Identification of ground types for the definition of the seismic action using V_S vs. N_{SPT} or c_u

Identification des catégories de sol pour la définition de l'action sismique à l'aide de V_S vs. N_{SPT} ou c_u

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ABSTRACT

This paper comments on the use of the "surrogate" parameters N_{SPT} (SPT blow count) or c_u (undrained shear strength), in place of the "primary" parameter V_S (shear wave velocity), for the identification of ground types required to define the seismic action according to the Eurocode 8. In particular, the paper illustrates direct comparisons of parallel profiles of $V_S - N_{SPT}$ and $V_S - c_u$ at various sites investigated by seismic dilatometer (SDMT) in the area of L'Aquila following the April 6, 2009 earthquake. In some cases the identification of ground types based on N_{SPT} or c_u vs. V_S proved to be inconsistent or ambiguous. The evidence emerging from such direct comparisons is indirectly reinforced by recent research on the experimental interrelationship between small strain and working strain stiffness using SDMT. Since several reliable and cost-effective routine in situ techniques for the direct measurement of V_S are available today, the possibility of seismic site classification based on N_{SPT} or c_u rather than on V_S appears somewhat outdated and should possibly be abandoned, or restricted to design of minor constructions/low-risk projects.

RÉSUMÉ

Cet article traite de l'utilisation des paramètres "de substitution" N_{SPT} (nombre de coups SPT) ou c_u (résistance au cisaillement non drainée), au lieu du paramètre "primaire" V_S (vitesse des ondes de cisaillement), pour l'identification des catégories de sol nécessaires pour définir l'action sismique selon l'Eurocode 8. En particulier, l'article illustre des comparaisons directes des profils parallèles de $V_S - N_{SPT}$ et $V_S - c_u$ sur différents sites étudiés par le dilatomètre sismique (SDMT) dans la région de L'Aquila après le tremblement de terre du 6 avril 2009. Dans certains cas, l'identification des catégories de sol fondée sur N_{SPT} ou c_u vs. V_S s'est avérée pour être discordant ou ambiguë. La preuve émergeant de telles comparaisons directes est indirectement renforcée par des recherches récentes sur l'interrelation expérimentale entre la rigidité en petites déformations et en déformations de service à l'aide du SDMT. Puisque plusieurs fiables et rentables techniques de routine pour la mesure directe de V_S in situ sont disponibles aujourd'hui, la possibilité de classification sismique des sites fondée sur N_{SPT} ou c_u plutôt que sur V_S semble dans une certaine mesure dépassée et devrait éventuellement être abandonnée, ou limitée à constructions mineurs/projets à faible risque.

Keywords: ground type identification, seismic action, shear wave velocity, seismic dilatometer test

1 INTRODUCTION

According to the Eurocode 8 – Part 1 [1], (§ 3 Ground conditions and seismic action), the local ground conditions and their influence of the seismic action may be taken into account by identification of ground types (A, B, C, D, E) described by the stratigraphic profiles and parameters given in Table 3.1. The site should be classified according to the value of the average (equivalent) shear wave velocity in the top 30 m $V_{S,30}$, if this is available. Otherwise the value of

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the SPT blow count N_{SPT} (in coarse-grained soils) or the undrained shear strength c_u (in fine-grained soils) should be used.

The same criteria are adopted by the recent EC8-inspired Italian Technical Code for Constructions NTC 2008 [2], which explicitly reports formulations for evaluating the "equivalent" $N_{SPT,30}$ and $c_{u,30}$ (formulations similar to $V_{S,30}$), also in the case of alternating layers of coarse- and fine-grained soils.

In the Eurocode 8 – Part 5 [3] (§ 4.2.2 Determination of the ground type for the definition of the seismic action) it is prescribed that the profile of the shear wave velocity V_S in the ground shall be regarded as the most reliable predictor of the site-dependent characteristics of the seismic action at stable sites. It is also specified that in situ measurements of the V_S profile by in-hole geophysical methods should be used for important structures in high seismicity regions, especially in the presence of ground conditions of type D, S_1, or S_2. However for all other cases, when the natural vibration periods of the soil need to be determined, the V_S profile may be estimated by empirical correlations using the in situ penetration resistance or other geotechnical properties, allowing for the scatter of such correlations.

The above statement offers the way to some criticism. Though in the EC8 the shear wave velocity V_S is clearly recognized as the key parameter for quantifying the influence of the local ground conditions on the seismic action, on the other hand, in many practical cases, the designer is allowed to calculate the seismic action based on "secondary" parameters such as N_{SPT} or c_u as a subjective option.

Since several reliable and cost-effective routine in situ techniques for the direct measurement of V_S are available today, the possibility of seismic site classification based on N_{SPT} or c_u rather than directly on V_S appears somewhat outdated. Moreover experience has shown that in some cases the identification of ground types based N_{SPT} or c_u vs. V_S, as defined in the EC8, may lead to contradictory or ambiguous evaluations.

