Fifth International Conference on Construction in the 21st Century (CITC-V)
"Collaboration and Integration in Engineering, Management and Technology"
May 20-22, 2009, Istanbul, Turkey

Effect of Kinematic Viscosity of Hydrocarbon Contaminants on Shear Strength and Compressibility of a Well Graded Sandy Soil

Salah A. Taqieddin
Department of Civil, Architectural and Environmental Engineering, Missouri University of Science and Technology,Rolla, Missouri, USA
salahta@mst.edu

Abstract
This study investigates the effect of contaminating, a well graded sandy soil, with lamp oil, on some selected geotechnical properties of this soil. In a previous study, the effect of contaminating the same type of soil, with diesel oil, on the same geotechnical properties was studied. These two studies are part of an ongoing research that aims at studying the effect of contamination of different hydrocarbons on the geotechnical properties of this soil.

The effect of kinematics' viscosity of the studied contaminants was made through comparing the behavior of shear strength and compressibility before and after contamination. The results indicate that the decrease in kinematics' viscosity, as exemplified by lamp oil, has resulted in decrease of both shear strength and compressibility of the contaminated soil. However, this decrease was less pronounced in the case of diesel oil. More than three hundred direct shear tests, ninety five one-dimensional compression tests, and one hundred proctor compaction tests were run. Five levels of relative densities were utilized; eight percentages of mixing proportion of each contaminant at variable levels of degree of saturation were adopted. Other parameters such as the hydraulic conductivity and behavior under cyclic loading are recommended for further studies.

Keywords
Contamination, Shear strength, Compressibility, Diesel-oil, Lamp-oil

1. Methodology

In this ongoing study, soil collected from nearby little Piney River sand were screened to #5, 10, 20, 40, 50, 70, 100, 200, and -200 sieve and a well graded soil with a pre-designed weight percentages of these sizes were mixed to prepare a manufactured soil identical to that used in the first part of this study. This was necessary in order to eliminate any variation in soil composition within the course of testing in this study and to make the comparison with results obtained in the first study possible.

The same procedures followed in the first study were adopted in this study. Soil samples were divided into two identical groups: the first group represented the 0% contaminated soils, while samples of the second group were mixed with variable percentages (by dry weight basis) of lamp oil. The lamp oil with fixed measured properties such as the viscosity, specific gravity, flash point and water content was used as contaminant at 2%, 3%, 4%, 5%, 6%, 7% and 8% in dry weight basis in a manner similar to that followed in the previous study when diesel oil was used as contaminant. Samples were left to cure for seven days before being subjected to the targeted tests.

2. Laboratory Studies

The same manufactured well graded sandy soil (SW- SM) that was used in the previous study was also used in this study. Lamp oil used in this study had lower kinematic viscosity and lower specific gravity than the diesel oil used as contaminant in the previous study. Table 1 presents the physical properties of the previous work as mentioned in the methodology and lamp oil used in this study.

Table 1: Physical Properties of Diesel Oil and Lamp Oil Used as Contaminants in this Study.

Item	***Diesel Oil***	***Lamp Oil***
Specific Gravity	0.836	0.786
Flash point	58 C	90 C
Kinematic Viscosity (C. Poise)	3.8	1.62
Heating Value (MJ/Kg)	43.9	42.1

The following laboratory tests were conducted in this study in parallel to those conducted in the previous study:

2.1 Compaction Test

The Standard Proctor Compaction Test (ASTM –D-698) was conducted on raw as well as on lamp contaminated samples following the same procedures that were adopted in the previous study. Half of the samples were tested using water as pore fluid and the other half were mixed with specified percentages of lamp oil and were left to attain equilibrium seven days prior to compaction. The mixing proportions were 2%, 3%, 4%, 5%, 6%, 7%, and 8%. The results of compaction test were expressed in terms of optimum moisture content expressed in percentage, versus maximum dry density expressed in kilopascals. Table 2 presents the results of the compaction test of this study using lamp oil as contaminant along with the results of compaction test using diesel oil as contaminant used in the previous study. Note that the Optimum Moisture Content is the maximum percentage of distilled water added to the contaminated sample to bring the dry unit weight to the maximum value.

