Experimental Shear Analyses of Oil Contaminated Sand

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Abstract
This article is discussing the effect of oil leak contamination on soil shear behavior. The authors also studied the effect of the natural existence of silt fraction, on shear properties of the same soil type. Sand soil is used as a foundation and replacement soil during civil construction in the region of Agrud Suez – EGYPT. In this research, direct shear tests were performed on pure sand and sand with 3% silt content soil, under various normal stresses to investigate the effect of soil grain size on shear properties. Moreover, shear properties were studied for oil-contaminated sand and sand with silt to determine the effect of oil contamination on both forms of soil. Results indicate that the presence of a small percentage of silt in sand soil may cause a significant decrease in shear strength. As it was observed that adding oil as a contamination material to sand may cause a decrease in shear resistance as well.

Keywords: Agrud sand, Suez sand, oil contamination of soil, silty sand shear properties, silt effect on sand, shear properties of soil, mechanical properties of soil, soil characterization

1 INTRODUCTION

To understand simple material behavior and establish their constitutive equations, homogeneous element tests are required. The purpose of this contribution is a critical view of some elementary laboratory tests performed on contaminated sand soil, which may affect significantly on mechanics of soil, although, it remains unpopular for most engineers and builders. Agrud (Agrod or Ajrud) is located in the western desert of Suez city (30°01'42.81" N 32°29'34.69" E), Egypt. It contains the famous archaeological area Tel Agrud of 50 acres, dating back to the Ottoman age. Agrud is also a valuable sand quarry supplying the city of Suez with sand used in construction works.

Recently, large oil tanks were erected in the same region. The exposed rock units in Agrud region are classified according to their relation to the Gulf of Suez rifting into pre-rift and syn-rift sequences; the former is Eocene rocks and could be subdivided into Observatory, Qurn, wadi Garawi, and wadi Hof formations. While the latter is represented by Oligocene and Miocene strata. These sequences are unconformably overlain by reworked Pliocene carbonates and Quaternary clastic sediments of poorly lithified sands, gravels, and recent alluvium, [1], [2], as shown in figure(1).

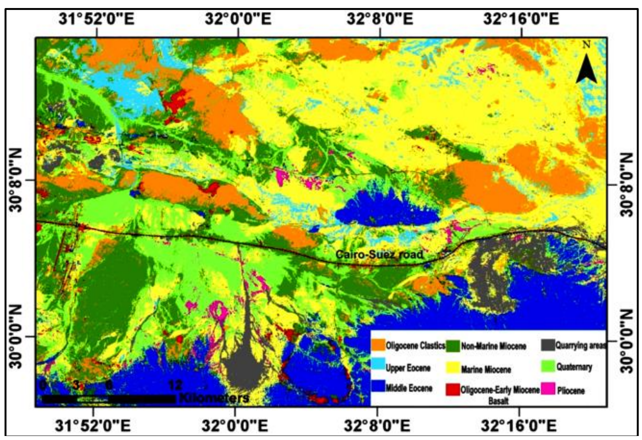


Figure 1 Geological map of Suez region generated supervised classification map, Hammam, A. & others, 2018

The soil oil contamination leads to changes in the soil properties. The geotechnical properties of contaminated soil had been studied by many researchers. Hasan et al. (1995), [3], proved that oil contamination of Kuwaiti sand caused decreasing in the permeability and strength of the soil, while it caused increasing in compressibility and CBR values with the presence of up to 4% oil by the soil weight. Puri. (2000), [4], stated that the internal friction angle of contaminated soil decreased amount of 20 to 25 % and the hydraulic conductivity depends on the viscosity of the contaminant oil. Therefore, this research focused on studying the effect of oil contamination of Agrod sand on the shear behavior and properties.

2 MATERIALS AND METHODS

Sand sample was collected in one batch from Agrud district, Suez governorate, Egypt. The collected sample initially contained some silt-sized grains and was used as a sample (1), while part of it was sieved wet into a 0.075 mm sieve to isolate silt-sized grains from it to be de-silted and was used as a sample (2), according to ASTM C 117 – 95, [5]. Sample (1) was mechanically sieved to obtain the percentages of grains passing through each sieve, the test is performed according to ASTM C 136-01, [6]. In addition, laboratory Compaction Characteristics of the two used samples had been performed using the Modified Effort test according to ASTM D1557 - 12(2021), [7]. The used soil contaminant is engine oil that is used for gasoline engines which has a specific gravity of 0.9050 at 15°c and viscosity index of 90. Soil samples were air-dried and then contaminated with oil at different concentrations (0%, 2%, 4%, 8%) of their dry weight and then kept for a day to ensure that soil absorbed the oil. Unit weight was tested for each of the soil samples at all used oil contamination concentrations according to ASTM D7263-21, [8] to observe changes corresponding to oil concentrations changes.

The direct shear test of oil-contaminated samples at concentrations (0%, 2%, 4%, and 8%) was performed according to ASTM D 3080, [9], using digital Direct Shear Apparatus 26-2114 ELE with 36 cm^2 samples using shear box assemblies, [10], strain rates were fixed at (one mm/minute). The shear test was performed at three different normal stresses, 28.7 Kpa, 56 Kpa, and 83.4 Kpa. The Shear apparatus was equipped with a load cell, with a max load of 500 kg, detailed specification is mentioned in [11]. The apparatus was also equipped with two displacement transducers, 25 mm and 50 mm, according to the specification mentioned in [12]. The first one was measuring vertical displacement, and the other was monitoring horizontal displacement. A data acquisition (Digital Indicator at four inputs, MP4 model), [13], had been used to collect and store readings from the three transducers to the PC. Figure (2), shows the measuring setup.

