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DETERMINATION OF SHEAR MODULUS (G_0) OF A CALCAREOUS SOIL BY MEANS OF SCPTU AND RESONANT COLUMN TESTS

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ABSTRACT

Cone Penetrating Test equipment with ability to measure pore pressure and seismic parameters is called “Seismic Piezocone” or “SCPTu”. It is one of the newest in-situ test devices in geotechnical practices. This device together with resonant column test apparatus are employed to measure small strain shear modulus (G_0) of sandy and clayey calcareous soils of southern Iran. The results are compared to some existing data. A comparison between G_0 by means of seismic wave measurement and resonant column test indicated a meaningful effect of sample disturbance. Comparing to the existing data, it seems that the disturbance effect is considerable for the studied soils. In general, in laboratory tests loose samples tend to become denser and therefore exhibit greater stiffness whereas dense samples tend to be loosen, showing a reduction in stiffness. Correlation of q_c of SCPTu test with shear velocity for two types of calcareous soils of the studied area are presented.

Keywords: Calcareous soil, Seismic Piezocone (SCPTu), Resonant Column, Maximum Shear Module,

INTRODUCTION

Proper design and construction of foundations and earth structures require a good knowledge of the mechanical behavior of soil and its spatial variation. Such information can be obtained from appropriate laboratory and in-situ testing programs. In-situ tests can often be preferable to laboratory tests because of important advantages such as cost-time effectiveness, the ability to assess the soil in its natural environment and the possibility to estimate the spatial variability of the deposit.

Among the vast number of in-situ devices, the static cone penetrometer (CPT) and the seismic piezocone (SCPTu) represent the most versatile tools currently available for soil exploration. The cone penetration and piezocone tests provide continuous sounding capability and good repeatability. They can also be run very cost- effectively.

An extensive site investigation has been conducted at southern coasts of Iran, adjacent to Persian Gulf. It included a series of in-situ and laboratory tests such as: SPT, CPT, SCPTu, Dynamic Probe tests, Pressuremeter tests, Vane Shear tests, Particle Size Distribution, Direct Shear tests, Consolidation tests, Resonant Column tests, Cyclic Tri-axial tests and Chemical tests. In this paper, the result of SCPTu and resonant column tests are considered and maximum shear modulus determined by these results (G_0) is evaluated.

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SITE DESCRIPTION

Location

As it is shown in figure 1 the study area was in southern coasts of Iran at Persian Gulf area. There are many engineering projects going on in this region. In particular existence of calcareous soils in this area requires special attention. Since the area is a seismically active, determination of dynamic soil parameters is of great importance.

Figure 1. Site Location

Soil type

The ultimate depth that seismic piezocone tests were performed was 20 m. For depth from 0.0 to 3.0m, there is an overburden layer which include silty sand with gravel. The medium dense silty and clayey sand is observed from 3.0 to 10.0m. Soft to firm silty clay is determined for depth from 10.0 to 20.0m. Soil classification based on grain size analysis and other physical tests showed that the soil types for these three layers are SM, CL and ML respectively. There are some evidences obtained from other tests that the soil lying in all depths is calcareous soil.

As a part of an engineering project for all of these layers, seismic piezocone and resonant column tests have been conducted. Figure2 shows the soil classification based on CPT results using the method proposed by Rabertson (1986). Acceptable agreement between this method and grain size analysis for distinguishing soil type is obvious.

