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Experimental Evaluation of Marly Soil's Mechanical and Dynamical Behavior

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ABSTRACT

Marls are among the problematic soils that threaten developmental projects. As moisture increases, the resistance of these types of soil decreases and their deformability increases. During an earthquake, its parameters and properties are likely to alter. The effect of moist Marl quality is considerable on both static behavior and dynamic properties of soil. These parameters include shear and pressure wave velocity, natural frequency, shear modulus, and damping ratio. The mechanical properties of soil might be specified through both laboratory experiments and field experiments. This research study was carried out on Marls of the north of Shiraz city to identify their dynamic behavior. To achieve this, in addition to field and laboratory static tests, cyclic triaxial test was also done on the samples. The obtained results revealed that in these Marly Soils, as the confined pressure increased (increase in soil depth), the shear modulus also increased. It was also understood that the damping ratio behaved slightly different for less than 1% and more than 1% strains. However, in general, for strains more than 1%, increasing confined pressure led to reduction of damping ratio. The study also showed that as the percentage of moisture increased, the shear and compression resistance decreased which, in turn, led to an increase of soil consolidation. Comparing the static and dynamic behavior of soil indicates that the cyclic shear modulus in 100 kPa stresses and 1% strain is roughly 60%; and in 10% strain, it is less than static modulus by almost 48%. This difference reduces as the enclosing pressure increases.

1. Introduction

In case of evaluating the response of earth to the imposed loads and seismic excitation, both mechanical and dynamic properties of soil need to be taken into consideration. From among the main properties of soil is specific gravity, hardness, Poisson's ratio, natural frequency, damping ratio, and strain level. These properties are directly utilized to study the seismological site effect. They are a good guide for estimating the soil response to earthquake excitation. Thus, much care and attention are required to evaluate the dynamic behavior of soils in resolving geo-technical issues. A wide range of field and laboratory experiments exist in this regard, each having its own advantage and disadvantage points. Some of the experiments are specifically for measuring soil parameters in small strains and many of the experiments are related to measuring properties which are likely to appear in large strains. Among the soil properties, hardness, natural frequency, and damping ratio are more influential both for small strain and large strain, due to their linear or non-linear behavior. In large strains, the impact of loading velocity and number of cycles on resistance is of great importance. Hence, it is necessary to know about the factors affecting the geo-technical and dynamic properties of soils and the interaction behavior of soil-structure with either small or large strains. During last five decades, several studies have been conducted to identify the dynamic properties of soils. Some researchers have focused on the relationship between shear modulus and shear strain range (Kokusho, 1980; Seed et al., 1986; Terzaghi, 1925). In the previously fulfilled studies, many of the factors affecting the

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shear modulus have been widely examined by researchers through running laboratory experiments and using resonant column device and cyclic triaxial device (Weissmann and Hart, 1962; Seed et al., 1986; Vucetic and Dobry, 1991; Nagy and Nagy, 2019). The conducted studies indicate that factors such as the properties of aggregates size, degree of saturation, void ratio, soil lateral pressure co-efficient, inner friction angle, and number of stress periodicity minimally affect the damping ratio of sands. In fact, the main influential factors affecting the damping rate are the strain level induced by the sand and the confined effective pressure (Weissmann and Hart, 1962; Seed et al., 1970). The curvature of the cyclic resistance graph of clay and silt mixture depends on its mineralogy composition. The existence of Montmorillonite instead of Kaolinite in soil increases the cyclic resistance of sample in that, as plasticity index increases the cyclic resistance also increases (Van der Schrier, 1988; Ulusay et al., 2001; Sonmez and Tunusluoglu, 2008; Hooshmand et al., 2012; Wang et al., 2015; Zhang, 2016; Ajmera et al., 2017). Wang et al. (2015) investigated the cyclic-shear behavior of silt soils containing varying amounts of clay and low plasticity in Mississippi river valley. The results of this study revealed that changing the amount of clay has a considerable effect on the shear behavior of sample including its resistance and stiffness. (Yılmaz et al., 2004; Azarafza et al., 2015; 2018) examined the behavior of deformation and non-drained cyclic shear resistance in clay and silt mixture in Adapazari city, Turkey. Additionally, the increase of clay leads to a reduction in the sample lubrication potential. The results of the study showed that the resistance and stiffness of these soils was not eliminated by earthquake and their plastic strain is critically dependent on the type and amount of loading. (Beroya and Aydin, 2007) investigated the effect of mineralogy of clay on cyclic behavior of silt and clay mixture. The obtained result was that the rate of clay minerals in this mixture played an important role in its cyclic behavior (Boulanger and Idriss, 2006; 2007).

Among clay soils, Marly Soils, largely due to their special properties, have special dynamic behavior. These types of soils behave differently especially when they are in saturated conditions and are compounded with other materials such as plaster. The dynamic behavior of Marly Soils has not been thoroughly investigated as yet. Therefore, the present research study tries to address such a gap by examining the properties of Marly Soils especially their dynamic properties. Besides, the status of input vibrations of structure located on them is based on frequency content. This would help researchers to recognize the technical specifications of these soils so that better engineering judgments might be made regarding future Marl structure projects.

2. Material and Methods

2.1. Mechanical Properties of Materials

This study was done on Marly Soils in the northwest of Shiraz city. The purpose was to identify the behavior of soils in small and large strains range. This type of soil is abundantly found in different parts of Fars, Hormozgan, and Bushehr provinces. In addition to clay Marls, a large part of the studied soil also contains gypsum minerals, which sometimes leads to swelling. To identify soil properties, first, a series of basic tests including moisture content, specific gravity, direct shear test, unconfined compression test, consolidation, and Atterberg limits have been performed. In the Unified Soil Classification System (USCS), this type of soil is classified in the rank of clays with high to low (CL) plastic property. Table 1 presents the primary properties of soil in different depths.

