An Experimental Comparison Between Static and Dynamic Behavior of Mixed Clay Core of Haraz Earth Dam

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Abstract

The response of Mixed clay materials to cyclic loading is less investigated compared to cohesive fine grained or cohesionless coarse grained soils. The aim of this paper is to study and compare static and dynamic behavior of mixed clay soils. In order that static and cyclic triaxial tests were conducted on mixed clay samples of core materials of Haraz earth dam. Another static triaxial test with 5 stages of loading and unloading were performed to compare modulus reduction and damping ratio obtained from these tests with real cyclic triaxial tests. The stress strain behavior of soil samples under static and cyclic tests arecompared. Although the results show relatively good agreement between normalized shear modulus obtained from cyclic triaxial and static tests, the damping ratio obtained from these two type of tests are not in accordance to each other.

Keywords: Shear modulus reduction, Damping ratio, Cyclic triaxial test, Mixed clay materials.

1. INTRODUCTION

The response of soil to cyclic loading has long been studied. However the role played by the soil in the transmission, dissipation and modification of vibrations is still little understood specially for mixed clay (clayey gravelly)soils. The normalized modulus (G/G0) and damping ratio (D) are the key parameters necessary to describe the dynamic behavior of soil.The relationship between shear modulus and shear strain and also the relationship between stress strain hysteresis loop for every cycle of loading and damping ratio is illustrated in Figure 1.

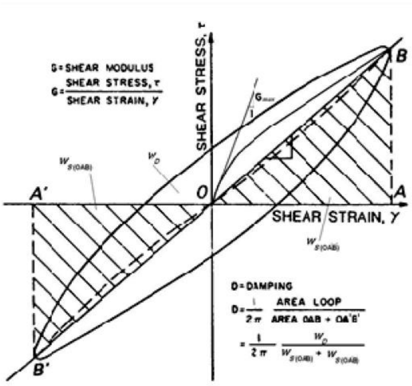


Figure 1.Typical hysteresis loop generated by cyclic loading

The secant young modulus (E) for a given hysteresis loop is evaluated from following equation:

$$E = \frac{\Delta \sigma d}{\varepsilon} \tag{1}$$

The shear modulus is then calculated knowing poison ratio from the following equation:

$$G = \frac{E}{2(1+\mu)} \tag{2}$$

The damping of soil which is representing consumed energy on every cycle will be evaluated from Kelvin-Voigt equations as following:

$$\zeta = \frac{1}{2\pi} \cdot \frac{A_{loop}}{A_t(OAB + OA'B')} \tag{3}$$

Too many studies have been performed in order to determine factors that affects foregoing parameters for different soils. Based on works by various researchers and investigators many factors including mineralogical composition, dry density, grain size distribution, drainage condition, moisture content, confining pressure, stress induced isotropy, strength, size and shape of particles, loading frequency and wave forms affect the dynamic parameters of a soil. shear strain, effective confining pressure and loading frequency are considered as the most important factors by AghaeiAraei et al (2012). Hardin and Drenvich (1972) on the other hand concluded from experimental studies that the primary factors affecting the stiffness and damping ratio of a dry sand are: strain amplitude, mean effective principal stress, void ratios and number of strain cycles. They concluded that the frequency of vibration has no effect on above mentioned dynamic parameters. Bolton and Wilson (1989) by comparing static and dynamic torsional tests on dry sands showed that the behavior of the soil is independent of the frequency of applied load.

In the early years of geotechnical earthquake engineering, the shear modulus behavior of coarse and fine-grained soils were treated separately as presented by Seed and Idriss (1970). Next researches however, has revealed a gradual transition between the shear modulus behavior of nonplastic coarse and plastic fine grained soils.(Kokoshu et al 1982). Vucetic and Dobry (1991) and Sun et al., (1988) concluded that the shape of the modulus reduction curve is influenced more by the plasticity index than by void ratio. Modulus reduction behavior is also influenced by effective confining pressure particularly for soils of low plasticity based on studies by Iwasaki et al., (1977) and Kokoshu et al., (1982). The effects of effective confining pressure and plasticity index on modulus reduction behavior were combined byIshibashi and Zhang (1993) in the form of following equation:

$$\frac{G}{G_{max}} = K(\gamma, PI)(\sigma_m)^{m(\gamma,PI)-m_0} \tag{4}$$

$K(\gamma, \mathrm{PI})$and$m(\gamma, \mathrm{PI})$ in the above equation are functions of shear strain and plasticity. The details of the above mentioned equation and relevant parameters are discussed more by Kramer.

