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Site Characterization by Dynamic In Situ and Laboratory Tests for Liquefaction Potential Evaluation during Emilia Romagna Earthquake

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Abstract: To investigate the geotechnical soil properties of Emilia Romagna Region, a large series of in situ tests, laboratory tests and geophysical tests have been performed, particularly at the damaged city of Scortichino—Bondeno. Deep site investigations have been undertaken for the site characterization of the soil also along the Burana-Scortichino levee. Borings, Piezocone tests (CPTU) and dynamic in situ tests have been performed. Among them, Multichannel Analysis of Surface Waves test (MASW) and Seismic Dilatometer Marchetti Tests (SDMT) have been also carried out, with the aim to evaluate the soil profile of shear wave velocity (V_s). Resonant Column Tests (RCT) were also performed in laboratory on reconstituted solid cylindrical specimens. The Seismic Dilatometer Marchetti Tests were performed up to a depth of 32 m. The results show a very detailed and stable shear wave profile. The shear wave profiles obtained by SDMT have been compared with other laboratory tests. A comparison between the in situ small shear strain, laboratory shear strain and shear strain obtained by empirical correlations, was also performed. Finally, using the results of SDMT tests, soil liquefaction phenomena have been analyzed with a new procedure based on SDMT, using the soil properties obtained by field and laboratory tests.

Keywords: in situ tests; laboratory tests; soil liquefaction; Seismic Dilatometer Marchetti Test

1. Introduction

On 20 May 2012 an earthquake of magnitude M_L = 5.9 struck the Emilia Romagna Region (Italy), with epicenter in the municipality of Finale Emilia and the hypocenter at a depth of about 6.3 km. On 29 May 2012 a new and very strong earthquake of magnitude M_L = 5.8 occurred, creating panic and disruption in many cities such as Ferrara, Modena, Reggio Emilia, Bologna and Rovigo; the epicenter was located in the area between Mirandola, Medolla and San Felice Panaro. The earthquakes caused 27 deaths, with about 12,000 buildings severely damaged; heavy damages occurred also to monuments and to cultural heritage.

Significant and widespread liquefaction effects, which caused damage to buildings and infrastructures, were also observed during the seismic events of May 2012 in various areas of Emilia-Romagna Region. These phenomena mainly involved the old river bed deposits and the ancient levees of the Reno River, principally near the two villages of San Carlo (Municipality of Sant'Agostino) and Mirabello. Phenomena of minor extension were observed also in other sites (e.g., Dodici Morelli, San Felice Panaro, etc.), in similar geo-morphological conditions, including also the Burana-Scortichino levee.

The paper illustrates the relevance of the Seismic Dilatometer Marchetti Test (SDMT) as an alternative or integration to other in situ tests for liquefaction studies. The novelties of this work are:

(i) to review the available knowledge on sand liquefiability assessment by use of SDMT; (ii) to use new tentative CRR-K_d correlations for evaluating the liquefaction resistance from SDMT, to be used according to the Seed & Idriss [1] "simplified procedure". When using semi-empirical procedures for evaluating liquefaction potential during earthquakes, it is important to use redundant correlations. The SDMT has the advantage, in comparison with CPT and SPT tests, by measuring independent parameters, K_d and V_s. Hence "matched" independent evaluations of liquefaction resistance can be obtained from K_d and from V_s according to recommended CRR-K_d and CRR-V_s correlations. CPT and SPT based correlations should be supported by large databases, while SDMT correlations are based on a limited database.

Similar studies have been conducted in other European seismic areas characterized by the presence of buildings of particular architectural value [2–10].

2. Geology and Seismicity of the Area

The area affected by the earthquake sequence of the Emilia Romagna Region in May 2012 is located to the south of the Po Valley; this basin lies between the Alps and the Northern Apennines. The main shock took place on 20 May causing seven deaths and significant damage to historic buildings, churches, industrial buildings and leaving 7000 people homeless. On 29 May another strong earthquake hit the Region, causing other damages and casualties [11].

The area is covered by alluvial deposits (Holocene) and deposits of fluvial-lacustrine soil. The southern part of the Province of Ferrara, where reside the investigated sites, is crossed by the river Reno. The Reno is an ancient river whose course on the plain varied over the centuries. Crespellani et al. [12], citing Cazzola [13], relate how the physical environment shapes were visibly modeled by man in the Emilian plain through interventions for flood defense. As a result, the plain is crisscrossed by ancient drainages and streams that cross the land. Over time, farming settled occupying the natural bumps built by rivers and their branches abandoned, extending to the surrounding areas even with the landfills. In many areas, the murky waters of the rivers were diverted in the areas bounded by levees, which currently occupy a large part of the territory. From the 60 s onwards, the considerable development of industrial activity and urban expansion led to even use areas—land filled and levees—that were reclaimed for agricultural use. The study area appears rather flat and characterized by lithological units trending sub-horizontal.

Various site investigation studies enabled also soil characterization affected by the earthquake sequence of May 2012 [14–16].

3. Investigation Program and Basic Soil Properties

The investigated area reaches the maximum depth of 40 m. The area pertaining to the investigation program (CPTU and SDMT field tests) is shown in Figure 1. Figure 2 shows the results obtained by one of the cone penetration tests performed on Scortichino—Bondeno area. The data reported in Figure 2 clearly indicate the presence of cohesive strata of soils from the top to the depth of about 10.00 m and of uncohesive soils from about 10.00 m to the bottom of the boreholes. This indication is also confirmed by comparing the penetration resistance from electric Piezocone tests (CPTU) performed at different locations over the investigated area (Figure 1). The q_c profile with depth clearly shows the existence of layers with very different mechanical characteristics. The upper silty clay presents meager mechanical characteristics with q_c of about 0.1 to 2.0 MPa. The deeper sandy soil presents q_c values of about 1 to 23.65 MPa.

