DYNAMIC GEOTECHNICAL CHARACTERIZATION OF SOILS SUBJECTED TO UMBRIA AND MARCHES EARTHQUAKE

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SUMMARY

The Umbria and Marches regions, in central Italy, were severely damaged by the seismic sequence initiated on September 26, 1997. After that event, Local Authorities, GNDT and Servizio Sismico Nazionale (SSN) have promoted and supported some rigorous (Grade 3) microzonation studies in those areas, in order to reduce the seismic risk and to rationalise the land use. A Grade 3 seismic microzonation of the city of Fabriano is under way. This paper presents the results of in situ and laboratory investigations performed in typical deposits of Fabriano area with the main purpose of obtaining representative shear modulus and damping ratio profiles.

INTRODUCTION

Microzonation studies are aimed at providing thematic maps for seismic hazards evaluation and then for a more rational use of the territory. The scope is to identify, in detail, those zones that are prone to disastrous events like liquefaction or seismic slope instability and those zones where site or topographic amplification of the seismic motion can occur. Grade 3 microzonation studies (TC4 1999) require the quantitative determination of mechanical soil properties. In the case of one-dimensional analysis it is necessary to assess the bedrock depth, a profile of the small strain shear modulus (G_o) and viscous damping ratio (D_o) and the dependence of G and D on the shear strain level. In the case of one-dimensional non linear analysis the definition of the stress-strain relationship for first loading and for unloading and reloading is necessary. Therefore, the measurement of stiffness and damping for the strain interval of interest (i.e. from 10^{-4} % to 10^{-1} %) is essential for this type of problems. In order to assess the dynamic characteristics of soils in Fabriano area a laboratory and in situ test programme has been carried out by the University of Florence and Politecnico di Torino. The laboratory tests were aimed at investigating the shear stiffness and damping characteristics of natural cohesive soils by means of resonant column and torsional tests. A down-hole seismic experiment has also been performed (Crespellani et al. 1999b). This enables one to evaluate site effects and earthquake design loads for the reconstruction, repair and strengthening of Umbria and Marches buildings.

GEOLOGICAL AND GEOTECHNICAL SITE CHARACTERISATION

The city of Fabriano (AN) is located in the central area of the Marches. Fabriano is an important town, with ancient origins, lying in a wide valley, which still preserves high and noble traces of its past in the narrow streets and in the ancient, medieval and 16th – 17th century fabrics of its historic centre. Because of its geographic location, it has played a leading role in the territory between the Marches and Umbria regions. At present it is also an important industrial centre for Marches region.

On 26th September 1997, two seismic shocks, having magnitudes respectively of MS = 5.5 and MS = 5.9, struck an area of central Italy, causing considerable damage in a wide zone situated on the boundary between the Marches and Umbria. The two shocks were followed, during the subsequent months, by a large number of others shocks of similar Magnitudo. The seismic events caused in the Umbria and Marches Italian regions heavy structural damages and some casualties. In a few villages the macroseismic intensity reached values of IX MCS;

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in a broad area of about 450 km^2 the intensity was greater than VII. Also at Fabriano the intensity reached VII MCS.

