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Antonio Cavallaro
CNR Ibam, Catania, Italy

Salvatore Grasso
University of Catania, Catania, Italy

Valentina Lentini
University of Catania, Catania, Italy

Michele Maugeri
University of Catania, Catania, Italy

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Antonio Cavallaro
CNR Ibam, Catania
Catania, (Italy)

Salvatore Grasso
University of Catania
Catania, (Italy)

Valentina Lentini
University of Catania
Catania, (Italy)

Michele Maugeri
University of Catania
Catania, (Italy)

ABSTRACT

The paper presents the geotechnical characterization of a clay soil subjected to a preloading embankment for the construction of an industrial electronics building in the industrial area (STM M6) of Catania (Sicily, Italy). To determine the geological profile and the geotechnical characteristics of the soil, the site was well investigated by means of in situ and laboratory tests. The following in situ geotechnical tests were carried out: Borings, SPT, CPT, PLT and dynamic in situ tests have been performed. Among them Down-Hole (D-H), Cross-Hole (C-H), SASW and recently Seismic Dilatometer Marchetti Tests (SDMT) have been carried out, with the aim to evaluate the soil profile of shear waves velocity (V_s). Moreover the following laboratory tests were carried out on undisturbed samples retrieved with a 86 mm diameter Shelby sampler: Oedometer tests, Direct shear tests, Triaxial Tests, Resonant Column and Torsional shear tests. Static and dynamic parameters were compared by in situ and laboratory tests. A significantly correspondence between the values of the geotechnical parameters derived from laboratory and in situ tests was observed. The in situ and laboratory geotechnical analysis gives the parameters to evaluate the performance of soil subjected to soil embankment by mathematical modeling.

INTRODUCTION

On 5 September 2000 in the industrial area (STM M6) of Catania (Sicily, Italy) (STM M6) started the construction of an instrumented circular test embankment of 2.50 meters high on a clayey deposit. The construction lasted ten days and was realized in four different phases. The hope of preloading technique by embankment was the investigation of the compressibility of soil. Successively on the basis of the results obtained a reinforced concrete building for an electronics industry was realized in an area near the embankment.
The site was well investigated by means of in situ and laboratory tests with particular attention to the soil stiffness at small strain. Soil stiffness is a relevant parameter in solving design of special foundations for which the serviceability limit allows only very small displacements. Moreover static and dynamic parameters were compared by in situ and laboratory tests.
The in situ and laboratory geotechnical analysis gives the parameters to evaluate the performance of soil subjected to soil embankment by mathematical modeling. This paper tries to summarize the geotechnical information in a comprehensive way in order to provide a case record of site characterization for a preloading technique study.

GEOTECHNICAL SOIL CHARACTERIZATION

The investigated STM M6 area, located in the South zone of the city, has plane dimensions of 212400 mq and a maximum depth of 100 m. The area pertaining to the investigation program and the locations of the boreholes and field tests are shown in Figure 1.
The STM M6 site consists of fine alluvial deposits. Undisturbed samples were retrieved by means of Osterberg (1973) piston sampler and an 86 mm Shelby tube sampler.
In the Catania STM M6 area, the clay fraction (CF) is predominantly in the range of 2 - 54 %. This percentage decreases to 0 - 2 % at the depth of 95 m where a sand fraction of 4 - 9 % is observed. The gravel fraction is always zero. The silt fraction is in the range of about 50 - 100 %. The values of the natural moisture content, w_n, range from between 22 and 56 %.
Characteristic values for the Atterberg limits are: w_L = 54 - 84 % and w_p = 27 - 46 %, with a plasticity index of PI = 22 - 41 %.
The good degree of homogeneity of the deposit is confirmed by comparing the penetration resistance q_c from mechanical cone penetration tests (CPT) performed at different locations over the investigated area (Figure 2).
The variation of q_c with depth clearly shows the very poor mechanical characteristics of soil. Typical values of q_c are in the range of 0.01 to 0.49 MPa. The soil deposits can be classified as inorganic silt of high compressibility and organic clay.
Typical range of physical characteristics, index properties and strength parameters of the deposit are reported in Table 1.

