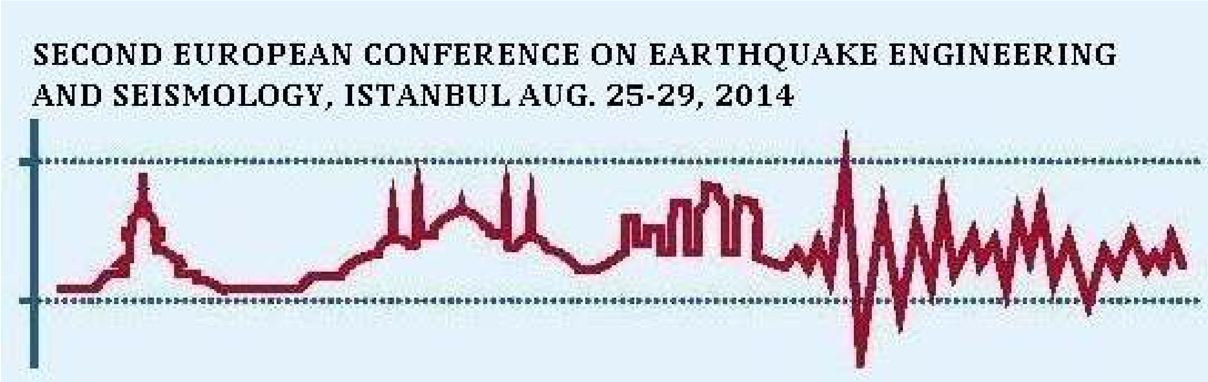

AN EXPERIMENTAL STUDY FOR DETERMINING THE SHEAR MODULUS OF TOYOURA SAND

M. İnanç ONUR[1] Mustafa TUNCAN[2] and Ahmet TUNCAN[3]

ABSTRACT

This study presents an experimental laboratory investigation about the shear modulus of reconstituted Toyoura sand samples by using resonant column test device. Dynamic properties of soils, such as shear modulus, damping ratio and/or shear velocities, could be determined in laboratory by resonant column test. A set of resonant column test was conducted on Toyoura sand samples prepared at different relative densities, confining pressures and saturation degrees. The results of the tests were presented and discussed by comparing the literature. Results of the tests showed that relative densities, confining pressures and saturation degrees have great influence on the shear modulus of the sandy soils.

INTRODUCTION

The resonant column test was used in 1937 but gained its popularity about determining the dynamic properties of soils after 1960's. Especially, it is used by many researchers in the laboratories due to the advantages such as simplicity and rapidity. In the test, soils are subjected to torsional loading with different frequencies. Wave velocities, damping ratios and shear modulus of the soil samples can be easily determined by using derivation of the function of the motion. Determining the dynamic characteristics of the soils can be done by laboratory tests. These laboratory tests are classified as; resonant column test, cyclic triaxial test, cyclic simple shear test and bender element test (Das, 1993). There are some variable factors that affect the dynamic characteristics. Especially, void ratio and confining pressure have great effect on the shear modulus and also degree of saturation can affect the damping (Onur et al., 2012). Youn et al. (2008) compared bender element, resonant column and torsional shear tests to measure shear modulus of dry and saturated sands. Naeini and Baziar (2004) investigated dynamic strength of silty sand mixtures by using dynamic triaxial tests. Okada et al. (2005) studied undrained shear behavior of sandy samples by using dynamic ring shear tests. Zhou and Chen (2005) determined loading history effect on the shear modulus of sandy soils. Yunmin et al. (2005) presented a correlation between the shear modulus of sands and confining pressure. Osinov (2003) improved a mathematical model about dynamic loading during the simple shear. Dano et al. (2003) analyzed soil strength against the dynamic loading by using bender element test. Kumar and Madhusudhan (2010) showed advantages of the using resonant column test for determining shear modulus of the soils.

Many researchers studied to determine shear modulus of the soils and defined as the ratio of the shear stress to the shear strain generally in the literature. Shear modulus is shown with the

[1] Research Assistant, Anadolu University, Eskişehir, Turkey, mionur@anadolu.edu.tr
[2] Professor Doctor, Anadolu University, Eskişehir, Turkey, mtuncan@anadolu.edu.tr
[3] Professor Doctor, Anadolu University, Eskişehir, Turkey, atuncan@anadolu.edu.tr

abbreviation “G” but initial shear modulus “Go” and maximum shear modulus “Gmax” are used frequently. Generally, two ways are used to determine shear modulus, one of them is determination from shear wave velocity and the other one is determination by using the functions that involve void ratio and mean effective principle stress. Equation (1) is showed the first way and shear modulus can be easily determined from density (ρ) and shear wave velocity (Vs). Equations (2) to (5) are showed some functions given by some researchers such as, Kokusho (2) , Hardin and Black (3), Iwasaka et al. (4), Yu and Richart (5) in the literature and involves void ratio (e) and confining pressures (σ_0) (Sawangsuriya, 2012).

