffness of the contaminated sand specimens for a period of six months. Puri. (2000) [3], In addition to the compaction and shear strength, deal with one dimensional compression, and hydraulic conductivity of soils contaminated by oil. The results showed the angle of friction decreased amount of 20 to 25% and the value of hydraulic conductivity depends on the viscosity of the contaminant oil. Khamehchiyan et al. (2007) [4] carried out the laboratory testing, including Atterberg limits, compaction, direct shear, uniaxial compression and permeability tests, on clayey and sandy soils such as CL, SM and SP sampled from the coastal soils. The contaminated samples were prepared by mixing the soils with crude oil in the amount of 2%, 4%, 8%, 12%, and 16% by dry weight. This research noted to some limitations for addition of more crude oil to the soil samples. The results indicated a decrease in strength, permeability, maximum dry density, optimum water content and Atterberg limits. The uncontaminated and crude oil-contaminated clay were compared by Habib-ur-Rehman et al. (2007) [5]. Habib-ur-Rehman et al. (2007) [5] performed laboratory tests including all basic and advanced geotechnical tests such as the scanning electron microscopy (SEM) technique cation exchange capacity (CEC), pH, and organic carbon tests, Standard Proctor compaction test, unconsolidated Untrained Triaxial compression tests, and one dimensional consolidation test for the study of respectively the physico-chemical nature of the soil, the compaction characteristics, strength evaluation of soil, and compressibility analysis. In shear strength results section of this investigation was expressed at low confining pressures, the strength of the contaminated soil was less than that of the uncontaminated specimen, while at high confining pressures; the strength was a little more than that of the uncontaminated specimen. These results showed the contamination has affected the plasticity as the contaminated clay behaves more like a cohesionless material.

On the other hand, the earthquake is very likely on oil fields. The earthquakes occurred in Kettleman North Coalinga and Dome Oil Field in California in 1983 and 1985, respectively as well as recently Bushehr in Iran (2014), for example, can be mentioned. In the oil fields near Coalinga, surface facilities such as pumping units, storage tanks, pipelines, and support buildings were all damaged to some degree. Therefore, the investigation of effects of dynamic loading on bearing capacity of surface facility foundations, stability of borehole walls, and etc., would be necessary; although, in this case, no research has been done up to now.

So, due to the lack of the Studies focused on investigating the effects of an earthquake in the oil regions, this paper studies potential of one of the most important cases in an earthquake, e.g. Liquefaction, of sand contaminated with crude oil. For this purpose, performed Dynamic triaxial tests on contaminated samples, were prepared by mixing the soils with crude oil in the amount of 0%, 4%, 8%, and 12% by dry weight.

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II. Materials Tested

A. Soil Tested

Firoozkooh sand (#161), uniformly graded sand (SP) with a mean grain size of 0.25mm, has been used for all tests presented in this research. The soil properties and the grain size distribution curves for the soil, used for this study, are shown in Table I and Fig. 1, respectively. The maximum and minimum void ratios for the entire range of fines were determined according to ASTM D4254 and ASTM D4253.

TABLE I
Soil Properties for Sandy Soil Used in This Study

Type of Material	e_{min}	e_{max}	e_{global}
Sand	0.58	0.87	0.83

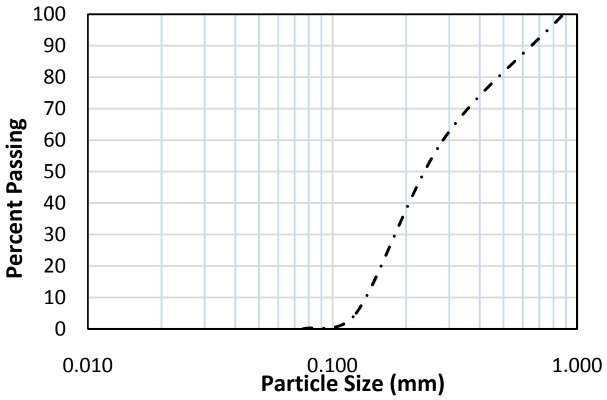


Fig. 1 Grain size distribution for sandy soil used in this study

B. Crude Oil Tested

Used crude oil, taken from Tehran refinery is chosen as the contaminant for the study. Crude oil properties are given in Table II.