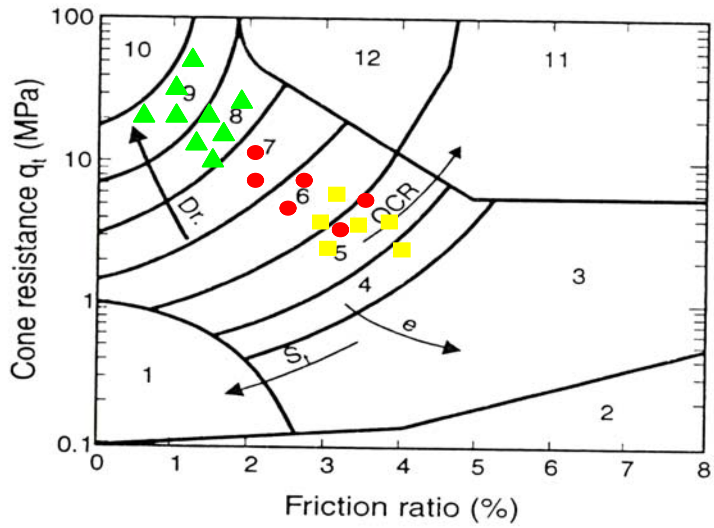
TESTS DESCRIPTION

The aim of this study is to compare the results of seismic piezocone as a field test and resonant column as a laboratory test to study sample disturbance of calcareous soils and achieve a correlation between SCPTu and resonant column results.

Only a limited number of laboratory tests are suitable to determine the properties of soils at low strain levels. These include resonant column test, ultrasonic pulse test and bender element test. Low-strain tests generally operate at strain levels that are not large enough to induce significant nonlinear stress-strain behavior in the soil, typically at shear strains below about 0.001%. Both employed tests i.e. SCPTu and resonant column tests are briefly explained here

Resonant column test

The resonant column test is the most commonly used laboratory test for measuring the low-strain properties of soils. This test allows stiffness and damping characteristics to be measured under controlled conditions. The effects of effective confining pressure, strain amplitude, and time can readily be investigated. However, measurement of pore water pressure is difficult, and the material properties are usually measured at frequencies above those of most earthquake motions. In fact this test is a dynamic test. Figure 3 shows a typical test results obtained from resonant column test.



Zone: Soil Behavior Type:

1- Sensitive fine grained
2- Organic material
3- Clay
4- Silty clay to clay
5- Clayey silt to silty clay
6- Sandy silt to clayey silt
7- Silty sand to sandy silt
8- Sand to silty sand
9- Sand
10- Gravelly sand to sand
11- Very stiff fine grained
12- Sand to clayey sand*

SM ML CL

* over consolidated or cemented

Figure 2. Soil classification using Rabertson's method

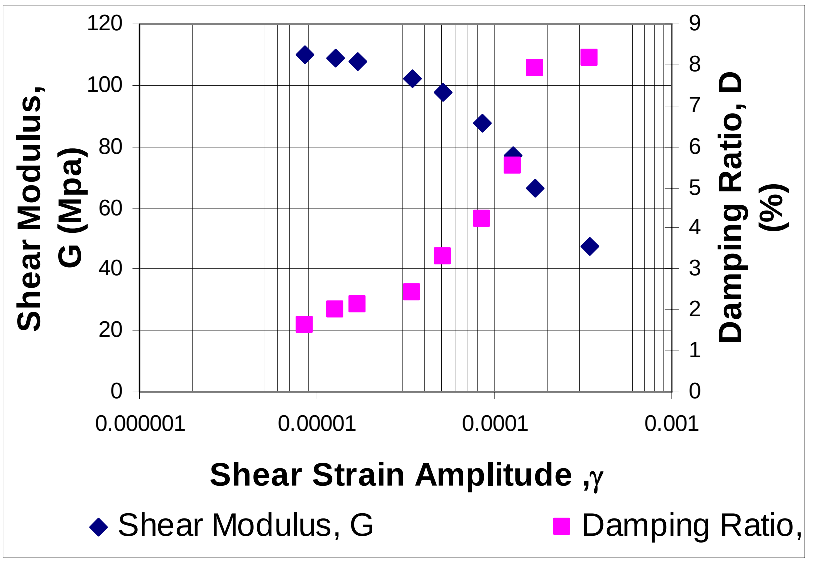


Figure 3. Typical results of resonant column test

Seismic Piezocone (SCPTu)

In Cone penetration Test (CPT), a cone at the end of a series of rods is pushed into the ground at a constant rate (20 mm/sec) and continuous measurements are made of the resistance to penetration of the cone. Measurements are also made on the outer surface of a surface sleeve and also on pore pressure that is generated during the pushing of the cone. The total force acting on the cone (Q_C) divided by the projected area of the cone (A_C) produces the cone resistance (q_C). The total force acting on the friction sleeve (F_S) divided by the surface area of the friction sleeve (AS) produces the sleeve friction (f_S).