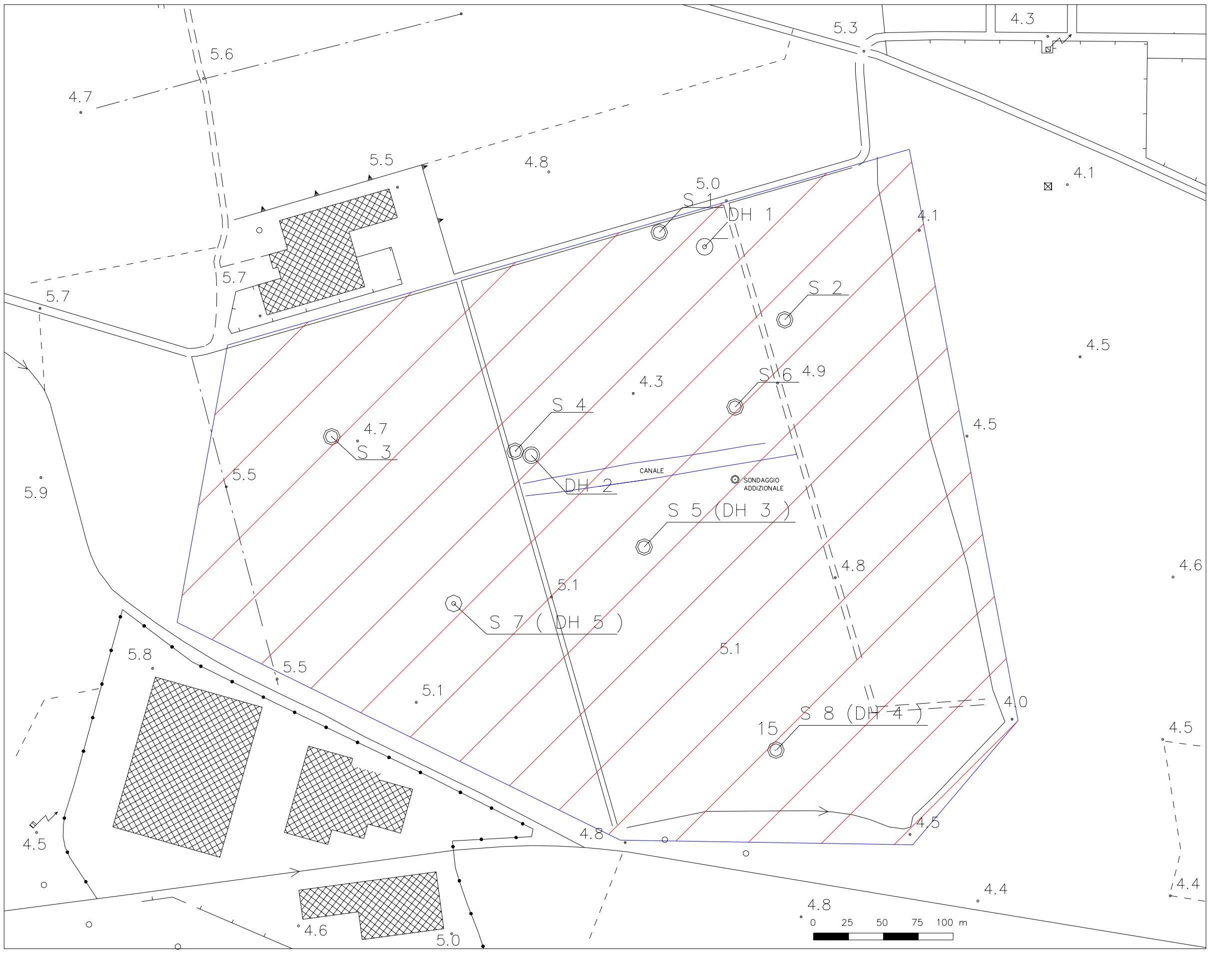

Fig.1. Layout of investigation area with locations of the boreholes and of field tests.

Table 1. Mechanical characteristics for Catania STM M6 area.

Site	γ [kN/m^3]	e	c_u [kPa]	c' [kPa]	ϕ' [°]
STM M6	16.6-20.2	0.56-1.51	28.75-203.61	2.41-21.7	16-18

where: c_u (Undrained shear strength), c' (Cohesion) and ϕ' (Angle of shear resistance) were calculated from and C-U and C-D Triaxial Tests.

The preconsolidation pressure σ'_p and the overconsolidation ratio OCR = σ'_p/σ'_{vo} were evaluated from the 24^h compression curves of 5 incremental loading (IL) oedometer tests. Moreover, a SDMT was used to assess OCR and the coefficient of earth pressure at rest K_o following the procedure suggested by Marchetti (1980).

