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Cyclic Parameters of Gas Oil Contaminated Fine Soils

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ABSTRACT: Extensive demands of societies to different oil products and the presence of these materials in large sectors of industrial and non-industrial regions may lead to pollute the shallow soil layers. Due to numerous obstacles and high expenses regarding remediation of these sites, knowing its altered properties may provide an adequate basis to more reliable land use of these sites for engineering purposes. In the present research, extensive studies regarding dynamic properties of gas oil contaminated sites consisting of pure and mixed kaolinite clay with fine sand contaminated by different gas oil contents (up to 16%) have been carried out on remolded soil samples. Based on the results, the presence of gas oil up to a certain content (8-10%) leads to an increase in the dynamic shear modulus and decrease in damping ratio of cohesive soils. The presence of some fine sand in clayey soils would cause the above gas oil content to increase to 12%.

KEYWORDS: Gas oil, Clayey soil, Shear modulus, Damping ratio, Contamination.

1. INTRODUCTION

Oil and other refined products such as gasoil, gasoline, motor oil, etc. are abundantly used in various sectors of industry, transportation, agriculture and also as energy sources directly in domestic appliances all over the world. What is inevitable in the processes of exploration, transportation, storage and exploitation is the likelihood of these oil products being poured or seeped into the surface of the ground and penetrates into the soil layers. Based on estimates over the years 1978 to 1992, approximately 7.5 million cubic meters of oil products have been entered into groundwater and water. These contaminations can cause changes in soil engineering and geotechnical properties through chemical absorption or by trapping in soil pores (Nikmanesh 1998). Placing or leaking from reservoirs during oil exploitation, depletion of operations, and the process of oil processing has caused a significant number of oil-contaminated sites to emerge. Among these, gas oil which is utilized as diesel fuel, industrial machinery, agriculture and thermal installations, is one of the most applicable petroleum products in the world that is being used today in a large scale. The leakage and emission of oil pollutants in the soil, while changing the physical and chemical properties of the soil, also change its behavior comparing with non-pollutant soils.

As we know soils are naturally or artificially subjected to various types of loads. These loads can be applied statically or dynamically, such as those occurring by buildings or construction of installations, earthquakes, ocean waves, vibrations of devices and explosions. In each of these conditions, soils can show a different behavior. Contaminated soils are not exempt from this rule, and due to the effect of contamination on their properties, the necessity of examining their behavior in different conditions becomes twofold. For instance, overflow and leakage of diesel fuel tanks of many engines and diesel (industrial and agricultural) just enter the substrate where the machinery is installed on it. This foundation should be designed according to engineering properties and geotechnical parameters of soil bed and during the years, the static and dynamic loads of the machine and the engine to the soil should be transferred to the soil in such a way that the bedding soil has a satisfactory performance. Definitely safe and reliable operation of them depends on the extent of our knowledge of how the soil properties change, especially its geotechnical characteristics. Therefore, in this section we study the behavior and dynamic properties of soil. It is worth mentioning that in the field of dynamic properties of contaminated soils, unlike their static properties, which have undergone extensive research, not a lot of work has been done so far.

Analysis of issues related to the dynamic loading of soils and foundation and the interaction of soil and structure requires the determination of two important soil parameters, namely shear modulus and damping ratio. These two parameters are usually determined either in the laboratory or locally. It should be noted that many studies have been done in the field of dynamic properties, and in particular the two effective parameters of shear modulus and the damping ratio of a wide variety of clean soils (Presti et al. (1997), Darendeli (2001), Stokoe et al. (1999), Richart et al. (1970), Haddad and Shafabakhsh (2007), Zhang et al. (2005), Kokusho et al. (1982), Dobry and Vucetic (1987), Stokoe and Darendeli (1998) and Caserta et al. (2012)). However, in the case of contaminated soils and especially soils contaminated with petroleum products that are the subject of the present research, there are few studies available and this study is one of the first studies in this field. Hence, in this section, a brief series of research on topics related to the subject of this study is discussed.

Karkush (2016) studied the effect of soil contamination on the response of piles foundation under a combination of loading in a laboratory study. The behavior of single piles driven into contaminated clayey soil samples subjected to a combination of static axial and cyclic lateral loadings have been studied in this research. For this purpose, a laboratory model for testing a solid circular cross sectional area pile of diameter 19 mm and made from aluminum was manufactured. The intact clayey soil samples were synthetically contaminated with four percentages of 10, 20, 40 and 100% of industrial wastewater were obtained from the center of Iraq and from the weight of water used in the soaking process which continued for a period of 30 days. In this study, he found that the lateral-bearing capacity of the piles decreased by 10–34% with increasing the percentage of contamination from 10 to 100%. In addition, the ratio of permanent lateral displacement to the total lateral displacement was increased by 23–27% when the concentration of contaminant increased by 10-100%.

Naeini and Shojaedin (2014) studied the effect of oil contamination on the liquefaction behavior of sandy soils. A series of experimental cyclic triaxial tests on specimens of Firoozkuh sand mixed with crude oil in 4, 8, and 12% by soil dry weight were carried out. 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.

Hosseini et al. (2018) investigated Pre- and post-cyclic behavior of an unsaturated clayey soil contaminated with crude oil. They conducted a series of constant water content (CW) static and dynamic triaxial tests on samples that were compacted to the same dry density but different degrees of saturation and net confining pressures. The soil samples were provided from a place near an oil refinery located in Tehran city and were artificially polluted with 3%, 6% and 9% crude oil. Based on the results, deformation modulus reduction due to cyclic loads application was considerably more than reduction of shear strength. Also, these parameters increased due to increasing net confining pressure and initial matric suction.