As modulus reduction behavior is influenced by plasticity characteristics, so is damping behavior (Kokoshu et al., 1982 ;Vucetic and dobry ,1991 ; Sun et al., 1988). It means that the damping ratio curves suggested by Vucetic and Dobry (1991) for different plasticity index can be applied to both fine and coarse grained soils. As modulus reduction curve, damping behavior is also influenced by effective confining pressure particularly for soils of low plasticity (Ishibashi and Zhang,1993).

In this study pseudo static triaxial test including stages of loading and unloading and cyclic triaxial tests were conducted on mixed clay samples in order to compare normalized shear modulus and damping ratio obtained from static tests with real cyclic triaxial tests. The stress strain behavior of soil samples under static and cyclic tests is also compared. Meanwhile the modulus reduction and damping ratio behavior of mixed clay sample are studied and discussed.

2. MATERIAL AND TEST METHOD

In this study experimental studies including static, pseudo static and cyclic triaxial tests are performed on clayey gravelly samples prepared from core materials of under construction Haraz earthfill dam located in North of Iran. The gradation curve of the sample which is modified considering diameter of triaxial specimen (6 inch) by cut and replace method is shown in Figure 2. the specimen is constructed with water content equal to 2 percent higher than optimum water content and related dry density obtained according to standard proctor test (ASTM 1556) which were modified for oversize percentage according to ASTM 4718.

Liquid limit and plasticity index of the mixed clay sample are 30 and 12 respectively. Maximum dry density and water content of the sample before triaxial tests are 2.06 gr/Cm^3 and 11% respectively.

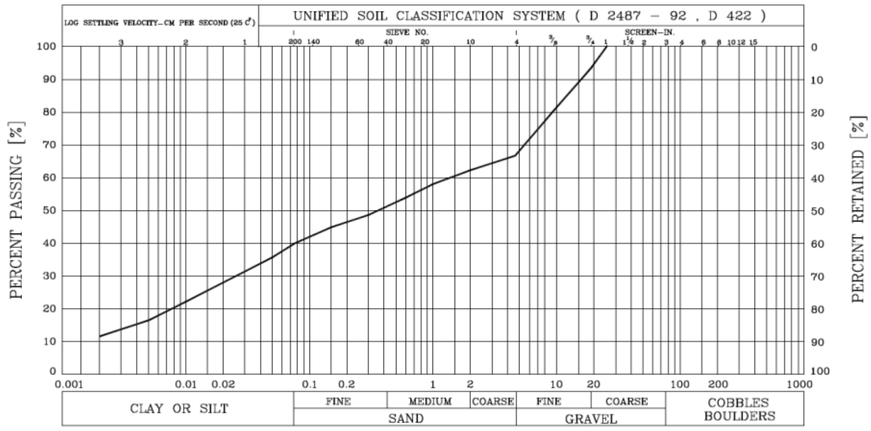


Figure 2. Grain size distribution of tested sample

Triaxial tests were carried out using triaxial apparatus on cylindrical samples of 6 inchdiameter and 12 inchheight. The specimens were prepared to desired water content and dry density. Static triaxial tests were carried out according to ASTM 7181. Saturation was achieved by back pressurization technique obtaining Skempton B value greater than 95 percent. The specimens were then subjected to the required consolidation pressures 1, 3 and 8 Kg/Cm^2.

Pseudo static triaxial tests were also performed on the same samples. The test method and procedure are the same as static triaxial tests except that during shear phase of the test, and at the stress level equal to about 80 percent of failure, 5 cycles of loading and unloading are carried out. Theaim of performing pseudo static triaxial tests are to compare shear modulus and damping obtained from static loading tests with high frequency cyclic triaxial loading test.

Cyclic triaxial tests were performed according to ASTM D3999. The samples were tested in consolidated undrained condition with A method (load control) at a frequency of 1 Hz. In order to avoid failure of specimens in extension, one-way compression cyclic loading applied to the specimens in order to study the behavior of the soil in higher stress levels. In order to develop a curve of modulus and damping versus strain, progressively increasing levels of cyclic load should be applied to the specimens. And at each stage of cyclic load, test sequences were applied according to the standards.