TABLE II
Crude Oil Properties

CRUDE TO REFINERY	0.8592		SP.GR.@15.6^{0}C
	0.1/.04		W.&S. Vol.%
	51		R.V.P.K.pa
	6		SALT Lb./1000B.bl.
CRUDE TO UNIT	TIME		SP.GR.@15.6^{0}C
	M A N	H.V.S.	0.858

III. Experimental Procedure

A. Sample Preparation

Since the current research is not intended to exactly mirror field conditions, it is main aim to identify the changes in liquefaction resistance which occurs as the fines content and crude oil percent of a sand increases. So, the specimens used in this experimental program were reconstructed by the moist tamping in multiple layers. This method, although does not mimic the deposition processes of natural deposits, eliminates the problems of particle segregation associated with water or air pluviation method, this factor is ideal for parametric study [6]. In order to ensure that the specimens have a uniform density throughout the specimen, the specimens were produced using the under compaction technique [7], [8] According to Chan's method, to obtain the specimens with consistent density throughout the specimen, considered a constant difference in relative density of one percent between each lift, with the lifts below the middle lift placed at lower relative densities than the average, the middle lift placed at the average relative density desired, and the lifts above the middle lift placed at higher relative densities than the average. Since the overall relative density of 30 percent is selected, the five layers would be placed from bottom to top at relative densities of 28, 29, 30, 31, and 32 percent, respectively.

In the field condition, the soil is contaminated with crude oil when the ground water level is low; so at first the crude oil in the amount of 4, 8 and 12%, and then the water in the amount of 5% were added (by the dry weight of the soil). According Khamehchiyan et al. (2007) [4] work, there are some limitations for addition of more crude oil to the soil specimens; because, at the saturation stage, the excess crude oil will drain out of the samples during passing the water.

The specimens had a diameter and height of 70 and 140mm, respectively.

B. Testing Procedure

The dynamic triaxial apparatus of Wykeham Farrance International is used in this work for performing the tests. After the specimen has been formed, the specimen cap is placed and sealed with O-rings, and a partial vacuum of 35 KPa [9] is applied to the specimen to reduce the disturbances. The specimen was permeated with CO_2, flushed with de-aired water and saturated under a back-pressure of 200 KPa. All specimens had a minimum pore pressure parameter B of 0.95. All the specimens were isotropically consolidated under the effective confining pressures (σ_u) of 100 KPa then subjected to undrained dynamic triaxial loading at a frequency of 1 Hz following the ASTM D5311 specification [9]. The intensity of the cyclic loading was varied in such a way to produce a wide range of cyclic stress ratios (CSR=τ_c/σ'_3) and corresponding number of cycles, N_l, required to initiate liquefaction. It should be noted that initial liquefaction was assumed to occur when the excess pore water pressure became equal to the initial consolidation stress (σ'_3) of the specimen, i.e. the pore pressure ratio (R_u) of 1, and/or double amplitude of 2.5% axial strain was achieved.

IV. Results and Discussion

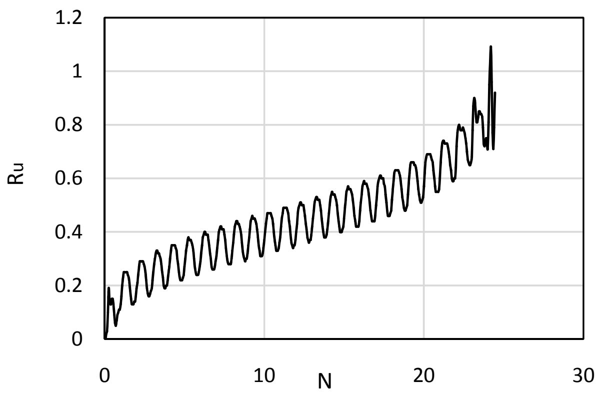
In this investigation, a total of 60 isotropically consolidated undrained cyclic triaxial tests were performed at varying percent of crude oil. For each specimen, with determined percent of crude oil, three tests were carried out. The characteristics of test mixtures, and the test conditions as well as the test results for all the tests conducted in this work are summarized in Table III.