Table 2: Results of Compaction Test Using Diesel Oil or Lamp Oil as Contaminants.

Mixing Proportion by weigh	Diesel Oil		Lamp Oil	
	Optimum Moisture Content	Maximum Dry Density	Optimum Moisture Content	Maximum Dry Density
0%	10.88	17.91	10.76	17.85
2%	10.27	18.03	10.02	17.88
0%	10.76	17.73	10.70	15.69
3%	11.42	17.80	10.82	17.30
0%	10.32	18.01	10.45	18.00
4%	10.88	18.03	10.65	18.20
0%	10.75	17.69	10.77	17.92
5%	10.87	18.04	10.82	17.99
0%	10.34	17.05	10.42	17.50
6%	10.49	18.12	10.44	18.02
0%	11.40	17.69	10.98	17.52
7%	12.49	17.91	12.11	17.84
0%	12.23	17.72	11.99	17.77
8%	10.28	18.15	12.01	18.03

2.2 Direct Shear Test

Direct shear tests (ASTM–D-3080-98) were conducted to examine the effect of both the relative density and the degree of saturation on the angle of internal friction (Φ) of lamp oil parallel to the previous tests conducted on the same soil that was contaminated with diesel oil.

Test procedures similar to those followed in previous study were adopted. However, in the first study limited number of tests, using diesel oil as contaminant, was conducted, therefore to insure the consistency of procedure shear tests with samples contaminated with diesel oil were tested under the same environment.

The shear strength tests were conducted on dry specimens of oven dry soils and also on specimens having diesel oil or lamp oil content of 2%, 3%, 4%, 5%, 6%, 7%, and 8% respectively. Five levels of relative density which represent the various consistency levels ranging from loose to very dense case were adopted for this test. These levels were 35%, 45%, 60%, 75%, and 90% respectively. Also three levels of normal stress magnitudes were applied namely 55kPa, 85kPa, and 110kPa, respectively. All tests were conducted under undrained conditions and at constant horizontal shear displacement of 1.00 mm/minute. Table 3 presents a comparison of the degree of saturation of both diesel oil and lamp oil contaminated samples at different levels of relative density and percentages of oil content.

Table 3: Values of Degree of Saturation of Diesel Oil and Lamp Oil at Different Levels of Oil Contents and Relative Density.

Contaminant	Contaminant Oil Content (%)									
	Property		0	2	3	4	5	6	7	8
Diesel Oil	Relative Density (%)	35	0	10.60	15.97	21.3	26.62	31.95	37.27	42.60
		45	0	11.20	16.79	22.93	27.99	33.60	39.19	44.79
		60	0	12.13	18.20	24.26	30.33	36.39	42.46	48.53
		75	0	13.24	19.86	26.48	33.10	39.72	46.34	52.96
		90	0	14.57	21.85	29.14	36.42	43.70	50.99	58.27
Lamp Oil	Relative Density (%)	35	0	11.32	16.99	22.65	28.32	33.98	39.64	45.30
		45	0	11.90	17.86	23.82	29.98	35.73	41.68	47.63
		60	0	12.90	19.35	25.81	32.26	38.71	45.16	51.62
		75	0	14.08	21.12	28.16	35.20	42.24	49.28	56.32
		90	0	15.49	23.24	30.99	38.74	46.48	54.23	61.97

2.3 One Dimensional Compression Test

The one directional test was performed to determine the effect of diesel and lamp oil contamination on the strength and deformation properties of soil. This test was conducted in a hollow cylindrical steel mold (similar to the one used in compaction test) having internal diameter of (104) mm and a height of (190) mm, with a steel plate below the base. The test samples were prepared in batches, at variable degrees of diesel oil saturation and five relative densities. A loading plate of (100) mm was placed in (Master Loader HM- 3000 Humboldt Machine) and was loaded from the top using constant rate of axial strain of (25mm/sec). The applied Load and the corresponding deformation of the sand specimen were measured. The tests were conducted under drained conditions only.