3. TEST RESULTS

The shear modulus and the damping ratio variations with shear strain are calculated based on stress strain hysteresis loop for all loading cycles according to ASTM D3999. The variations of shear modulus and damping ratio with cyclic shear strain are then obtained. Besides cyclic triaxial tests, the shear modulus and damping are calculated from cycles of pseudo static triaxial tests and compared with cyclic tests.The stress-strain behavior of mixed clay samples under static, pseudo static and cyclic loadings are also studied.

3.1 NORMALIZED SHEAR MODULUS

The variation of normalized shear modulus of samples with cyclic shear strain obtained from cyclic triaxial tests are shown in Figure 3. The test results for different confining pressure (100, 300 and 800 Kpa) are presented in this figure. The curve suggested by Ishibashi and Zhang (1993) for soils with plasticity index of 12 (as the tested sample) for confining pressure equal to100 Kpa is also shown. The range suggested by Seed et al., (1984) forgravelly soil is also presented in figure 3. As seen, the results of the tests are located inside the range suggested by Seed for Gravelly soils. On the other hand, there is considerable difference between the obtained results with the relation suggested by Ishibashi and Zhang for cohesive soil (PI=12). The relation suggested by one of the authors of this paper for mixed clay(clayey gravel) material of Gotvand earthfill dam is also presented in figure 3. As seen, there is a relatively good agreement between the results of this study with relation suggested for Gotvand materials. So it seems that the normalized shear modulus behavior of mixed clay materials could be defined in the range suggested for Gravelly soils and considerably differ with the results of pure clay materials. More details about Gotvand mixed clay materials specifications, test procedure etc. are presented in Salehi[16].

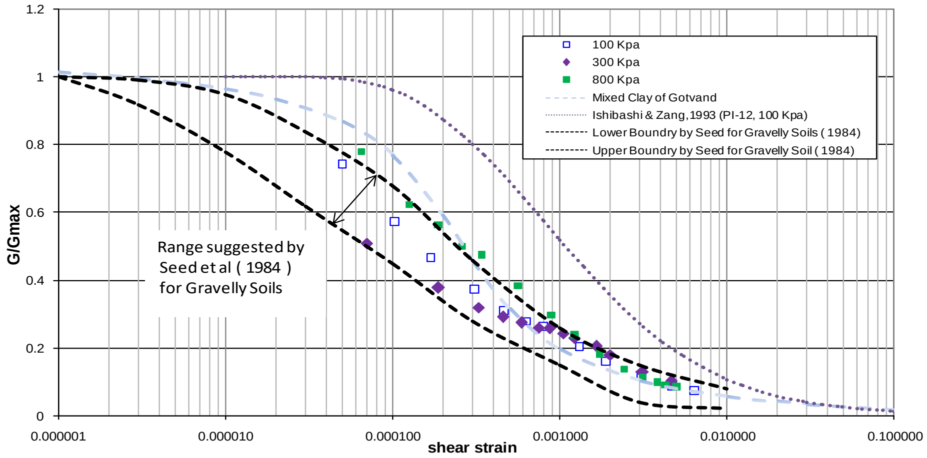


Figure 3.Results of normalized shear modulus

3.2 Damping Ratio

Figure 4 shows the results ofdamping ratio of mixed clay samples obtained from cyclic triaxial tests. The test results for different confining pressure (100, 300 and 800 Kpa) are presented along withthe range suggested by Seed et al., (1970) for gravelly soils and sands. The curve suggested by Ishibashi and Zhang (1993) for soils with plasticity index of 12 (as the tested sample) for confining pressure equal to100 Kpa is also shown in this figure. As normalized modulus behavior, damping ratio of tested samples are mostly in the range suggested by Seed for Gravelly soils and sands. It should be mentioned that in cyclic triaxial tests bedding error and system compliance effects generally limit measurements to shear strain greater than about 0.01% (Kramer, 1996). Many experimental experiences have also revealed that the results of cyclic triaxial tests at cyclic shear strain lower than about 0.05% is not reliable enough and low strain element tests such as resonant column are suggested to measure low strain properties of soils. As an appropriate low strain test is not performed in this study, it should be noticed that measured properties lower than about 0.05% might not be reliable. The relation suggested for mixed clay (clayey gravel) material of Gotvand earthfill dam is also presented in figure 4. But unlike normalized modulus behavior, the results of damping ratio for tested samples is considerably different from the relation suggested for Gotvand mixed clay material.