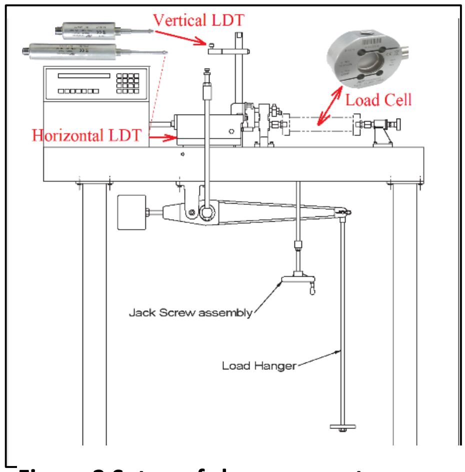


Figure 2 Setup of shear apparatus

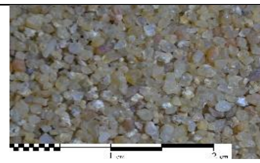
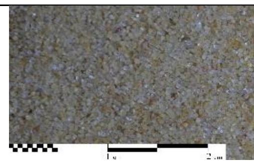
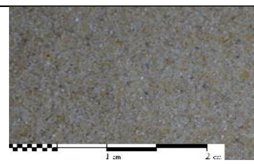
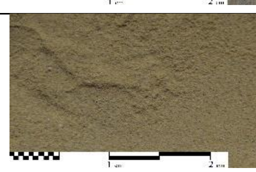
The specimen was placed in the shear box and the loads applied and the lateral strain-induced were recorded at frequent intervals to determine the shear stress-lateral strain curve for each normal stress. Several specimens were tested at varying normal stresses to determine the shear strength parameters, the soil cohesion (c), and the angle of internal friction, commonly known as friction angle (ϕ). All tests were performed in laboratories of the faculty of petroleum and mining engineering- at Suez University, Egypt.

3 RESULTS AND DISCUSSION:

3.1 Characterization of Soil Used :

In the present study, grain size analyses of sand soil used had been performed as described previously, using mechanical sieving; results are shown in Table 1). Wet sieving through a sieve (75 µm) is used to separate the silt and clay fraction from the original soil sample, which was found to be 3% of the total sample weight. The total dissolved salts measured in washed soil water solution were founded as 0.03% of the sample total weight. The graph in Figure (3), presents the particle-size distribution of Agrud sand, used to classify the type of tested soil based on the shape of the graph. According to the Unified Soil Classification System (USCS) as well as ASTM D 2487, (D10, D30, and D60) for Agrud sand were determined from the graph, Figure (3). Uniformity coefficient was calculated as ($C_U = [D60/D10] = 2.3$) and coefficient of curvature was calculated as ($C_C = [(D30)^2/(D60*D10)] = 1.29$). Agrud sand used was described as SP poorly graded sand.

Table 1: Results of sieve for sample (1)

Sieve Size (mm)	Passed % wt.	Image
2.8	99.4%	
1.7	98.4%	
0.85	87.4%	
0.6	59.6%	
0.425	24.6%	
0.3	13.6%	
0.212	6.0%	
0.18	5.4%	
0.09	3.2%	

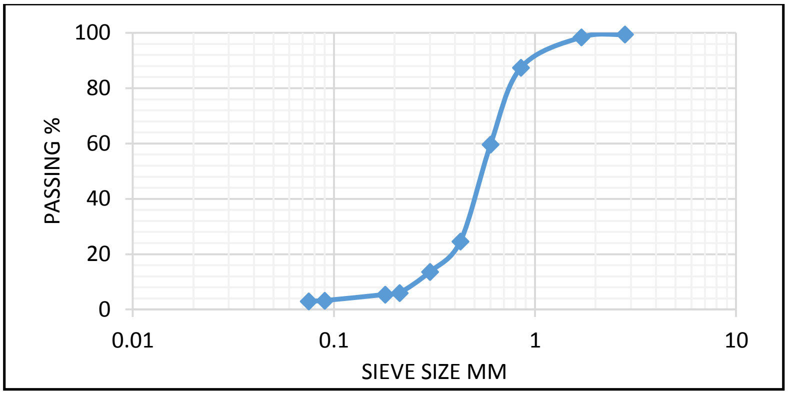


Figure 3: Grain size distribution of sample (1)

Maximum dry density and optimum moisture content of sample (1) and sample (2) were obtained by using the Modified Effort test according to ASTM D1557, which showed a maximum dry density of 1.911 gm/cm^3 at 8.95% optimum moisture content for sample (1), and maximum dry density of 1.884 gm/cm^3 at 13.04% optimum moisture content for sample (1), results are shown in Figure (4) and Figure (5).