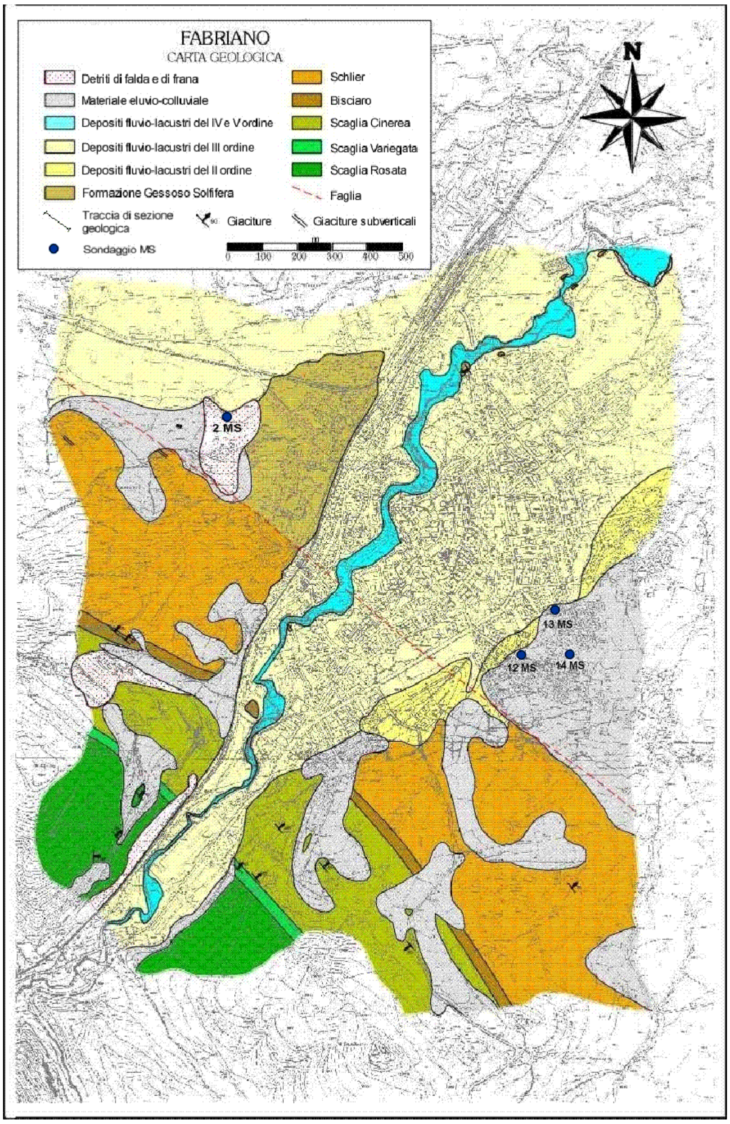

Figure 1. Geological map of Fabriano.

Two zones of the town were particularly damaged: the zone of Borgo (Figure 1, Borehole 2) which is a zone of recent expansion and the zone of Serralaloggia-La Spina (Figure 1, Boreholes 12, 13 and 14). The bedrock consists of a marl formation that is located at a depth of between 10 (at the Borgo zone) and 17 m (at Serralaloggia-La Spina zone). Overlying strata, from bottom to top, mainly consist of: lacustrine silty clay each from 5 to 10 m thick, eluvio-colluvial silty clay with a thickness ranging from 6 to 10 m. In the case of boreholes 2 and 12, the lacustrine silty clay strata were not observed. Nevertheless a certain soil variability, simplified stratigraphy indicate the presence of soft deposits overlying the bedrock that is about 15 m deep. Undisturbed samples were retrieved from boreholes shown in Figure 1 to provide a more detailed geotechnical characterisation (Crespellani et al. 1999).

General characteristics and index properties of Fabriano soil (Serralaloggia-La Spina) are shown, as a function of depth, in Figure 2 (Crespellani, 1999a). The soils can be classified as CH (Figure 3) with a plasticity index (PI) mainly ranging from 22 to 38 %. The highest values of PI (45 %) were observed in the shallowest stratum of Borgo (Borehole 2).

The preconsolidation pressure σ'_p and the overconsolidation ratio OCR = σ'_p/σ'_{vo} were evaluated from incremental loading oedometer tests. Moreover, the coefficient of earth pressure at rest K_o was evaluated by means of the empirical correlations proposed by Schmidt (1966), Alpan (1967) and Massarsch (1979):