$$G = (V_s)^2 \cdot \rho \tag{1}$$

$$G_{max} = 8400 \frac{(2,17-e)^2}{(1+e)} \sigma_0^{-0,5} \tag{2}$$

$$G_{max} = 3270 \frac{(2,97-e)^2}{(1+e)} \sigma_0^{-1/2} \tag{3}$$

$$G_{max} = 9000 \frac{(2,17-e)^2}{(1+e)} \sigma_0^{-0,38} \tag{4}$$

$$G_{max} = 7000 \frac{(2,17-e)^2}{(1+e)} \sigma_0^{-1/2} \tag{5}$$

Table 1 shows the typical values of the initial shear modulus for different types of soils. The factors that affect the shear modulus can be given as; stress state, over consolidation ratio, density, void ratio, microstructure, anisotropy, degree of saturation, aging, cementation and temperature in the literature (Sawangsuriya, 2012).

Table 1. Typical Values of G_0 (AASHTO, 1996)

Soil Type	Shear Modulus, G_0 (kPa)
Dense Sands & Gravels	69000 – 345000
Silty Sand	27600 – 138000
Medium Stiff Clay	6900 – 34500
Soft Clays	2750 – 13750

In this study, shear modulus of Toyoura sand samples was measured at different relative densities with confining pressures and saturation degrees. Factors effecting on the shear modulus of the samples were investigated by comparing the test results.

EXPERIMANTAL STUDY

The test procedures were designed according to the ASTM D4015-07. Resonant column test results are found independent from the methods of sample preparation (Tatsuoka et al., 1979). Results are not much affected above 100 kPa confining pressure from laboratory factors such as saturation techniques, sample preparation, etc. (Onur et al., 2012).

Non-plastic, fine-grained and typical clean Toyoura sand is used. Basic characteristics are given in Table 2. The reconstituted samples have 70 mm in diameter and 145 mm in length, respectively. In this study samples were prepared by compacting 10 mm layers by wooden compacter for the desired density.

Table 2. Basic Characteristics of Toyoura Sand

USCS	SP
Coefficient of Uniformity, Cu	1,33
Coefficient of Curvature, Cc	0,98
Maximum Bulk Density, ρ_{maks}	1.34 Mg/m^3
Minimum Bulk Density, ρ_{min}	1.64 Mg/m^3
Maximum Void ratio, e_{maks}	0,98
Minimum Void Ratio, e_{min}	0,62

Resonant column device was used to perform tests. The system is using fixed-free configuration and a cylindrical soil specimen is excited in torsion at its fundamental frequency. Firstly, resonant frequency is found by measuring the motion from free end and then wave velocity can be determined. The resonant column device is shown in Figure 1. A sinusoidal torque is applied to the specimen by electromagnetic drive. Motion is produced by applying voltage in the magnetic field. Frequency and amplitude of the voltage are recorded and the resonant frequency is determined by plot of the accelerometer against frequency. Figure 2 shows an example screen of the result of a torsional test.

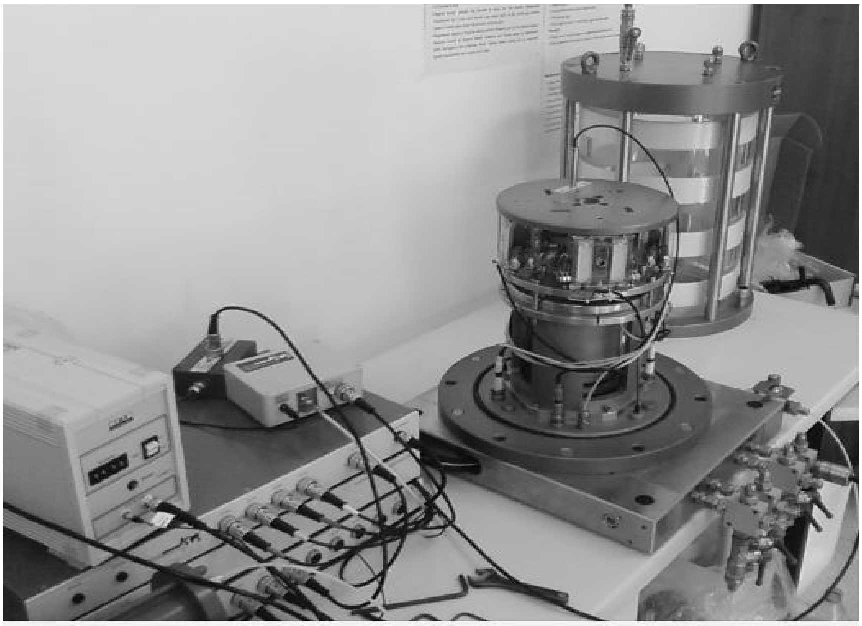

Figure 1. GDS Resonant Column Device.