TABLE III
SUMMARY OF THE TEST RESULTS

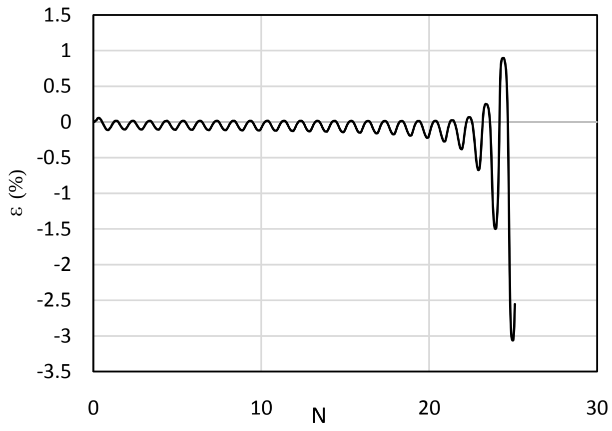
No	Oil (%)	q (N)	CSR	N
1	0	115	0.15	24
2	0	130	0.17	3
3	0	100	0.13	191
4	4	130	0.17	4
5	4	123	0.16	9
6	4	100	0.13	239
7	8	100	0.13	245
8	8	123	0.16	12
9	8	130	0.17	5
10	12	100	0.13	133
11	12	130	0.17	1
12	12	115	0.15	25

A. Typical Results

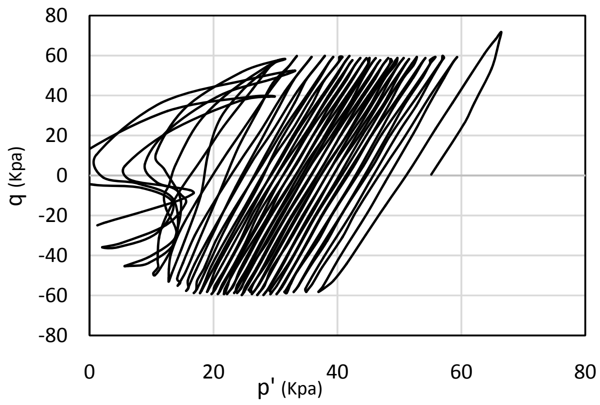
Typical results obtained from a cyclic triaxial test conducted on a clean sand specimen, are shown in Fig. 2. As illustrated in Fig. 2 (a), cyclic stress ratio (CSR) of 0.1 was applied to the sample and after 34 number of cycles excess pore pressure is equaled to effective stress (R_u=1). It should be noted, the amount of the double amplitude strain exceeds 5%, after the 34thcycle as shown in Fig. 2 (b). The hysteresis loops of the test (Fig. 2 (c)) shows that the secant shear modulus decreases with increase in the number of loading cycles. This cyclic degradation occurs due to an increase in pore water pressure and finally causes the loops to become flat after the occurrence of liquefaction. It can be inferred from these plots that the specimen loses its strength quickly after initiation of liquefaction and undergo excessive deformations. The corresponding diagrams of the effective stress path of the particular test are shown in Fig. 2 (d). This figure expresses a movement of the stress path from right to left due to decrease in effective confining pressure with the development of pore water pressure.



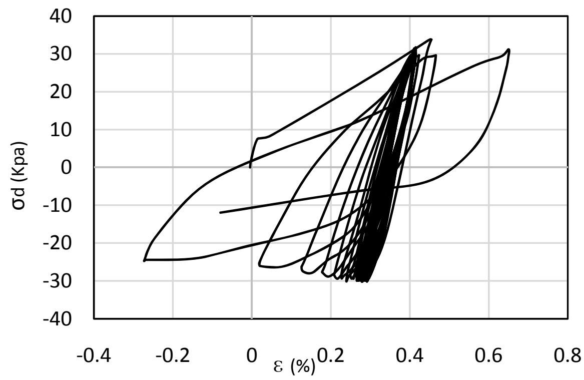
(a)



(b)



(c)



(d)

Fig. 2 Typical results for sandy specimen with 0% oil

By combining the results of all tests it became possible to plot the liquefaction Resistance diagram (CSR-N curves), presented in Fig. 3.