The information obtained from laboratory and in situ tests is summarized in Figure 3. The OCR values obtained from SDMT range from 1 to 10 (K_o = 0.5 to 1) with an average value equal to 1.2 up to about 10 for the 40 m deep sounding.

The OCR values inferred from oedometer tests are lower than those obtained from in situ tests.

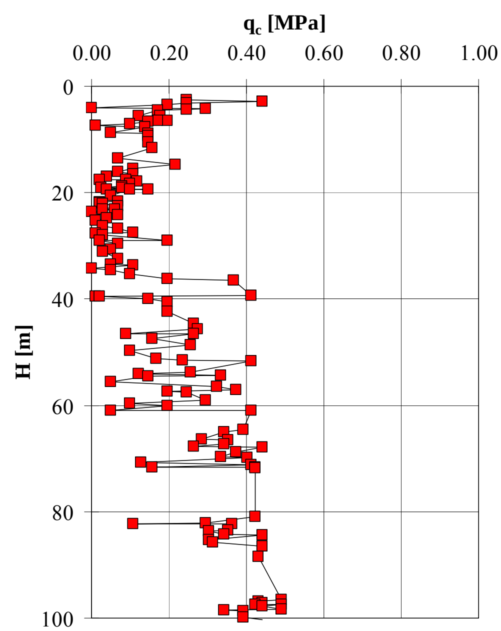

Fig. 2. Static cone penetration test results.

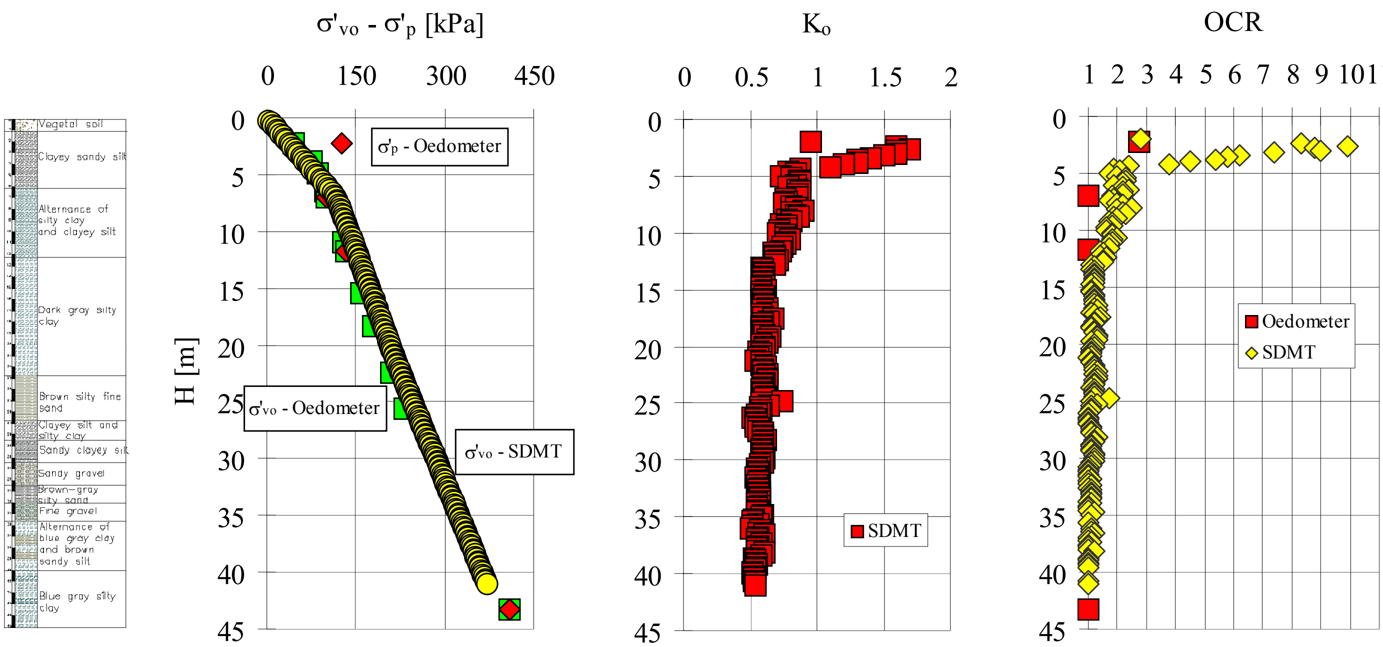

Fig. 3. Stress history from in situ and laboratory tests.