Seismic Piezocone (SCPTu) that is used in this study is able to measures compression (P) and shear (S) waves velocities. The used device is a modern version of the seismic cone that consists of a piezocone unit with a wave receiver above it. One example where the receiver is a miniature velocity seismometer that is used in this study and is shown in Fig.4. A schematic diagram with the layout of the standard technique using a seismic cone and the operation of the conducted tests are shown in Fig.5. The shear wave is generated by hitting the beam-ends horizontally with the hammer in the direction of the long axis. Normally the seismic cone penetrometer is pushed into the ground and penetration is stopped at 1 m intervals. During the pause in penetration, a shear wave is generated at the ground surface and the time required for the shear wave to reach the seismometer in the cone penetrometer is recorded. Using the measured data shear wave velocity can be estimated. Elastic theory relates the small strain shear modulus (G_0) and shear wave velocity Vs as below:

$$G_0 = \rho (V_s)^2 \qquad (1)$$

Where, ρ is the soil mass density of soil.

The small strain shear modulus is an essential input for prediction of ground-surface motions from earthquake excitation.

According to the above explanation the a series of seismic tests were conducted on calcareous soil of the study area. The estimated G0s are presented in Fig6.

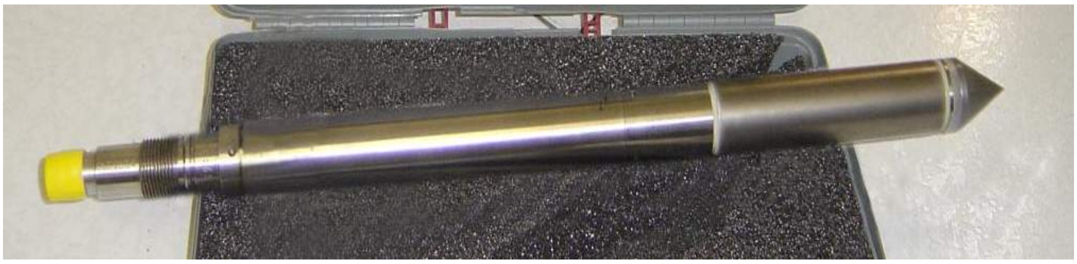


Figure 4. Seismic cone used in this study

Figure 5. Principles of the seismic cone survey technique [1]