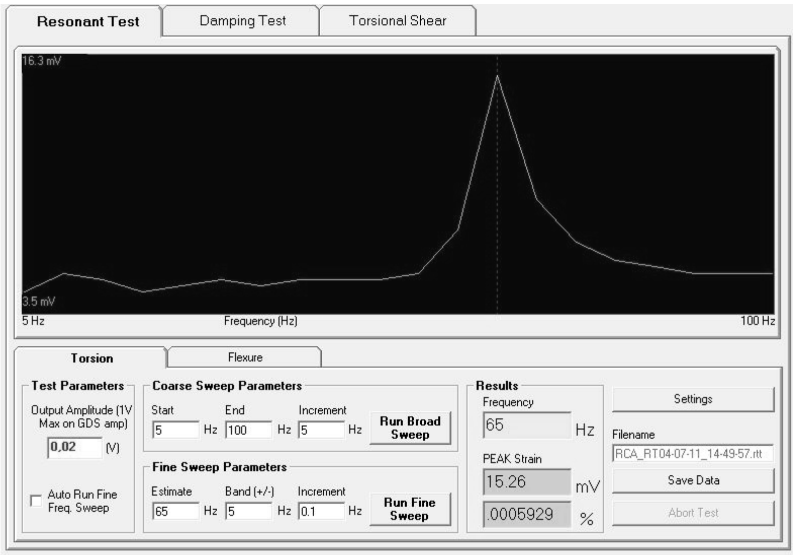

Figure 2. Example Screen of a Torsion Test.

Resonant column tests were run by applying different cell pressures at different saturation degrees and different relative densities. Saturation and consolidation test steps were performed by following standard techniques. Cell pressures were applied as 100, 150 and 250 kPa. Saturation degrees were applied as 40% and 100% and relative densities were calculated from void ratio and found as 40, 60 and 80%. All pressures, saturations and relative densities were given in Table 3.

Table 3. Test Details

Test Number	Relative Densities (%)	Saturation Degrees (%)	Confining Pressures (kPa)
Test A	40	40	100 -150- 250
Test B	40	100	100 -150- 250
Test C	60	40	100 -150- 250
Test D	60	100	100 -150- 250
Test E	80	40	100 -150- 250
Test F	80	100	100 -150- 250

Back pressure was applied as 50 kPa due to minimize disturbing the samples in the saturation step. All tests were performed after reaching 0.95 Skempton B value for fully saturated tests. Dry-pluviation technique was chosen for the partially saturated tests as well. Consolidation tests were performed after saturation. And then, resonant frequencies were measured and values of shear modulus were calculated.

RESULTS

While performing resonant column tests, resonant frequencies were measured between 50 Hz and 120 Hz. Shear wave velocities were founded between 250 m/s and 310 m/s. Therefore, shear modulus of the samples were calculated between 40 Mpa and 160 Mpa. The calculated shear modulus values were given in Table 4.

Table 4. Test Results

Test Number	Confining Pressures (kPa)	Shear Modulus (MPa)
Test A	100	45,90
Test A	150	72,60
Test A	250	93,12
Test B	100	45,45
Test B	150	72,07
Test B	250	94,82
Test C	100	57,76
Test C	150	91,23
Test C	250	120,76
Test D	100	60,01
Test D	150	94,35
Test D	250	125,20
Test E	100	73,71
Test E	150	100,32
Test E	250	155,47
Test F	100	77,30
Test F	150	109,80
Test F	250	159,93

Shear modulus of the samples was calculated by the equations and compared with the results of this study. Figure 3 and 4 show the similarities of the results.