One possible explanation of these differences could be that lower values of the preconsolidation pressure σ'_p are obtained in the laboratory because of sample disturbance.

SHEAR MODULUS

The small strain ($\gamma \leq 0.001$ %) shear modulus, G_o, was determined from SDMT and a Down Hole (DH) test. The equivalent shear modulus (G_{eq}) was determined in the laboratory by means of a Resonant Column test (RCT) performed on Shelby tube specimens by means of a Resonant Column. Moreover it was attempted to assess G_o by means of empirical correlations, based either on penetration test results or on laboratory test results (Jamiolkowski et al. 1995).

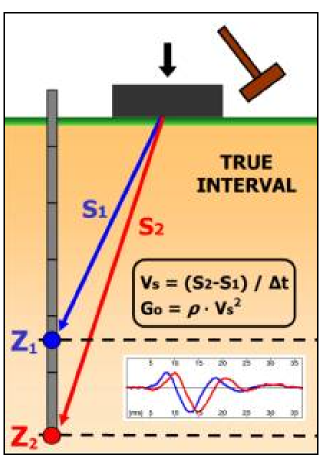

Fig. 4. SDMT scheme for the measure of V_s.

Small strain shear modulus G_o: in situ vs. laboratory measurements

The SDMT provides a simple means for determining the initial elastic stiffness at very small strains and in situ shear strength parameters at high strains in natural soil deposits.
Source waves are generated by striking a horizontal plank at the surface that is oriented parallel to the axis of a geophone connects by a co-axial cable with an oscilloscope (Martin & Mayne, 1997, 1998). The measured arrival times at successive depths provide pseudo interval V_s profiles for horizontally polarized vertically propagating shear waves (Figure 4).
The small strain shear modulus G_o is determined by the theory of elasticity by the well known relationships:

$$G_o = \rho V_s^2 \tag{1}$$

where: ρ = mass density.
A summary of SDMT parameters are shown in Figure 5 where:
- I_d: Material Index; gives information on soil type (sand, silt, clay);
- M: Vertical Drained Constrained Modulus;
- C_u: Undrained Shear Strength;
- K_d: Horizontal Stress Index; the profile of K_d is similar in shape to the profile of the overconsolidation ratio OCR. $K_d = 2$ indicates in clays OCR = 1, KD > 2 indicates overconsolidation. A first glance at the K_d profile is helpful to "understand" the deposit;
- V_s: Shear Waves Velocity.

In Figure 6 the Poisson ratio variation with depth, obtained from a Down Hole (D-H) test, is plotted to show site characteristics. It is seen that the values oscillates around 0.49.