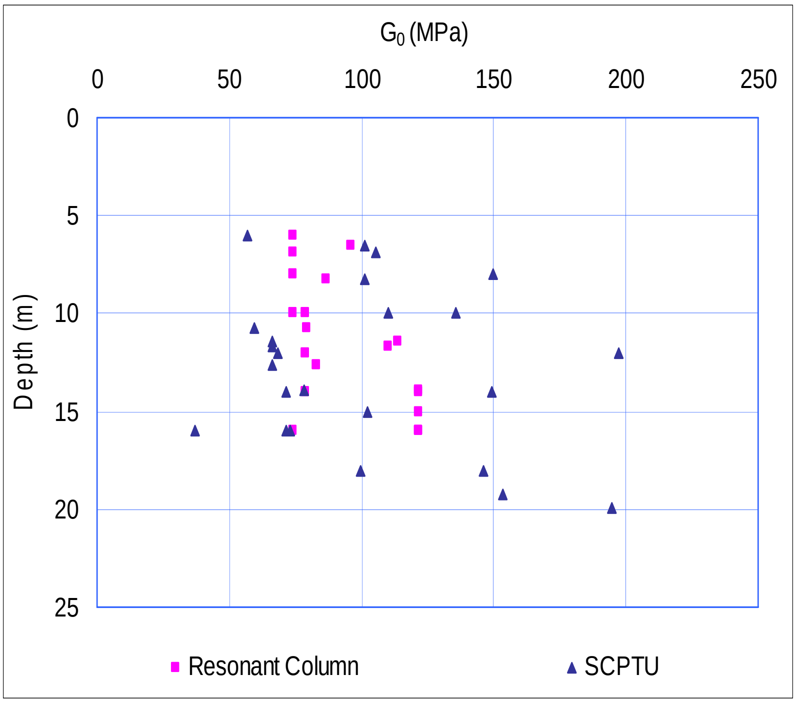


Figure 6. Variation with depth of shear modulus at small strain amplitude determined by SCPTU and resonant column test

COMPARISON OF G_0 MEASURED BY SCPTU AND RESONANT COLUMN TESTS

In this part small strain shear modulus that is obtained by means of resonant column tests and seismic SCPTu tests are compared to each other. Moreover the data of the current study is compared to the data presented by Yasuda & Yamaguchi (1985) who compiled a profusion of test data to provide diagrams in which the ratio between the laboratory-determined and in-situ measured shear modulus is plotted versus the shear modulus determined from the in-situ velocity logging. Fig 7 is the similar plot that represents the data of this study together with those of Yasuda & Yamaguchi. The presented data in this figure belongs to the SM sandy soil. Fig.7 shows a general tendency of the laboratory-obtained shear modulus to decrease as the stiffness of the sand becomes greater. From the Fig.7, it may be argued that for Yasuda & Yamaguchi curve for lower range of in-situ G_0 (30-50 MPa) the ratio of G_{0L}/G_{0F} is greater than 1.0. This shows that for the soil with lower stiffness G_{0L} is greater than G_{0F} that indicated the effect of some factors such as sample disturbance. As it can be seen in this figure for hardest soil sample disturbance could cause reduction in G0L in laboratory tests It is interesting that the changing point of the ratio of G_{0L}/G_{0F} for the data of the current study is almost 70-100 MPa. In general, loose samples tend to become more dense thereby exhibiting greater stiffness and dense samples to loosen showing a reduction in stiffness. The soil that is observed in this study is calcareous soil. Therefore, for the studied SM soil it seems there is more disturbance effect than that of Yasuda & Yamaguchi's soil. The other reason may be considered is that the soil of this site is more sensitive than Yasuda & Yamaguchi's one.

In another set of data Yokota et al. (1985) presented their results for silty and clay deposits as shown in Fig 8. This figure shows a comparison of the shear module between in-situ and laboratory values for clay and sandy soils. G_{0F} and G_{0L} indicate the shear module determined in the field and in the laboratory tests, respectively.

According to Fig.8 and Yokota's results, for soils with small shear module, it may be seen that the resonant column test tends to yield approximately the modulus values as those obtained in the field by the use of SCPTu test. This limit is about 40 MPa for clayey deposits and 60 MPa for sandy deposits.