Due to the use of the bender element for measuring shear modulus and damping ratio at small strains in the present study, a brief statement is made regarding bender element testing. Bender elements have become more and more commonly used for measuring the shear wave velocity in soil specimens, with the purpose of estimating the small strain shear modulus (G_o) of the material. A pair of in-line bender elements is usually used, where one acts as the transmitter sending off the shear waves, while the other on the opposite end captures the arriving waves. The shear wave velocity (V_s) is derived by dividing the travel distance of the waves (between the transmitter and receiver) to the arrival time, which in turn is squared and multiplied with the specimen's bulk density to obtain G_o on the assumption of a plane wave traversing a homogeneous and elastic material (Ming Chan ,2010).

Shirley and Hampton (1987) used ceramic bender transducers to measure the shear-wave speed of in *situ* acoustic parameters of kaolinite clay sediments. Transducers consisting of an array of ceramic benders have been found to be the most useful in measuring shear-wave parameters of high-porosity laboratory sediments. These clays exhibit calculated shear modulus as low as 1.7×10^5 Dyn. /cm^2 with shear-wave speeds from 2 to 40 m/s and attenuations from less than 100 dB/m to more than 500 dB/m.

Rajabi and Sharifipour studied the characterization of shear wave velocity (V_s) in clean and hydrocarbon-contaminated sand experimentally in 2017. An Iranian light crude oil, a standard type of silica sand (Ottawa sand), and a bender element and resonant column tests apparatus were used to minutely measure shear wave velocity of clean and crude oil contaminated sand samples (containing 4, 6, 8, 10, and 12% of crude oil). Based on the results, it was found that the shear wave velocity of 4% contaminated sand (V_s-4%) was about 1.2 times higher than that of the clean one (V_s-clean), and contrastingly adding further crude oil up to 6% made a significant reduction in value of shear wave velocity to some extent that Vs-6% was slightly lower than that of the V_s-clean (V_s-6% = 0.95–0.97V_s-clean). Moreover, adding more contaminant (8–12%) into sand had negligible influences on shear wave velocity.

With a review of researches on the dynamic properties of contaminated soils, it is noteworthy that the history of dealing with this issue has not been so long and at most covers the past two decades. Regarding contaminated materials and fluids, although gasoil has a large share of oil production and consumption among petroleum products, the focus of studies has been less on it. According to a few studies on cyclic behavior of contaminated soils, there is still a great gap about fine-grained contaminated soils, especially the need to carry out a comprehensive study of the contaminated soil hardness in a wide range of strains in cyclic loading. Because pollution of the major part of the sites located at the terminals of transportation (especially oil products), coastal areas and adjacent areas of refineries and oil facilities is inevitable, and these areas are permanently under the influence of static and cyclic loads such as traffic, waves, wind, earthquakes, and so on, knowing dynamic properties of such contaminated soils is of great necessity.

In order to fill the mentioned shortcomings, cyclic strain controlled tests were carried out on clean and gasoil contaminated samples in the soil dynamic laboratory of Amirkabir University of Technology in constant strain amplitudes under several load cycles and the induced stresses in the sample were read continuously and the dynamic parameters of the materials, including shear modulus and damping ratio, which are required in many design and dynamic analyzes, were determined based on the results of the tests.

2. THE TESTING MATERIALS AND SAMPLE PREPARATION

The soil used in the current research is pure and mixed clay with different fine sand contents. The clay for all samples is kaolinite and the sand which is used for mixed samples is Firozkooh fine sand (grade No. F161) 161crushed silica with angular grains usually available in north of Tehran that was added to kaolinite with different percent by weight of pure clay up to 20%, in order to simulate the condition of some contaminated sites. Tables 1 & 2 show the results of an X-ray diffraction (XRD) for clay composition and the clay mineralogy. A hydrometer, (ASTM D422) was done to determine the clay grain size distribution (Figure 1a.). Also Figure 1(b) shows the grain size distribution of the fine sand. Tables 3 and 4 summarize the physical properties and soils characteristics used in this research. According to the Unified Soil Classification System (ASTM D2487), the pure clay and fine sand are classified as low plastic clay (CL) and poorly graded sand (SP) respectively. The specific gravity (G_s) was determined by Water pycnometer (ASTM D854). The Atterberg limits were determined based on the standard method of ASTM D4318. The maximum dry density of soil samples were done according to standard proctor tests (ASTM-D698). The gas oil used in this study is prepared from the National Iranian Oil Refining and Distribution Company (NIORDC). Its specifications are given in table5. The scanning electron microscopic (SEM) images of some samples are shown in Figure 2.