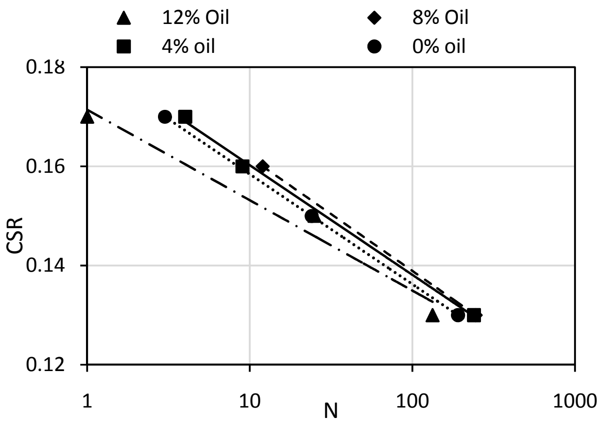


Fig. 3 Variation of CSR with respect to the Number of cycles

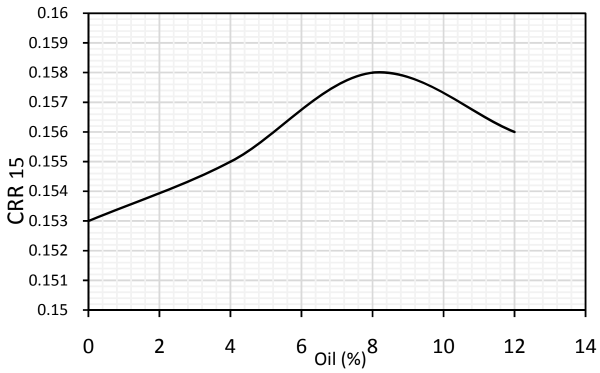


Fig. 4 Effect of oil content on the liquefaction resistant of sandy soil

In liquefaction analyses, usually a reference earthquake of magnitude equal to 7.5, causing the liquefaction at 15 cycles is used (e.g.[1], [2]). For this reason, the Cyclic resistant ratio (CRR15) will be primarily used below as index of the cyclic soil strength. This factor was estimated from regression of the logarithm of CSR and the logarithm of N. The values of CRR15 are also summarized in Table III for all states and mixtures obtained from the liquefaction curves of Fig. 3.

B. Discussion

Fig. 4 represents the influence of oil-contamination on the liquefaction resistant of specimens. According to the results, with increase in the oil content up to 8%, the soil liquefaction strength is increased and then, with more increase in the contamination, the inverse trend could be observed. This behavior could be interpreted on the basis of the variation of the oil-contaminated soil strength parameters. Almost all of past investigations, reveal that the oil contamination, reduces the soil internal fiction angle [1], [4], [10]; whereas, the cohesive performance of these soils is different from their frictional behavior. As the experimental tests results of the [4], [11] illustrate that the oil-contaminated sandy soil shows the cohesive strength. These changes in the strength parameters of the sandy soils are due to the inherent viscosity and cohesion of the oil. More exactly, with oil addition into the soil, the pore fluid viscosity, affected by the oil viscosity, increases and accordingly the lubrication will be increased. The considerable note is the similarity of the variation trends of cohesion in [4] study, and liquefaction resistant, in this work. As for the both investigations, with increase in the oil content up to 8%, the increasing trend (for cohesion and CRR) can be seen and then, passing over the 8%, the trend is inverted.

V. Conclusion

In this work, simulating the oil contamination of sandy soils through excremental tests, its liquefaction potential has been studied. A series of triaxial cyclic tests has been performed for different oil concentrations (0, 4, 8 and 12 percent of the soil dry weight). The results show, the present of crude oil up to 8%, cause to reduce in the liquefaction potential. Lubrication, developed due to increase in the pore fluid viscosity, lead to increase in the cohesion and ultimately in the liquefaction resistance, whereas the soil frictional angle is decreased. Adding oil contamination more than 8% causes to increase in liquefaction potential. The reason may refer to significant reduction of the soil frictional angle, against to the cohesion increase. However, as the soil frictional angle and cohesion are altered simultaneously, carrying out the microscopic investigations as well as the static tests, are advised to obtain more accurate interpretation.

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