The basic soil properties of the Scortichino—Bondeno (Table 1) area are based on the three CPTU test results [17–21]: from the top to the depth of about −1.00 m there is the presence of a debris soil layer overall the area; from −1.00 m to −1.50 m depth there is the presence of a cohesive soil layer with q_c values of about 0.49 MPa, f_s = 0.01 MPa, U = 0.00 MPa, C_u = 22 kPa, OCR = 10; from −1.50 m to −3.20 m depth there is the presence of a cohesive soil layer with q_c of about 0.83 MPa, f_s = 0.04 MPa, U = 0.11 MPa, C_u = 45 kPa, OCR = 10; from −3.20 m to −6.50 m depth there is the presence of a cohesive soil layer, of probably organic nature, with q_c of about 0.36 MPa, f_s = 0.03 MPa, U = 0.08 MPa, C_u = 17 kPa, OCR = 3; from −6.50 m to −10.00 m depth there is the presence of a cohesive soil layer with q_c of about 0.62 MPa, f_s = 0.02 MPa, U = 0.15 MPa, C_u = 29 kPa, OCR = 3; from −10.00 m to −11.00 m depth there is the presence of a sandy soil layer with q_c of about 3.30 MPa, f_s = 0.06 MPa, U = 0.03 MPa, D_r = 27%, ϕ′ = 31°; from −11.00 m to −12.00 m depth there is the presence of a thickened sandy soil layer with q_c of about 11.19 MPa, f_s = 0.06 MPa, U = 0.20 MPa, D_r = 76%, ϕ′ = 37°; from −12.00 m to −12.80 m depth there is the presence of a sandy soil layer with q_c of about 11.53 MPa, f_s = 0.06 MPa, U = 0.08 MPa, D_r = 73%, ϕ′ = 37°; from −12.80 m to −15.40 m depth there is the presence of a sandy soil layer with q_c of about 16.80 MPa, f_s = 0.12 MPa, U = 0.07 MPa, D_r = 85%, ϕ′ = 39°. The water table level is at the depth of about −1.2 m.

Table 1. Basic Soil Properties of the Scortichino—Bondeno Area.

Depth [m]	q_c [MPa]	f_s [MPa]	U [MPa]	C_u [kPa]	D_r [%]	ϕ′ [°]	OCR [-]
from −0.80 m to −1.00 m	-	-	-	-	-	-	-
from −1.00 m to −1.50 m	0.49	0.01	0.00	22	-	-	10
from −1.50 m to −3.20 m	0.83	0.04	0.11	45	-	-	10
from −3.20 m to −6.50 m	0.36	0.03	0.08	17	-	-	3
from −6.50 m to −10.00 m	0.62	0.02	0.15	29	-	-	3
from −10.00 m to −11.00 m	3.30	0.06	0.03	-	27	31	-
from −11.00 m to −12.00 m	11.19	0.06	0.20	-	76	37	-
from −12.00 m to −12.80 m	11.53	0.06	0.08	-	73	37	-
from −12.80 m to −15.40 m	16.80	0.12	0.07	-	85	39	-

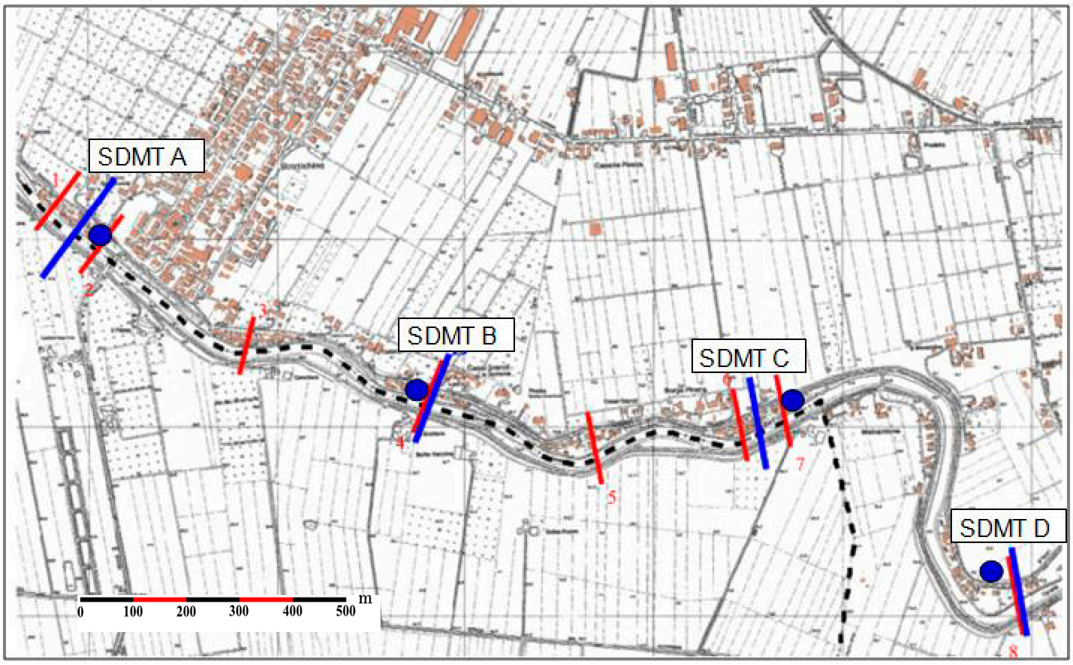


Figure 1. Lay-out of SDMT investigation program. Red lines represent sections along boring locations (8) along the levee; blue lines and blue points represent respectively sections and SDMT tests location in terms of coordinates: SDMT A 44°87′80.4″ N 11°32′26.0″ E, SDMT B 44°87′38.0″ N 11°33′37.9″ E, SDMT C 44°87′32.3″ N 11°34′62.1″ E, SDMT D 44°86′88.7″ N 11°35′29.7″ E.