Table 1 XRD analysis of the kaolinite

Chemical component	L.O.I (loss of Ignition)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	Na_2O	K_2O	CaO	MgO
(%)	8.9	64.4	21.2	0.26	0.05	1.11	1.15	2.2	0.73

Table 2 Clay mineralogy

Kaolinite	Feldspar	Silicon
52.57%	16.22%	31.21%

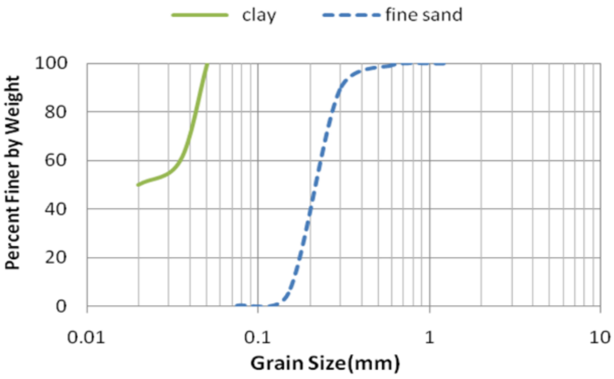


Figure 1 Particle size distribution of the soil materials

Table 3 The clay properties and indices

w_{opt} (%)	γ_{dmax}(g/cm^3)	Gs	PL (%)	LL (%)	PI (%)
28.84	1.46	2.66	32	48	16

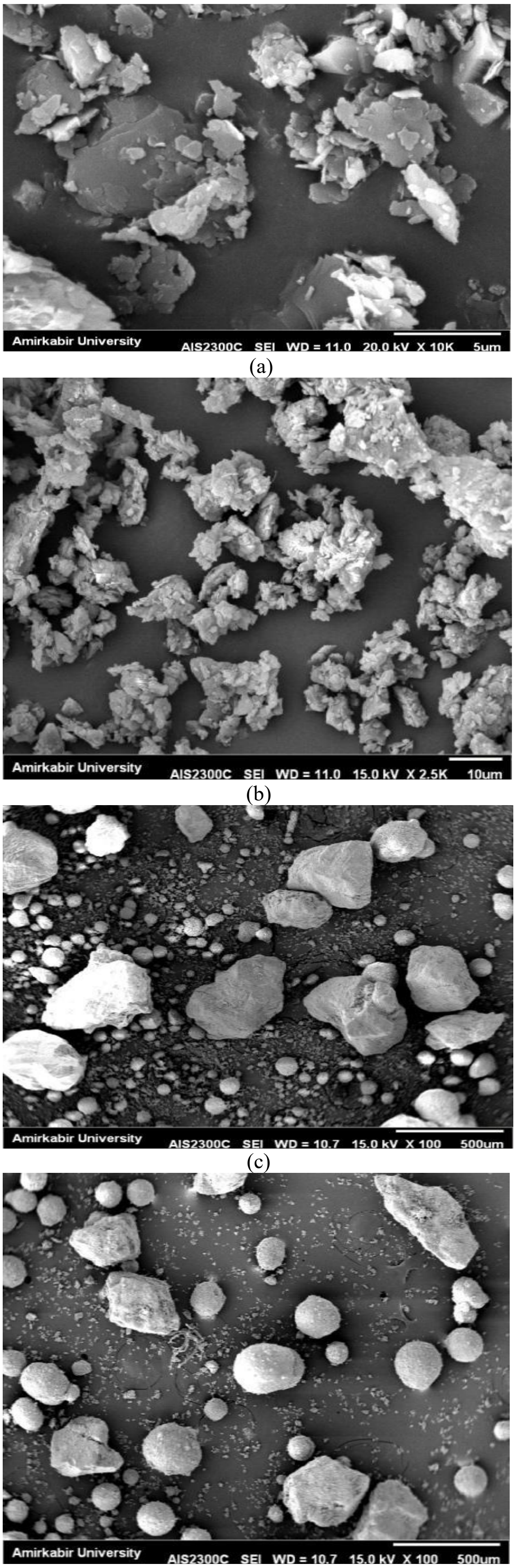
Table 4 Firozkooh fine sand (F161) specifications

C_c	C_u	e_{max}	e_{min}	G_s	D_{60} (mm)	D_{50} (mm)	D_{30} (mm)	D_{10} (mm)
0.96	1.625	0.931	0.58	2.65	0.26	0.25	0.20	0.16

Table 5 The gas oil specifications (NIORDC, Iran)

F.F.P** (min)	F.B.P* (max)	Density in 150 ° C
(°C)	(°C)	(Kg/L.)
54	385	0.82-0.86

**F.F.P. = Fuel Flash Point, *F.B.P. = Final Boiling Point



(a)

(b)

(c)

(d)

Figure 2 Scanning Electron Microscopic (SEM) images of: (a) Pure Clay, (b) Clay+16%gas oil, (c) Clay+20%sand, (d) Clay+20%sand+8%gas oil

The kaolinite was pulverized in order to pass through a No. 4 sieve. And since it was quite dry, there was no need to be dried in furnace. To make contaminated specimens, the gasoil with the amount of 0, 4, 8, 12 and16% was added to pure clay by weight of dry soil and the soil was stirred with gasoil to get a homogenous mixture. Also different contents of Firozkooh fine sand (10, 15 and 20%) was mixed with pure clay by weight of the dry kaolinite to make the sandy–clay samples. The type and composition of prepared samples that were used for the tests of this study are given in Table 6. All specimens were kept in fully sealed dark plastic bags in the temperature of 30 °C for 7–10 days for curing and preventing gasoil evaporation. This period is based on the proposed time of 3–7 days in the literature for soil–contaminant mixtures (Khosravi et al. 2013; Singh et al. 2008). Like the curing duration period, the temperature was chosen according to literature too. This temperature corresponds with the average temperature of reasonable depth in the oil facility and sites prone to similar contaminations (Khosravi et al. 2013).