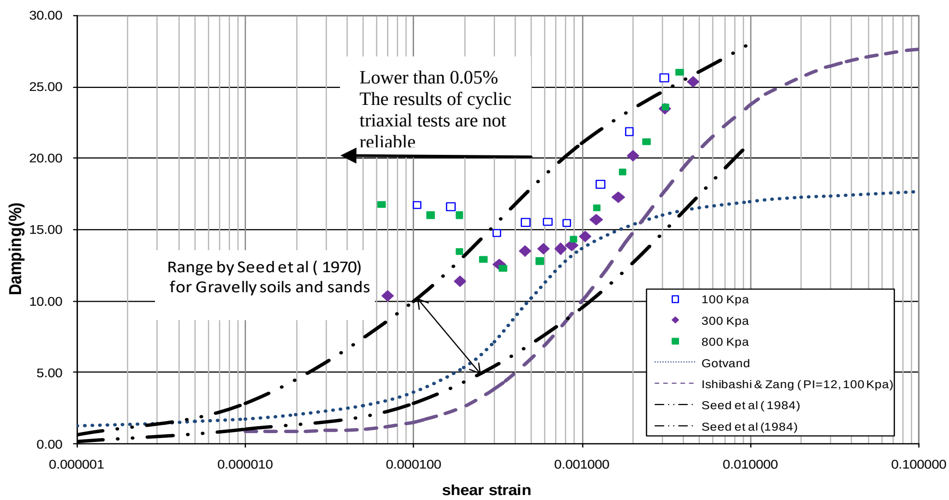


Figure 4.Results of damping ratio

4. COMPARISON OF CYCLIC AND STATIC TESTS

4.1 STRESS STRAIN BEHAVIOR

The stress-strain behavior of mixed clay samples under static and cyclic loadings are shown in Figure 5. As shown, at small strains, the initial modulus of the sample under cyclic loading is considerably higher than staticloadings. The ratio of cyclic to static shear strength of the sample decrease with increasing confining pressure. As seen, at confining pressure of 100, 300 and 800 Kpa, the ratio of cyclic to static shear strength is respectively more than, equal and less than unity.The differences between stress-strain behavior of samples might be partly related to drained and undrained loadings in static and cyclic tests, althoughdeviatoric stressremains constant in both conditions.

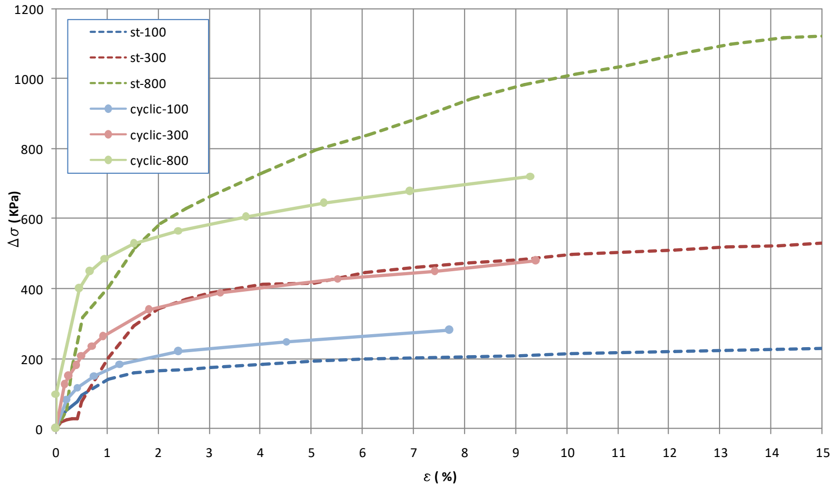


Figure 5.Stress Strain behavior of samples under staticand cyclic tests.