2.4 Hydraulic Conductivity Tests

A direct method for measuring the raw and the contaminated soils were conducted to compare the effect of contamination of this well graded soil on the hydraulic conductivity. A compaction permeameter type K-610 manufactured by (ELE) was used in this study. In this permeameter, five levels of relative densities were designed with raw as well as with eight levels of contamination. However, this test is relatively slow and results obtained are limited and require further time to accomplish conclusive results.

3. Test Results and Analysis

In this study, a total of 1600 kilogram of manufactured soil was used to prepare raw (non-contaminated) soil samples as well as contaminated samples with two types of contaminants namely diesel oil which was never tested as contaminant in assessing its effect as contaminant on the geotechnical properties of well-graded sandy soil and lamp oil with a different kinematic viscosity to compare its effect as contaminant with diesel oil.

About 300 direct shear tests were conducted in both contaminated and non-contaminated samples and more than 95 samples were tested in the one dimensional compaction test and a similar number of samples were tested in the normal proctor tests. Most of the data acquired in this study were obtained via a data acquisition system that helps analyze and plot relationship between variables.

3.1 Compaction Test

The results of the compaction tests conducted on samples contaminated with either the diesel oil or lamp oil are plotted in the form of the degree of saturation versus the dry unit weight as exemplified in figure 1. From this figure, it can be seen that the maximum dry unit weight for both contaminants was achieved when the degree of saturation was above 60%. However, the maximum dry unit weight was higher in the case of diesel oil than in lamp oil, and the maximum dry unit weight was higher in case of lamp oil than that when water was used to fill the pores. This is probably due to the fact that the oils used were more effective in reducing the friction between the sand grains thus helping them to be closely packed resulting in higher dry unit weight.

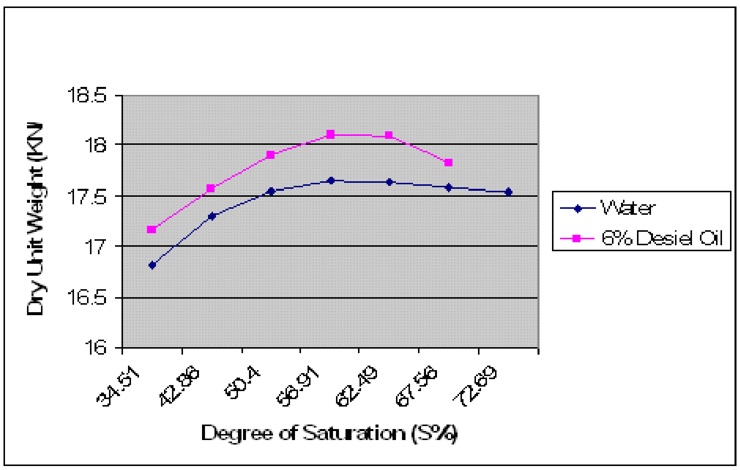

Figure 1: Variation of Dry Unit Weight with the Degree of Saturation of Diesel Oil

3.2 Shear Strength

The data from the direct shear tests were used to obtain shear stress versus horizontal displacement plots for the specimens of raw sand, diesel oil, and lamp oil contaminated samples. Figures 2 and 3 show typical plots of the direct shear test on samples contaminated with diesel oil and lamp oil at the same normal stress (i.e. 50 kPa) and initial relative density of 75%, respectively. These curves were filtered to obtain the smoothness needed to locate the peak shear strength and/or the residual strength if needed.

It can be seen from these figures that the peak shear stress for dry sand drops as the degree of saturation increases for both contaminants. Also, from the same figures it can be seen that the magnitude of the horizontal displacement needed to mobilize peak shear stress increase largely with the increase of the degree of saturation in both contaminants. For example, the peak shear stress for the case of dry sand is mobilized at horizontal displacement of 2.0 mm. However, it is observed that the amount of the horizontal displacement for mobilizing shear stress is in the order of 3.0 mm when the degree of saturation of diesel oil was 14.0% in the case of diesel oil and 2.8 mm in the case of lamp oil contamination. In general, the order for mobilizing peak shear stress in diesel oil, or lamp oil was in the order of 3 to 5 times the value obtained for dry sand.