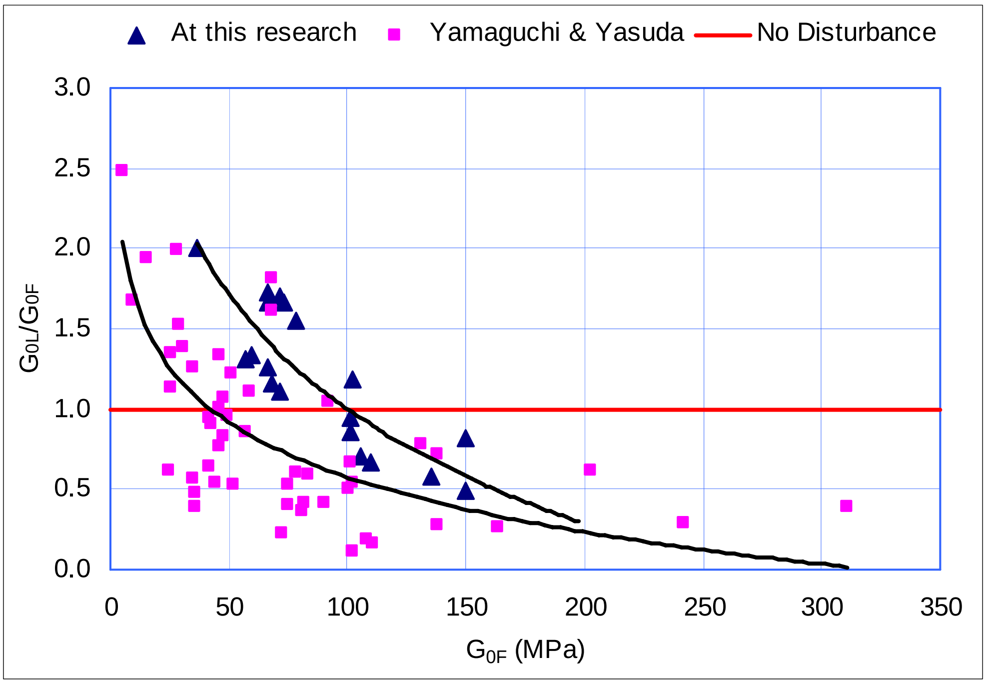


Figure 7. Comparison of Yasuda & Yamaguchi (1985) with our results for sands

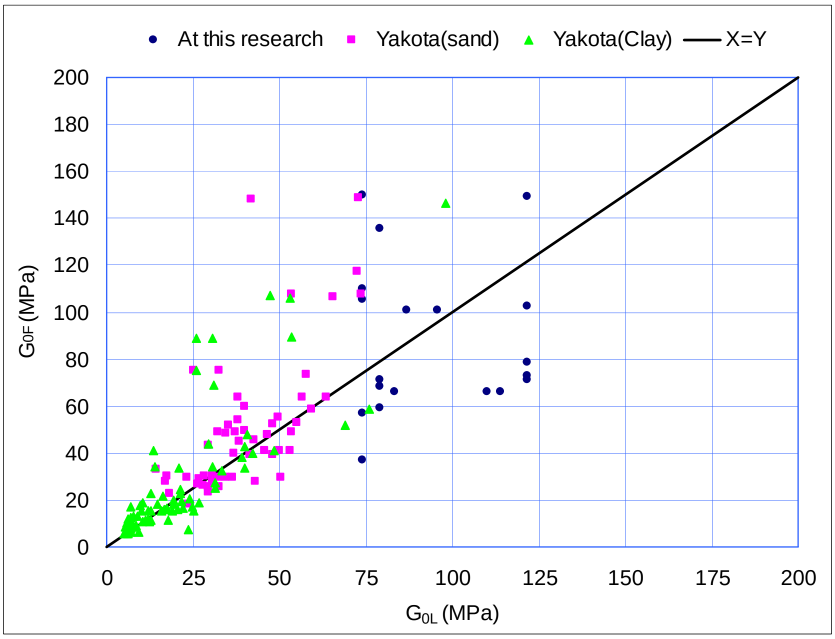


Figure 8. Comparison of Yokota et al. (1985) with our results for sand & clay deposits

CORRELATIONS PROPOSED TO DETERMINE SHEAR MODULUS FOR THE CACAREOUS SOIL

Current cone penetrometer manufactures can easily incorporate a seismometer into their penetrometers, however, many contractors either do not want to pay the extra cost of the seismometer or they are not set up to conducted seismic testing. Therefore, correlations to directly determine the shear modulus or shear wave velocity for the cone penetration data. The correlations were developed for both sandy and clayey soils from either field comparisons with Cross-Hole and Down-Hole testing or from calibration chamber testing. [FHWA 2001-032]

However, in this study we have presented new correlations for both calcareous sandy and clayey soils from field tests (SCPTu).