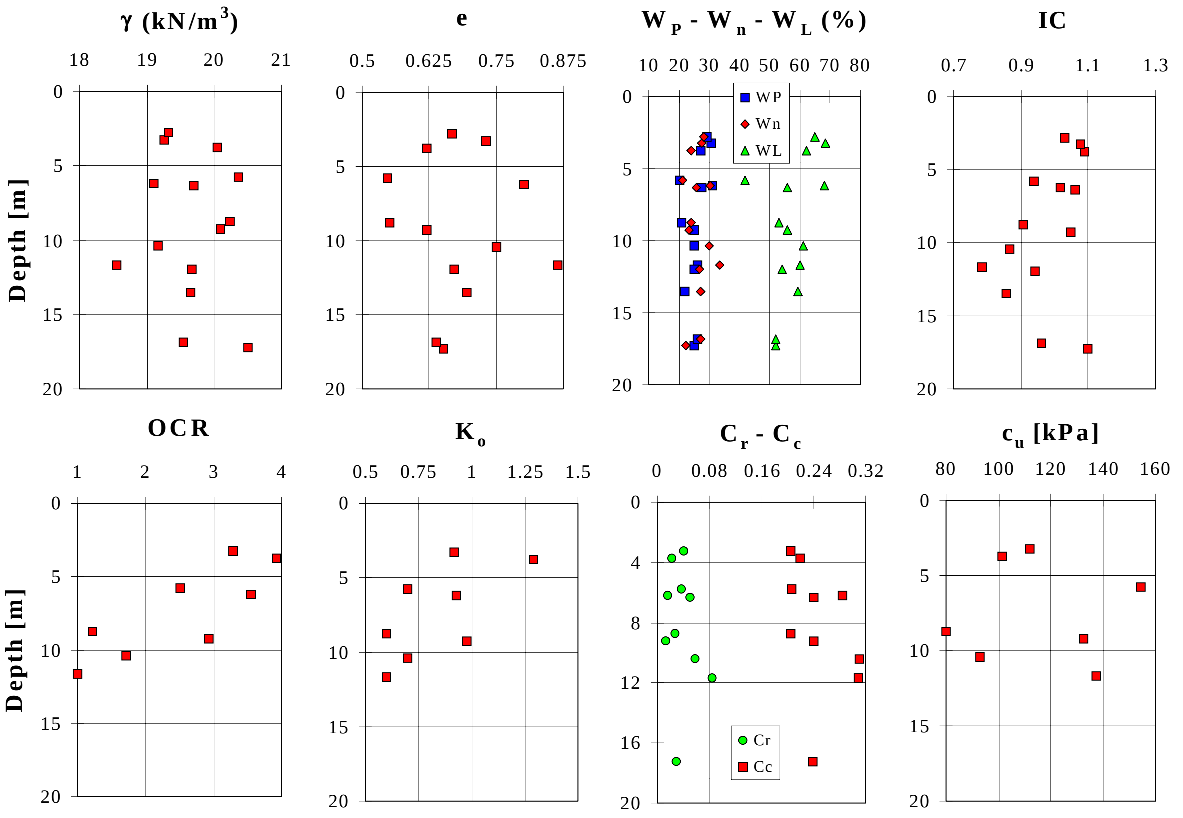

Figure 2. General characteristics and index properties of Fabriano area.

$$K_o(OC) = K_o(NC) \cdot OCR^{\alpha}$$

where: $K_o(NC)$ and α are empirically inferred from PI values.

OCR and K_o values are also reported in Figure 2 and clearly show that the shallowest strata are overconsolidated with OCR values from 2 to 4. The values of compression and recompression indexes, inferred from odometer tests, are also reported in Figure 2. The undrained shear strength (C_u) was obtained from unconfined compression tests. The measured values are also reported in Figure 2.

As far as the marl bedrock is concerned the following general characteristics have been found: G_s = 2.62 (specific gravity), γ = 21.7 kN/mc, e = 0.32, w = 12.4%, w_L = 53.8 %, w_P = 24 %, PI = 30 % (Crespellani et al. 1999).

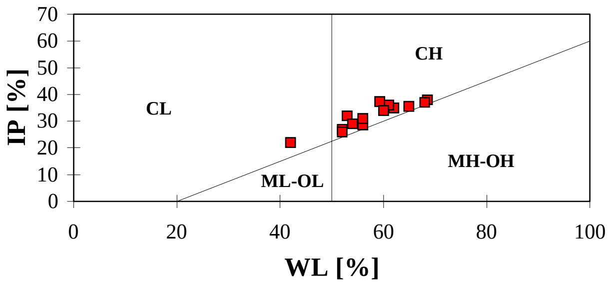

Figure 3. Plasticity chart.

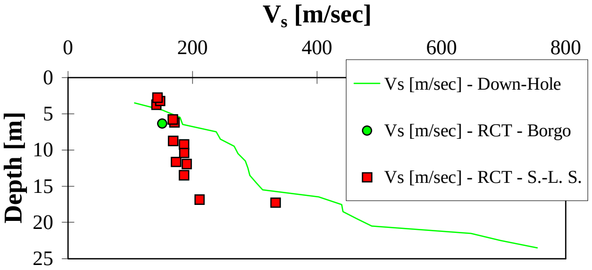

Figure 4. Shear wave velocity from laboratory and in situ tests

Table 1. Test conditions for the two Fabriano zones.

