Dynamic laboratory investigation for soil seismic response

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SUMMARY:
Laboratory determination of soil properties can be used in addition or to confirm the results of field measurements. They are useful to establish values of damping and modulus at strains larger than those in the field or to measure the properties of materials that do not exist in the nature. The dynamic deformation characteristics of the soil are used to calculate seismic response of soil, earth structures and soil structure interaction effects. The paper present results for clay soil samples from Bucharest, Romania. The equipment for dynamic laboratory soil testing consists of Seiken triaxial testing equipment, data acquisition system and processing software. In the triaxial test a cyclic load is applied to a soil sample over a number of cycles slowly enough that inertial effects do not occur. Results are given in the form of G-γ and D-γ variation curves and are compared with other results from literature.

Keywords: clay dynamic properties, triaxial equipment

1. INTRODUCTION

In many cases, for the design of engineering structures the dynamic properties of soil are necessary to be evaluated and field and laboratory investigation are conducted. A large number of laboratory tests for dynamic purposes have been developed, and research continues in this area. These tests can generally be classified into two groups: tests that apply dynamic loads and tests that apply cyclic loads slow enough that inertial effects do not occur.

The paper presents dynamic parameters of soils obtained in laboratory of National Center for Seismic Risk Reduction (NCSRR, Bucharest) which functioned from October 2002 until august 2010 as implementing agency of the Japan International Cooperation Agency Technical Cooperation (JICA) Project in Romania entitled "Seismic risk reduction for buildings and structures". The equipments for dynamic laboratory soil testing at NCSRR consist of triaxial testing equipment, data acquisition and processing software made by Seiken, Japan.

2. LABORATORY EQUIPMENT

The equipment used for tests is a Triaxial Testing Apparatus Model No. DTC-367 - Seiken Inc., which fulfils all the requirements of The Japanese Geotechnical Society (2000).
The triaxial equipment can solve the following types of problems: (i) static problems with strain level at 10^{-3} or greater (the main concern regarding the static problems is used to evaluate the degree of safety of foundations or soil structure against the failure); (ii) dynamic problems with soils subjected to a strain levels as small as 10^{-6} (used to evaluate the soil strength in comparison with stresses induced by external loading and the settlement of ground or structures associated with the deformation of soils. In Fig. 2.1 is presented the Seiken Triaxial Testing Equipment.

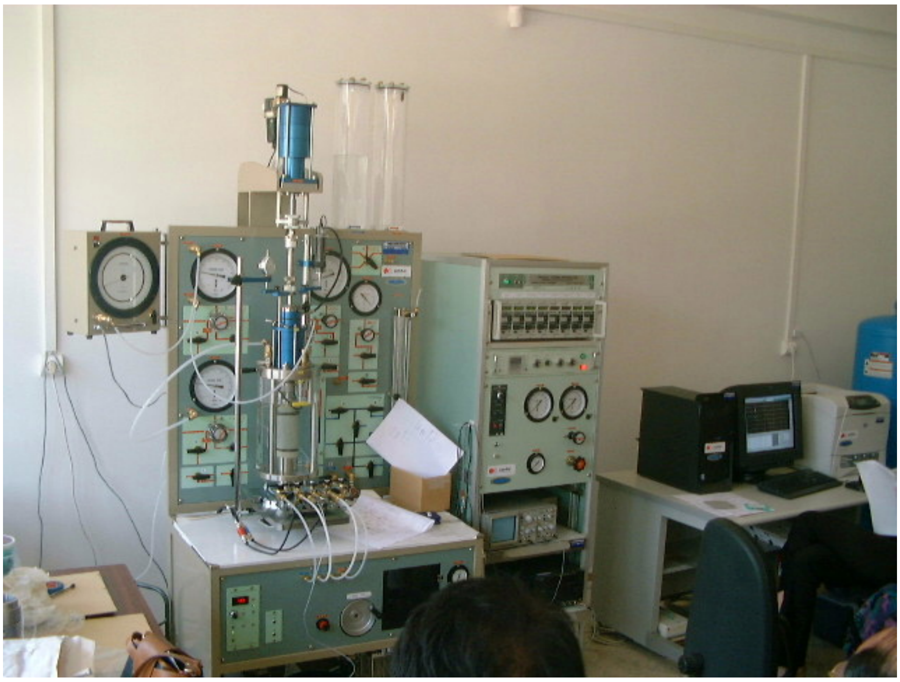

Figure 2.1. Triaxial Testing Apparatus Model DTC-367 by Seiken. Inc. Japan

The equipment has the following specifications and components:

- Triaxial Cell equipped with Water-proof and Pressure-proof Load cell 3kN
    - Air bushed piston of extremely small friction
    - Specimen Size: Diameter 50mm X 100mm
    - Lateral Pressure Capacity: Max. 1Mpa
    - Axial Loading Capacity: 5kN
- Vertical Pressure Loading Unit with Air & Water Panel
    - Static Vertical Loading: Electric Strain Control by Mechanical jack, Capacity 5kN, (0.002 – 2 mm/min. Step-less variable type)
    - Dynamic Vertical Loading: Stress Control by Pneumatic bellofram cylinder, Capacity 2kN
    - Lateral & Back Pressure Loads: Both 0 – 1Mpa by Air regulators, Manual operation
    - Volume Change Apparatus: Double tube burette type 25ml
    - Master Gauge: Dia.200 ×1Mpa, Min. div. 1/500
- Pneumatic Sine Loader
    - Electric-Pneumatic pressure conversion type & Loading control type
    - Range of Vibration: 0.001 – 2 Hz
    - Loading Wave: Sine wave
    - Setting of Load: Both Static Bias & Dynamic loading are 1000 Division, Potentiometer type
    - Loading Number of Times: Random Preset type with 6 Figures Digital Counter
    - Pneumatic Pressure Capacity: 1Mpa
    - Electric Power Source: AC Single phase local voltage
- Transducers & Amplifier
    - Inner Load Cell: 2kN or 500N
    - Large Vertical Displacement Transducer: 25mm
    - Pores Water Pressure Transducer: 1Mpa
    - Small Vertical Displacement Transducers (gap sensors) +/- 1mm & Amplifiers
    - Lateral Pressure Transducer: 1Mpa
    - Volume Change Transducer: 25ml
    - Amplifier suitable for the above converter: 5ch.

3. CYCLIC TRIAXIAL TEST TO DETERMINE DEFORMATION PROPERTIES OF GEOMATERIALS

The laboratory test used for dynamic parameters of soils estimation is the cyclic triaxial test. In this test load is applied as cyclic axial load by pneumatic actuator to a cylindrical soil sample over a number of cycles. The soil sample response at one amplitude of load is observed and the test is repeated at higher load amplitude.

The deformation properties determined are the equivalent Young's modulus defined from amplitudes of cyclic deviator stress and cyclic axial strain, and hysteretic damping ratio defined from a hysteretic loop of the relationship between deviator stress and axial strain. Axial stress is applied in the axial direction of the soil sample subjected to test, while lateral stress is applied in the radial direction of the sample.

Though soil deformation under seismic loading is relatively small, its modulus is dependent on dynamic stress or strain level. Soil moduli such as Young's modulus (*E*) and shear modulus (*G*) decrease as the level of stress or strain increases. Therefore nonlinearity of dynamic deformation characteristics is significant in seismic response analysis. The evaluation of shear modulus of soils at very small levels of strains was a main concern of researchers. This modulus is called maximum shear modulus, initial shear modulus, or low amplitude shear modulus and is noted by G_{max} or G_0. To obtain a $10^{-4} – 10^{-5}$ axial strain a very small deviator stress must be applied.

4. PROCEDURE TO CALCULATE THE DYNAMIC DEFORMATION CHARACTERISTICS

Dynamic properties of soils are estimated on each cyclic axial loading cycle. Loading process and axial strain are monitored for each loading cycle (Fig. 4.1).