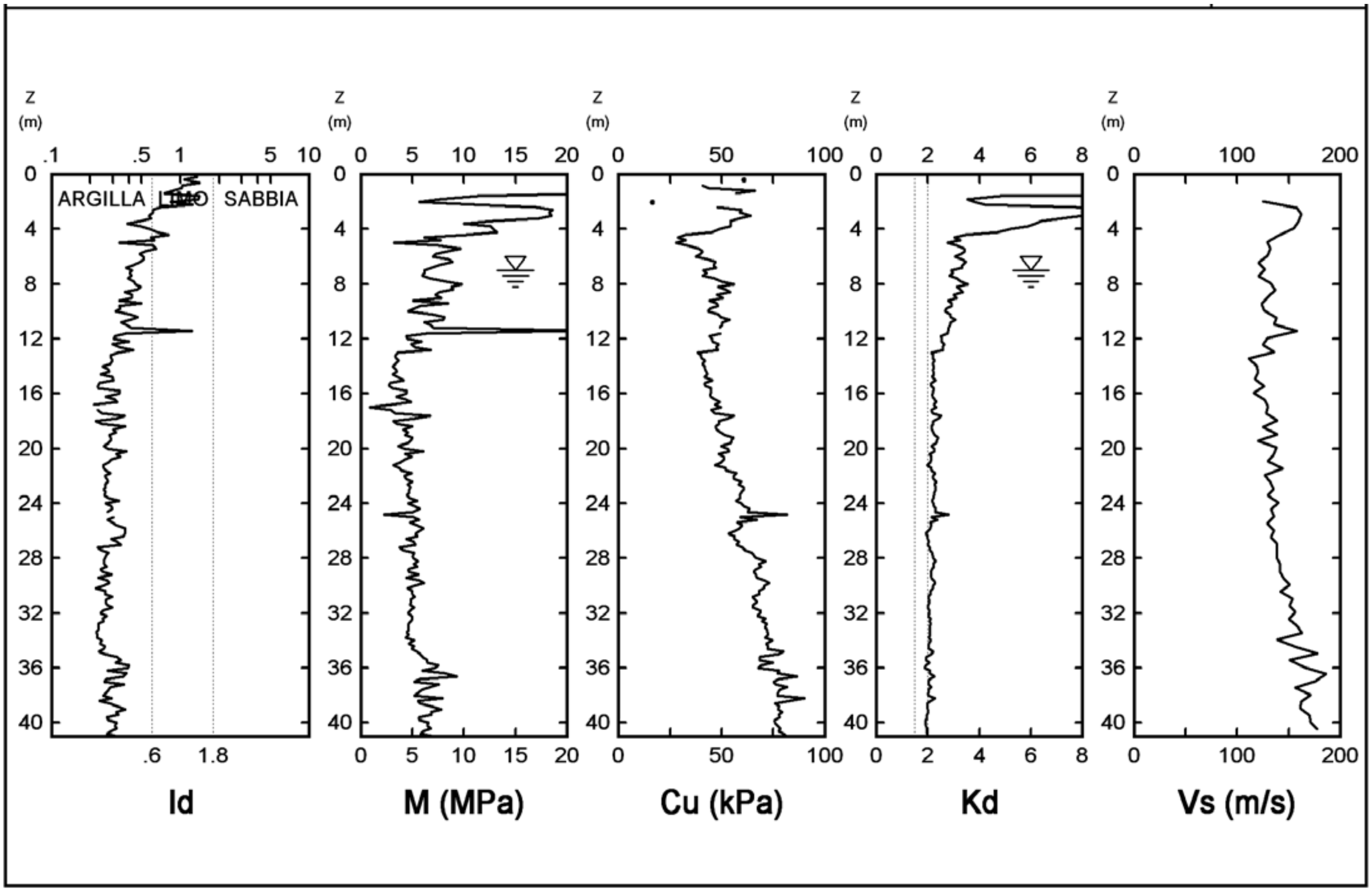

Fig. 5. Summary of SDMTs in STM M6 area.

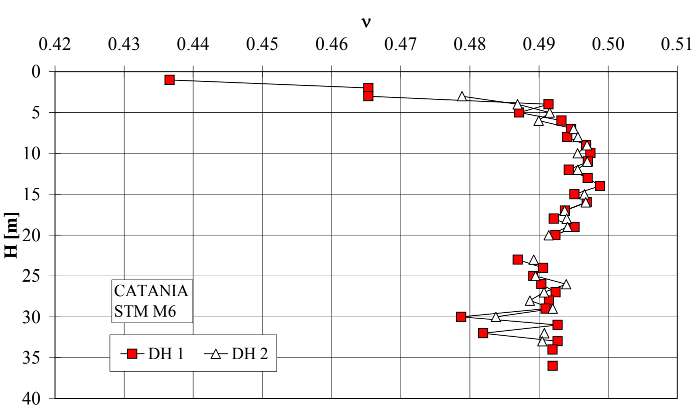

Fig. 6. Poisson ratio from in D-H tests

Figure 7 shows the values of G_o obtained in situ from a D-H test and SDMT and those measured in the laboratory from RCT performed on undisturbed solid cylindrical specimens which were isotropically reconsolidated to the best estimate of the in situ mean effective stress. The G_o values are plotted in Figure 7 against depth (Carrubba and Maugeri 1988). In the case of laboratory tests, the G_o values are determined at shear strain levels of less than 0.001 %.

Quite a good agreement exists between the laboratory and in situ test results. On average the ratio of G_o (Lab) to G_o (Field) by SDMT and DH was equal to about 0.90 at the depth of 29.5 m.