2.2. . Field Experiments

Pressure-meter test device is used to gain the soil elasticity modulus and limit pressure strength. Pressure meter experiment is based on installing a cylinder membrane, under fluid pressure, into a cylinder borehole. When the pore pressures increases and consequently, the bulk of membrane and cavity increases, it can measure and record the volume and pressure changes. This test is taken as the most reliable and valid soil mechanic field as it has theoretically and scientifically been promoted. The capability of this test is to gain profuse quantitative information in high depths. To do these experiments, a borehole with depth of 45 meters was created. Figs. 1 and 2 depict a summary of these tests

To determine the field dynamic properties of soil, down-hole experiment was used. Down-hole experiment was done for two boreholes with 35 meters and 27 meters depth. In this method, a seismic source was used in a specific point of earth to produce seismic wave of P or S or both of them and then the seismic waves were received by the wave receiver located in the borehole. The vibration detection notes were then measured and recorded by the three-component seismometer inserted into the borehole at different depths and creating waves by mechanical wave source, by a hammer hitting the metal screen to produce pressure wave (P) and shear wave (S). In this case, the wave received by the seismometer is direct and it is tried to put the wave production source near the borehole entrance. Figs. 3 and 4 show the results of down-hole experiment. In order to better discern the used materials, photos were taken from the under-study soil at Amir Kabir University via an electron microscope. Fig. 5 shows the used electron microscope (SEM) and Figs. 6 to 8 present samples of taken photos.

Table 1. Mechanical Properties of Marly Soil

Parameter	Unit	Value
Max wet density	gr/cm^3	2.02
Max dry density	gr/cm^3	1.7
Optimum moisture content	%	19.39
Soil adhesive coefficient	kg/cm^2	0.21
Internal friction angle	degree	19
Unconfined compression strength	kg/cm^2	0.98
California Bearing Ratio, CBR	-	6
Soil Lime percentage	%	37.5
Fine aggregates percentage	%	88
Soil swelling percentage	%	16
Liquid limit, LL	%	31
Plastic index, PI		16
Unified soil classification system	-	CL

This microscope is a kind of electron microscope with the ability to take photos with magnification of 10 to 500000 and separation (resolution) power less than 1 to 20 nanometers (depending on the type of sample). According to Figs. 6 to 8, the studied Marls have laminations of clay and silt with wind source. These kinds of Marls might be taken as the border of deposition cycles.

2.3. Cyclic Experiments

Cyclic triaxial experiment is used to specify the mechanical properties of soil in high strains. Figure 9 shows a scheme of this device. In laboratories, this device is widely used on soil samples under both monotonic and cyclic conditions tests. In advanced triaxial devices, putting the measurement cell of axial force into the compartment removes the friction impact of loading piston. Additionally, the capability of tensional loading can be checked by hard fastening of the sample vertical loading screen to the cap. To measure the shear modulus in highly small strains 10-6 by the triaxial device, three ways could be used: in triaxial device, highly sensitive sensors on top of the sample and in its compartment are used. These sensors are referred to as gap sensors and contain two small non-contact discs with a magnetic couple in each of them. Trivial changes in the gap between these two discs can be shown by the amplifier. Two sets of these sensors are placed opposite to each other on the two top sides of the sample. By recording the average of measured data, shear strains from 10-6 to 10-3 could be estimated. To do the test, the cyclic triaxial device of Tehran University was utilized. To make the measurement conditions equal, the compaction energy specification to the soil was taken into account.

Sampling process is done by keeping the energy level fixed. To achieve this, the number of layers, hammer weight, fall height, and number of impacts are kept fixed for all samples so that identical samples would be collected. To condensate the sample, a 500-gram weight with fall height of 5 cm was used. The measurement mold was 7 cm diagonal and 14 cm in height. After consolidating the sample, cyclic loading is started. Loading was done with one second period of rotation. All conditions of loading such as period of rotation and imposed tensions were the same for all samples. Diagrams related to cyclical loading and graphs of damping ratio and shear modulus changes are brought in the following sections. For every composition of soil, the tests were done in eight different confined pressures as the effect of cyclic loading on soil behavior is different at different depths. The under-test pressures are 50, 100, 1550, 300, 400, 470, 520, and 600 kPa. In fact, the effect of depth on soil behavior has been studied. The loading process on all samples was done with the fixed one Hertz frequency and it continued in an ascending order until rupture of samples. Figure 10 shows the shear modulus changes of the studied soil in different confined pressures to the shear strain with logarithm scale. Figure 11 also represents the soil damping ratio changes in different confined pressure. Samples are consolidated by confined pressure. As this pressure increases, the consolidation treatment increases, as a result, the sample would have less settlement. These settlements remain in the sample in the form of cumulative strains. Figure 12 depicts a ring of load-transmission temporal history diagram in the cyclic loading experiment for 300 to 520 kPa enclosing strains.

