7. savjetovanje Hrvatskog geotehničkog društva s međunarodnim sudjelovanjem
7th Conference of Croatian Geotechnical Society with international participation
Varaždin, Croatia, 10-12.11.2016.
ISBN 978-953-95486-5-8

DYNAMIC CHARACTERIZATION OF THE FOUNDATION SOIL IN THE ENNA AREA.

DINAMIČKA KARAKTERIZACIJA ZEMLJANE PODLOGE U PODRUČJU OPĆINE ENNA

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ABSTRACT

The paper reports the results of the static and dynamic characterization of an area within the industrial zone of the municipality of Enna, where an integrated pole of Research, Higher Education and Innovation called "Project LEDA (Laboratory of Earthquake Engineering and Dynamic Analysis)" has been realized and equipped with experimental apparatus in the field of structural and geotechnical engineering.

A Resonant Column/Torsional Cyclic Shear apparatus to perform laboratory tests on soil samples retrieved from the site, has allowed to obtain the values of shear modulus G and damping ratio D as a function of the shear strain level. The experimental results are in good agreement with the well-known curves relating to soil with similar characteristics.

Keywords: Seismic zonation, dynamic characterization, shear modulus, shear strain

SAŽETAK

Ovaj rad prenosi rezultate statičke i dinamičke karakterizacije područja u sklopu industrijske zone općine Enna, gdje je realiziran integrirani centar za istraživanje, visoko obrazovanje i inovacije pod nazivom "Projekt LEDA (Laboratorij za potresno inženjerstvo i dinamičku analizu)" te opremljen eksperimentalnim uređajima za testiranje u području strukturnog i geotehničkog inženjerstva.

Rezonanti stupac / Aparat za torzijski ciklički posmik u svrhu izvođenja laboratorijskih ispitivanja na uzorcima tla dobivenim s mjesta ispitivanja, omogućio je da se dobiju vrijednosti posmičnog modula G i omjer prigušenja D kao funkcija posmična deformacija. Ti eksperimentalni rezultati su u priličnom skladu s dobro poznatim krivuljama koje se odnose na tlo sa sličnim karakteristikama.

Ključne riječi: Seizmičko zoniranje, dinamička karakterizacija, posmični modul, posmično naprezanje

INTRODUCTION

Geotechnical issues related to the seismic prevention are of great relevance in Italy, and are significant in relation to the scientific studies on the effects caused by the recent earthquakes that hit the city of L'Aquila (2009), Emilia Region (2012) and central Italy (2016).

To achieve the target of reducing the seismic risk it is necessary to develop innovative experimental activities that enable the advancement of knowledge in the field of seismic hazard assessment of sites (Castelli et al. 2008; Castelli et al. 2013; Castelli et al., 2015; Castelli et al. 2016; Castelli & Lentini, 2010,

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2016; Maugeri et al. 2013; Grasso et al. 2016) and the vulnerability of the structures in relation to the effective seismic action.

A proper evaluation of the response of the soil and of soil-structure interaction requires accurate geotechnical investigations, not only in the static but also in the dynamic field.

The determination of the initial shear modulus G0 of the soil, in particular, has assumed considerable importance in many problems of geotechnical engineering, in particular concerning the dynamic modelling and local seismic zonation, as well as for its correlation to problems of soil-structure interaction occurring also in static conditions.

The difficulty of a correct and complete determination of the dynamic parameters of the soils, often involves the use of empirical relationships that refer to other parameters that can be easily evaluate under static conditions. On the other hand, the refinement of new experimental techniques of measurement in the dynamic field of testing, allows estimation of the static deformation modules, starting from the dynamic ones, determined with higher precision within a range of deformations, far from failure, usually within the yield surface of the soil.