Test No.	Borehole Sample	Depth [m]	Laboratory	σ'_{vc} [kPa]	e	PI	D_o (1) [%]	D_o (2) [%] (SSM)	D_o (2) [%] (ADM)	G_o (1) [MPa]	G_o (2) [MPa]	Specimen Shape
1	2 - 1	6.35	FI	65	0.713	28			-		38	S
2	2 - 1	6.35	FI	80	0.706	28			-		44	S
3	2 - 1	6.35	FI	120	0.690	28			3.28		53	S
4	2 - 1	6.60	TO	98	-	26	1.45	4.55	8.54	36	46	S
5	2 - 1	6.60	TO	99	-	26	1.00	4.11	5.71	37	43	S
6	12 - 2	3.75	FI	90	0.663	35			3.05		41	S
7	12 - 4	9.25	FI	190	0.612	31			5.35		71	S
8	13 - 1	3.25	FI	110	0.725	38			5.18		43	S
9	13 - 2	6.20	FI	120	0.768	37			5.06		57	S
10	13 - 3	10.40	FI	170	0.737	36			3.74		68	S
11	13 - 4	13.50	TO	245	0.608	37	1.41	4.74	1.69	69	64	H
12	13 - 5	17.25	FI	250	0.419	27			4.27		232	S
13	14 - 1	2.80	TO	60	0.588	35	1.74	8.33	8.03	24	41	H
14	14 - 2	5.8	FI	120	0.561	22			7.45		59	S
15	14 - 3	8.75	FI	150	0.576	32			3.81		59	S
16	14 - 4	11.66	FI	230	0.657	34			3.1		57	S
17	14 - 5	16.85	FI	230	0.637	26			3.91		73	S
18	14 - 5	16.85	TO	280	0.626	26	1.47			89		H

where: U = Undrained. D_o (1) and G_o (1) from CLTST, D_o (2) and G_o (2) from RCT. H = Hollow cylindrical specimen (R_o = 25 mm; R_i = 15 mm; h = 100 mm). S = Solid cylindrical specimen (R = 25 mm; h = 100 mm).

DYNAMIC SITE CHARACTERISATION

The equivalent shear modulus (G_{eq}) and damping ratio D of Fabriano deposit were determined in the Firenze and Torino laboratories by means of Resonant Column (RCT) and cyclic loading torsional shear tests (CLTST) performed on undisturbed specimens isotropically reconsolidated. CLTST were performed at frequency of 0.1 Hz.

In the case of CLTSTs the damping ratio was determined using the following definition of hysteretic damping ratio:

$$D = \frac{\Delta W}{4\pi W}$$

where: ΔW is the area enclosed by the unloading-reloading loop and represents the total energy loss during the cycle and W is the elastic stored energy.

In the case of RCT the damping ratio was determined using two different procedures: following the steady-state method (SSM), the damping ratio was obtained during the resonance condition of the sample; following the amplitude decay method (ADM) it was obtained from the log decrement during free vibration.

G_{eq} was determined from the slope of the unload-reload loops in the case of CLTST and from frequency equation for RCT.

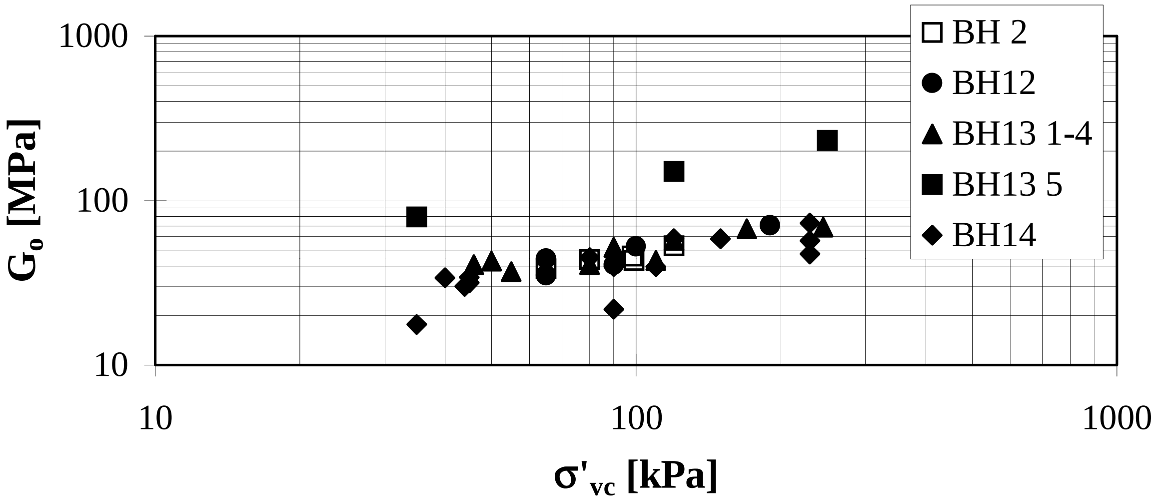

Figure 5. Small strain shear modulus vs. consolidation pressure.