Table 6 The composition of prepared and tested samples

Sample Code	Sample Type	Sample number
C	Pure Clay	1
CG4	Clay+4%gas oil	2
CG8	Clay+8%gas oil	3
CG12	Clay+12%gas oil	4
CG16	Clay+16%gas oil	5
CS10	Clay+10%sand	6
CS10G4	Clay+10%sand+4%gas oil	7
CS10G8	Clay+10%sand+8%gas oil	8
CS10G12	Clay+10%sand+12%gas oil	9
CS10G16	Clay+10%sand+16%gas oil	10
CS15	Clay+15%sand	11
CS15 G8	Clay+15%sand+8%gas oil	12
CS15 G16	Clay+15%sand+16%gas oil	13
CS20	Clay+20%sand	14
CS20G4	Clay+20%sand+4%gas oil	15
CS20G8	Clay+20%sand+8%gas oil	16
CS20G12	Clay20%sand+12%gas oil	17
CS20G16	Clay20%sand+16%gas oil	18

3. THE TESTING APPARATUS AND PROCEDURES

The dynamic triaxial apparatus which is an electromechanical dynamic triaxial testing system (GCTS) in the soil dynamic laboratory of Amirkabir University of Technology is used in this work for performing the tests. This device can apply uniform dynamic loads in the ranges of very low to very high frequency (0.005-20 Hz) and uses an automated electro-hydraulic closed loop control system for loading on specimens. A compressor provides cell pressure and back pressure in the system with a nominal capacity of 10 bars that the maximum 8.75 bars of this capacity can be controlled and applied to the samples. Sensors with adequate accuracy and sensitivity perform all measurements automatically and a hydraulic jack applies load in this system. Also a sensor with a capacity of 8.8 KN reads the applied vertical force. The amount of vertical jack displacement is read by normal and miniature axial deformation sensors with capability of measuring deformations up to 51 ±1 mm.

The cyclic tests in this study are strain- controlled type on unsaturated soil samples. Dimensions of samples are 50 and 100 mm in diameter and height respectively. The wet tamping method was used to prepare homogeneous samples with uniform density. In order to have the same condition for comparison of all samples, they should be all in one side of the compaction curve (dry side). Having the same condition as is the case for bed soils in many engineering practices; all specimens were prepared and compacted in 90% of their maximum dry density based on the results of compaction tests performed in the basic and static tests of the current research. Therefore, by having the desired density and volume of the samples for making different testing specimens as given in table 6, the required materials (kaolinite, fine sand, and gas oil) for each sample (clean or contaminated) have been determined mixed and compacted in 4 layers. According to the main aim of the current study which is the evaluation of the soil contamination effects on dynamic characteristics of shallow fine soil layers under cyclic loadings, such as traffic loadings, machine foundations etc, that usually induce low confining pressure in shallow soil layers, the confining pressure of 200 KPa has been selected and applied to all testing samples which is an appropriate mean values for mentioned circumstances.

As cited before, strain- controlled cyclic tests with sinusoidal wave load and a frequency of 1 Hz was applied to the sample. Although maximum 50 loading cycles are sufficient for measuring the shear modulus and damping ratio, for further information, the loading cycles continued up to 200 cycles in these studies. These tests were performed in 4 shear strain amplitudes from very small to large shear strains of 0.0001, 0.05, 0.1 and 1%. To measure the dynamic parameters of the samples for three shear strain amplitudes of 0.05, 0. 1 and 1%, cyclic triaxial apparatus was used and for the strain amplitude of 0.0001 %(10^{-6}) which is in low strain levels ($10^{-5} > \gamma$) and beyond the capability of the cyclic triaxial apparatus, the bender element device was used.

In bender element experiments, a small strain test system with a semi-automatic model, MTM (Global Material Testing Manufacturers) was used. This system was installed on both sides of the triaxial cycling machine. A special feature of this system is the presence of components with common uses such as high flexibility. It also has two input channels and one output channel. The maximum frequency of the sent wave is 20 MHz and the maximum received wave frequency is 50 MHz. The sampling rate of input waves is 125 and the sampling rate of received waves is 500 million signals per second. In this study, due to the more similarity with vibrational waves, the incoming sinusoidal waveform has been selected. Since Bender element was installed on a triaxial machine, the sampling and testing procedures did not differ from those tested with a triaxial device. When the specimen was made in the form of triaxial machine, the bending elements on the top and bottom of the sample were mounted on the cap and the metal plate of the triaxial device, which penetrates some 3 mm on each side of the specimen. An element is shaken by changing the voltage across it. A shear wave is released and propagated all over the sample and the other element is shaken accordingly. Then the input and output voltages are recorded. The oscillator has a digital detector, whereby the time delay measurements between the specific points of the signals are determined directly on the display screen and the wave travel time between the two elements is obtained by microsecond. These data are digitally stored and transmitted to the computer for numerical analysis. Figure 3 and Figure 4 are presented a view of triaxial device and Bender element system used in this study respectively.