Shear modulus correlation- calcareous sands

One of the earliest correlations developed for sands is from calibration chamber work initially conducted by Baldi et al. (1982) and then added to by Baldi et al. (1989). The calibration chamber housed two different quartz sands (Ticino and Hokksund sands) with known properties for different levels of compaction and confining stresses. Based on the hundreds of cone penetration tests, the following correlation to shear wave velocity was developed:

$$V_s = 277(q_T)^{0.13}(\sigma'_V)^{0.27} \tag{2}$$

Where,

V_S: Shear wave velocity (m/sec)

q_T: Cone tip resistance (MPa)

σ'_V : Effective overburden pressure (MPa)

Based on result of SCPTu tests that has done in southern coasts of Iran (adjacent to Persian Gulf), we have presented a new correlations for calcareous sandy soil:

$$V_s = 250(q_T)^{0.15}(\sigma'_V)^{0.09} \qquad \text{With } R^2 = 0.929 \tag{3}$$

Shear modulus correlation- calcareous clays

Mayne and Rix (1995) compiled data from 31 different sites where subjected to both cone penetration testing and shear wave velocity measurements. The shear wave velocity measurements were conducted by one or more of the following types of testing: cross hole, Down-Hole, or spectral analysis by surface waves (SASW). The clays ranged from intact to fissure with a wide range of plasticity characteristics and over consolidation stresses. Mayne and Rix (1995) looked at a number of characteristics in their regression analysis. The regression that provided the best agreement included the parameter void ratio (R^2=0.846, n=364). However, the field determination of the void ratio is extremely difficult and would most likely need samples recovered and tested in the laboratory. Therefore, they presented following equation as a correlation to shear wave velocity for clayey soils:

$$V_s = 1.75(q_C)^{0.627} \tag{4}$$

Where:

V_S: Shear wave velocity (m/sec)

q_C: Tip resistance not corrected for pore pressure effects

The term q_C, which is the tip resistance not corrected for pore pressure effects, is extremely important to note. In some cases, such as sand, the correlation to the tip resistance due to any pore pressured effects is very minimal to the point where q_T= q_C. However, in soft soils like clays, the correction to the tip resistance could be as high as 20%.

Utilizing the seismic piezocone (SCPTu), a new correlation for calcareous clayey soil is presented:

$$V_s = 11.128(q_C)^{0.4074} \tag{5}$$

Where:

V_S: Shear wave velocity (m/sec)

q_C: Tip resistance not corrected for pore pressure effects

CONCLUSION

In this study, there is a general tendency of the laboratory-obtained shear modulus to decrease as the stiffness of the sand become greater. From the Fig.7, it may be argued that for Yasuda & Yamaguchi curve, if the shear modulus determined by the velocity logging is in the range of 30-50 MPa, the low amplitude shear modulus obtained from the laboratory test could give a value that is reasonably close to the field modulus determined by the velocity logging. But this range for our curve is around 70-100 MPa. It may be referred to the disturbance of samples during sampling and handling. In general, loose samples tend to become more dense thereby exhibiting greater stiffness and dense samples to loosen showing a reduction in stiffness. The soil that is observed in this study is calcareous soil. Therefore, it seems there is more undisturbancy than Yasuda & Yamaguchi's soil that was studied. The other reason may be considered is that the soil of this site is more sensitive than Yasuda & Yamaguchi's one.

Yokota et al. (1985) presented their results for silty and clay deposits in Fig 8. Fig.8 shows a comparison of the shear module between in situ and laboratory values for clay and sandy soils. G_{0F} and G_{0L} indicate the shear module determined in the field and in the laboratory tests, respectively. According to Fig.8 and Yokota's results, for soils with small shear module, it may be seen that the resonant column test tends to yield approximately the modulus values as those obtained in the field by the use of SCPTu test. This limit is about 40 MPa for clayey deposits and 60 MPa for sandy deposits.
In addition to these observations, for calcareous sands and clays of Persian Gulf area, two empirical equation are presented for shear velocity estimation.

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