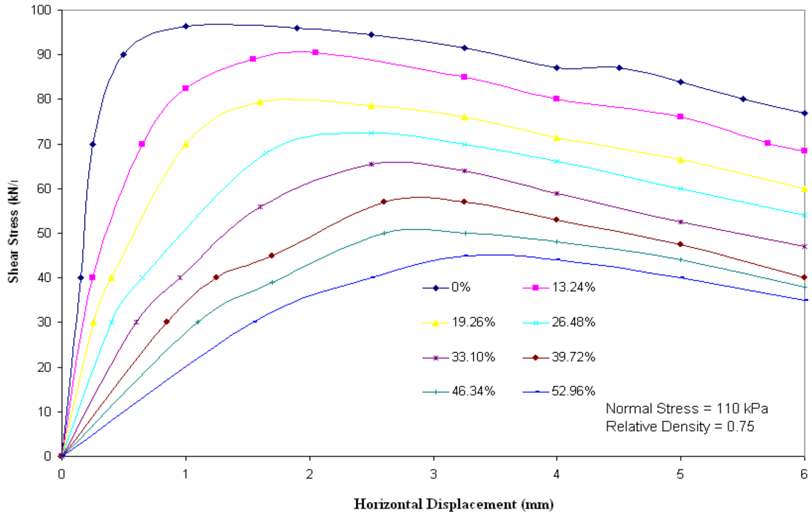

Figure 2: Shear Stress vs. Horizontal Displacement of Diesel Oil Contaminated Samples for Different Degrees of Saturation under a Constant Normal Stress and Relative Density

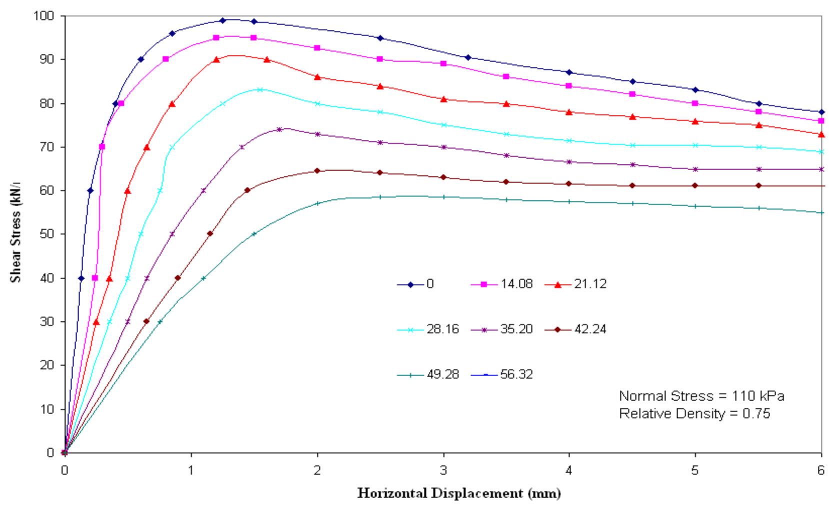

Figure 3: Shear Stress vs. Horizontal Displacement of Lamp Oil Contaminated Samples for Different Degrees of Saturation under a Constant Normal Stress and Relative Density

The angle of internal friction based on total stress also decreases due to the presence of either diesel oil or lamp oil in the pore spaces. The variation of the angle of internal friction Φ with the degree of saturation for diesel oil and lamp oil are shown in Figure 4 and Figure 5, respectively. For tests at relative density $D\gamma$= 90%, the angle of internal friction was 49 degrees for dry sand and its value decreased to about 37 degrees when the degree of saturation increased to about 35%. For tests at relative density of 60%, the angle of internal friction decreased from 45 degrees for dry sand to about 37 degrees as the degree of saturation increased to about 20%. The decrease in angle of friction is observed to be a function of the initial relative density of soil and the degree of oil content. In both studies the percentage of decrease of values of angle of friction ranged between 22 to 29% as compared to its value at the same relative density in dry sand.