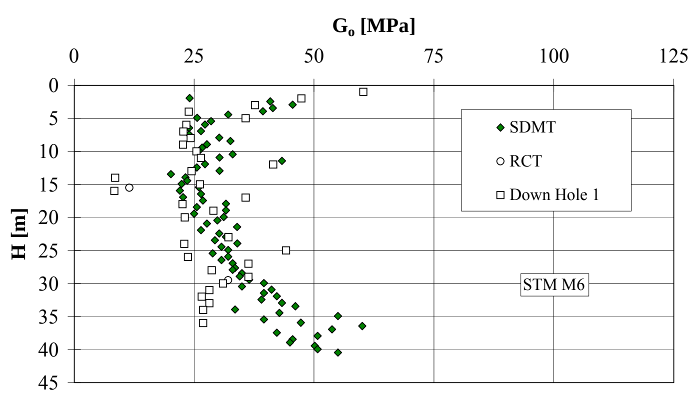

Fig. 7. G_o from laboratory and in situ tests.

In the superficial strata G_o by SDMT assumed the value of 45 MPa. In the medium Holocene strata G_o values are between 20 and 35 MPa. In the lower Holocene soil G_o increases with depth to 55 MPa.

The experimental results of specimens obtained by RCT were used to determine the empirical parameters of the eq. proposed by Yokota et al. (1981) (Figure 8) to describe the shear modulus decay with shear strain level:

$$\frac{G(\gamma)}{G_o} = \frac{1}{1+\alpha\gamma(\%)^{\beta}} \tag{2}$$

in which:
$G(\gamma)$ = strain dependent shear modulus;
γ = shear strain;
α, β = soil constants.
The expression (2) allows the complete shear modulus degradation to be considered with strain level (Maugeri 1995).
The values of α = 7.15 and β = 1.223 were obtained for STM M6 clay by Carrubba and Maugeri (1988).

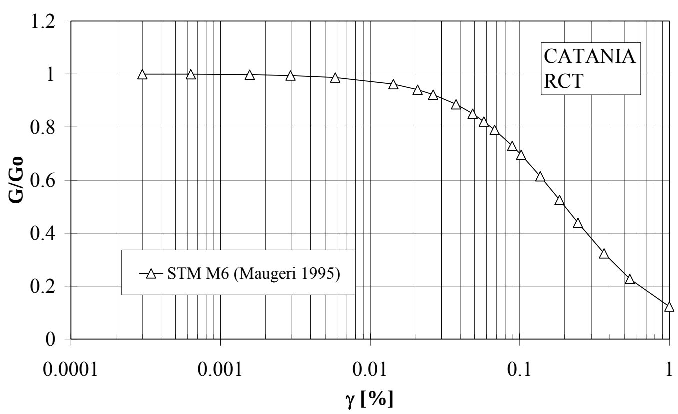

Fig. 8. G/G_o-γ curves from RCT tests.

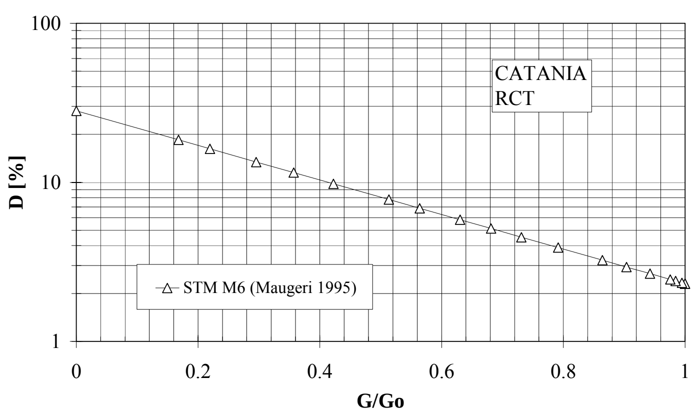

Fig. 9. D-G/G_o curves from RCT tests.

As suggested by Yokota et al. (1981), the inverse variation of damping ratio with respect to the normalised shear modulus has an exponential form as that reported in Figure 9 for the central area of Catania (Maugeri 1995):

$$D(\gamma)(\%) = \eta \cdot \exp\left[-\lambda \cdot \frac{G(\gamma)}{G_o}\right]$$

(3)

in which:
$D(\gamma)$ = strain dependent damping ratio;
γ = shear strain;
η, λ = soil constants.
The values of η = 28.12and λ = 2.50 were obtained for STM M6 clay by Carrubba and Maugeri (1988).
The equation (3) assume maximum value D_{max} = 28.12 % for $G(\gamma)/G_o$ = 0 and minimum value D_{min} = 2.30 % for $G(\gamma)/G_o$ = 1.
Therefore, eq. (3) can be re-written in the following normalised form:

$$\frac{D(\gamma)}{D(\gamma)_{max}} = \exp\left[-\lambda \cdot \frac{G(\gamma)}{G_o}\right] \tag{4}$$

These parameters were obtained from the damping values assessed by means of the steady-state method.