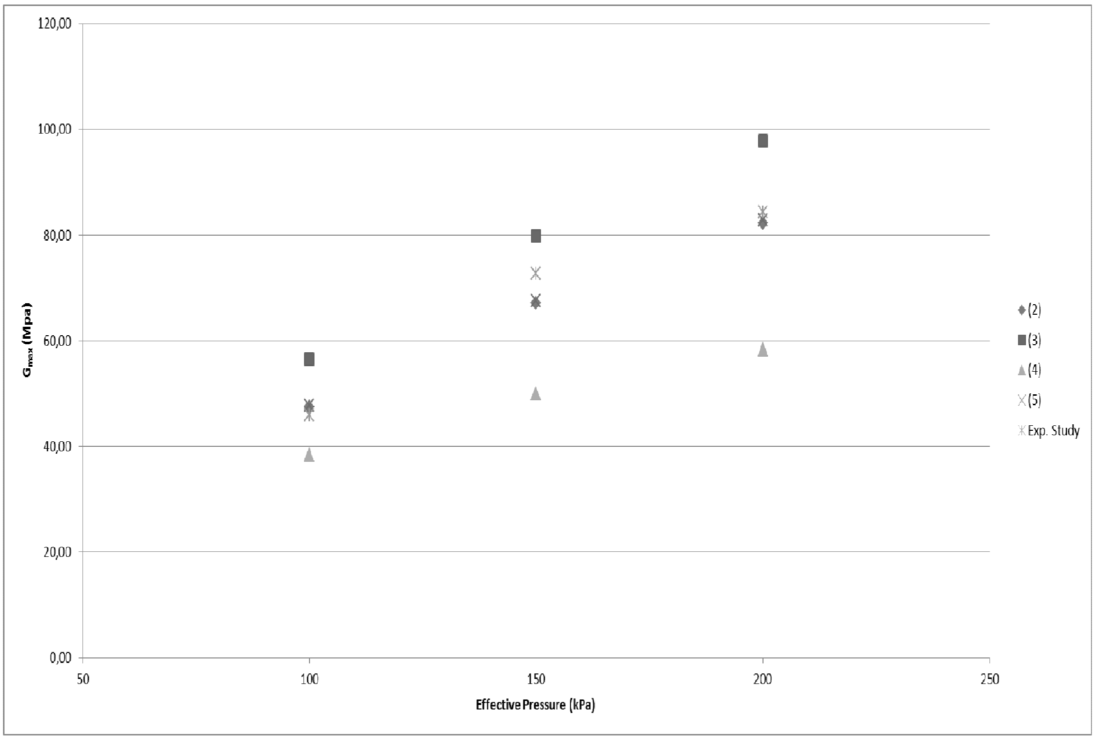

Figure 3. Comparison of the Results-1.

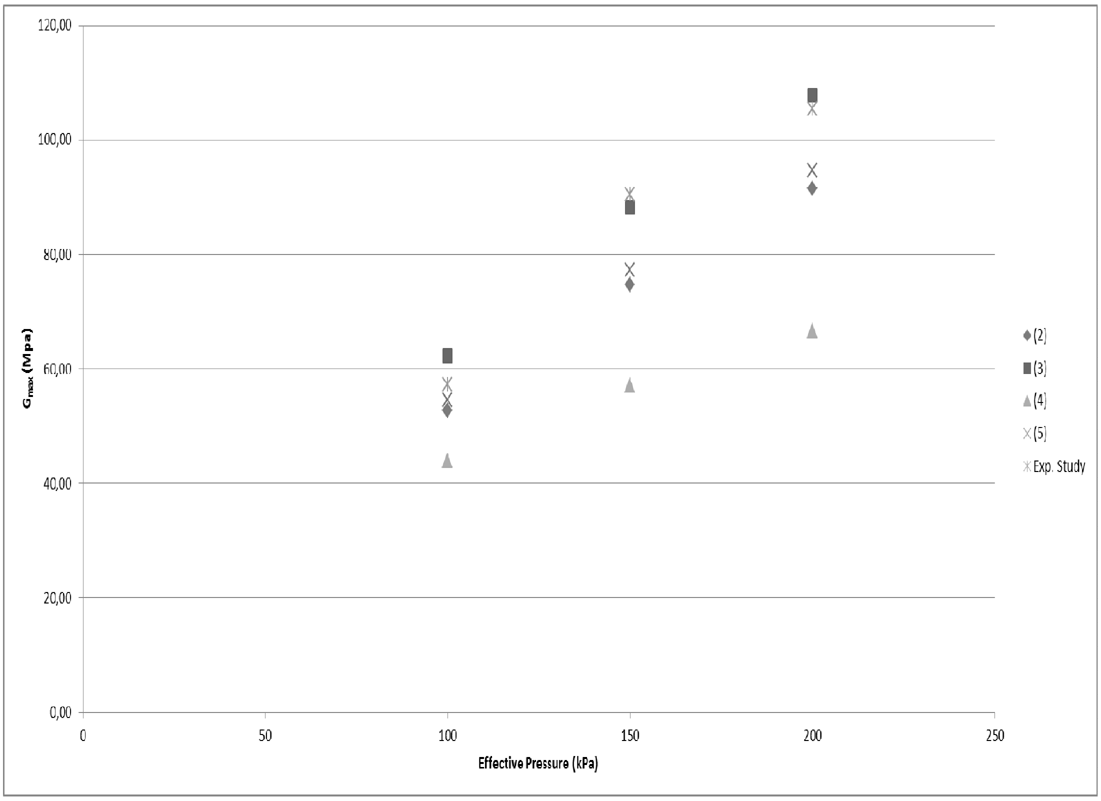

Figure 4. Comparison of the Results-2.