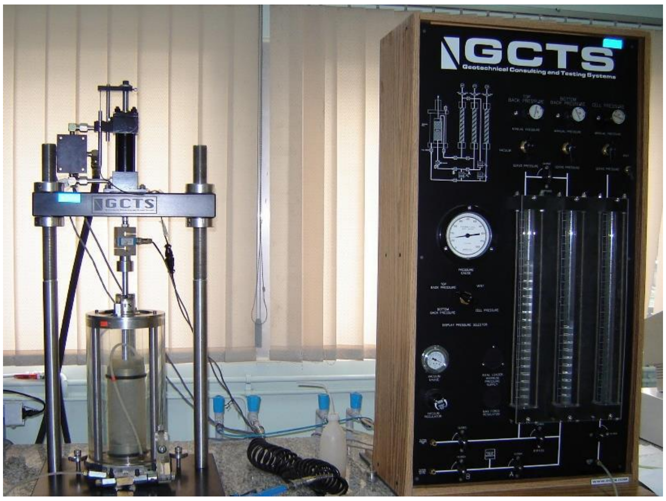


Figure 3 Triaxial apparatus (GCTS) of Amirkabir University of Technology

Figure 4 Bender element accessories for small strain wave testings

4. TEST PROGRAMS, AND EQUATIONS OF BASIC PROPERTIES

As previously mentioned some 72 strain- controlled cyclic experiments were carried out on clean and contaminated pure clay and mixed clay samples as described in Table 7.

Due to the fact that in triaxial cyclic tests, the parameters that can be controlled and applied to the test apparatus are axial stress and axial strain, and it is not possible to directly measure the shear stress and shear strain on the sample, these two parameters can be calculated from the following equations.

$$\gamma = (1+\upsilon)\,\varepsilon_v \qquad (1)$$

$$\tau = (\sigma_1 - \sigma_3)/2 = \Delta\sigma/2 \qquad (2)$$

In equation (1), γ, υ and ε_v are shear strain, Poisson ratio and vertical axial strain respectively. In this study, the Poisson ratio was considered as 0.4 according to the texture density of samples (AASHTO, 1995).

Table 7 Cyclic tests program

Sample type	Added materials	Applied shear strains in triaxial cyclic tests	Bender element tests	No. of tests	Added materials	Applied shear strains in triaxial cyclic tests	Bender element tests	No. of tests
	Fine Sand content (%)	Gas oil content (%)	10E-2	10E-3	5*10E-4	Shear strain 10E-6	In each case	In each sample
Pure clay	0	0	1	1	1	1	4	20
	0	4	1	1	1	1	4	
	0	8	1	1	1	1	4	
	0	12	1	1	1	1	4	
	0	16	1	1	1	1	4	
Mixed clay	10	0	1	1	1	1	4	20
	10	4	1	1	1	1	4	
	10	8	1	1	1	1	4	
	10	12	1	1	1	1	4	
	10	16	1	1	1	1	4	
Mixed clay	15	0	1	1	1	1	4	12
	15	8	1	1	1	1	4	
	15	16	1	1	1	1	4	
Mixed clay	20	4	1	1	1	1	4	20
	20	8	1	1	1	1	4	
	20	12	1	1	1	1	4	
	20	16	1	1	1	1	4	
Total test numbers carried out in the present study								**72**

Damping ratio (D) is obtained from the following relationships (3) and (4). Figure 5 shows the parameters of these equations in one cycle of loading. In equation (4), ΔW and W are the total area of the hysteresis loop and the area of the triangles shown in Figure 5. It is worth mentioning that in this research, according to the ASTM D3999 standard, the damping ratio and shear modulus are calculated for the tenth cycle of loading.

$$G = \frac{\tau}{\gamma} = \frac{\tau_{\max} - \tau_{\min}}{\gamma_{\max} - \gamma_{\min}} \qquad (3)$$

$$D = \Delta W / 4\pi W \qquad (4)$$

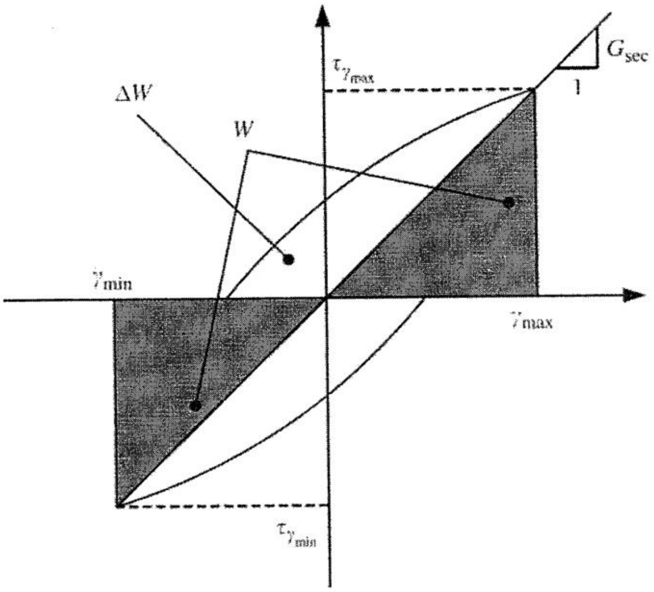


Figure 5 A hysteresis loop of shear stress - shear strain (Hesami, 2016)

Based on the elastic theory for materials with unit mass of ρ, the shear modulus in the small strains obtained from equation 5. Therefore, this relationship was used to calculate the shear modulus in bender element tests. In this equation, ρ and Vs are unit mass and shear wave velocity of tested soil sample respectively. The shear wave velocity in the sample can be calculated from equation 6 in which t and L are travel time and the distance between the two bender elements.

$$G_{max} = \rho \cdot V_s^2 \qquad (5)$$

$$V_s = L / t \qquad (6)$$

Among the available methods for finding the travel time of the shear wave in the literature, with respect to the repetition and the possibility of verification, the peak-to-peak time method (transmitted wave and received wave) was used for this study.