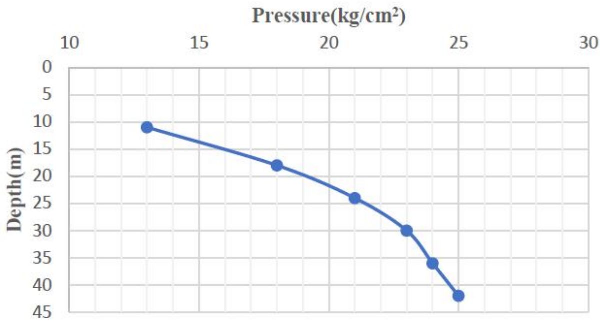


Figure 1. Pressure limit changes based on depth variation obtained from pressure-meter test

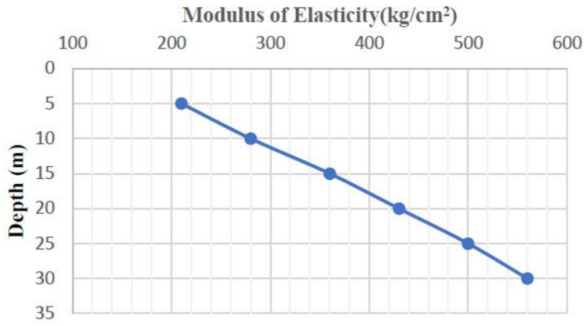


Figure 2. Elasticity modulus changes based on depth in pressure-meter experiment

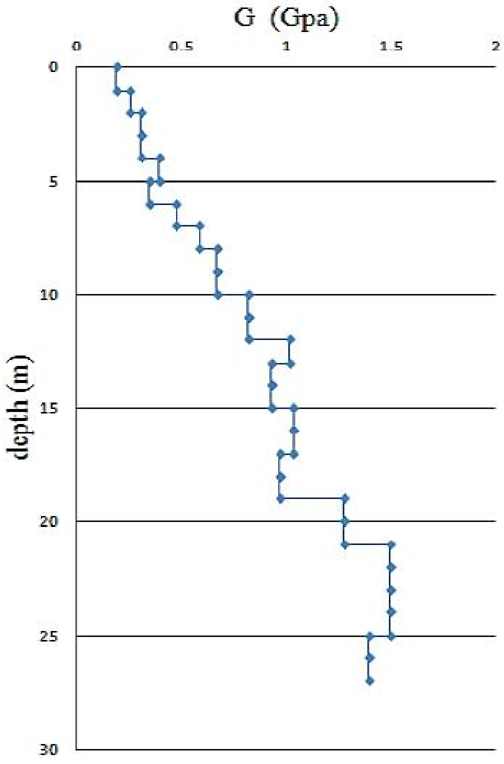


Figure 3. Shear modulus variation of Marly soil in different depth