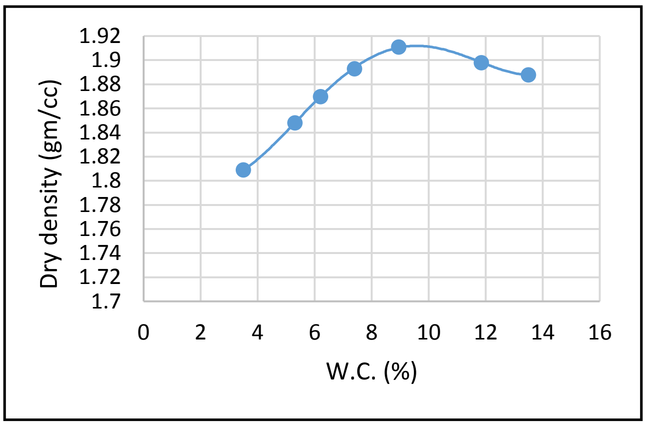


Figure 4 dry density relationship with water content percentage of sand with 3% silt sample (1)

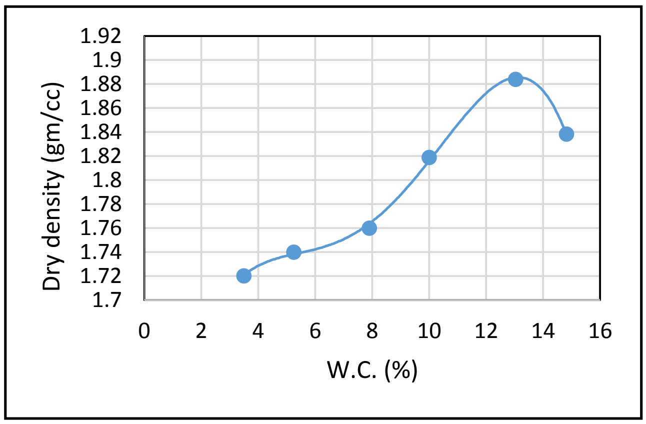


Figure 5 dry density relationship with water content percentage of sand sample (2)

3.2 Shear Behavior of Agrud Sand

According to J. K. M. Gan & others, [14], The shear strength parameters of unsaturated soil can be obtained using a direct shear apparatus. Sand samples were subjected to a direct shear test, using the previously mentioned shear machine setup. Results were plotted on graphs with shear stress on the y-axis and the lateral strain on the x-axis under different normal stresses. Shear behavior of sand and sand with 3% silt samples was represented in, Figure (6), Figure (7), and Figure (8) which illustrate the effect of a very small silt fraction in the sand sample on values of shear stress at three levels of normal stresses, 28.7 Kpa, 56 Kpa, and 83.4 Kpa. Results illustrate that the shear resistance of sand with silt is always less than pure sand without silt. , Figure (6), Figure (7), and Figure (8) demonstrate a more curious behavior is noticed across these curves, where samples start failure at lower shear stress values, stated in this text as a primary failure, which can be recognized by the long lateral strain reaching about 0.02 as a common value under the different normal stresses, stalked by the gradual increase in shear resistance, where in this part, the relation stress-strain is acting linearly. Finally, an endless strain exists with a slight decrease in shear resistance, indicating complete failure of the sample. Table (2) shows equations describing shear resistance under different values of normal stresses.

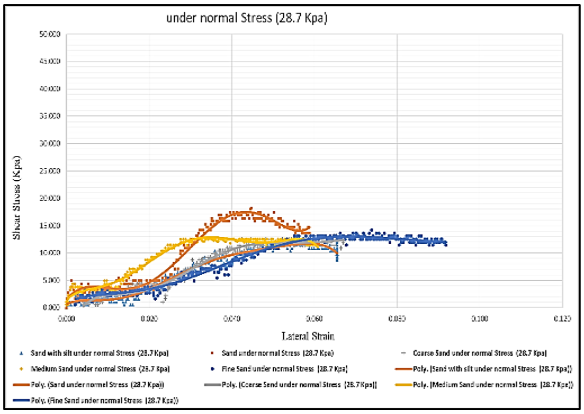


Figure 6 shear behavior of sand and sand with 3% silt under normal stress of 28.7 Kpa

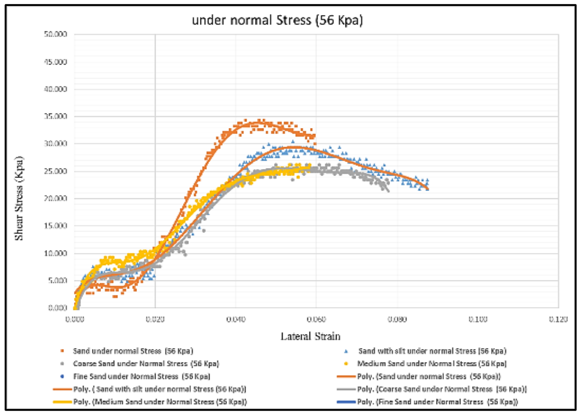


Figure 7 shear behavior of sand and sand with 3% silt under normal stress of 56 Kpa

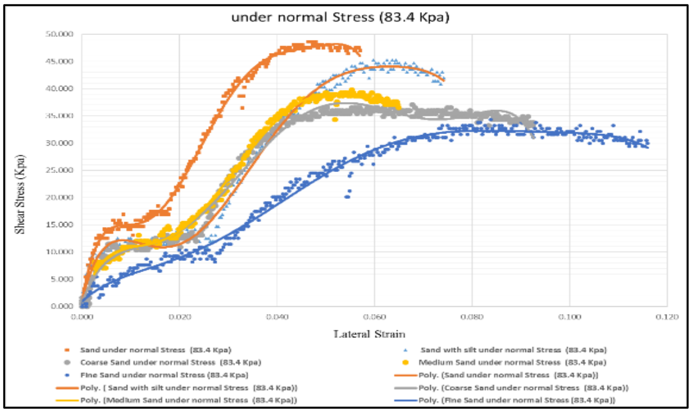


Figure 8 shear behavior of sand and sand with 3% silt under normal stress of 83.4 Kpa