Considering the fact that in bender element tests, the system has been set up in a way to propagate shear waves within the soil sample in very small strain conditions. Hence, the sample behaves elastic in which the hysteresis loop becomes nearly linear and the damping ratio would be very small. Thus, in our studies using the bender element system, we have considered the damping ratio of about 1%.

5. THE TESTING RESULTS AND DISCUSSIONS

Typical shear stress- shear strain curves of some tested samples under controlled-strain conditions which are called hysteresis loops are shown in Figures 6 and 7. Although the shear modulus and damping ratio can obtain from both stress- controlled and strain-controlled tests, in the present study due to high density of the samples and the possibility of accurate applying and controlling shear strains and also the great dependency of the two parameters to shear strains, the strain–controlled tests were performed and used accordingly.

As can be seen in Figures 6 and 7 adding gasoil to pure clay sample would cause the hysteresis loop to get inclined and its area become greater. It means that the shear modulus would decrease and the damping ratio will increase.

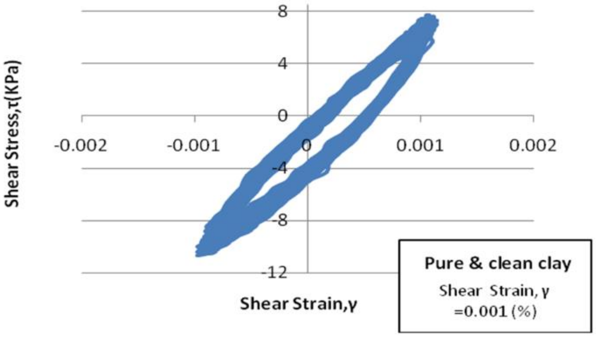
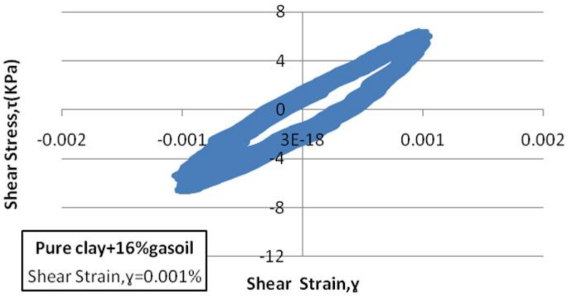


Figure 6 Stress- strain curves obtained from strain- controlled cyclic triaxial tests on pure (no fine sand) & clean (no gas oil) clay sample under shear strain of 0.001(%).



sample under shear strain of 0.001(%).

Figure 7 Stress- strain curves obtained from strain-controlled cyclic triaxial tests on pure (no fine sand) clay sample contaminated by 16% gas oil under shear strain of 0.001(%).

To study entirely the effect of contamination levels on the shear modulus and damping ratio of pure and mixed clay samples, some 72 cyclic triaxial and bender element tests (as given in table 7), were carried out on different specimens contaminated by 0, 4, 8,12, and 16% gasoil content tested at different shear strains of 1, 0.1, 0.005, and 0.0001% .Tests with The former three shear strains(i.e., 1, 0.1, & 0.005%) were done by cyclic triaxial and with the last shear strain (i.e., 0.0001%) were performed by bender element apparatus.

The results of some tests are given in Figures 8, 9, 10 and 11. As can be observed from the figures, the shear modulus for all samples (either clean and contaminated, or pure and mixed clay with fine sand) decreases with increasing the shear strain whereas, the damping ratio increases with increasing the shear strain. Although the above general responses of samples are expected due to great dependency of shear modulus and damping ratio to the shear strain, the level of contamination also influences these parameters by a special trend.

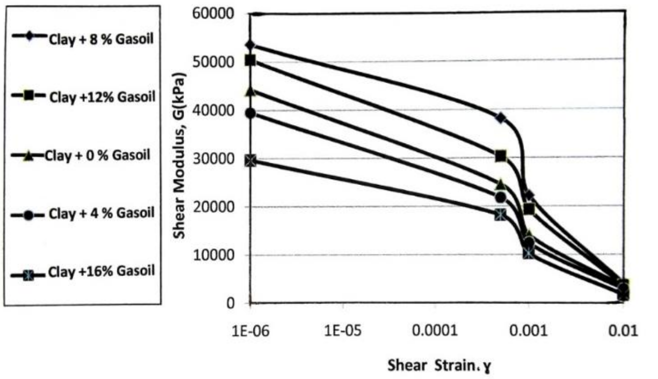


Figure 8 Variation of shear modulus versus shear strains for pure clay samples contaminated with different gas oil contents

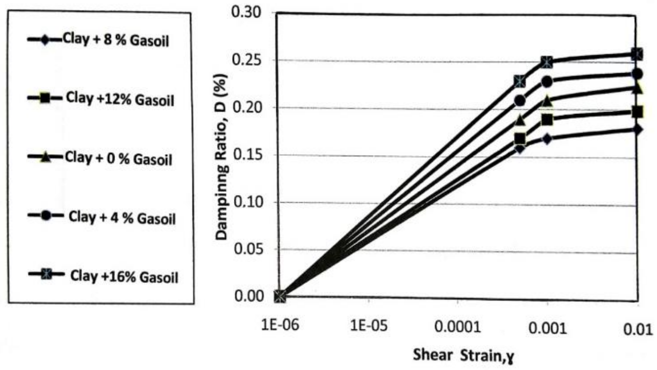


Figure 9 Variation of damping ratio versus shear strains for pure clay samples contaminated with different gas oil contents.