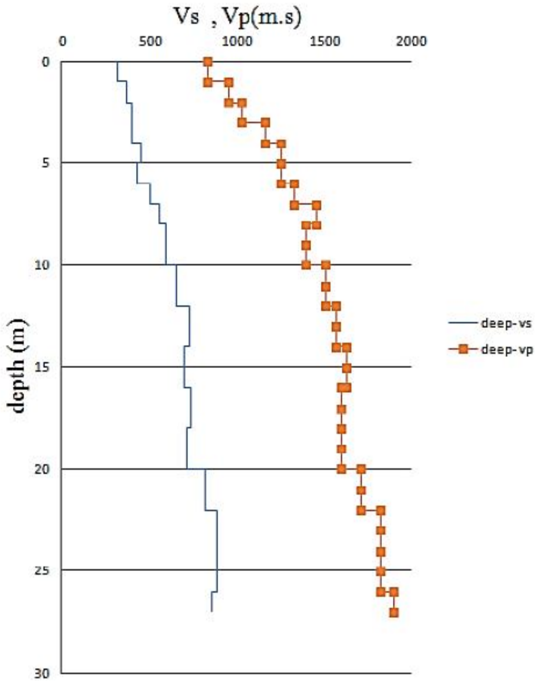


Figure 4. Pressure and Shear waves velocity in studied site

Figure 5. Scanning electron microscope

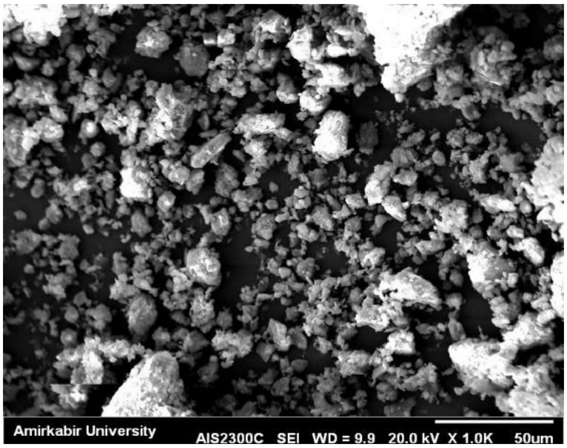


Figure 6. Microscopic photo of sample at 50 mm scale

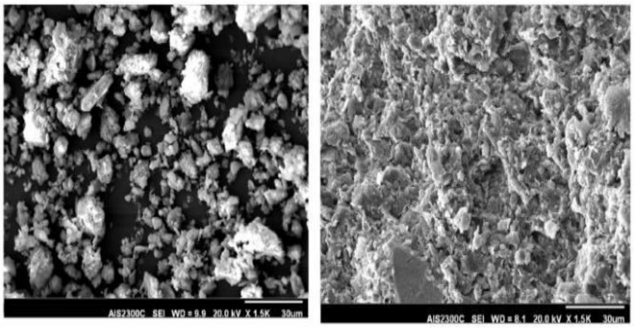


Figure 7. Microscopic photo of sample at 30 mm scale