Table 2: Polynomials describing shear resistance under different values of normal stresses

Grain Type	Polynomials	R^2
sand @ (28.7 KPa)	$y = -2E+10x^6 + 3E+09x^5 - 2E+08x^4 + 9E+06x^3 - 143952x^2 + 1117.3x - 1.875$	0.97
Sand @ (56 KPa)	$y = -5E+09x^6 + 1E+09x^5 - 1E+08x^4 + 6E+06x^3 - 113664x^2 + 970.32x + 2.7236$	0.99
sand @ (83.4 KPa)	$y = -1E+11x^6 + 2E+10x^5 - 1E+09x^4 + 5E+07x^3 - 716132x^2 + 5108.2x + 1.1975$	0.99
Sand with silt @ (28.7 KPa)	$y = -6E+09x^6 + 1E+09x^5 - 1E+08x^4 + 3E+06x^3 - 40871x^2 + 252.15x + 0.7214$	0.93
Sand with silt @ (56 KPa)	$y = -5E+09x^6 + 1E+09x^5 - 1E+08x^4 + 6E+06x^3 - 99409x^2 + 814.15x + 3.0528$	0.98
Sand with silt @ (83.4 KPa)	$y = -2E+10x^6 + 4E+09x^5 - 4E+08x^4 + 2E+07x^3 - 402856x^2 + 3536.8x + 1.3508$	0.99
Coarse sand (28.7 KPa)	$y = -1E+10x^6 + 2E+09x^5 - 2E+08x^4 + 1E+07x^3 - 200838x^2 + 1974.6x - 5.0663$	0.97
Coarse sand (56 KPa)	$y = -1E+10x^6 + 3E+09x^5 - 3E+08x^4 + 1E+07x^3 - 255141x^2 + 2246x - 0.8991$	0.99
Coarse sand (83.4 KPa)	$y = -8E+09x^6 + 2E+09x^5 - 2E+08x^4 + 1E+07x^3 - 225682x^2 + 2353.9x + 0.8078$	0.98
Medium sand (28.7 KPa)	$y = -2E+10x^6 + 3E+09x^5 - 2E+08x^4 + 5E+06x^3 - 61745x^2 + 504.73x + 1.5967$	0.97
Medium sand (56 KPa)	$y = -1E+10x^6 + 3E+09x^5 - 2E+08x^4 + 7E+06x^3 - 109679x^2 + 1302.4x - 0.7046$	0.99
Medium sand (83.4 KPa)	$y = -1E+10x^6 + 3E+09x^5 - 3E+08x^4 + 1E+07x^3 - 287513x^2 + 2739.5x + 0.8092$	0.99
Fine sand (28.7 KPa)	$y = -7E+08x^6 + 2E+08x^5 - 3E+07x^4 + 1E+06x^3 - 29630x^2 + 331.53x + 0.9689$	0.98
Fine sand (56 KPa)	$y = -7E+08x^6 + 2E+08x^5 - 3E+07x^4 + 2E+06x^3 - 60474x^2 + 1116.6x + 1.1576$	0.98
Fine sand (83.4 KPa)	$y = -6E+08x^6 + 2E+08x^5 - 3E+07x^4 + 2E+06x^3 - 54691x^2 + 968.21x + 0.0189$	0.97

Different sets of grain size, coarse sand (2.0:0.5 mm grain size), medium sand (0.5:0.25 mm grain size), and fine sand (0.25:0.075 mm grain size), [15], were tested in the shear box. The results also prove that grain size distribution is affecting the results of shear resistance. Under low normal stress, there is no significant order for overall behavior; however, it appears that the integrity of all grain sizes is improving results. At higher normal stress (56 Kpa), the effect of fine becomes clearer as it reduces soil shear resistance. When it reaches (83.4 Kpa), washed sand without silt has the highest value, followed by the sand with silt. Grain size separation negatively affects mechanical properties, which again proves that variable grain size improves results, except for silt size, which decreases the resistance of sand soil, Figure (9).

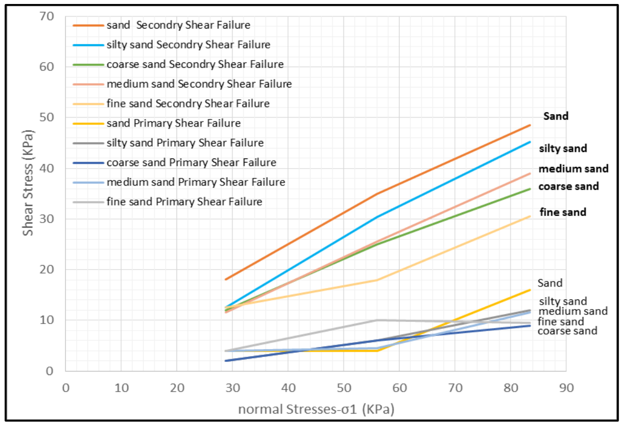


Figure 9 Shear strength for different graded sand under different values of normal stresses