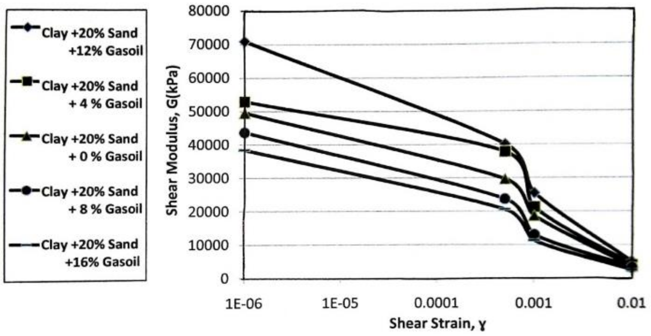


Figure 10 Variation of shear modulus versus shear strains for clay samples having 20% fine sand contaminated with different gas oil contents.

To evaluate the effect of contamination level on shear modulus and damping ratio, the variations of these parameters against gas oil contents are plotted and shown in Figs. 12 to 15.

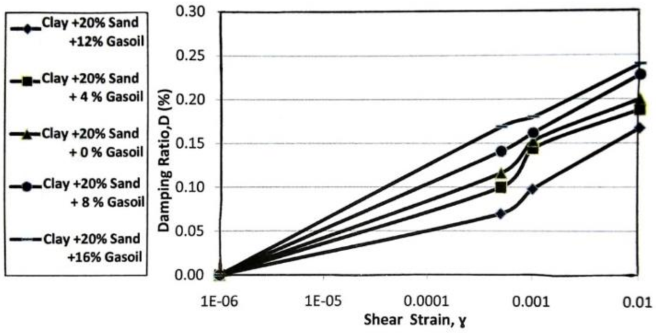


Figure 11 Variation of damping ratio versus shear strains for clay samples having 20% fine sand contaminated with different gas oil contents.

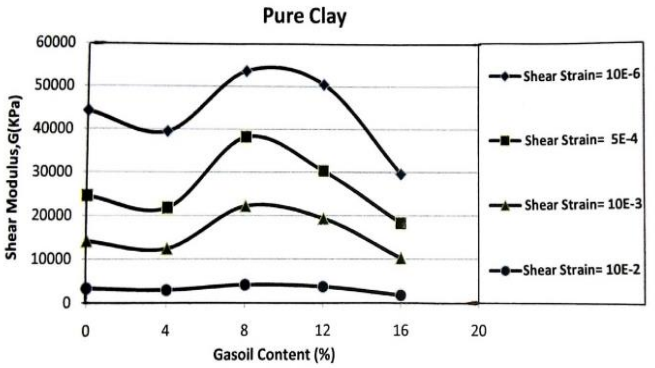


Figure 12 Variation of shear modulus versus gas oil content for pure clay samples at different shear strains.

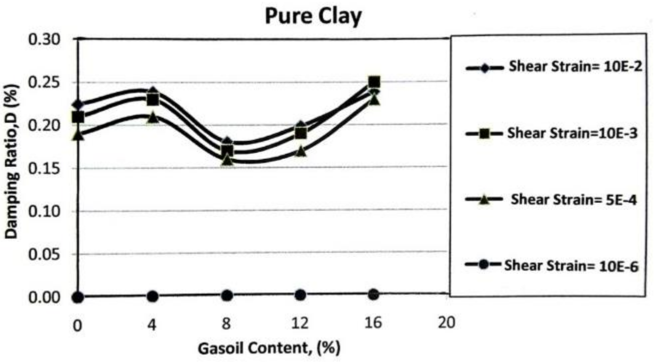


Figure 13 Variation of damping ratio versus gas oil content for pure clay samples at different shear strains.

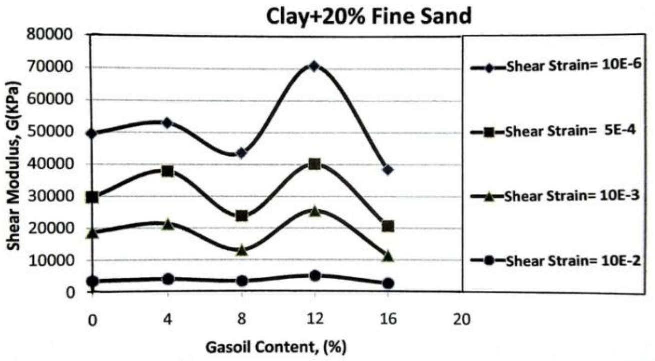


Figure 14 Variation of shear modulus versus gas oil content for clay samples having 20% fine sand at different shear strains.

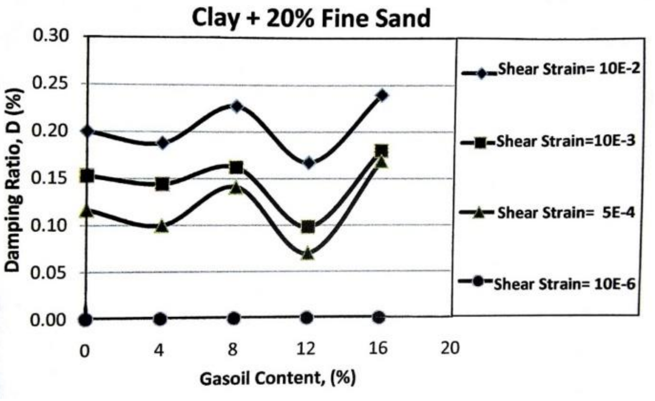


Figure 15 Variation of damping ratio versus gas oil content for clay samples having 20% fine sand at different shear strains.