3.3 One Dimensional Compression Test

Typical results from one dimensional compression tests for specimen at initial relative density of 65% for dry sand as well as for diesel oil and lamp oil contaminated samples are shown in Figures 6 and Figure 7, respectively. The presence of oil contaminants in the soil mass, in general, had an adverse effect on one dimensional compression characteristics of sand. It is possible to construct a graphical relation of the constrained modulus E and the degree of saturation from either one of Figures 6 or Figure 7. However, it is very clear that as the degree of saturation, for the same strain level, the constrained modulus decreases in both cases.

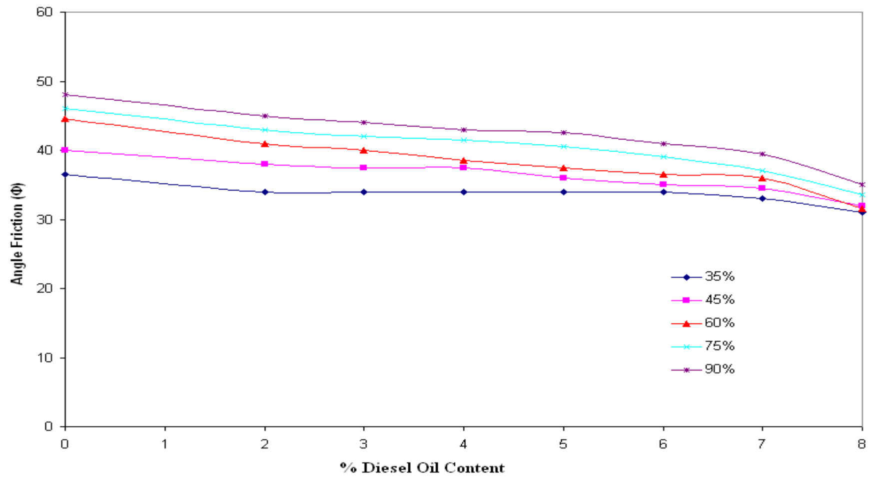

Figure 4: Variations of Angle of Friction vs. Percent Diesel Oil Content

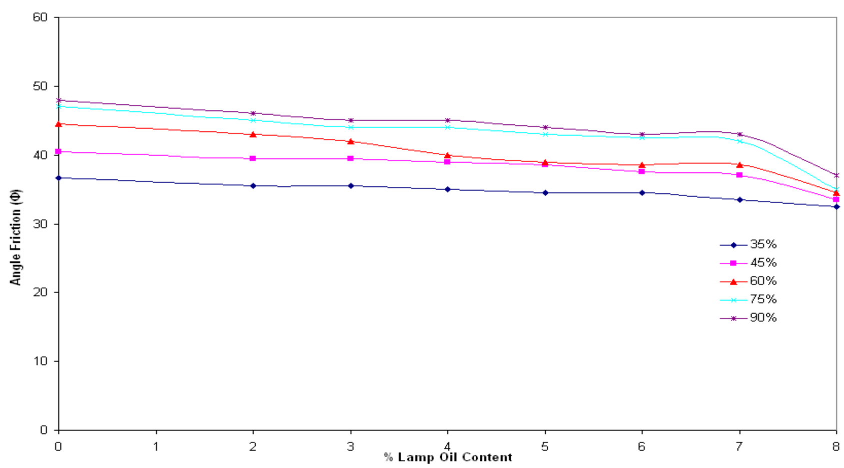

Figure 5: Variations of Angle of Friction vs. Percent Diesel Oil Content

3.4 Other Tests

Results obtained from permeability tests indicated that the magnitude of the coefficient of hydraulic conductivity of all samples contaminated by diesel oil or lamp oil has decreased significantly for all the levels of oil contents. However, the magnitudes of these coefficients are so small that a general conclusion in this regard needs to be more thoroughly analyzed.

Tests to measure the behavior of the contaminated soils under cyclic loading were designed to explore the possibility of utilizing such contaminated soils for pavement or for other engineering uses. These ongoing tests will, hopefully, solve the environmental problems resulting from this contamination.