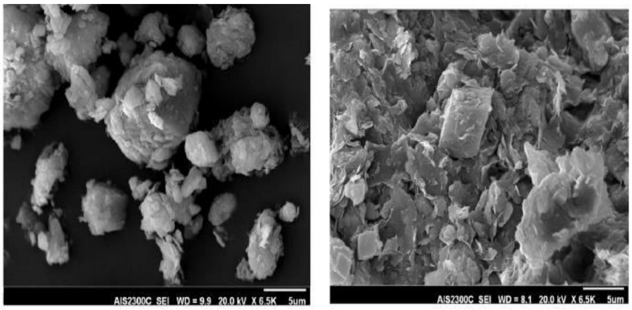


Figure 8. Microscopic photo of sample at 5 mm scale

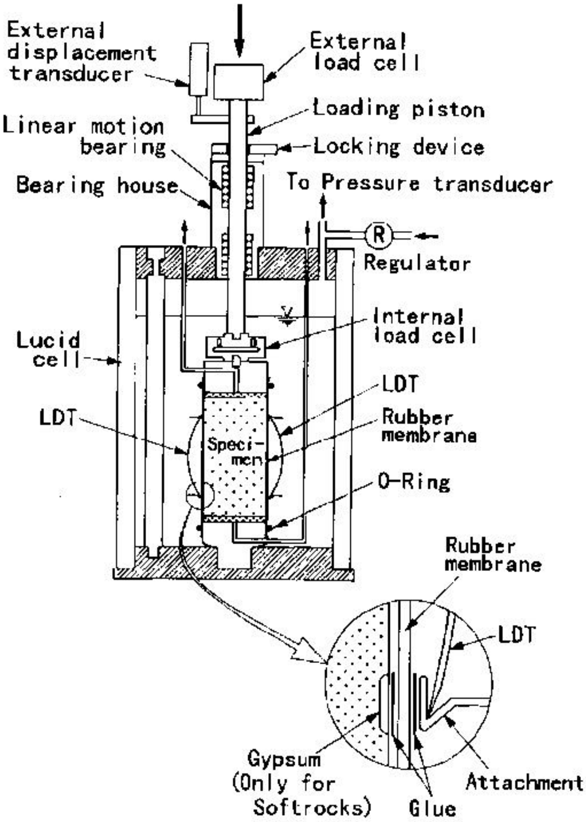


Figure 9. Cyclic triaxial Device

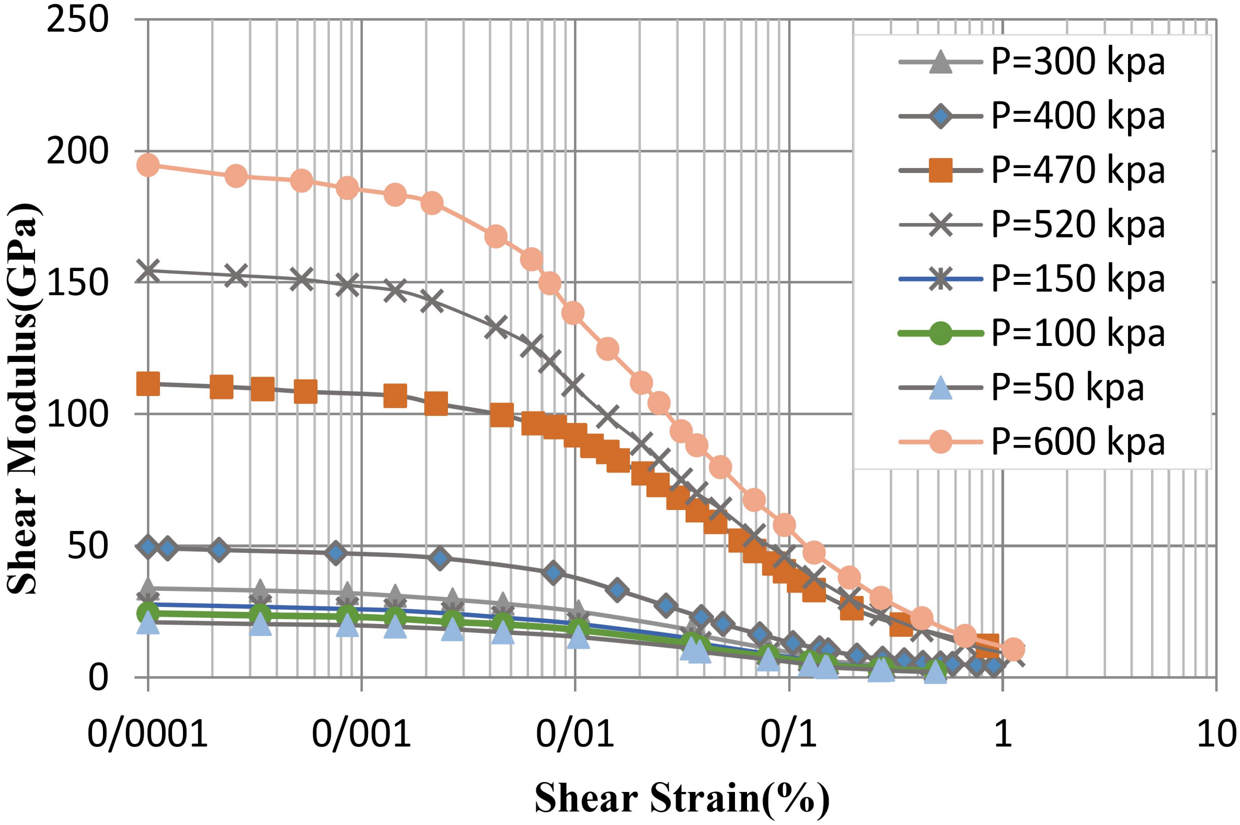


Figure 10. Shear modulus changes of the soil in different normal pressure

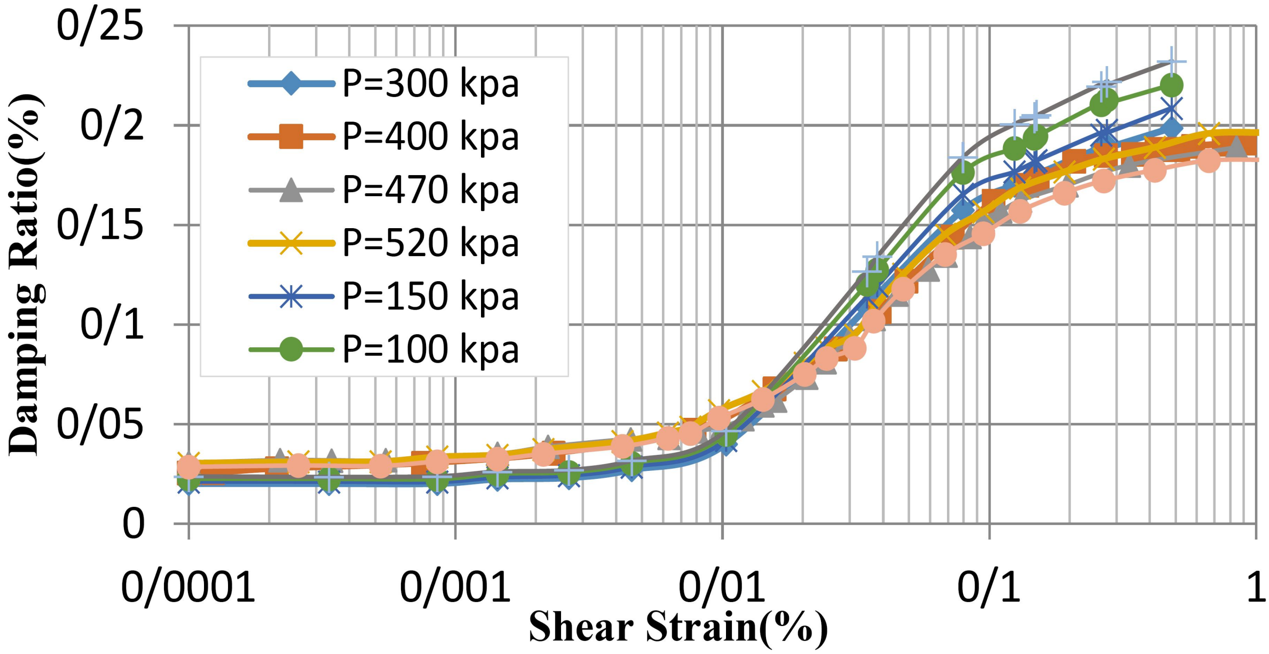
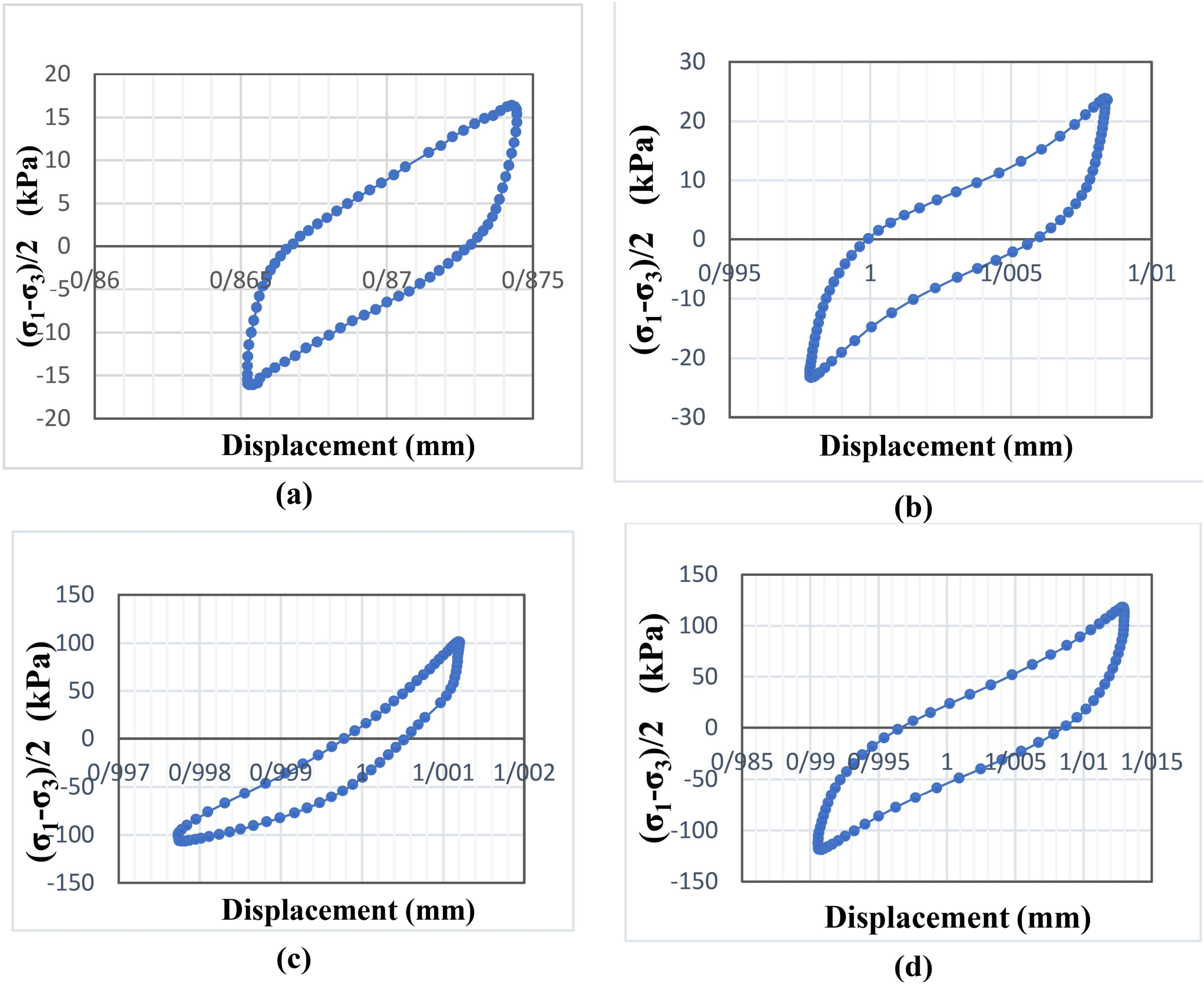