It can be seen from the Figures 3 and 4 that test results of the experimental study show similar behavior with the results of the equations. Especially, relative density has great effect on the shear modulus of the samples. Shear modulus of the samples is affected from the saturation but the differences are in small proportions. Additionally, laboratory conditions can affect the actual values. And also, the shear modulus of the samples is increasing with the increase of confining pressure. Sand particles are getting closer to each other and therefore void ratios decrease with the increasing of the relative densities of the samples. As a result, the shear modulus increases with increasing strength of soil.

CONCLUSIONS

In this study, an experimental laboratory investigation was performed by using resonant column test device. The shear modulus of sand samples was determined in laboratory. A set of resonant column test was conducted on Toyoura sand samples prepared at different relative densities, confining pressures and saturation degrees. The results of the tests were showed that relative densities, confining pressures and saturation degrees have great influence on the shear modulus of the sandy soil. On the other hand, field test should be done to simulate site conditions, besides laboratory tests.

ACKNOWLEDGMENT

This research is part of a study Project No: 09-02-05 and supported by Anadolu University Research Fund. Special thanks to Anadolu University Scientific Research Project Presidency.

REFERENCES

AASHTO, 1996. Standard Specification for Highway Bridges

ASTM D4015-2007. Standard Test Methods for Modulus and Damping of Soils by Resonant-Column Method

Dano, C., Hareb, H., Hicher, P. (2003) "Characterization of Loire river sand in the small strain domain using new bender-extender elements", *Proc.of the 16th ASCE Engineering Mechanics Conference, Seattle*

Das, B.M. (1993) Principles of Soil Dynamics, PWS-KENT Publishing Company, USA

Kumar, J., Madhusudhan,B.N. (2010) "On determining the elastic modulus of a cylindrical sample subjected to flexural excitation in a resonant column apparatus", *Canadian Geotechnical Journal*, vol. 47, 1288-1298

Naeini, S.A, Baziar, M.H. (2004) "Effect of fines content on steady-state strength of mixed and layered samples of sand", *Soil Dynamics and Earthquake Engineering*, vol. 24, 181-193

Okada, Y., Sassa, K., Fukuoka, H. (2005) "Undrained shear behavior of sands subjected to large shear displacement and estimation of excess pore-pressure generation from drained ring shear tests", *Canadian Geotechnical Journal*, vol. 42, 787-800

Onur, M.I., Umu, S.U., Okur, D.V., Tuncan, M., Tuncan, A. (2012) "An experimental comparison between the shear and the plane waves by using resonant column test", *Proc. of the 22th International Offshore and Polar Engineering Conference*, Rhodes, 865-870

Osinov, V.A. (2003) "Cyclic shearing and liquefaction of soil under irregular loading: an incremental model for the dynamic earthquake-induced deformations", *Soil Dynamics and Earthquake Engineering*, vol. 23, 535-551

Sawangsuriya, A. (2012) Wave Process in Classical and New Solids, InTech, USA

Tatsuoka, F., Iwasaki, T., Yoshida, S., Fukushima, S., Sudo, H. (1979) "Shear modulus and damping by drained tests on clean sand specimens reconstituted by various methods", *Japanese Society of Soil Mechanics and Foundation Engineering*, Vol. 19, pp. 39-54

Yunmin, C., Han, K., Ren-peng, C. (2005) "Correlation of shear wave velocity with liquefaction resistance based on laboratory tests", *Soil Dynamics and Earthquake Engineering*, vol. 25, 461-474

Youn, J.U., Choo, Y.W., Kim, D.S. (2008) "Measurement of small strain shear modulus Gmax of dry and saturated sands by bender element, resonant column and torsional shear test". *Canadian Geotechnical Journal*, vol. 45, 1426-1438

Zhou, Y., Chen, Y. (2005) "Influence of seismic cyclic loading history on small strain shear modulus of saturated sands", *Soil Dynamics and Earthquake Engineering*, vol. 25, 341-351