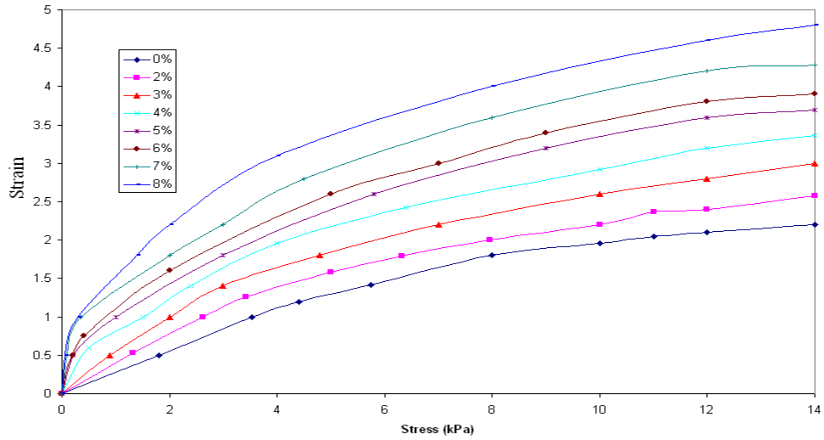

Figure 6: Axial Stress vs. Strain in One Dimensional Compression Test on Diesel Oil Contaminated Samples

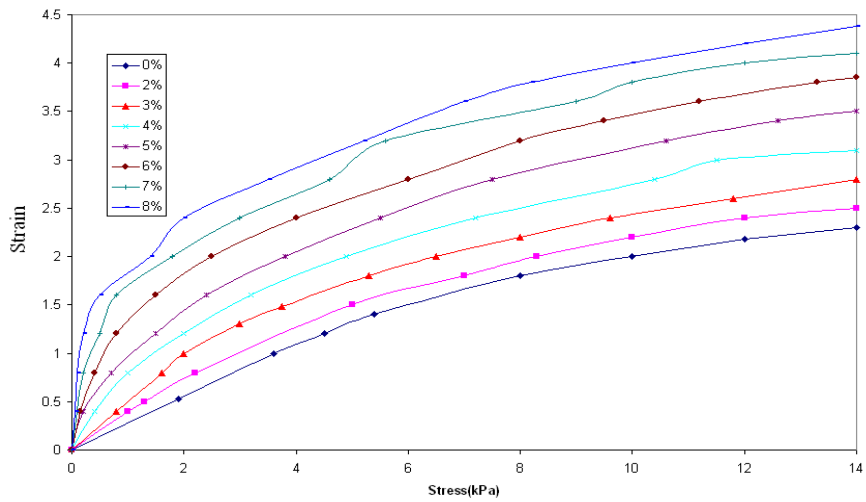

Figure 7: Axial Stress vs. Strain in One Dimensional Compression Test on Lamp Oil Contaminated Samples

4. Conclusions

Based on the results obtained in the study, the following conclusions are reached:

1) Shear strength parameters of the tested samples were adversely affected by diesel oil and lamp oil contamination. A considerable reduction in the value of the internal angle of friction was observed with both contaminants.
2) Maximum dry unit weight under fixed compactive energy was higher when both diesel oil and lamp oil were used for compaction as compared to water as pore fluid.
3) An increase in compressibility in one dimensional compression test was observed in both contaminants specifically in the range of 4% - 6% of contaminant content. This conclusion could be very important in predicting the settlement under a structure overlying formations that are prone to contamination by any of these contaminants.
4) For a given relative density of soil compaction the friction angle decreased with the increase in contaminant content.
5) For given oil content and relative density of compaction the decrease in shear strength is related to the increase in the kinematic viscosity of the contaminant.
6) Compressibility of this type of soil changes with type and amount of the contaminant fluid.

7) Compaction characteristics of the tested soil improve with presence of contaminant oil up to an optimum value based on type and percentage by weight of the contaminant. If this value is exceeded, the maximum dry density decreases sharply indicating an excess of contaminant in the soil.
8) Although not completed yet, available data indicate that there is reduction in the magnitude of permeability (hydraulic conductivity) due to contamination of these contaminants.
9) It is possible to dispose of the contaminated soil by using them as stabilizing materials for projects such as road construction. However, such contaminated soil should be capped or enclosed to prevent environmental pollution.