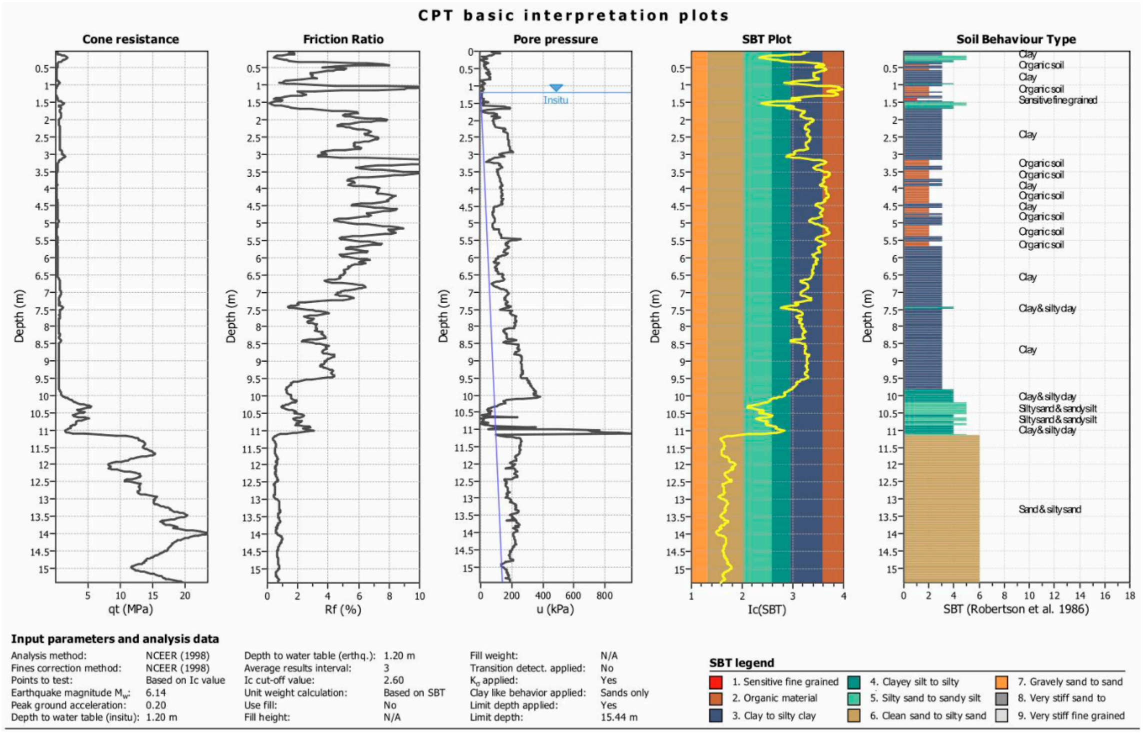


Figure 2. Static cone penetration test results.

4. Shear Modulus and Damping Ratio

The small strain ($\gamma \leq 0.001\%$) shear modulus, G_o, was determined from SDMT tests and from the Multichannel Analysis of Surface Waves (MASW) test. The equivalent shear modulus (G_{eq}) was determined in the laboratory by means of a Resonant Column test (RCT) performed with a Resonant Column apparatus. Moreover it was attempted to assess G_o by means of empirical correlations, based either on penetration test results or on laboratory test results [22–24]. 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 [25–28]. Shear waves are generated by striking a horizontal plank at the surface that is oriented parallel to the axis of a geophone connected by a co-axial cable with an oscilloscope [29,30].

The measured arrival times at consecutive depths provide pseudo interval V_s profiles for horizontally polarized vertically propagating shear waves. The small strain shear modulus G_o is determined by the theory of elasticity by the well-known relationships:

$$G_o = \varrho V_s^2 \quad (1)$$

where: ϱ = mass density.

A summary of SDMT parameters is shown in Figure 3 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, K_d > 2 indicates overconsolidation. A first glance at the K_d profile is helpful to "understand" the deposit;
- V_s: Shear Wave Velocity.

Figure 4 shows the values of G_o obtained in situ from MASW and SDMT tests and G_o values measured in the laboratory from RCT performed on sandy reconstituted 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 4 against depth. In the case of laboratory tests, the G_o values are determined at shear strain levels of less than 0.001%. It is possible to observe that quite a good agreement exists between the laboratory and in situ test results. The laboratory test conditions and the obtained small strain shear modulus G_o are listed in Table 2. In the present work solid cylindrical specimens were reconstituted by using tapping [31]. The mold is assembled and a little depression is applied to let the membrane adhere to the inside surfaces. The material is placed into the mold using a funnel-pouring device.