Effective Shear strength parameters of mixed clay samples are evaluated based on static and cyclic triaxial tests and are shown as p'-q function in Figure 6. It should be noticed that effective parameters were evaluated measuring pore pressure during cyclic test. As seen, the drained cohesion of soil derived from cyclic test are more in comparison with static test which means higher shear strength of cyclic sample for low stress level. The drained friction angle of the soil sample on the other hand, under cyclic condition is less than static condition.The results of effective shear strength parameters under static and cyclic conditions are presented in Table 1.

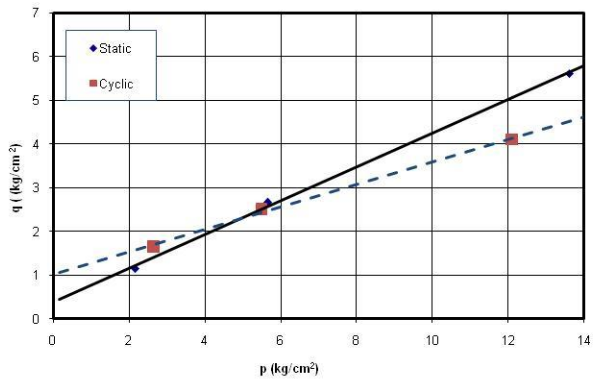
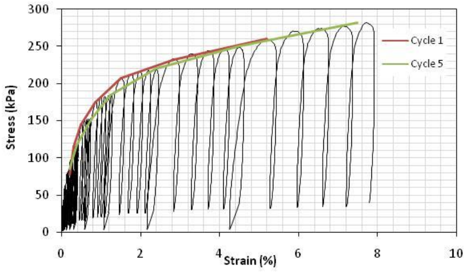


Figure 6.p'-q relationship for static and cyclic condition

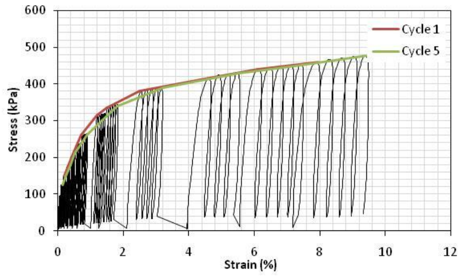
Table 1- Effective shear strength parameters obtained from static and cyclic triaxial tests

	Cohesion (Kg/ Cm2)	Friction angle
Static	0.4	22.7
Cyclic	1.0	13.5

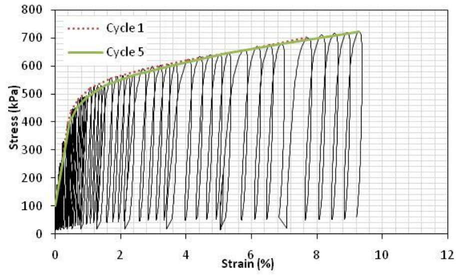
The cyclic stress strain behavior of the sample in different confining pressure is shown in Figure 7 with failure envelope on 1st and 5th cycle of loading. As seen, for the mixed clay sample which is tested, there is no considerable difference between failure envelope in 1st and 5th cycle and a unique failure envelope could be considered in all loading cycles.



(a)



(b)



(c)

Figure 7.Cyclic stress-strain behavior for confining pressures of (a)100 (b)300 and (c)800 Kpa

4.2 Shear Modulus and Damping Ratio

The results of normalized shear stress and damping ratio obtained from cyclic and pseudo static tests are shown in figure 8 and 9 respectively. The fitted relation to the cyclic test results is also presented in this figure. The results of normalized shear modulus obtained from cyclic tests have a good agreement with results of pseudo static tests. The fitted curve to cyclic test results could be also defined as an appropriate relation to results of pseudo static test. So it can be interpreted that the frequency or shape of the loading has not considerable effect on normalized shear stress modulus of mixed clay sample in this study.

The results of damping ratio obtained from pseudo static tests, on the other hand, are considerably different from the results of cyclic tests as shown in figure9 and there is not an acceptable agreement between tamping ratio obtained from cyclic and pseudo static tests.