As part of the National Operational Programme for Research and Competitiveness 2007-2013 for the regions of the convergence objective (Campania, Puglia, Calabria, Sicily) - Axis I: "Support to structural changes" (Operational Objective 4.1.1.4 "Strengthening of structures and of scientific and technological facilities - Action: structural reinforcement "), MIUR Agency has funded the University of Enna "Kore" a project for the creation of an integrated pole of Research, Higher Education and Innovation called "Project L.E.D.A. (Laboratory of Earthquake Engineering and Dynamic Analysis) ", equipped with specialized facilities in the field of Seismic Engineering and Experimental Dynamics and with a Laboratory of Soil Dynamics.

The project also involved the upgrading of the Laboratory of Geotechnical Engineering and the acquisition of specific equipment for the dynamic characterization of soils, with the establishment of a special soil dynamics section. Advancing knowledge in the field of soil dynamics characterization is the first step in the evaluation of local seismic response and seismic zoning of the territory. It is a matter of fact that it is possible to define the behaviour of soils in seismic conditions through the interpretation of the results of laboratory tests, in order to get experimental monitoring of cyclic and dynamic behaviour.

Referring to the strain levels investigated, the dynamics and cyclic laboratory tests can be aggregated into two main groups:

- tests at low / middle levels of deformation Resonant Column (RC) and Cyclic Torsional Shear (CTS)
- tests at high levels of deformation Cyclic Triaxial tests (CTX)

The equipment used in this study are provided at the University of Enna "Kore" - Department of Geotechnical Engineering - and have been used to characterize the subsoil in the land of the new L.E.D.A. laboratory, in order to obtain information on the shear modulus G and on the damping ratio D and derive the degradation law of G and the increment of D vs. shear strain levels, as well as to characterize the stress-strain behaviour at high strain levels.

The study of the dynamic properties of these soils is of particular interest, since, especially for the presence of organic deposits, for their low stiffness against shear and limited dissipating capacity, seismic amplification phenomena may occur, even at high levels of shear strain (Stokoe et al., 1994; Boulanger et al., 1998).

In this specific application the dynamic properties of the soils, expressed in terms of shear modulus G and damping ratio D, have been evaluated in the range of shear strain γ between 0.00091% and 0.44% and for different confining pressure. The frequency of application of the shear strain was varied between 20 and 80 Hz.

Degradation curves of the shear modulus and increment curves of damping ratio vs. shear strains have been compared with other reference curves and found in good agreement with those most credited relating to subsoils of the same nature.

EXPERIMENTAL PROGRAM

Due to the importance of the buildings to be constructed, the design of structures was preceded by a detailed survey campaign, comprising in situ tests (surveys, geo-seismic tests, etc.), static and dynamic laboratory tests.

Three vertical continuous borings were performed (Figure 1), down to a depth of 20.0 m (S1), up to 30.0 m (S2) and up to 20.0 m (S3) below the ground level.

The boring S2 was equipped to perform seismic testing Down Hole-type (DH), while S1 and S3 have been equipped with piezometers, in order to monitor the water level, detected in two of the three surveys carried out at different depths between 3.0 and 5.0 m from the ground level.

An examination of the stratigraphy resulting from the survey shows that foundation soils include: in the first five meters of depth, fine sand and silty and / or clayey silt slightly sandy; at a depth of approximately 6.0 m from the ground level, blue-grey silty clay.

To determine the propagation speed of the body waves, from which it is possible to go back to the deformability parameters of the ground, a Down-Hole test (DH) has been carried out in the S2 boring.

Figure 1 shows the profiles of the propagation speed of compression waves (Vp) and shear waves (Vs) obtained through the Down-Hole test. The performance of the two profiles shows a progressive increase with depth of both Vs and Vp, within a range of about 124 and 384 m / sec for (Vs) and about 351 and 1340 for (Vp). These values are in good agreement both with Vs obtained through surface seismic survey MASW type (Tokimatsu, 1995), the results of which are reported in Table 1.