Evaluation of G_o from empirical correlations

It was also attempted to evaluate the small strain shear modulus by means of the following empirical correlations based on penetration tests results or laboratory results available in literature.

a) Hryciw (1990):

$$G_o = \frac{530}{(\sigma'_v/p_a)^{0.25}} \frac{\gamma_D/\gamma_w - 1}{2.7-\gamma_D/\gamma_w} K_o^{0.25} \cdot (\sigma'_v \cdot p_a)^{0.5} \tag{5}$$

where: G_o, σ'_v and p_a are expressed in the same unit; p_a = 1 bar is a reference pressure; γ_D and K_o are respectively the unit weight and the coefficient of earth pressure at rest, as inferred from SDMT results according to Marchetti (1980);

b) Mayne and Rix (1993):

$$G_o = \frac{406 \cdot q_c^{0.696}}{e^{1.13}} \tag{6}$$

where: G_o and q_c are both expressed in [kPa] and e is the void ratio. Eq. (6) is applicable to clay deposits only;

c) Jamiolkowski et. al. (1995):

$$G_o = \frac{600 \cdot \sigma_m^{'0.5} p_a^{0.5}}{e^{1.3}} \tag{7}$$

where: $\sigma'_m = (\sigma'_v + 2 \cdot \sigma'_h)/3$; p_a = 1 bar is a reference pressure; G_o, σ'_m and p_a are expressed in the same unit. The values for parameters which appear in equation (7) are equal to the average values that result from laboratory tests performed on quaternary Italian clays and reconstituted sands. A similar equation was proposed by Shibuya and Tanaka (1996) for Holocene clay deposits.

Equation (7) incorporates a term which expresses the void ratio; the coefficient of earth pressure at rest only appear in equation (5). However only equation (5) tries to obtain all the input data from the SDMT results.

The G_o values obtained with the methods above indicated are plotted against depth in Figure 10. The method by Jamiolkowski et al. (1995) was applied considering a given profile of void ratio. The coefficient of earth pressure at rest was inferred from SDMT.

All the considered methods show very different G_o values of the Holocene soil. On the whole, equation (5) and (7) seems to provide the most accurate trend of G_o with depth, as can be seen in Figure 10. It is worthwhile to point out that equation (7) overestimated G_o for depths greater than 25 m.

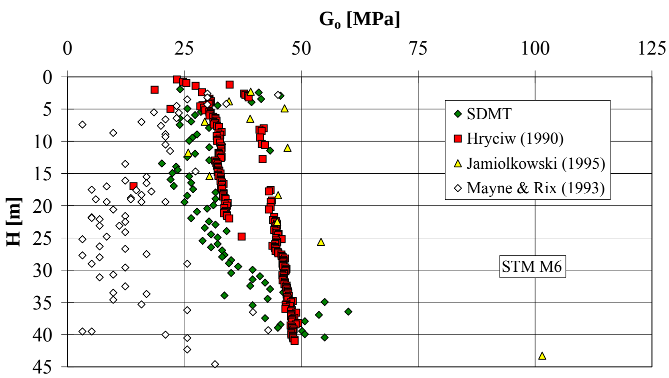

Fig. 10. G_o from different empirical correlations.

CONCLUDING REMARKS

A site characterization for preloading technique analysis has been presented in this paper. On the basis of the data shown it is possible to draw the following conclusions:

- the site under investigation consists of an overconsolidated clay deposit;
- SDMT were performed up to a depth of 42 meters. The results show a very detailed and stable shear wave profile. The shear wave profiles obtained by SDMT compare well with laboratory tests;
- the small strain shear modulus measured in the laboratory is on average 0.90 of that measured in situ by means of SDMT and DH tests;
- empirical correlations between the small strain shear modulus and penetration test results were used to infer G_o from CPT and SDMT. The values of G_o were compared to those measured with SDMT and DH tests. This comparison indicates that some agreement exists between empirical correlations and SDMT and DH test;
- moreover SDMT measurements are much more stable and repeatable than DH test, so the SDMT is a powerful investigation tool.
- SDMT, because of three independent measurements of p_o, p_1 and V_s, gives shear modulus at small strain and large strain for detecting soil non linearity.

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