Figure 11. Damping ratio changes of the soil in different normal pressure



(a) (b) (c) (d)

Figure 12. Load-Displacement diagram based on confining pressure: (a): p=300kPa, (b): P=400 kPa, (c): P=470kPa, (d): P=520 kPa

3. Results and Discussions

3.1. Soil Properties variation with water content

The tests indicate that the resistance properties of Marly Soil are considerably dependent on moisture percentage. Figure 13 to 17 shows the changes of soil properties based on moisture percentage changes. As Fig. 13 reveals, as moisture increases, soil resistance decreases in a linear way. Soil special weight, shear resistance, and enclosing resistance also increase as moisture increases. This phenomenon might be attributed to the reduction of ionic bonding among soil components.

3.2. Examining the Consolidation Properties of Marly Soil

According to Fig.17, examining the moist changes trend on Cc index in consolidation test implies that, as the moisture percentage of Marly Soil of Shiraz city increases by 12, 15, 18, and 21%, the compression index also increases but swelling (Cs) index decreases minimally (Fig. 18). In addition, according to Fig. 19, examining the moist changes trend on porosity ration of Marly Soils of Shiraz city reveals that as moisture percentage increases, porosity rate decreases

3.3. Determination of the Cyclic Properties of Marly Soil

As the shear strain in soil increases, the shear modulus decreases. According to Fig. 21, the behavior of damping rate for lower strains and more than 1% is is slightly different. However, in general, for strains higher than 1%, increase of all-round pressure leads to decrease of damping ratio. For better comparison of shear modulus and damping ratio changes based on confined pressure, Figs. 20 and 21 show the values of these two parameters based on different enclosing pressure. As Fig. 20 reveals, for pressures of 50 to 400 kPa, as pressure increases, the soil shear modulus value also increases steadily.