For the geotechnical characterization and evaluation of the mechanical properties of the foundation soils, specific laboratory tests were carried out on samples taken from the survey borings; in details: grain size analysis, determination of bulk density, specific weight of grains, natural moisture content, degree of saturation and Atterberg Limits.

Table 1. Results of MASW test

Layer	Depth (m)	Thickness (m)	V_S (m/sec)	H/V_S
1	1.51	1.51	111	0.0136
2	3.40	1,89	121	0.0156
3	5.77	2.36	175	0.0135
4	8.72	2.95	200	0.0148
5	12.41	3.69	286	0.0129
6	17.03	4.62	320	0.0144
7	30.00	12.98	281	0.0462

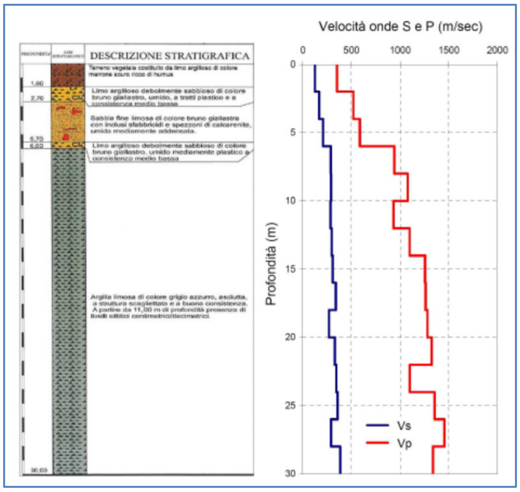

Figure 1 ***Profiles of the velocities obtained from a DH test.***

Several edometer and direct shear tests have been carried out for the evaluation of the compressibility and shear strength parameters under drained conditions. For silty clay soil samples unconsolidated undrained triaxial tests (UU) have been also carried out. The test results are reported on Table 2.

Grain size analysis of the soil samples under test have included both sandy soils and silty clays. Atterberg Limits carried out on soils passing n.er 40 sieve (ASTM series) have given the following results: w_L = 29 - 66%, I_P = 9 - 34%, while the natural moisture content w_N = 14 - 31%.

Undrained shear strength Cu of the silty clay samples measured by UU triaxial tests, ranging between 44 - 153 kN/m^2. Shear strength parameters φ’ of the sandy soil samples in drained conditions obtained from direct shear tests, ranging between 22 – 31°.

Table 2. Geotechnical parameters

Sample	Depth (m)	I_P (%)	e_0	C_u (kN/m^2)	ϕ'
S1/C2	6.00	-	-	77	22
S2/C1	2.00	-	-	-	-
S2/C2	5.50	33.47	0.731	44	-
S2/C4	15.50	42.12	0.581	-	-
S3/C1	1.50	11.58	-	-	-
S3/C2	4.00	-	0.584	-	31
S3/C3	8.00	8.58	0.569	153	-
S3/C4	15.30	48.84	0.608	-	-

DYNAMIC CHARACTERIZATION

To evaluate the dynamic properties of the soil several tests at different confining pressure were performed. For the experimental determination of the laws of degradation of shear modulus G and of increase of damping ratio D, on several specimens taken from S1 / C2, S2 / S2 and C1 / C4 samples, the stiffness measurements were performed with the Resonant Column apparatus, under confining pressures roughly corresponding to the effective lithostatic pressure.

In RC tests, sinusoidal torsional forces are generally applied at high frequencies, so as to reach the resonance conditions. For low and medium levels of deformation torsional forces are generally applied at frequencies between 1 and 100 Hz. At higher levels of deformation, the frequency of torsional forces ranges from 0.01 to 1 Hz.

If it is not necessary to investigate the behaviour of the soil at failure, the Resonant Column (RC) and the Cyclic Torsional Shear (CTS) tests are sufficiently adequate for its characterization under seismic conditions.