Dinesh B. Shrestha, [16], observed that increasing montmorillonite proportions in sand will significantly reduce soil strength. Salgado et al. [17], further said that fines entirely control the soil behavior in terms of dilatancy and shear strength when fines content is more than 20%. Xenaki and Athanasopoulos [18] stated that laboratory investigations proved that, for silt content from 0 to 44%, the liquefaction resistance of the sand with a constant global void ratio decreased, compared to that of clean sand. Triaxial tests of Salgado et al. [17], determined that the addition of even small percentages of silt to clean sand considerably increases both the peak friction angle at a given initial relative density and the critical-state friction angle. They also suggest that silty sands with non-floating fabric in the 5–20% silt content range are more dilatant than clean sands. This may be interpreted as follows: initially, the fine particles are not positioned to provide optimum interlocking, and small shear strains are imposed on the soil with greater ease than if the fines were not present. As shearing progresses, the fines reach more stable arrangements and ultimately increase interlocking, dilatancy, and shear strength. Increasing fine content would separate sand particles and consequently reduce the sand's initial contact surfaces. Meanwhile, the strength of the sand fabric of carrying loads becomes weaker, and the critical state parameter increases with the increase of fine content leading to the reduction of shear strength. M. Derkaoui et al, [19], concluded after working on monotonic undrained triaxial tests, that particle breakage and rounding during shearing can cause a substantial decrease in friction angle at higher normal stresses. H. G. Brandes, [20], said that this decrease is more severe in the calcareous sands due to lower grain hardness and more prevalent intraparticle voids. A.F. Cabalar, [21], said that shape of the finer grains does not have a significant impact on the behavior of specimens. However, higher roundness (R) and lower sphericity (S) of the host sand, lead to higher strength. The quantity of finer grains has a major influence on the behavior of specimens. On the other side Thian, S. and Lee, C., [22], said that silt content enhances the strength of sand-silt specimens. Where our author's present study proves the different statement.

In Figure (10) and figure (11), shear stress-lateral strain curves show an initial sharp peak, followed by a large softening stage, before starting a second larger peak. Desrues, J.et al., [23], suggested a graphical incremental distortion model $d\gamma = (d\varepsilon_1 - d\varepsilon_2)$, as shown in Figure (12), which describes a shear band mechanism, initiated at the middle of the sample and a secondary shear band developed beside the major one. The two bands have approximately the same direction. It should be noted that this initiation of the localization is observed in a very early stage of the deformation process, not after the peak but before. Desrues, stated that the localization initiation can take place before the peak in the overall stress-strain curve, the shear band is not simultaneously initiated, but it propagates at every point, from an initiating point with a constant direction.

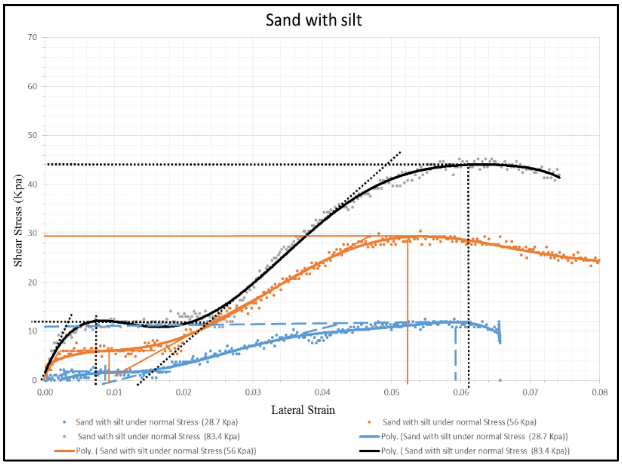


Figure 10 shear behavior of sand with silt samples

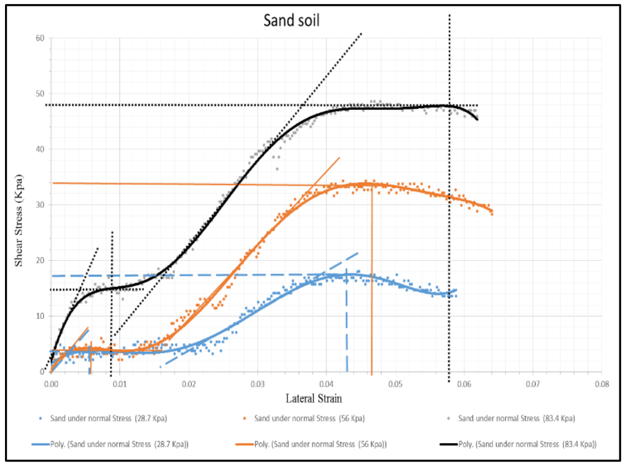


Figure 11 shear behavior of sand samples

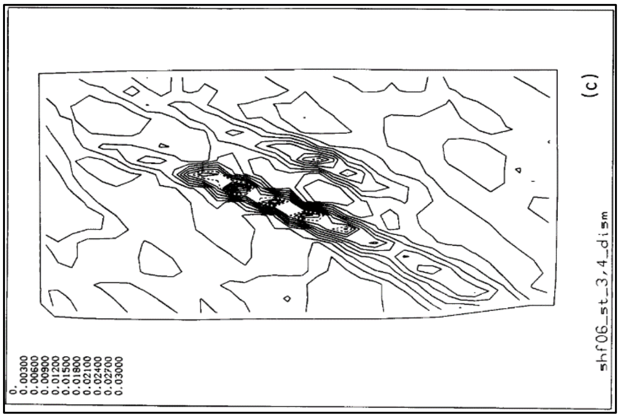


Figure 12: Initiation of the shear band as iso-value of distortion, after Desrues, J.et al., [22]

3.3 Effect of oil contamination on unit weight of sand

Soil samples of sand containing 3% silt and pure sand were contaminated with oil at different percentages (0%, 2%, 4%, 8%) of the soil weight, the effect of soil oil contamination on the unit weight of samples was represented as shown on figure (13) and figure (14). Unit weight of sand containing 3% silt samples was slightly increased by adding 2% oil contamination While the increase in oil contamination percentages in the sample to 4% and 8% led to an obvious increase in the unit weight of the samples to reach 1.772 g/cm3. The unit weight values of pure sand samples increased continuously with increasing oil contamination percentages until they reached 1.775 g/cm3 with 8% oil contamination percentage.