The small strain shear modulus (G_o) and damping ratio (D_o) were determined at shear strain levels of about 0.0001 %. The measured values are reported in Table 1 with laboratory test conditions. In some cases, the same specimen was first subjected to CLTST and after a rest period of 24 hrs with opened drainage to RCT. The size and shape of the specimens are also indicated in Table 1.

Shear wave velocity and hence small strain shear modulus were also inferred from in situ down hole test performed at Borgo in Borehole 2 (Crespellani et al. 1999). Figure 4 compares the shear modulus from laboratory and in situ tests. The ratio G_o(lab)/G_o(field) is about 0.85 if appropriate laboratory consolidation stresses (σ'_v = 100 - 120 kPa) are considered. The G_o values of specimens from boreholes 12, 13 and 14, are also reported in order to evaluate possible spatial (horizontal and vertical) variability.

Figure 5 shows the small strain shear modulus against the consolidation pressure. It is possible to notice that almost all data fall within a narrow band. Samples retrieved from borehole 13 give higher values of G_o in the case of sample 5 that was retrieved from the marl formation. CLTST and RCT give on the whole the same values of G_o, even though in some cases the G_o values from CLTST are smaller than those from RCT.

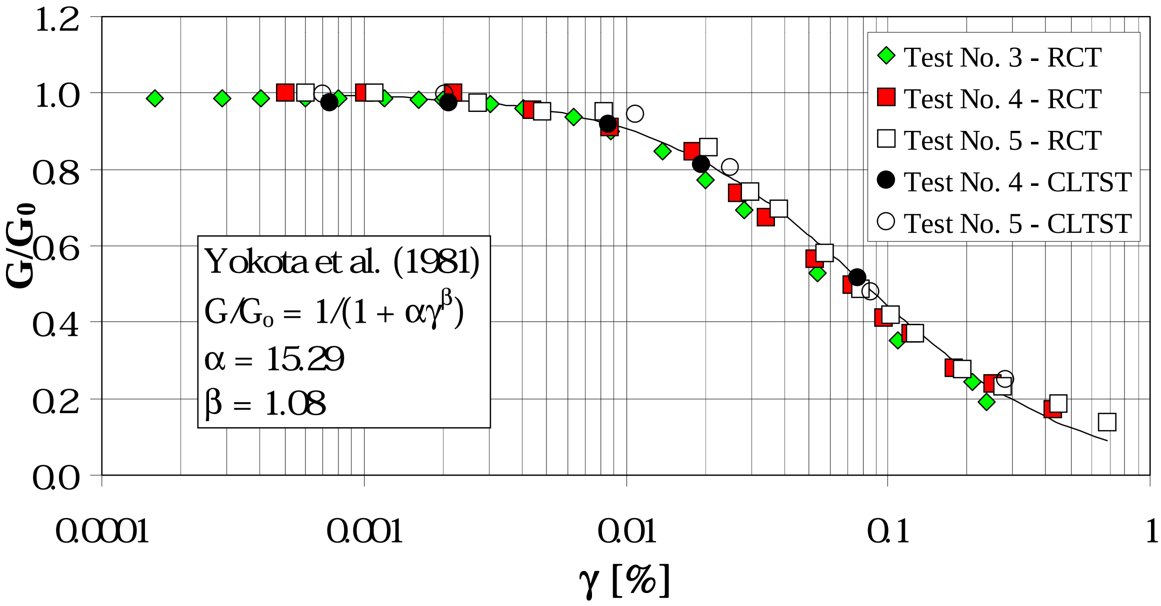

Figure 6a. Shear modulus decay vs. shear strain of Borgo zone.