On the other hand, to investigate the stress-strain behaviour at high strain levels (ε_a > 10-2 %), to determine the ultimate strength in the dynamic field, as well as to analyse the post-cyclic behaviour, cyclic triaxial tests (CTX) are generally recommended. From the results of CTX tests the hysteresis cycles can be represented on the plane (τ - γ) as well as those data that provide axial stress, axial strain and pore pressure vs. time. From the hysteresis loops it is possible to derive the parameters of deformation (G and D) at high levels of deformation and to observe the behaviour in compression and extension of the samples under test.

Resonant Column (RC), Cyclic Torsional Shear (CTS) and Cyclic Triaxial (CTX) apparatus used for this program of investigation are in use at the Soil Mechanics Laboratory of "Kore" Enna University (Figure 6).

The shear modulus G is obtained from the load-unload hysteresis cycles monitored along RC and CTS tests, while Go is the maximum value or the "plateau" value observed on the curve G-log(γ). Generally, the value of G is constant until a strain threshold limit is not exceeded. This strain limit is known as the threshold of elastic shear strain, below which the soil shows a reversible elastic behaviour.

RC tests have been carried out on cylinder soil samples, 50 mm diameter x 100 mm length, by the use of electromagnetic actuators, in order to perform both RC and CTS tests with the same equipment on the same sample. The laws of degradation of G modulus and increase of damping ratio D for several samples under test are shown in Figure 2 and 3, respectively.

Experimental results have been used to define the empirical parameters of the following relationship proposed by Darendeli (2001), to describe the decay of the normalized shear modulus G(γ)/Go:

$$\frac{G}{G_o} = \frac{1}{1+\left(\frac{\gamma}{\gamma_r}\right)^a}$$

where:

$$\gamma_r = \left(\phi_1 + \phi_2 \cdot PI \cdot OCR^{\phi_3}\right) \cdot \sigma_o'^{\,\phi_4}$$

a = 0,92; ϕ_1 = 0,0352; ϕ_2 = 0,00010; ϕ_3 = 0,3246; ϕ_4 = 0,3483.

The relationship between the damping ratio and shear strain is described as follows:

$$D_\gamma = D_{min} + b \cdot D_{Masing}(\gamma) \cdot \left(\frac{G}{G_o}\right)^{0,1} \qquad (3)$$

where:

$$D_{min} = \left(\phi_6 + \phi_7 \cdot PI \cdot OCR^{\phi_8}\right) \cdot \sigma_o'^{\,\phi_9} \left(1 + \phi_{10} \ln(freq)\right) \qquad (4)$$

$$b = \phi_{11} + \phi_{12} \cdot \ln N \qquad (5)$$

freq = frequency in Hz
N = number of load cycle
ϕ_6 = 0,8005; ϕ_7 = 0,0129; ϕ_8 = -0,1069; ϕ_{10} = 0,2919; ϕ_{11} = 0,6329; ϕ_{12} = -0,0057

$$D_{Masing,a=1}(\gamma) = \frac{100}{\pi}\left[4 \cdot \frac{\gamma - \gamma_r \ln\left(\frac{\gamma + \gamma_r}{\gamma_r}\right)}{\frac{\gamma^2}{\gamma + \gamma_r}} - 2\right]$$

For other values of *a* (e.g. *a* = 0,92, used to calculate *G*) the following relationship is adopted:

$$D_{Masing,a}(\gamma) = c_1\left(D_{Masing,a=1}\right) + c_2\left(D_{Masing,a=1}\right)^2 + c_3\left(D_{Masing,a=1}\right)^3$$

where:

$$c_1 = 0,2523 + 1,8618 \cdot a - 1,1143 \cdot a^2$$

$$c_2 = -0,0095 - 0,0710 \cdot a + 0,0805 \cdot a^2$$

$$c_2 = 0,0003 + 0,0002 \cdot a + 0,0005 \cdot a^2$$

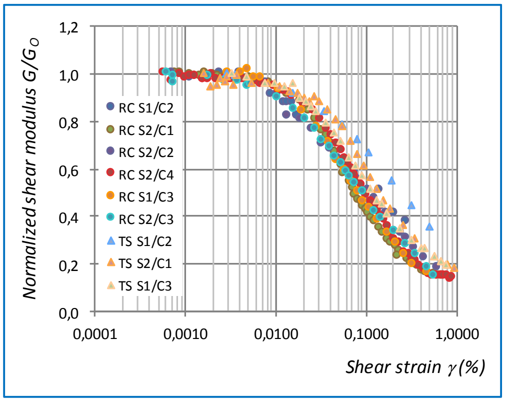

Figure 2 ***Reduction curves of Shear Modulus***

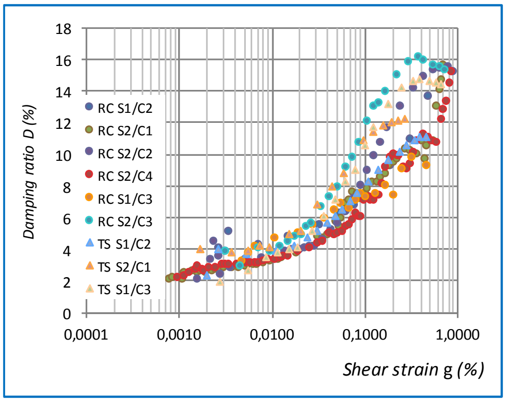

Figure 3 ***Damping Ratio D vs. shear strain γ***

The Figures 4-5 show the comparison between experimental values of *G/Go* vs *γ* obtained by Resonant Column and Cyclic Shear Test and those deducted by equation proposed by Darendeli (2001) for a sample tested at pressure *σ'o* = 200 kPa. It is possible to observe good agreement between experimental and computed values.

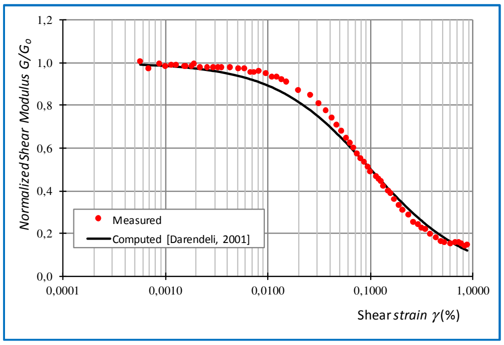

Figure 4 ***Comparison between experimental values G/Go – log γ and the corresponding curves proposed by Darendeli (2001).***

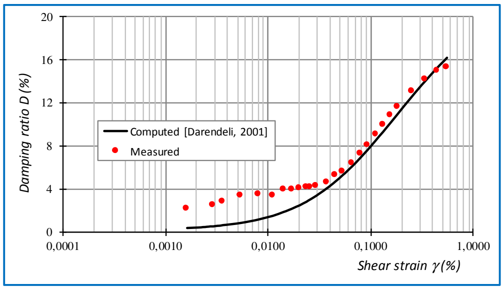

Figure 5. ***Comparison between the experimental curve D – log γ and the corresponding curves by Darendeli (2001).***

CONCLUDING REMARKS

The present paper reports the preliminary results of the static and dynamic characterization on a site of the city of Enna. The objective of this work is primarily to highlight the importance of an adequate geotechnical characterization as part of the problems related to soil behaviour under cyclic and dynamic loads. A Resonant Column apparatus has been used in order to derive the law of variation of the shear modulus G and of the damping ratio D for any level of shear strain. The obtained results have been compared with the literature relationships.

ACKNOWLEDGMENTS

National Operational Programme for Research and Competitiveness 2007-2013 for the regions of the convergence objective (Campania, Puglia, Calabria, Sicily) - MIUR - "Project L.E.D.A. (Laboratory of Earthquake Engineering and Dynamic Analysis).

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