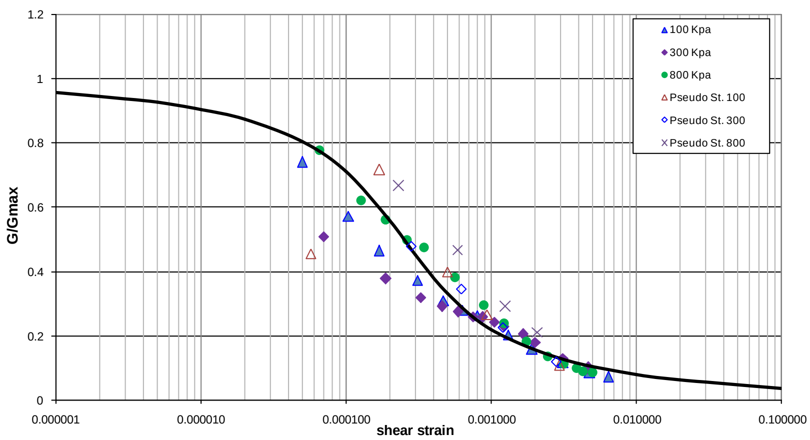


Figure 8.Normalized shear modulus obtained from cyclic and pseudo static tests

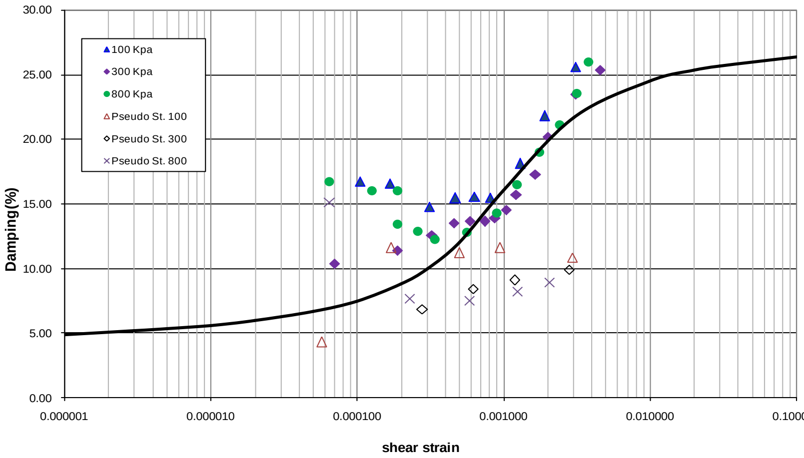
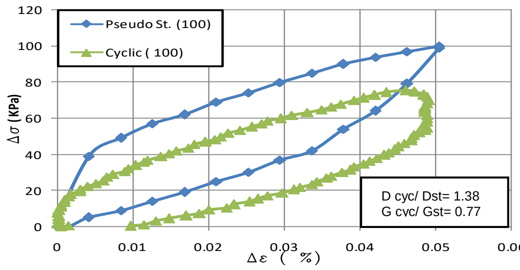
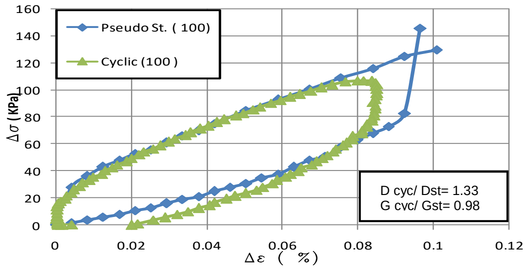


Figure 9.Damping ratio obtained from cyclic and pseudo static tests

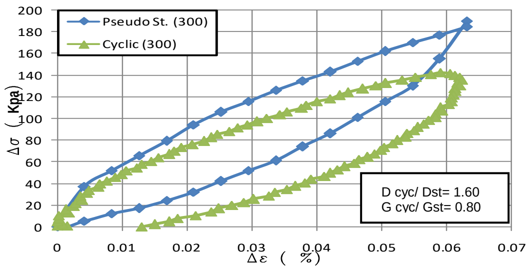
In order to have a better understanding, loops created by loading and unloading in the pseudo static test compare with hysteresis loop obtained in cyclic triaxial test. In most of strain amplitudes, the inclination of loops created in both tests which describe shear modulus of the samplesare considerably near to each other. The width of created loops which represent damping ratio in cyclic tests are bigger than pseudo static tests. It should be noticed as the cyclic triaxial tests are performed in undrainedcondition, some parts of damping in cyclic testsare influenced by plastic characteristics.The comparison between shear modulus and damping ratio obtained from cyclic and pseudo static tests and the created loopsin both tests are shown for some strain amplitudes in Figure 10.