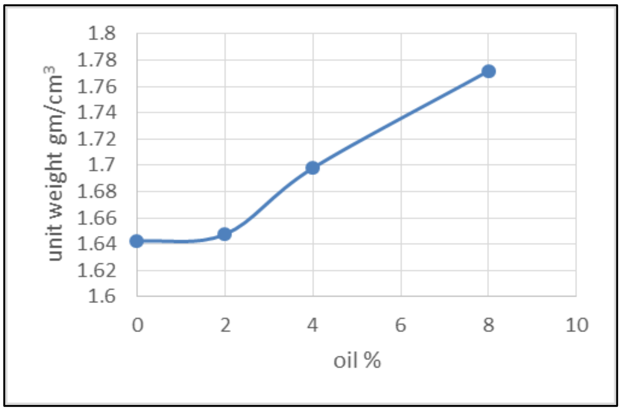


Figure 13 Effect of oil contamination percentages on the unit weight of sand with 3% silt samples

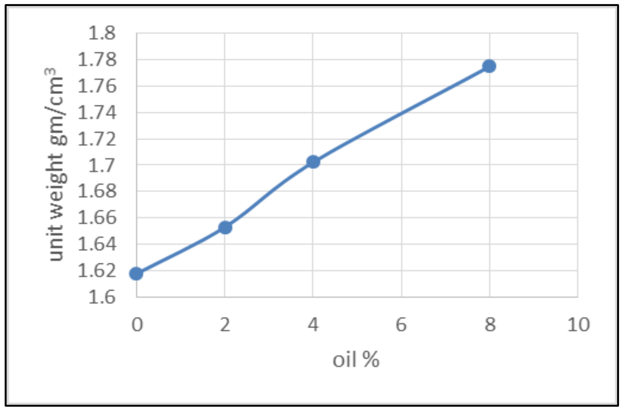


Figure 14 effect of oil contamination percentages on the unit weight of sand sample

3.4 Effect of oil contamination on Shear Behavior of Agrud sand

Samples of sand containing 3% silt and pure sand contaminated with oil at different concentrations (2%, 4%, 8%) were tested on the shear box for shear behavior investigation. shear stress - lateral strain relationships for sand containing 3% silt samples were represented as shown in figure (15), figure (16), and figure (17) which illustrate the effect of oil contamination on soil shear behavior at three levels of normal stresses on sample 28.7 Kpa, 56 Kpa, and 83.4 Kpa. The observation is that oil contamination makes a noticeable change in the shear strength of sand with 3% silt samples. However, there is not any clear behavior of shear strength changes either increasing or decreasing.

However, the relationships of shear stress with lateral strain for pure sand samples are represented in figure (18), figure (19), and figure (20) which show the shear behavior of pure sand samples when contaminated with different oil concentrations and were subjected to three values of normal stress 28.7 Kpa, 56 Kpa, and 83.4 Kpa, results show that the shear strength values have significant decreasing by adding oil contamination at 2%, 4%, and 8% concentrations in the sand samples. This decreasing effect is due to the effect of oil contamination which acts as a lubricant helping sand aggregates to slide easier, which helps in decreasing shear stress needed to make a certain value of shear strain.