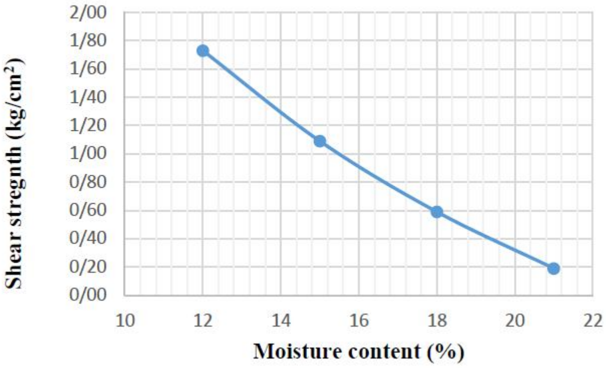


Figure 13. Shear stress changes with moisture content variation

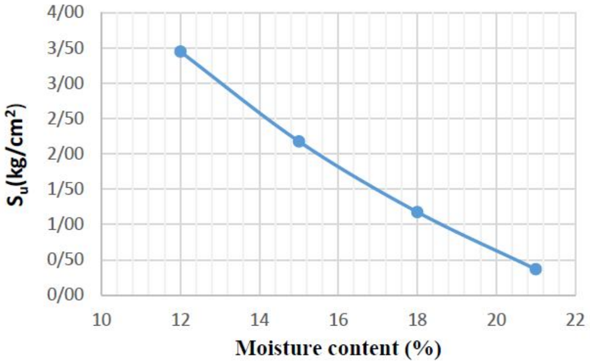


Figure 14. Unconfined pressure changes based on moisture content variation

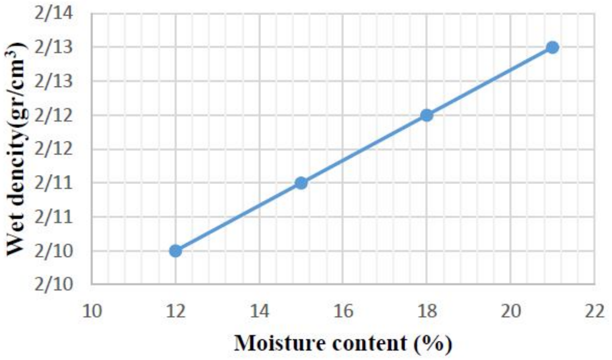


Figure 15. Density variation related on moisture content change

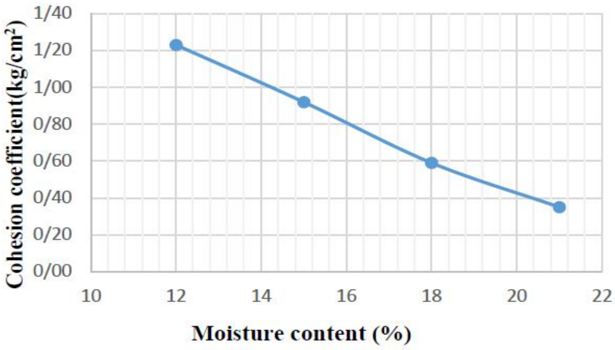


Figure 16. Cohesive coefficient variation related to difference moisture content

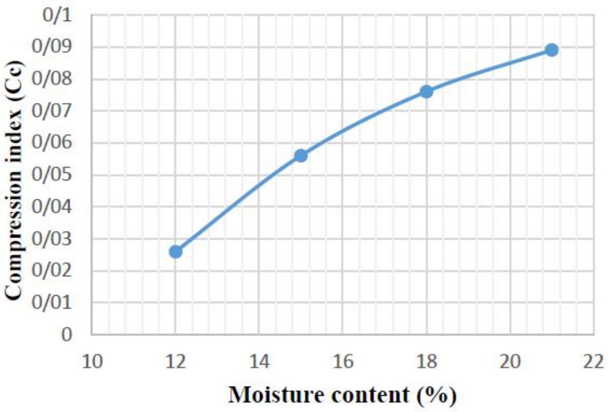


Figure 17. Compression index (Cc) changes based on moisture content variation

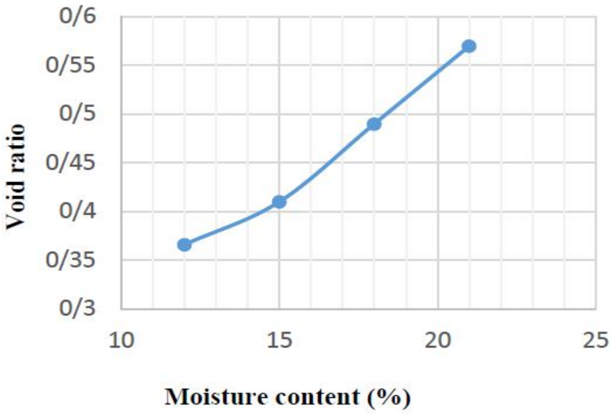


Figure 18. Void ratio changes based on moisture content variation

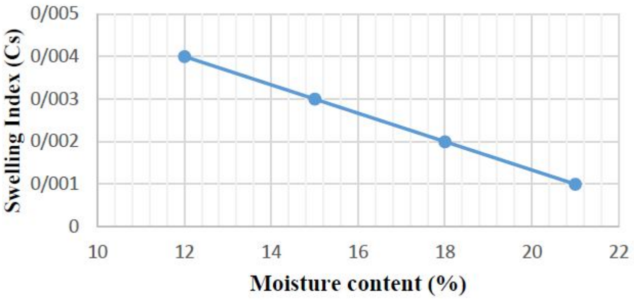


Figure 19. Swelling Index (Cs) changes based on moisture content variation

However, from 400 to 520 kPa stress, this increase occurs more considerably and then from 520 to 800 kPa stress, this increase becomes slower and more moderate. According to Fig. 21, the general trend of damping ratio is descending as confining pressure increases. To compare the obtained results for shear modulus of Marl samples in cyclic and static cases, the results obtained in the cyclic triaxial test and those of direct shear test have been compared in Table 2. This table compares the shear modulus results for three pressures of 100, 200, and 300 kPa in 1 and 10 strains. Figure 22 compares the shear modulus results of cyclic triaxial test and direct shear test for three enclosing pressures of 100, 200, and 300 kPa in 1 and 10 strains.

According to Fig. 22, the shear modulus in the cyclic and static cases increases as confining pressure increases. Additionally, the values of shear modulus in dynamic case are more than those in static case. For example, in 100 kPa, the cyclic shear modulus in 1% strain is more than that of static shear modulus by relatively 66%. Therefore, using cyclic shear modulus especially when soil is affected by high strains is more effective as it provides more accurate results in comparison with static shear modulus. As confining pressure increases, the difference degree between the two modulus decreases. In other words, in 1% strain, as confining pressure increases from 100 to 300 kPa, the cyclic shear modulus percentage change, in comparison with the static case, decreases from 66% to 27%. This decrease is even more for 10% strain.

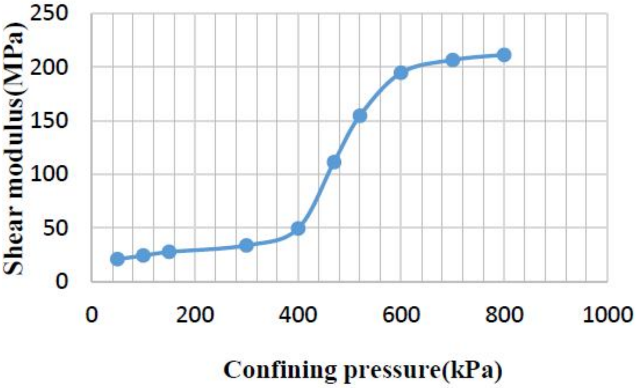


Figure 20. Dynamic shear modulus changes against confining pressure

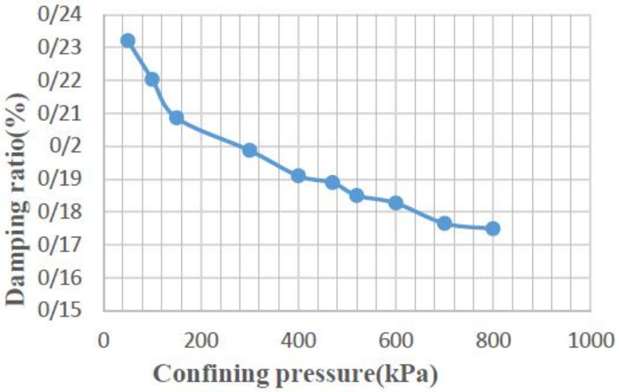


Figure 21. Damping ratio changes against confining pressure

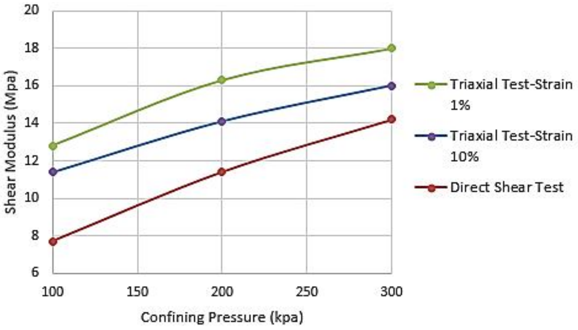


Figure 22. Comparison of shear modulus results from cyclic triaxial and direct shear test