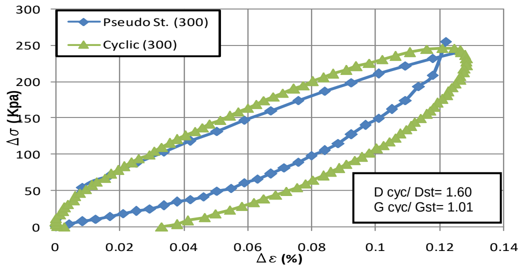
(a) σ_3= 100 Kpa, ε= 0.05%



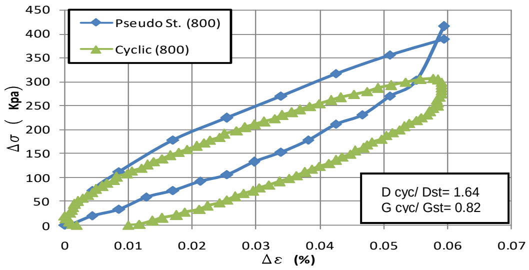
(b) σ_3= 100 Kpa, ε= 0.09%



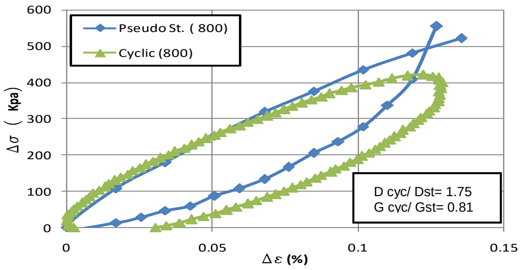
(c) σ_3= 300 Kpa, ε= 0.062%



(d) σ_3= 300 Kpa, ε= 0.12%



(e) σ_3= 300 Kpa, ε= 0.060%



(f) σ_3= 300 Kpa, ε= 0.125%

Figure 10. Comparison between loops created in cyclic and pseudo static tests in different strain amplitude

5. CONCLUSIONS

- In this study normalized shear modulus and damping ratio behavior of mixed clay materials were studied.According to the results of this study, the normalized shear modulus behavior of mixed clay materials could be defined in the range suggested for Gravelly soils by Seed et. Al., (1970) and considerably differ with the results of pure clay materials. There is also a relatively good agreement between the results of this study with relation suggested for Gotvand mixed clay materials by one of the authors of this study.

- As normalized modulus behavior, damping ratio of tested samples are mostly in the range suggested by Seed et. Al., (1970) for Gravelly soils and sands at strain level greater than about 0.05%.

-Comparison between shear strength parameters obtained from static and cyclic tests show that the cohesion of mixed clay sample derived from cyclic tests are more than static tests, while friction angle of the sample in cyclic tests is less than static tests. The initial modulus of the sample under cyclic loading is considerably higher than static loadings. The ratio of cyclic to static shear strength of the sample decrease with increasing confining pressure.

- Pseudo static triaxial tests including 5stages of loading and unloading were also conducted on mixed clay samples in order to compare normalized shear modulus and damping ratio obtained from static tests with real cyclic triaxial tests. The results of normalized shear modulus (G/G_0) obtained from cyclic tests have a good agreement with results of pseudo static tests. The fitted curve to cyclic test results could be also defined as an appropriate relation to results of pseudo static test. It can be concluded from this study that the frequency or shape of the loading has not considerable effect on normalized shear modulus of mixed clay sample. The results of damping ratio obtained from pseudo static tests, on the other hand, are considerably different from the results of cyclic tests and there is not an acceptable agreement between damping ratio obtained from cyclic and pseudo static tests.

- In this study, one-way compression cyclic loading applied to the specimens in order to study the behavior of the soil in higher stress levels and prevent failure of the sample in extension. The results show a relative good agreement between the normalized shear modulus evaluated in this study with the results obtained from famous traditional sinusoidal loading on approximately similar sample in the other study(salehi,2018). So it could be concluded that the shape and frequency of loading may not have considerable effect on normalizedshear modulus. According to the results of this study, the above conclusion could not be applied for damping ratio.

6. ACKNOWLEDGMENT

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