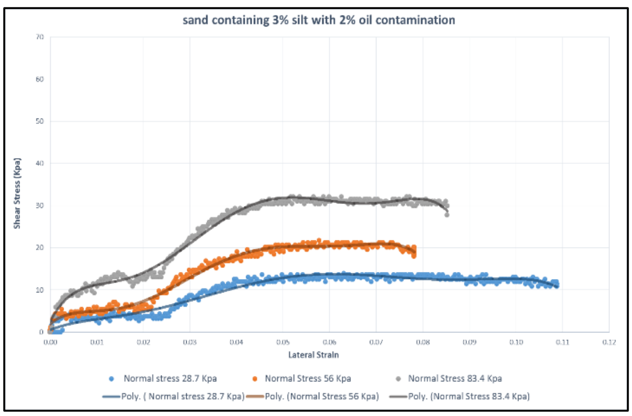


Figure 15 shear behavior of sand containing 3% silt contaminated with 2% oil

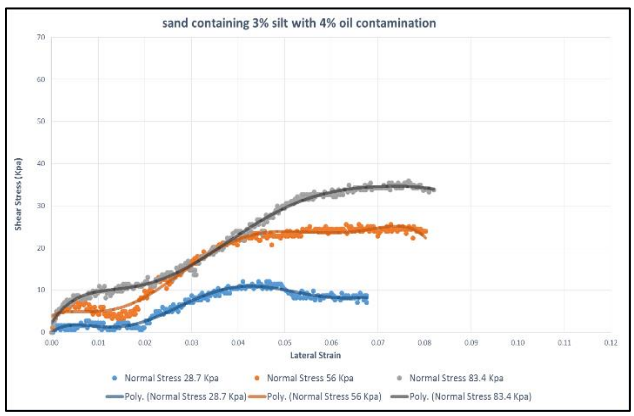


Figure 16 shear behavior of sand containing 3% silt contaminated with 4% oil

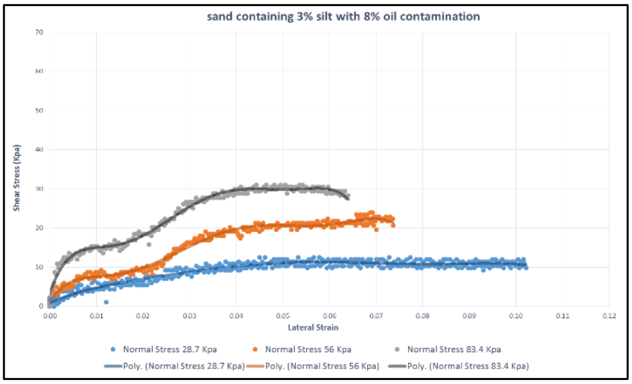


Figure 17 shear behavior of sand containing 3% silt contaminated with 8% oil

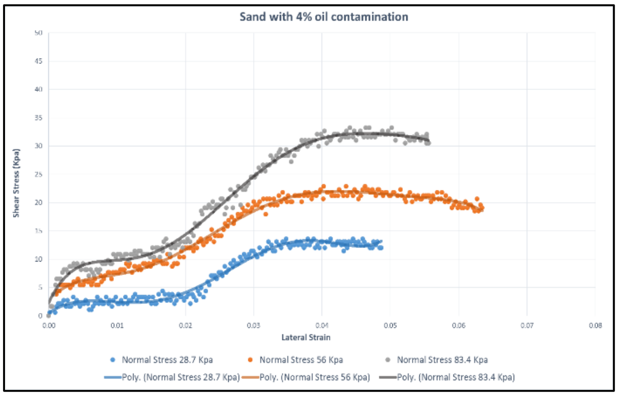


Figure 18 shear behavior of pure sand contaminated with 2% oil

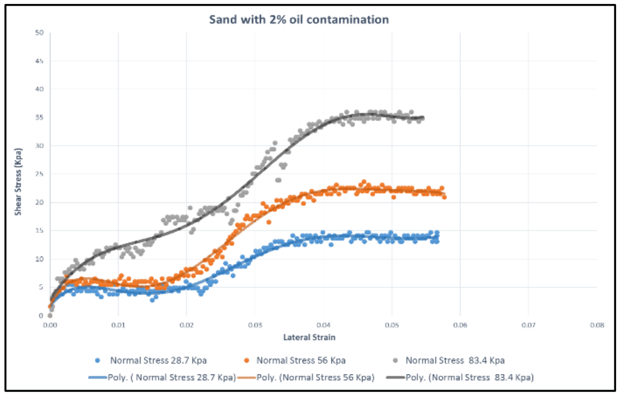


Figure 19 shear behavior of pure sand contaminated with 4% oil

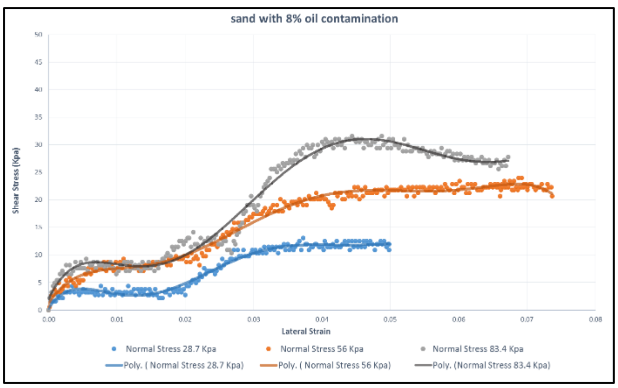


Figure 20 shear behavior of pure sand contaminated with 8% oil

To facilitate a comparison of the effect of oil contamination on the shearing behavior of samples, the shear strength values of the investigated soil had been represented in relationship with the ratios of oil contaminations during applying the three different values of normal stresses as shown in figure (21).

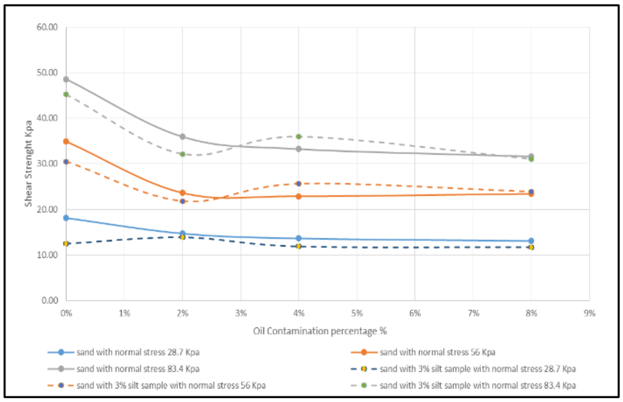


Figure 21 effect of oil contamination on shear strength values for sand containing 3% silt and pure sand samples

4 CONCLUSION:

1. The maximum dry density of sand with 3% silt soil is higher than pure sand soil and its optimum moisture content is lower than pure sand soil, which indicates that only 3% silt of sand weight can increase sand's maximum dry density by 1.4% and decrease optimum moisture content by 31.4 %.
2. Shear strength values of sand containing 3% silt can be enhanced by removing silt fractions from sand soil.
3. Fine-grained sand has a much lower shear strength than coarse and medium-grained sand.
4. The grain size separation of sand soil reduces the shear strength of the soil, which proves that well-sorted sand improves the shear strength values.
5. The shearing behavior of sand containing 3% silt and pure sand soil shows a sudden attitude during application of the direct shear test, which shows the constancy of shear stress with increasing lateral strain, appears at the beginning of the test called in this article the as primary failure.
6. Bulk density values show a smooth increase with the increase of oil contamination of sand.
7. Laboratory tests have proved that oil contamination, in general, can cause decreasing in shear strength values for both sand and sand containing 3% silt soils, except in one case when sand containing 3% silt soil was mixed with only 2% oil and subjected to 28.7 kpa normal stress, it shows an increase in shear strength value.
8. Laboratory tests prove that 2 % of oil contamination in sand soil, is a critical percent of contamination that can alter soil properties by significant change more than any higher oil contamination concentration.