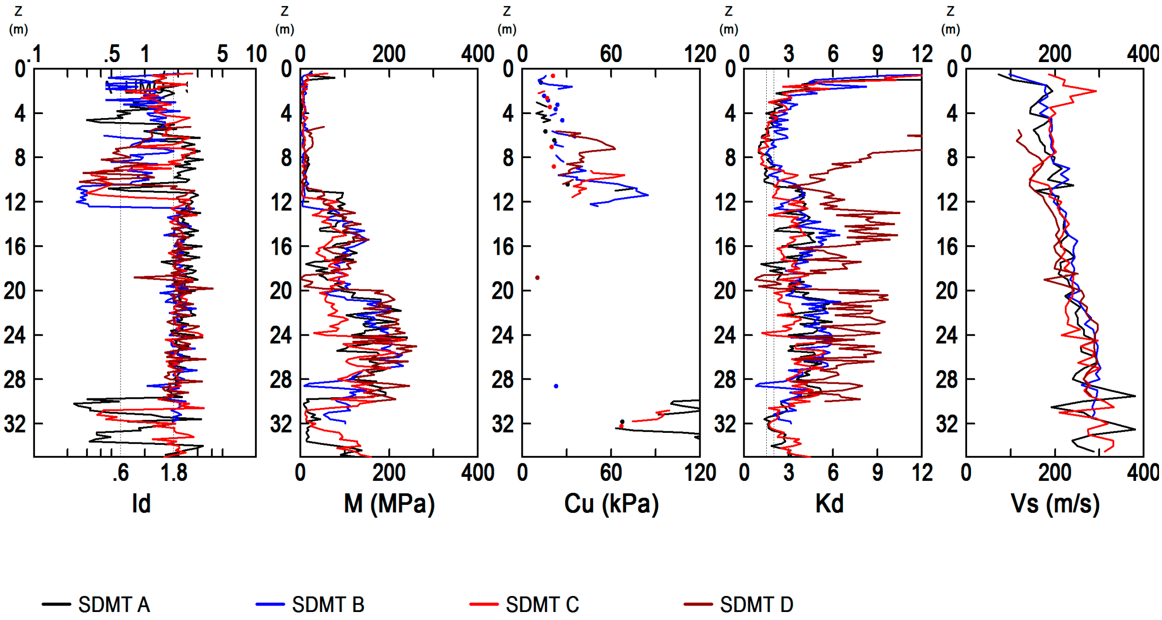


Figure 3. Summary of SDMTs in Scortichino—Bondeno area.

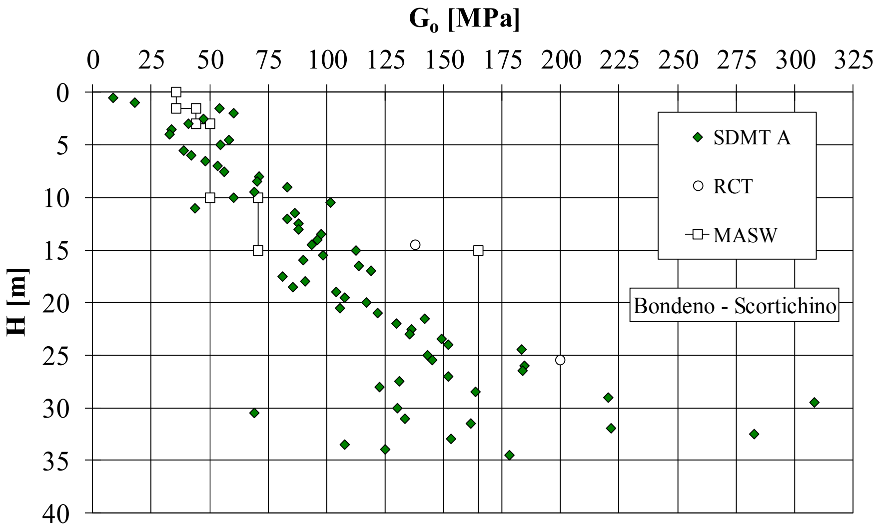


Figure 4. G_o from laboratory and in situ tests.

It is possible to obtain different values of relative density changing the height of deposition. In order to realize high values of relative density it could be necessary to beat delicately the mold surface during the deposition. Each sample has been reconstituted with fresh sand. Each specimen was subjected to an isotropic load achieved in a Plexiglas pressure cell, using an air pressure source. The axial strain was measured by using a high-resolution proximity transducer, which monitors the aluminum top-cap displacement. Shear strain was measured by monitoring the top rotation with a couple of high-resolution proximity transducers. During a resonant column test, the proximity transducers are not able to appraise the value of the targets displacements, because of the high frequency of the oscillations. The rotation on the top of the specimen is measured by means of an accelerometer. The dry reconstituted specimens were isotropically submitted to a confining stress to simulate the real pressure conditions. The size of solid cylindrical specimens is: Diameter = 50 mm and Height = 100 mm.

Table 2. Test Condition for Scortichino—Bondeno Specimens.

Test No.	σ'_{vc} [kPa]	D_r [%]	G_o [MPa]
1	100	80	138
2	200	80	200
3	300	80	257
4	400	80	294

Quite a good agreement exists between the laboratory and in situ test results. Ratio of G_o (Lab) to G_o (Field) by SDMT and MASW was equal to about 0.90 at the depth of 25.5 m.

Upper strata show G_o values by SDMT of about 45 MPa. In the cohesive strata G_o values are between 50 and 90 MPa. Uncohesive soils show G_o values increasing with depth from 90 to 165 MPa. It is worthy to note that MASW tests results show the existence of transition layers from soft to stiff layers because of the occurrence of refraction phenomena. In the transition strata from cohesive to uncohesive strata the G_o values by MASW rapidly vary from 70 to 165 MPa with depth. Higher values of G_o were obtained by RCT respect to SDMT probably caused by higher sample density value during the RCT. The experimental results of specimens obtained by RCT were used to determine the empirical parameters in the equation proposed by Yokota et al. [32] (Figure 5) 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 with strain level [33].

The values of α = 70 and β = 1.050 were obtained for the Scortichino—Bondeno area.

As suggested by Yokota et al. [32], the inverse variation of damping ratio with respect to the normalized shear modulus has an exponential form as reported in Figure 6 for the Scortichino—Bondeno area:

$$D(\gamma)(\%) = \eta \cdot \exp\left[-\lambda \cdot \frac{G(\gamma)}{G_o}\right] \tag{3}$$

in which:

$D(\gamma)$ = strain dependent damping ratio;
γ = shear strain;
η, λ = soil constants.

The values of η = 29 and λ = 3.50 were obtained for the Scortichino—Bondeno area.

The Equation (3) reaches maximum value D_{max} = 29% for $G(\gamma)/G_o = 0$ and minimum value D_{min} = 0.87% for $G(\gamma)/G_o = 1$.