In Figure 12 it is quite evident that increasing the gasoil content to pure clay soils would marginally decrease the shear modulus up to 4%, after which would sharply increase it up to about 8-10%. Further increase in gas oil content will cause the shear modulus to decrease considerably. The mentioned trend is highly appreciable as the level of shear strain gets smaller (i.e., the modulus becomes greater). The influence of gas oil content on damping ratio, as expected, is quite in the opposite direction (Figure 13). The only difference in this case is a smaller variation of damping within the ranges of selected shear strains which may be due to the relatively less sensitivity of the damping ratio to shear strain.

The same trend nearly can be observed when the samples are clay mixed with fine sand (Figures 14 and 15). The main and obvious change in the former trend here is the critical level of contamination (by most impact) which is shifted from 8-10% gas oil content for pure clay to 12% for mixed clay. It may be attributed to presence of sand particles in the specimen which changes the medium from pure cohesive to a medium with both cohesion and friction properties. The greater values of shear modulus at 10E-6 shear strain in this case compared with that of pure clay sample may also have the same reason.

The variations trends of shear modulus of pure and mixed clay samples with gas oil contents in facts stem in impact of gas oil presence in soils basic parameters, namely cohesion and angle of internal friction. Prior to the current dynamic tests a series of static tests on the same samples were carried out to study the effect of gas oil on the shear strength parameters. Based on the results of those test for pure clay samples the gas oil content up to about 8% caused the cohesion of the contaminated specimens to increase beyond which it started decreasing (Figure 16). The prominent peak values of shear modulus of contaminated pure clay samples at 8% gas oil content, particularly at small strains may be attributed to the peak values of samples' cohesion at the same contamination level (i.e.8%) as the main and important shear strength factor of cohesive soils. Minimum values of damping ratio of the samples are naturally expected to happen at this gas oil content since at which the specimens get their strongest status.

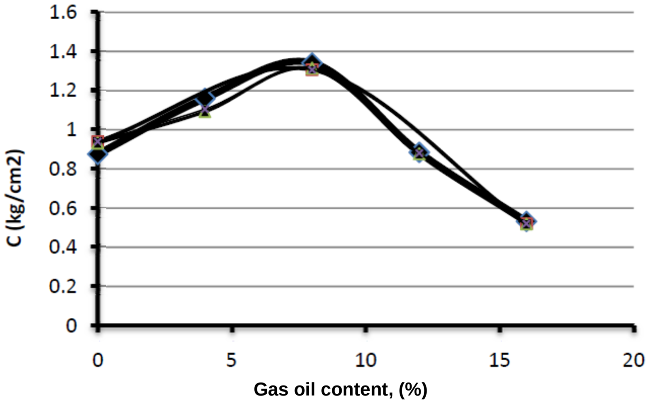


Figure 16 Variations of cohesion versus gas oil content for 4 similar pure clay samples measured by static triaxial apparatus

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Adding fine sands to pure clay, due to increasing some frictional grains to the media and participation of both shear strength parameters of the soil (i.e.; cohesion and angle of internal friction) in interaction with gas oil as a non-polar liquid, the gas oil critical content would be shifted from 8% to 12%, as it was the case in some other static tests in the previous stage of the current research. Thus, appearance of the peak values of shear modulus of contaminated clay samples having 20% of fine sands at 12% gas oil content may be due to this fact.

There are many other basic issues regarding the interaction between the water, as a polar liquid by relatively great dielectric constant, gas oil as a non-polar liquid by small dielectric constant, kaolinite plates by hydrostatic surcharges, and sand grains by frictional surface that in the so called contaminated samples play a great role on the soil basic indices and parameters the scope of which is out of the present paper and a lot of which have been presented and discussed in a separate paper by Mir Mohammad Hosseini et al. (2017).

6. SUMMARY AND CONCLUSIONS

Dynamic properties of contaminated fine soil grounds ,where nor the remediation measures can be performed neither the land use for engineering practices may be ignored, for designing purposes particularly dynamic loadings is of great necessity and importance. Among them the shear modulus and damping ratio are the most applicable and required parameters in this regard.

In the present studies pure and mixed kaolinite with fine sands were contaminated by different gasoil content up to 16% and remolded in the laboratory to evaluate the influences of contamination on shear modulus and damping ratio of the clayey soils. A series of cyclic triaxial tests under strain- controlled condition were carried at 3 different shear strains of 1, 0.1, and 0.005%. Also some experiments performed for very small shear strain using bender element system. Some of the main and important results concerning the influences of gas oil content on shear modulus and damping ratio of the clayey soils are as follows:

- Increasing gas oil content up to 4% would decrease the shear modulus of pure clay marginally, beyond which the modulus increases sharply up to 8-10%. Further increase in contamination level will decrease the modulus.
- The damping ratio of contaminated clay samples experiences the opposite changes versus gas oil content compared with that happens for modulus (as expected).
- The critical gas oil content causes the most changes in shear modulus and damping ratio is in the ranges of 8-10%.
- For mixed clay soils having some fine sands (about 20%), gasoil contamination would cause almost the same changes in these two parameters. The only appreciable difference in this case is the critical gas oil content which is shifted to about 12%.

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