The same shear modulus decay have been obtained from CLTST and RCT. Results concerning the Borgo zone are shown in Figure 6a, while those of Serraloggia-La Spina are shown in Figure 6b. Only the marl sample (Borehole 13, sample 5) shows a different decay (more brittle). Experimental data of Borgo were fitted by the Yokota et al (1981) law the parameters of which are reported in Figure 6a. The Ramberg-Osgood (1943) equation was used for the Serraloggia-La Spina data (Crespellani et al. 1999b).

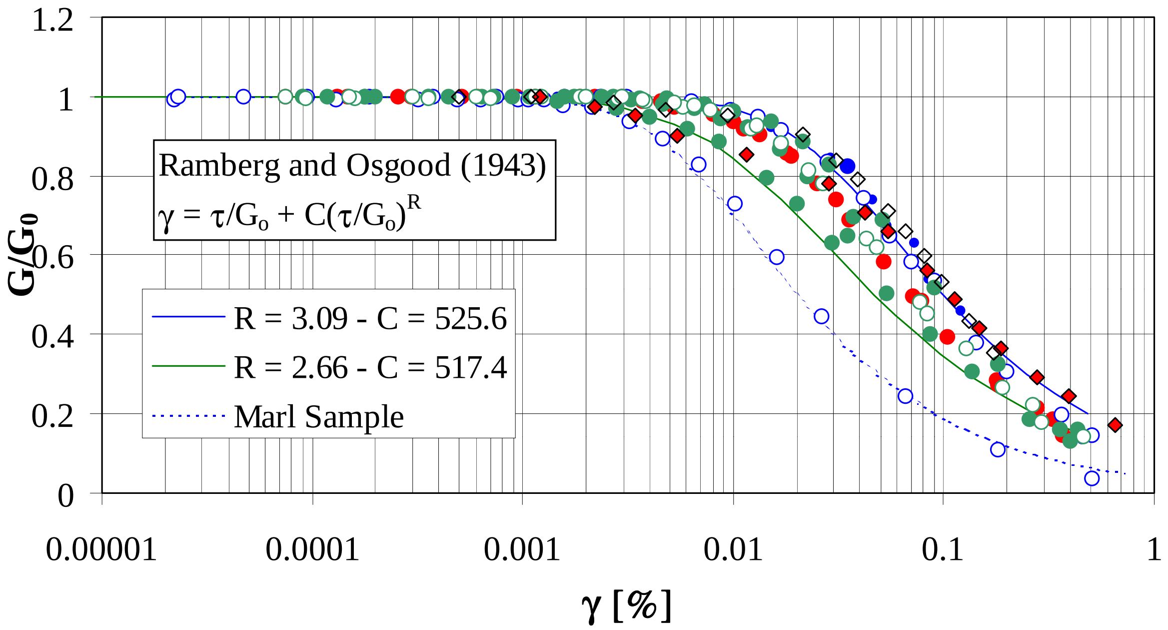

Figure 6b. Shear modulus decay vs. shear strain of Serraloggia-La Spina zone.

Figures 7a and 7b show the damping ratio vs. shear strain for the two considered sites. The damping ratio values obtained from RCT using two different procedures are similar even if, for strain level greater than 0.01 %, higher values of D have been obtained from amplitude decay method. It is possible to see that the damping ratio from CLTST, at very small strains, is equal to about 1.5 %. Greater values of D at small strain, ranges from about 3.1 % to 8.3 %, are obtained from RCT. Also, on the whole investigated strain interval, RCT gives higher values of D than CLTST.