Therefore, Equation (3) can be re-written in the following normalised form:

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

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

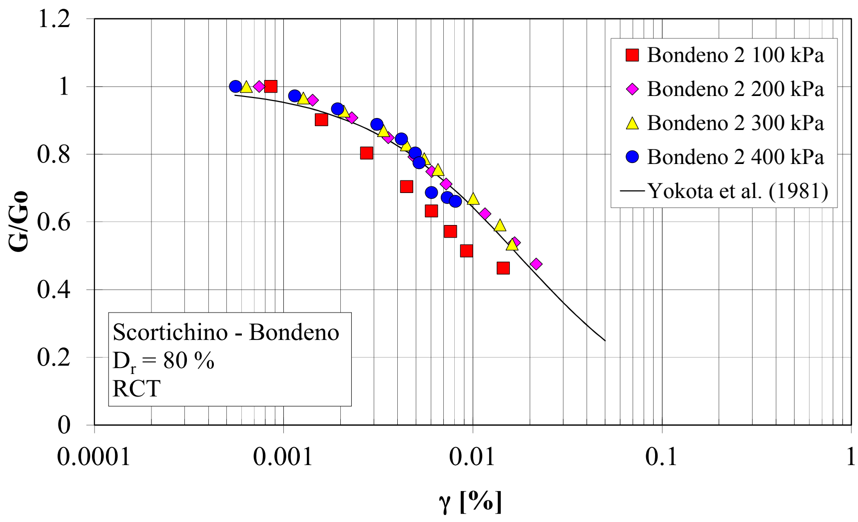


Figure 5. G/G_o-γ curves from RCT tests.

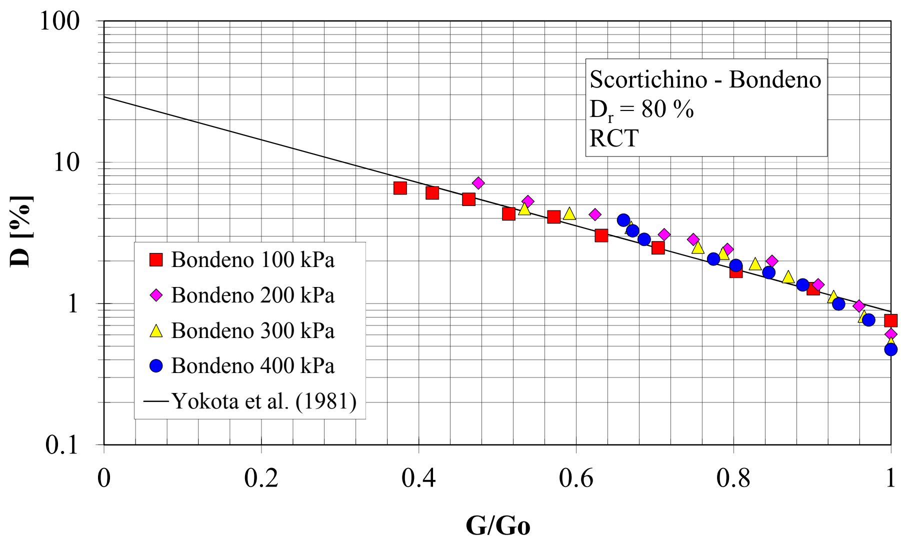


Figure 6. D-G/G_o curves from RCT tests.

5. Evaluation of G_o from Penetration Tests

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 [22]

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

where: 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 [34].

(b) Mayne and Rix [23]

$$G_o = \frac{406 \cdot q_c^{0.696}}{e^{1.13}} \quad (6)$$

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

(c) Jamiolkowski et al. [24]

$$G_o = \frac{600 \cdot \sigma'^{0.5}_m p_a^{0.5}}{e^{1.3}} \quad (7)$$

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 of parameters of Equation (7) are equal to the average values from laboratory tests performed on quaternary Italian clays and reconstituted sands. A similar equation was proposed by Shibuya and Tanaka [35] for Holocene clay deposits. Equation (7) incorporates a term for the void ratio; the coefficient of earth pressure at rest only appears 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 7. The method by Jamiolkowski et al. [24] was applied considering a given profile of void ratio and K_o. The coefficient of earth pressure at rest was inferred from SDMT. The method by Mayne and Rix [23] was applied only to the cohesive strata, disregarding the high values of q_c encountered in the sandy layers that exist for a depth higher of 10 m. Consequently, the obtained G_o values, in the transition zone, resulted to be quite high using the Mayne and Rix [23] equation. The SDMT material index indicated the presence of sandy layers for a deeper depth than 10 m and at the same depths the dilatometer modulus greatly increases [27,28]. However, the method by Hryciw [22] was not capable of detecting these stiff strata as shown in Figure 7. On the whole considering the G_o results obtained directly by SDMT, Equation (7) seems to provide the most accurate trend of G_o with depth, as shown comparing the data in Figure 7. It is worthwhile to point out that the considered Hryciw [22] equation underestimates G_o values for depths deeper than 20 m.