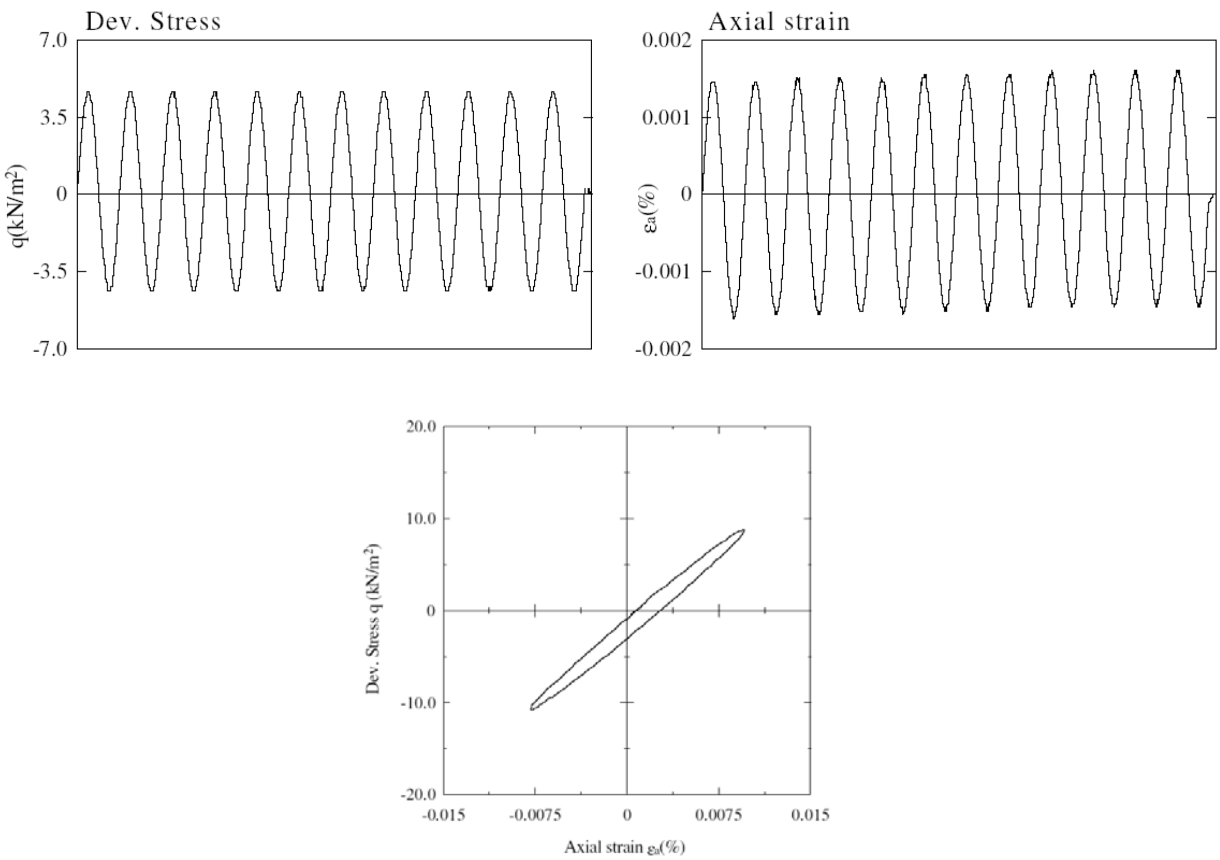

Figure 4.1. Example of axial loading and axial cyclic deformation monitoring

Following are presented the main steps in calculation of dynamic characteristics of a soil sample subjected to a dynamic triaxial test:

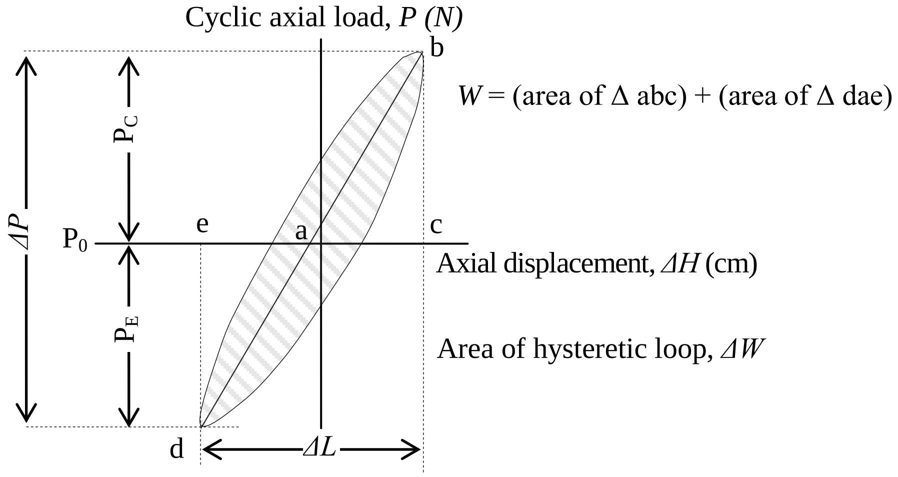

Figure 4.2. Estimation of dynamic deformation characteristics

- Calculate the single amplitude of cyclic deviator stress, σ_d (kN/m^2),

$$\sigma_d = \frac{P_C + P_E}{2A_n} \times 10 \tag{4.1}$$

where
P_C, P_E (N) are single amplitude of cyclic axial loads in compression and in extension, respectively;
A_n (cm^2) is the cross-sectional area of the soil sample at the start of the cyclic loading stage.

- Calculate the single amplitude cyclic axial strain, $(\varepsilon_a)_{SA}$ (%):

$$(\varepsilon_a)_{SA} = \frac{\Delta L}{2H_n} \times 100 \tag{4.2}$$

where
ΔL (cm) is double amplitude axial displacement of the soil sample,
H_n (cm) is the soil sample height at the start of each cyclic loading stage,

- Calculate the equivalent Young's modulus, E_{eq} (MN/m2), as follows:

$$E_{eq} = \frac{\sigma_d}{(\varepsilon_a)_{SA}} \times \frac{1}{10} \tag{4.3}$$

- Calculate the hysteretic damping ratio, D (%):

$$D = \frac{1}{2\pi} \cdot \frac{\Delta W}{W} \times 100 \tag{4.4}$$

where
ΔW is damping energy in a single loading cycle, which is defined as the area of the hysteretic loop on the deviator load, P, versus axial displacement, ΔH, curve,
W is the equivalent elastic energy input in a single cyclic loading, defined in Eqn. 4.5:

$$W = \frac{(P_C + P_E)\Delta L}{4} \tag{4.5}$$

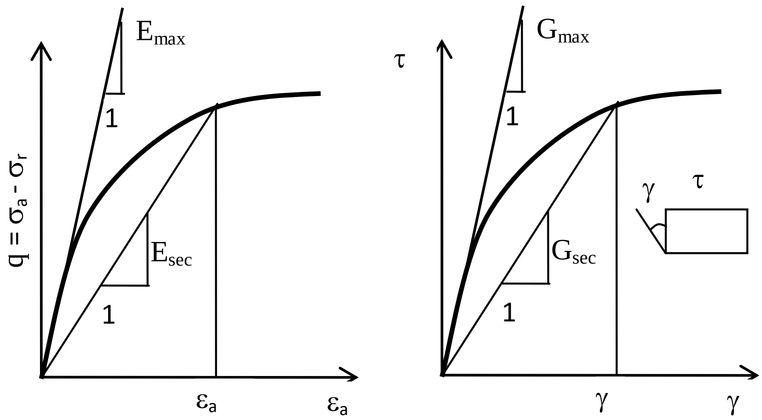

Figure 4.3. Definitions of Young's modulus and shear modulus

In Fig. 4.4 and 4.5 are presented examples of normalized shear modulus and damping variation with shear strain. Such soil behaviour curves are used for numerical analysis of site response.