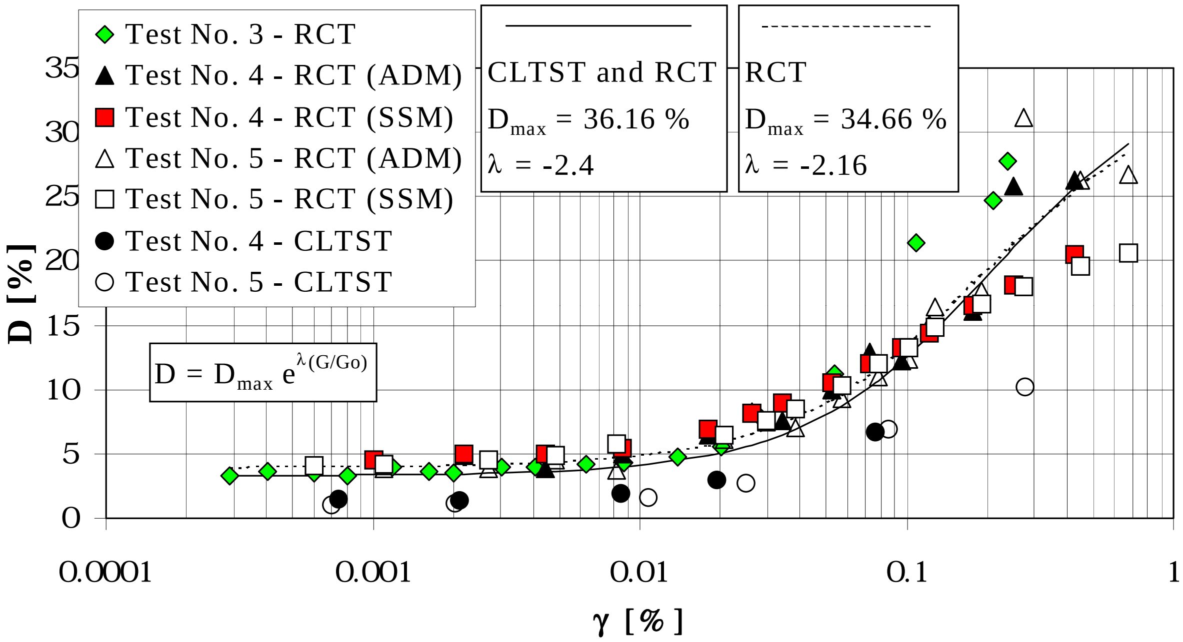

Figure 7a. Damping ratio vs. shear strain of Borgo zone.

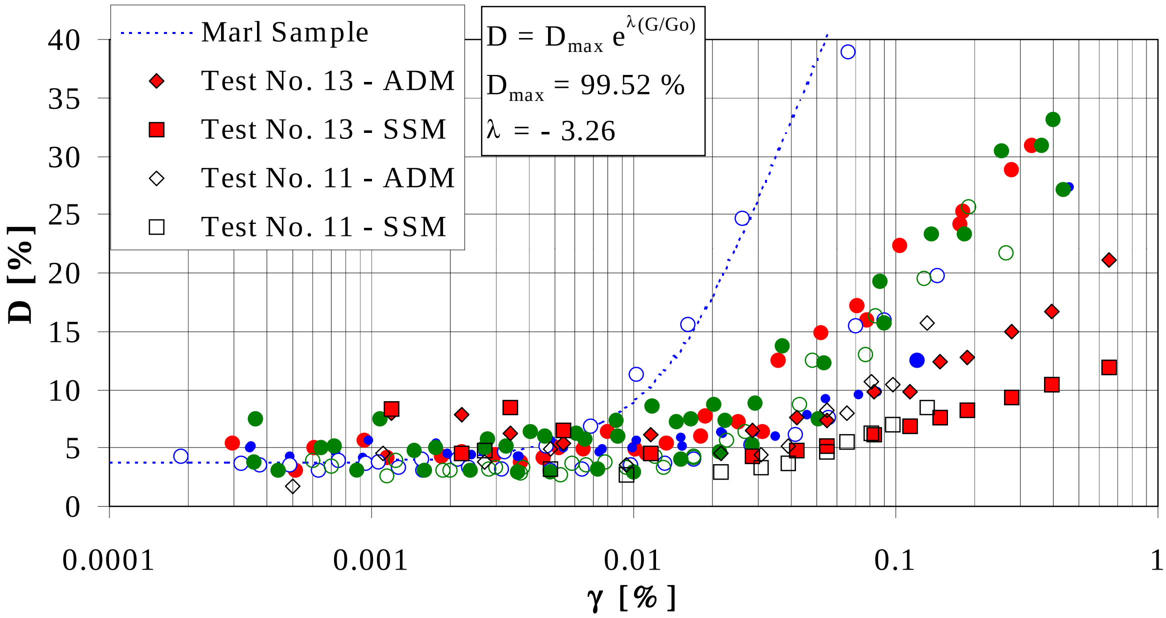

Figure 7b. Damping ratio vs. shear strain of Serraloggia-La Spina zone.