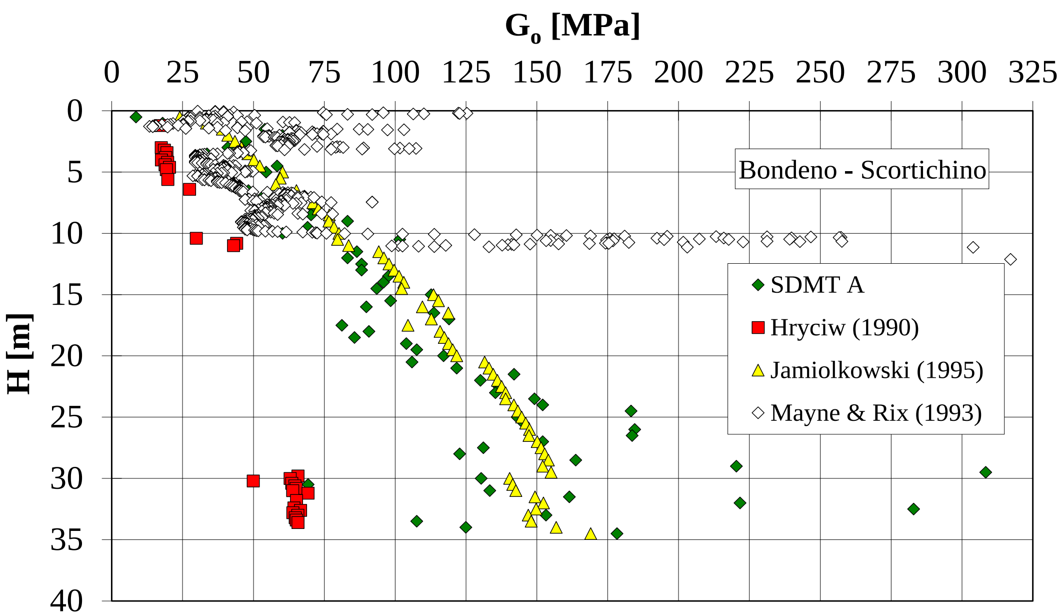


Figure 7. G_o from different empirical correlations.

6. SDMT-Based Procedure for Evaluating Soil Liquefaction

The traditional procedure, introduced by Seed & Idriss [1], has been applied for evaluating the liquefaction resistance of soils. This method requires the calculation of the cyclic stress ratio CSR, and cyclic resistance ratio CRR. If CSR is greater than CRR, liquefaction may be. The cyclic stress ratio CSR is calculated by the following equation [1]:

$$CSR = \tau_{av}/\sigma'_{vo} = 0.65\ (a_{max}/g)\ (\sigma_{vo}/\sigma'_{vo})\ r_d \quad (8)$$

where τ_{av} = average cyclic shear stress, a_{max} = peak horizontal acceleration at the ground surface generated by the earthquake, g = acceleration of gravity, σ_{vo} and σ'_{vo} = total and effective overburden stresses and r_d = stress reduction coefficient depending on depth. The r_d has been evaluated according to Liao and Whitman [36]. Marchetti [37] and later studies [38,39], suggested that the horizontal stress index K_d from DMT ($K_d = (p_o - u_o)/\sigma'_{vo}$) is a suitable parameter to evaluate the liquefaction resistance of sands by CRR. Previous CRR-K_d curves were formulated by Marchetti [37], Robertson & Campanella [38] and Reyna & Chameau [39]—the last one including liquefaction field performance data-points (Imperial Valley, South California). A new tentative correlation for evaluating CRR from K_d, to be used according to the Seed & Idriss [1] "simplified procedure", was formulated by Monaco et al. [40] by combining previous CRR-K_d correlations with the vast experience incorporated in current methods based on CPT and SPT (supported by extensive field performance data-bases), translated using the relative density D_R as intermediate parameter. Additional CRR-K_d curves were derived by translating current CRR-CPT and CRR-SPT curves (namely the "Clean Sand Base Curves" recommended by the '96 and '98 NCEER workshops, Youd & Idriss [41]) into "equivalent" CRR-K_d curves via relative density. D_R values corresponding to the normalized penetration resistance in the CRR-CPT and CRR-SPT curves, evaluated using current correlations (D_R-q_c by Baldi et al. [42] and Jamiolkowski et al. [43], D_R-NSPT by Gibbs & Holtz [44]), were converted into K_d values using the K_d-D_R correlation by Reyna & Chameau [39]. The "equivalent" CRR-K_d curves derived in this way from CPT and SPT plot in a relatively narrow range, very close to the Reyna & Chameau [39] curve. The CRR-K_d curve is approximated by the equation:

$$CRR = 0.0107\ K_d^3 - 0.0741\ K_d^2 + 0.2169\ K_d - 0.1306 \quad (9)$$

and was proposed by Monaco et al. [40] as "conservative average" interpolation of the curves derived from CPT and SPT. An additional CRR-K_d curve was derived by translating current CRR-CPT and CRR-SPT curves into "equivalent" CRR-K_d curve via relative density. New tentative CRR-K_d curve approximated by the equation:

$$CRR = 0.0308\ e^{(0.6054\ Kd)} \quad (10)$$

has been proposed by the authors as interpolation of the K_d curves derived from SPT and CPT. Figure 8 shows the evaluation of CRR, for SDMT A, according to different correlations given by Equations (9) and (10). Equation (9), given by Monaco et al. [40], provides lower values than those obtained using Equation (10).

Figure 9 shows the variation with depth of CRR given by correlation with SDMT A, performed at Scortichino test site. CSR has been evaluated assuming in Equation (8) a_{max} = 0.264 g. The ratio CRR to CSR is called the liquefaction resistance factor (FSL). Then it is possible to evaluate the liquefaction potential index P_L [45], given by the following expression:

$$P_L = \int_0^{20} F(z) w(z) dz \quad (11)$$

where $w(z) = 10 - 0.5z$ and $F(z)$ is a function of the liquefaction resistance factor (FSL) and its values are: $F(z) = 0$ for FSL ≥ 1 and $F(z) = 1 -$ FSL for FSL < 1. If the liquefaction potential index P_L is greater than 5 liquefaction can occur.