Even though this study made very important conclusions, it still needs to be further extended to address some of the issues that needed to be studied, some of which include using two other contaminants on the same tested parameters to make the conclusions more sound and general. Also some parameters were not fully studied due to the lack of time such as the hydraulic conductivity which needs to be addressed with variable contaminants. Contaminant oil penetration test should be designed to study the effect of variables that control the depth of penetration such as the relative density, percent of fines in the sample, type of contaminant and the hydraulic gradient head. Also, study should be made to find a method to dispose of such contaminated soils to protect the environment.

5. References

Abu-Ashour, J., and Shahlam, A. B. (2002). "Water infiltration through diesel contaminated soil". *Journal of Environmental Science and Health*, Vol. A37, No. 6, pp. 1041-1049.

Al- Sanad, H. A., Eid, W. K., and Ismael, N. F. (1995). "Geotechnical properties of oil-contaminated Kuwait sand". *Journal of Geotechnical & 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 sands". *Journal of Geotechnical & Geoenvironmental Engineering, ASCE,* Vol. 123, No. 3, pp. 290- 293.

Bradt, J. P. (1997). *Experimental Soil Mechanics*, Prentice-Hall, New Jersey.

Cook, E. E., Puri, V. K., and Shin, E. C. (1992). "Geotechnical properties of oil-contaminated sand". *Proceeding of 2nd International Conference on Offshore and Polar Engineering*, Vol. 1, pp. 384-387.

Evgin, F., and Das, B. M. (1992). "Mechanical behavior of an oil-contaminated sand", *Proceeding of the Mediterranean Conference on Environmental Geotech*, pp. 101-108.

Fan, C. Y., Krishnamurthy, S., and Chen, C. T. (1994). "A critical review of analytical approaches for petroleum contaminated soil". *Analysis of Soils Contaminated with Petroleum Constituents, ASTM STP 1221*, pp. 61- 74.

Ghaly, A. M. (2001). "Strength remediation of oil-contaminated sands", *Proceedings of the Seventeenth International Conference on Solid Waste Technology and Management*, Philadelphia, USA.

Meegoda, N. J., and Rajapakse, R. (1993). "Long-term and short-term hydraulic conductivities of contaminated clays". *Journal of Environmental Engineering,* Vol. 119, No. 4, pp. 725-743.

Meegoda, N., J., and Ratnaweera, P. (1994). "Compressibility of contaminated fine-grained soils". *Geotechnical Testing Journal*, Vol. 17, No. 1, pp. 101-112.

Puri, V. K., Das, B. M., Cook, E. C., and Shin, E. C. (1994). "Geotechnical properties of crude oil-contaminated sand", *Analysis of Soils Contaminated with Petroleum Constituents, ASTM STP Publication 04-012210*, pp. 75-88.

Ratnaweera, P., and Meegoda, J. N. (2006). "Shear strength and stress strain behavior of contaminated soils". *Geotechnical Testing Journal*, Vol. 29, No. 2, pp. 1-7.

Shin, E. C., and Das, B. M. "Bearing capacity of unsaturated oil-contaminated sand". *International Journal of Offshore and Polar Engineering*, Vol. 11, No. 3, pp. 220-226.

Shin, E. C., Omar, M. T., Tahmaz, A. A., and Das, B.M. (2002). "Shear strength and hydraulic conductivity of oil-contaminated sand", *Proceedings of the Fourth International Congress on Environmental Geotechnics, A.A* Balkema publishers, Vol. 1, pp. 9-13.

Taqieddin, S. (2008). “Shear strength, compressibility of diesel-oil contaminated sandy soil”, *Proceedings of the 8th International Congress on Advances in Civil Engineering,* Famagusta, N. Cyprus.

Tuncan, A., and Pamukcu, S. (1992). “Prediction mechanism of crude oil and marine clay interactions in salt water environment”, *Proceedings of Mediterranean Conference on Environmental Geotech*, pp. 109-191.