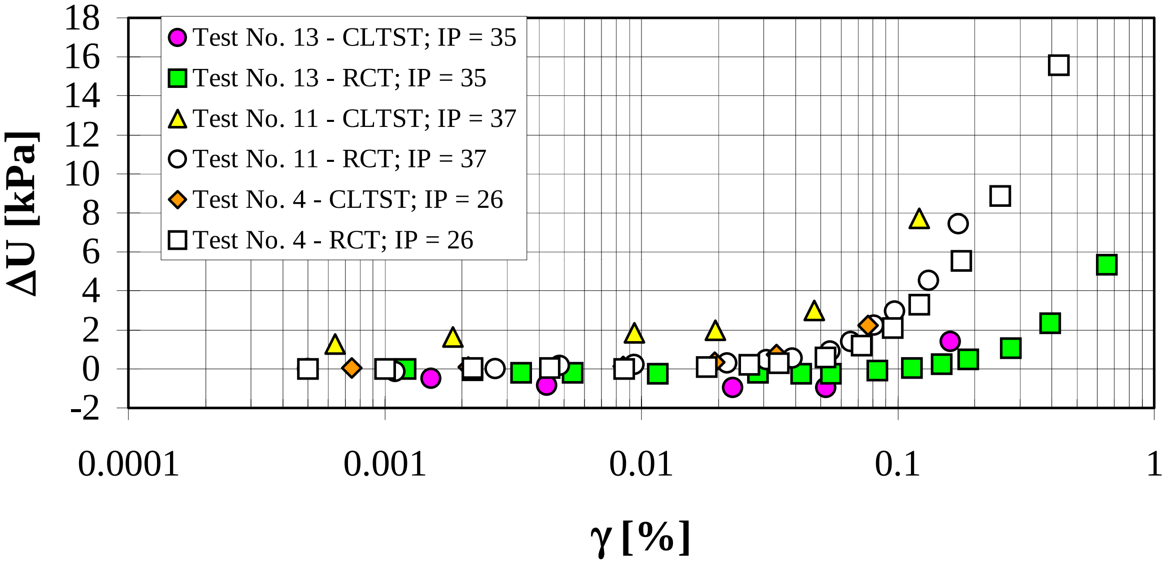

Figura 8. Accumulated pore pressure vs. shear strain.

Considering that the influence of number of cycles N on D has been found to be negligible, in the case of clayey soils for strain levels of less than 0.1 % (Cavallaro 1997, Lo Presti et al. 1996 and 1998), it is supposed that RCT provide larger values of D than CLTST because of the rate (frequency) effect, in agreement with data shown by Shibuya et al. (1995) and Tatsuoka et al. (1995). According to these researchers the nature of soil damping in soils can be linked to the following phenomena: i) non-linearity which governs the so called hysteretic damping and is controlled by the current shear strain level. This kind of material damping is absent or negligible at very small strains; ii) viscosity of the soil skeleton (creep) which is relevant at very small strain rates and iii) viscosity of the pore fluid which is relevant at very high frequencies (due to higher rate in RCT). It is believed that very high and unrealistic values of D are obtained from RCT because of the high frequencies used in such a test.

Figure 8 shows the accumulated pore pressure vs. shear strain during some CLTST and RCT performed at Torino laboratory. The pore pressure build up in cyclic undrained tests generally indicates the occurrence of relevant plastic strains and degradation phenomena. The strain level, which triggers the pore pressure increase, ranges from 0.05 and 0.1 %. These kinds of phenomena are generally associated with unstable loops.

CONCLUSIONS

In this paper some information concerning G and D of two zones in the Fabriano area has been presented. On the basis of the experimental results obtained, it is possible to draw the following conclusions:

- the same values of the small strain shear modulus are obtained from RCT and CLTST. Some differences are probably due to a less good repetitively of CLTST;
- the same shear modulus decay with shear strain level has been obtained from CLTST and RCT;
- damping ratio at small strains is never equal to zero for clay, the values so far obtained range between 1.0 % and 1.8 % for CLTST and 3.1 % and 8.3 % for RCT;
- damping ratio values determined from RCT are considerably greater than those obtained from CLTST at any strain level;
- differences between RCT and CLTST results are probably due to rate and/or frequency effects;
- degradation phenomena have been observed for strain level of between 0.05 to 0.1 %; the material degradation is more relevant for tests performed at lower strain rates (CLTST).

ACKNOWLEDGEMENT

This study was financially supported by CNR/GNDT (contract N°. 97/00523.PF54).

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