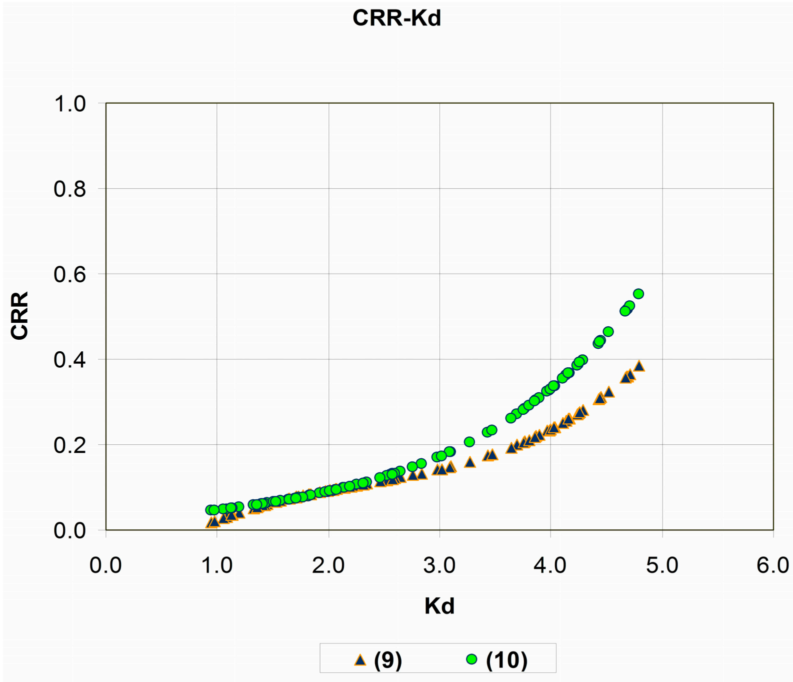


Figure 8. CRR-K_d curves given by different correlations for SDMT test A.

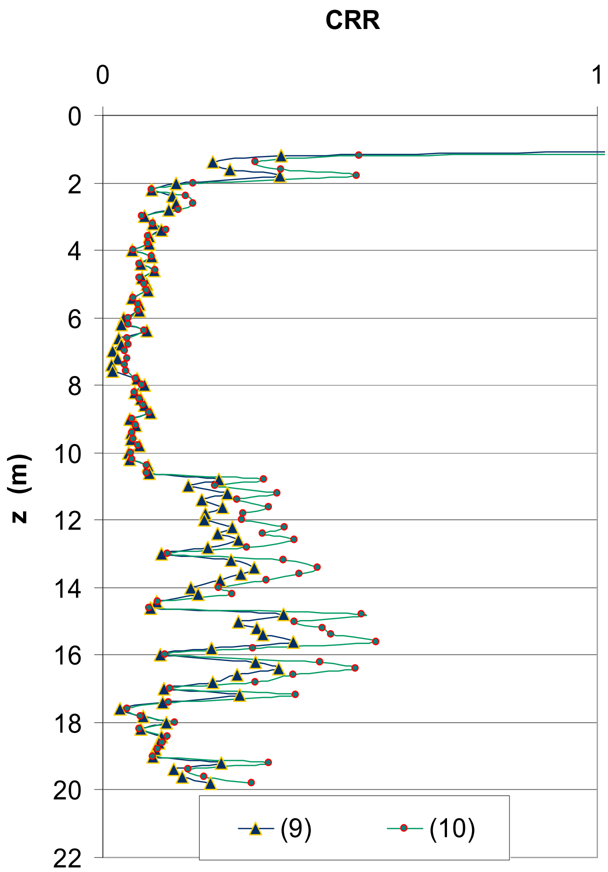
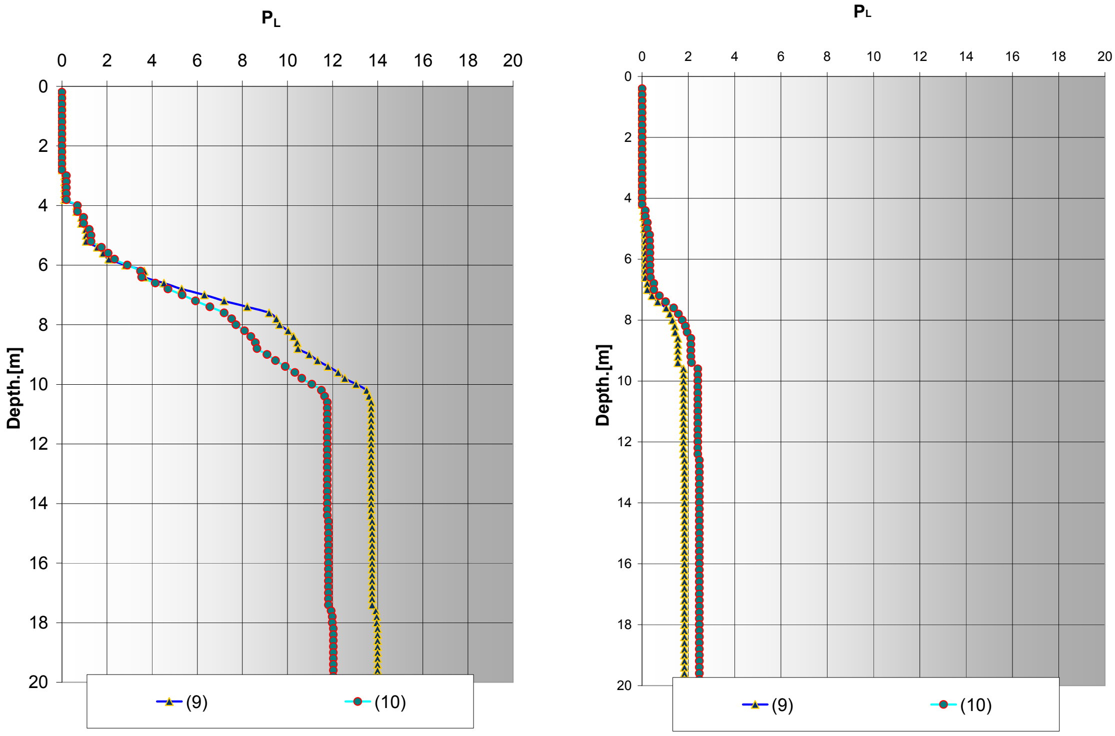