CONFLICT OF INTEREST STATEMENT

On behalf of all authors, the corresponding author states that there is no conflict of interest

5 REFERENCES:

[1] A. Hammam, A. Gaber, M. Abdelwahed, and M. Hammed, “Geological mapping of the Central Cairo-Suez District of Egypt, using space-borne optical and radar dataset,” Egyptian Journal of Remote Sensing and Space Science,. Volume 23, Issue 3, December 2020, pp 275-285

[2] M. E. Mohamed Adel, A. Deif, S. El-Hadidy, S. R. Moustafa Sayed, and A. El Werr, “Definition of soil characteristics and ground response at the northwestern part of the Gulf of Suez, Egypt,” Journal of Geophysics and Engineering, vol. 5, no. 4, pp. 420–437, 2008, doi: 10.1088/1742-2132/5/4/006.

[3] Al-Sanad, H.A., W.K. Eid, and N.F. Ismael, Geotechnical properties of oil-contaminated Kuwaiti sand. Journal of geotechnical engineering, 1995. 121(5): p. 407-412.

[4] Puri, V.K., Geotechnical aspects of oil-contaminated sands. Soil and Sediment Contamination, 2000. 9(4): p. 359-374.

[5] ASTM C117-95, Standard Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing, no. 200. 1995.

[6] ASTM, C 136-01, Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates, vol. 13, no. 50. 2005.

[7] ASTM D1557 - 12, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort, vol. 04.08. 2021

[8] ASTM D7263-21 Standard Test Methods for Laboratory Determination of Density and Unit Weight of Soil Specimens vol. 04.09. 2021

[9] ASTM D3080-04, Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions, vol. 04.08. 1998.

[10] Operating Instructions, "Digital Direct / Residual Shear Apparatus," no. 4.

[11] https://www.aep.it/en/product/load-cells/ts-amp/.

[12]https://www.aep.it/en/product/displacement-transducers/ldt/.

[13]https://www.aep.it/en/product/instruments/mp4plus/.

[14] J. K. M. Gan, D. G. Fredlund, and H. Rahardjo, "Determination of the shear strength parameters of an unsaturated soil using the direct shear test," Canadian Geotechnical Journal, vol. 25, no. 3, pp. 500–510, 1988, doi: 10.1139/t88-055.

[15] D. A. MORRIS and A. I. JOHNSON, "Summary of Hydrologic and Physical Properties of rock and Soil Materials, as analyzed by the Hydrologic laboratory of the J.S. Geological Survey," UNITED STATES DEPARTMENT OF THE INTERIOR STEWART L. UDALL, Secretary GEOLOGICAL SURVEY William, vol. 53, no. 9, pp. 1689–1699,.

[16] Dinesh B. Shrestha, "undrained shear behavior of sand-clay mixed soil," Master of Science thesis, 2010.

[17] R. Salgado,1 Member, ASCE, P. Bandini,2 Student Member, ASCE, and A. Karim3, "shear strength and stiffness of silty sand" journal of geotechnical and geoenvironmental engineering, pp. 451–462, May 2000.

[18] V. C. Xenaki and G. A. Athanasopoulos, "Liquefaction resistance of sand-silt mixtures: An experimental investigation of the effect of fines," Soil Dynamics and Earthquake Engineering, vol. 23, no. 3, pp. 1–12, 2003, doi: 10.1016/S0267-7261(02)00210-5.

[19] M. Derkaoui, H. Missoum, K. Bendani, and F. Belhouari, "Shear Behavior of Sand–Silt Mixtures: A Laboratory Investigation of Coastal Silty Sand Soils of Mostaganem," Marine Georesources and Geotechnology, vol. 34, no. 7, pp. 668–680, 2016, doi: 10.1080/1064119X.2015.1070388.

[20] H. G. Brandes, "Simple Shear Behavior of Calcareous and Quartz Sands," Geotechnical and Geological Engineering, vol. 29, no. 1, pp. 113–126, 2011, doi: 10.1007/s10706-010-9357-x.

[21] A. F. Cabalar, "Influence of grain shape and gradation on the shear behavior of sand mixtures," Scientia Iranica, vol. 25, no. 6A, pp. 3101–3109, 2018, doi: 10.24200/sci.2017.4223.

[22] S. Thian and C. Lee, "Shear Behaviour of Sand with Fines," Advances in Research, vol. 2, no. 12, pp. 1031–1039, 2014, doi: 10.9734/air/2014/12109.

[23] J. Desrues, J. Lanier, and P. Stutz, "Localization of the deformation in tests on sand sample," Engineering Fracture Mechanics, vol. 21, no. 4, pp. 909–921, 1985, doi: 10.1016/0013-7944(85)90097-9.