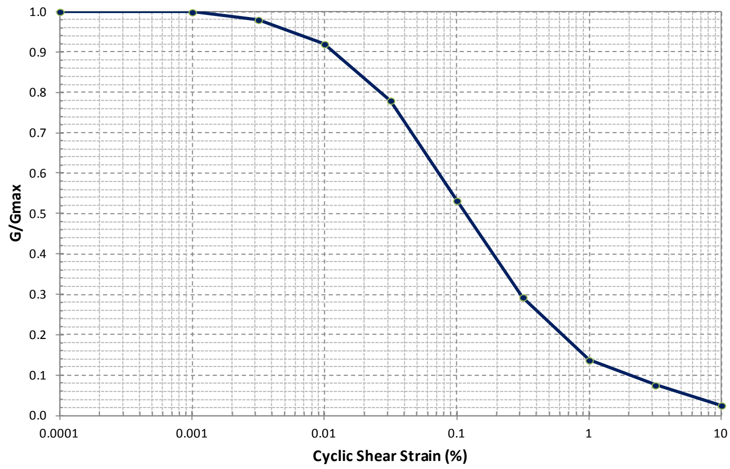

Figure 4.4. Normalized shear modulus variation with shear strain

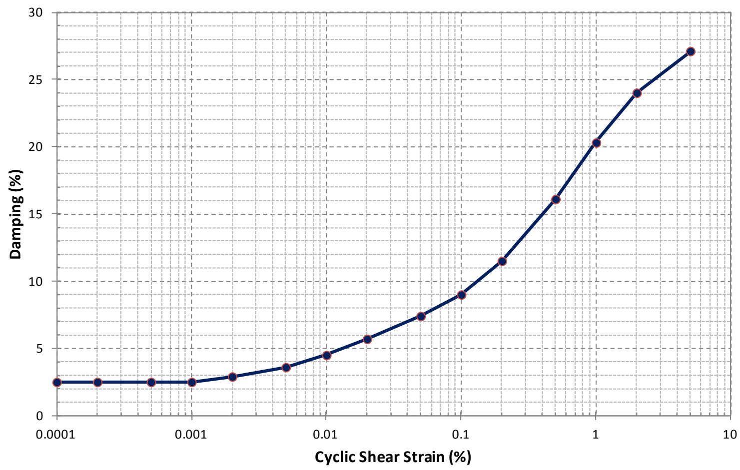

Figure 4.5. Damping variation with shear strain

5. TESTS RESULTS

During the NCSRR activities a series of dynamic triaxial tests were conducted on soil samples mainly from Bucharest but also from other location in Romania. Fig. 5.1 present the locations in Bucharest of the boreholes from which were extracted soil-samples for triaxial tests.

Figure 5.1. Location in Bucharest of the boreholes from which were extracted soil-samples for triaxial tests

Fig. 5.2 present the steps of preparation of the soils samples, sampling on boring site, transport, trimming and test setup.

Figure 5.2. Sampling, preparation and testing of the soil samples

Results of dynamic triaxial tests cohesive soils are presented in form of shear modulus ratio versus shear strain $G/G_{max} - \gamma$ and the strain dependent damping $D - \gamma$. In Fig. 5.3 and 5.4 are presented comparisons of the obtained laboratory tests' results with results from literature. Vucetic & Dobry (1991) plasticity index Ip=0 and Ip=50 are used to compare with clayey soils from Bucharest tested.