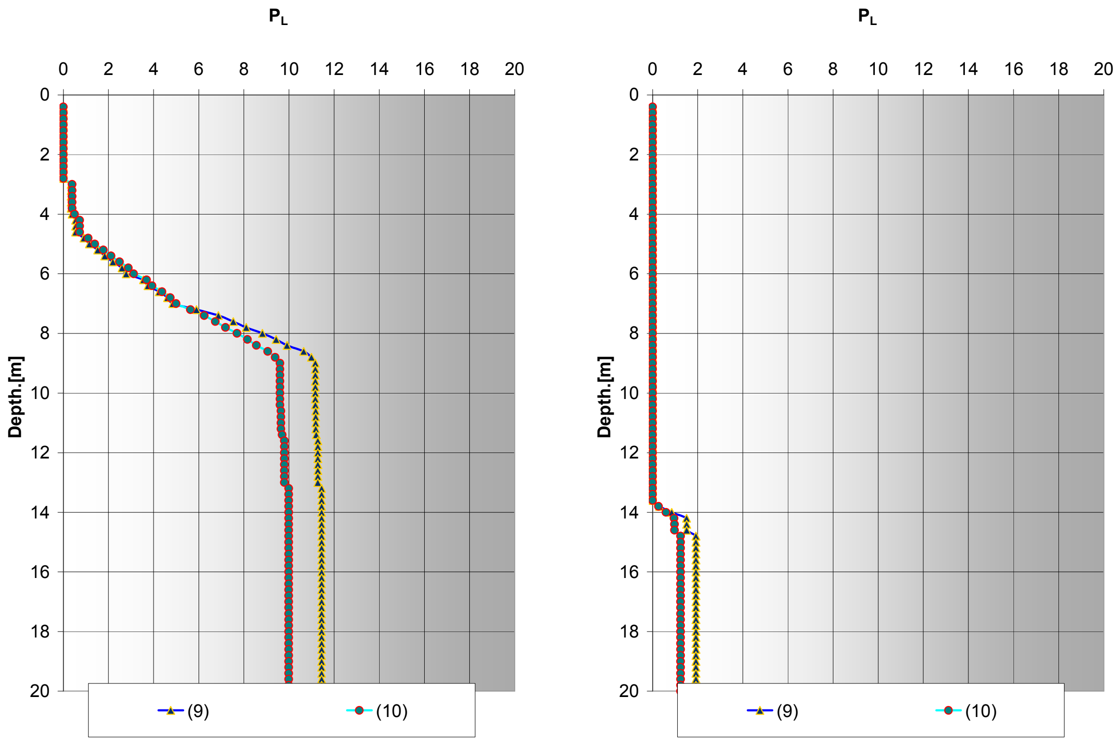
Figure 9. CRR with depth, from K_d data from SDMT test A, at Scortichino test site.

Figures 10 and 11 show the evaluation of the liquefaction potential index, P_L, obtained from K_d data respectively for SDMT A, B, C, D of Figure 1.



(**a**) (**b**)

Figure 10. Evaluation of Liquefaction potential Index P_L from K_d data: (**a**) SDMT A; (**b**) SDMT B.



(**a**) (**b**)

Figure 11. Evaluation of Liquefaction potential Index P_L from K_d data: (**a**) SDMT C; (**b**) SDMT D.

7. Discussion

The SDMT tests performed show some different results in terms of predicting liquefaction phenomena. The SDMT A shows the presence of silt layer up to the depth of about 4.0 m. Silty sands and sands can be recognized at a depth between 4.0 and 28.0 m. The water table is at the depth of about 6.00 m. According to the soil profile it is possible to observe absence of liquefaction up to the depth of about 7.0 m. At a greater depth, as reported in Figure 10a, the liquefaction potential index P_L values (>5) predict liquefaction phenomena. In the case of SDMT B up to the depth of about 12.0 m it is possible to recognize silt and silty clay layers. The water table is at the depth of about 8.00 m. So, according to Figure 10b, it is possible to observe absence of liquefaction due to the liquefaction potential index P_L values (<5) obtained through Equations (9) and (10). The SDMT C test results show a comparable situation of SDMT A, with a water table at the depth of about 8.00 m. The SDMT D test results show a comparable situation of SDMT B, excluding liquefaction phenomena according to the liquefaction potential index P_L values (<5) obtained through Equations (9) and (10).

8. Conclusions

In this paper in situ and laboratory tests and also geophysical tests were performed at the city of Scortichino—Bondeno to investigate the geotechnical soil properties of Emilia Romagna Region. Borings, Piezocone tests (CPTU) and dynamic in situ tests (MASW and SDMT) have been performed with the aim to evaluate the soil profile of shear wave velocity (V_s). Resonant Column Tests were performed in laboratory on reconstituted solid cylindrical specimens. The experimental results were used to determine two equations to draw the shear modulus decay with shear strain level and the inverse variation of damping ratio with respect to the normalised shear modulus. Moreover empirical correlations, based on in situ and laboratory results, were also used to evaluate the small strain shear modulus. On the basis of the obtained results it is possible to draw that the method by Mayne and Rix [23] can be applied only to the cohesive strata and the method by Hryciw [22] is not capable of detecting stiff strata, while the method by Jamiolkowski et al. [24] seems to provide the most accurate trend of G_o with depth. A good agreement of G_o values was obtained by MASW and SDMT. SDMT gives also the possibility to use two independent measurements V_s and K_d for evaluating soil liquefaction. New tentative CRR-K_d correlations have been used for evaluating the liquefaction resistance from SDMT, according to the Seed & Idriss [1] "simplified procedure". The SDMT tests performed at Scortichino site, Italy, show that especially in the area of SDMT A (near the damaged Scortichino city) and SDMT C, liquefaction potential index P_L is high and almost always greater than 5, predicting liquefaction phenomena, as demonstrated by the liquefaction phenomena of 20 May and 29 May 2012. Results obtained are also in agreement with other studies performed in the same area [46,47].

Author Contributions: This paper presents the results of a working group and it is not easy to define a specific area of individual contribution. Nonetheless, P.P.C. and A.C. worked with greater attention on the performance of laboratory tests and on their interpretation based on in-situ tests, while S.G. was more involved in studying and applying methods for the evaluation of the potential liquefaction of soils, including the new SDMT procedure based on V_s and K_d.

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