Table 2. Static and dynamic Comparison of Shear modulus

Test	Test step 1	Test step 2	Test step 3
	(N: 100 kPa)	(N: 200 kPa)	(N: 300 kPa)
Cyclic triaxial (1% strain)	12800	16300	18000
Cyclic triaxial (10% strain)	11400	14100	16000
Direct shear	7700	11400	14200
Cyclic variation (1% strain-static)	66%	43%	27%
Cyclic variation (10% strain-static)	48%	24%	13%

4. Conclusion

Depicting the ground motion of earth in the area near the seismic source and its effects on structures performance is among the important issues to be taken into consideration in geotechnical engineering, earthquake geotechnics, structure, and earthquake engineering. Marly Soils are one of the most common types of soil which can be abundantly found in vast areas of the world. The present study dealt with the evaluating the impact of cyclic loads on geotechnical properties of Marls in the northwest of Shiraz city. The most important obtained findings were:

- Changes in moisture percentage led to a reduction in soil resistance and an increase in its deformability,
- In general, in Marly Soil, damping ratio decreases as confined pressure increases,
- In the studied Marly Soil, shear modulus increased as the confined pressure increased,
- Confined pressure increase affects the rate of settlement. In every Marly Soil composition, the finer the gradations, the higher the settlement rate,
- The rate of increasing shear modulus in cyclic case, in comparison with the static shear modulus (direct shear test), decreased as the confining pressure increased,
- Shear modulus values in cyclic manner were less than those of static case by almost 60%. The degree of this increase would rise as the shear strain increases,
- In dynamic analysis, especially when soil is under high strains, using cyclic shear modulus instead of static shear modulus are of greater importance to achieve accurate results.

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References

Ajmera B., Brandon T., Tiwari B., 2017. Influence of index properties on shape of cyclic strength curve for clay-silt mixtures. *Soil Dynamics and Earthquake Engineering*, 102: 46-55.

Azarafza M., Asghari-Kaljahi E., Moshrefy-far M.R., 2015. Effects of clay nanoparticles added to the bonab landfill soil to reduce the permeability and control of leachate. *Iranian Journal of Environmental Geology*, 8(26): 7-18 [in Persian].

Azarafza M., Ghazifard A., Asghari Kaljahi E., 2018. Effect of clay minerals on geotechnical properties of fine-grained alluviums of South Pars Special Zone (Assalouyeh). In: *Proceedings of the 36th National and the 3rd International Geosciences Congress*, Tehran, Iran, Feburary.

Beroya M., Aydin A., 2007. First-level liquefaction hazard mapping of Laoag City, Northern Philippines. *Natural Hazards*, 43(3): 415-430.

Boulanger R.W., Idriss I., 2006. Liquefaction susceptibility criteria for silts and clays. *Journal of Geotechnical and Geoenvironmental Engineering*, 132(11): 1413-1426.

Boulanger R.W., Idriss I., 2007. Evaluation of cyclic softening in silts and clays. *Journal of Geotechnical and Geoenvironmental Engineering*, 133(6): 641-652.

Hooshmand A., Aminfar M.H., Asghari E., Ahmadi H., 2012. Mechanical and physical characterization of Tabriz Marls, Iran. *Geotechnical and Geological Engineering*, 30(1): 219-232.

Kokusho T., 1980. Cyclic triaxial test of dynamic soil properties for wide strain range. *Soils and Foundations*, 20(2): 45-60.

Nagy G., Nagy L., 2019. Dispersive clays–approach, assessment, connections. In: *Proceedings of the XVII ECSMGE-2019*, Doi: 10.32075/17ECSMGE-2019-1039.

Seed H.B., Idriss, I.M., 1970. Soil moduli and damping factors for dynamic response analysis. In: *Proceedings of the*, Technical Report, California Univ., Berkeley. Earthquake Engineering Research Center.

Seed H.B., Wong R.T., Idriss I., Tokimatsu K., 1986. Moduli and damping factors for dynamic analyses of cohesionless soils. *Journal of Geotechnical Engineering*, 112(11): 1016-1032.

Sonmez H., Tunusluoglu C., 2008. New considerations on the use of block punch index for predicting the uniaxial compressive strength of rock material. *International Journal of Rock Mechanics and Mining Sciences*, 45(6): 1007-1014.

Terzaghi K., 1925. Principles of Soil Mechanics. *Engineering News-Record*, 95(19-27): 19-32.

Ulusay R., Gokceoglu C., Sulukcu S., 2001. Draft ISRM suggested method for determining block punch strength index (BPI). *International Journal of Rock Mechanics and Mining Sciences*, 38(8), 1113-1119.

Van der Schrier J., 1988. The block punch index test. *International Association of Engineering Geology-Bulletin*, 38(1): 121-126.

Vucetic M., Dobry R., 1991. Effect of soil plasticity on cyclic response. *Journal of Geotechnical Engineering*, 117(1): 89-107.

Wang S., Luna R., Zhao H., 2015. Cyclic and post-cyclic shear behavior of low-plasticity silt with varying clay content. *Soil Dynamics and Earthquake Engineering*, 75: 112-120.

Weissmann G., Hart R., 1962. The damping capacity of some granular soils. In: *Proceedings of the Symposium on Soil Dynamics*, ASTM International, West Conshohocken, PA, USA.

Yılmaz M., Pekcan O., Bakır B., 2004. Undrained cyclic shear and deformation behavior of silt–clay mixtures of Adapazarı, Turkey. *Soil Dynamics and Earthquake Engineering,* 24(7): 497-507.

Zhang L., 2016. Engineering properties of rocks. Butterworth-Heinemann, Oxford, 394 p.