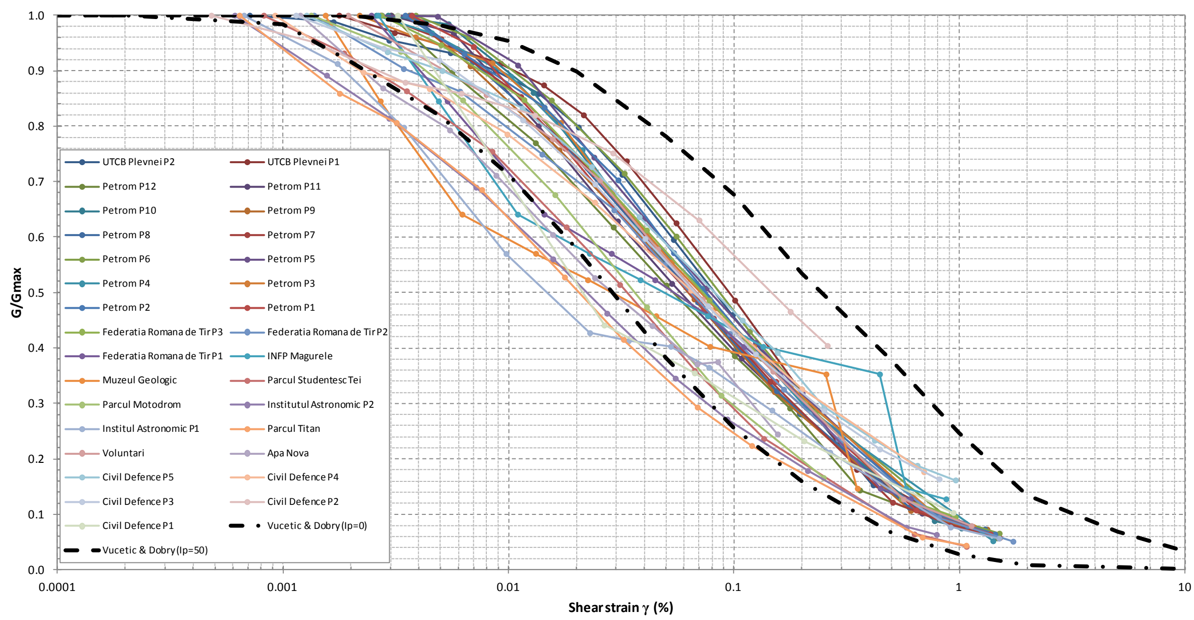

Figure 5.3. Normalized shear modulus variation with shear strain for clay samples from Bucharest and comparison with Vucetic & Dobry (1991) curves

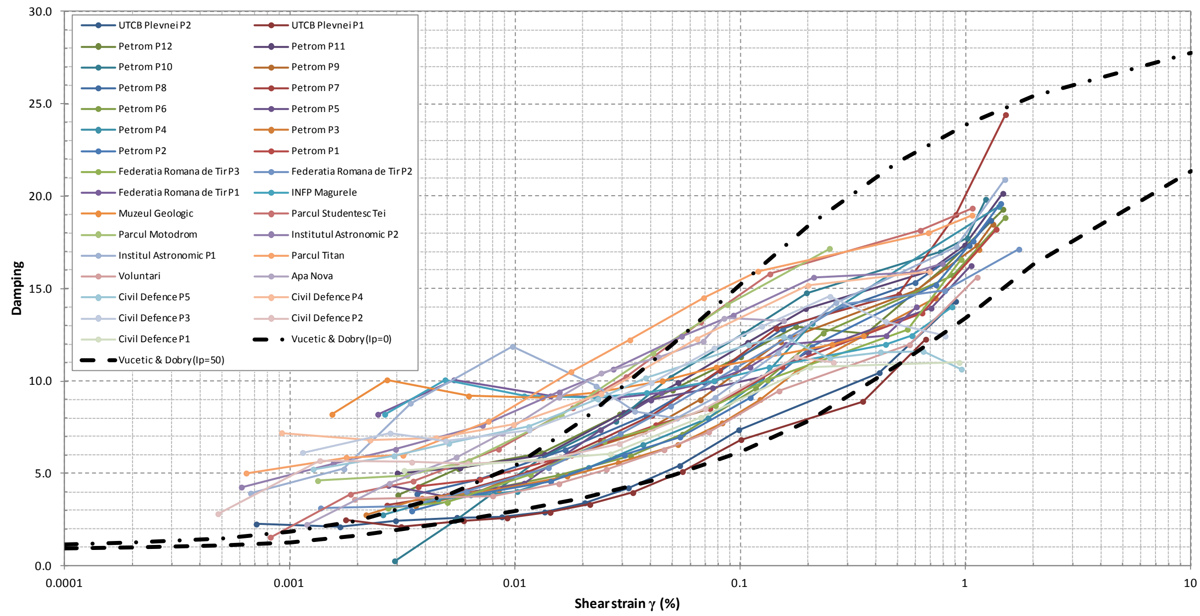

Figure 5.4. Damping variation with shear strain for clay samples from Bucharest and comparison with Vucetic & Dobry (1991) curves

6. CONCLUDING REMARKS

The normalized shear modulus reduction of Bucharest clay is in a good agreement with the Vucetic &

Dobry (1991) curves for clays with a plasticity index Ip between 0 and 50.

In what concerns the increase of damping, one may notice the relatively good agreement with the Vucetic & Dobry (1991) curves for shear strains larger than 0.02%. Bellow this shear strain the results obtained for Bucharest clays are larger.

The accuracy of results are dependent of the quality of the sampling process, soil samples transport from the boring site to the laboratory, storage conditions, test sample preparation and test setup.

Further work will focus on the study of geotechnical data available in Bucharest for identifying, as much as possible, the plasticity index of the clay at each borehole site, and will try to group the clay samples according not only to the plasticity index but also to the depth level and to the geologic profile beneath the city. The final purpose if to define characteristics of different soil profiles within the city allowing the numerical analysis of site response for microzonation studies.

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