This paper is intended to provide a contribution on this topic based on the experience accumulated in the recent years using the seismic dilatometer (SDMT). The SDMT equipment, test procedure and interpretation are briefly described in the paper. The available experience, summarized in [4], indicates that the SDMT provides accurate and highly reproducible measurements of V_S, in addition to the parameters obtained from the usual flat dilatometer interpretation (e.g. the undrained shear strength c_u in clay).

The issue of the identification of ground types based on the "surrogate" parameters N_{SPT} or c_u, in place of the "primary" parameter V_S, is discussed in this paper based on direct comparisons of V_S – N_{SPT} and V_S – c_u profiles at various sites investigated by SDMT in the area of L'Aquila following the April 6, 2009 earthquake, indirectly reinforced by recent research on the experimental interrelationship between small strain and working strain stiffness using SDMT.

2 THE SEISMIC DILATOMETER (SDMT)

The seismic dilatometer (SDMT) is the combination of the mechanical flat dilatometer (DMT), introduced by Marchetti in 1980 [5], with a seismic module for measuring the shear wave velocity V_S.

The seismic dilatometer test, conceptually similar to the seismic cone penetration test (SCPT), was first introduced by Hepton in 1988 [6] and subsequently improved at Georgia Tech, Atlanta, USA ([7], [8] and [9]). A new SDMT system, described in [4], has been recently developed in Italy. Information on the mechanical DMT can be found in the comprehensive report by the ISSMGE Technical Committee TC16 2001 [10].

The schematic layout of the seismic dilatometer test is shown in Figure 1. The seismic module (Figure 1a) is a cylindrical element placed above the DMT blade, provided with two receivers spaced 0.50 m. The shear wave source at the surface is a pendulum hammer (≈ 10 kg) which hits horizontally a steel rectangular plate, pressed vertically against the soil (by the weight of the truck) and oriented with its long axis parallel to the axis of the receivers, so that they can offer the highest sensitivity to the generated shear wave. The signal is amplified and digitized at depth.

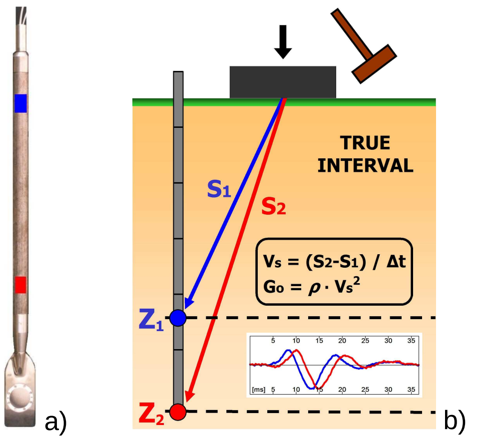

Figure 1. Seismic dilatometer test. (a) DMT blade and seismic module. (b) Schematic test layout.

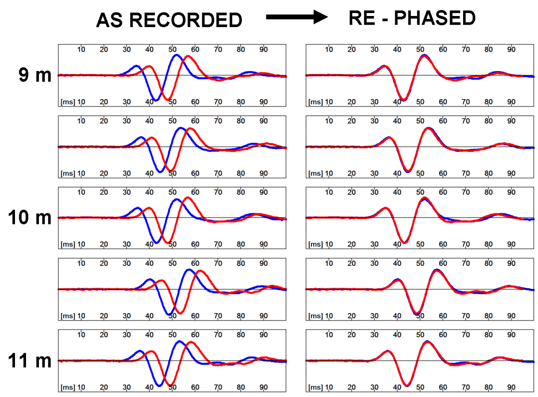

Figure 2. Example of seismograms obtained by SDMT

The *true-interval* test configuration with two receivers avoids possible inaccuracy in the determination of the "zero time" at the hammer impact, sometimes observed in the *pseudo-interval* one-receiver configuration. Moreover, the couple of seismograms recorded by the two receivers at a given test depth corresponds to the same hammer blow and not to different blows in sequence, which are not necessarily identical. Hence the repeatability of V_S measurements is considerably improved (observed V_S repeatability ≈ 1-2 %).

V_S is obtained (Figure 1b) as the ratio between the difference in distance between the source and the two receivers ($S_2 - S_1$) and the delay of the arrival of the impulse from the first to the second receiver (interval time Δt). V_S measurements are typically obtained every 0.50 m of depth (while the mechanical DMT readings are taken every 0.20 m).

The determination of the delay from SDMT seismograms, normally obtained using a cross-correlation algorithm, is generally well conditioned, being based on the waveform analysis of the two seismograms rather than relying on the first arrival time or specific single points in the seismogram. An example of seismograms obtained by SDMT – as recorded and re-phased according to the calculated delay – is shown in Figure 2. Validations of V_S measurements by SDMT compared to V_S measurements by other in situ techniques at various research sites are reported in [4].

Besides the shear wave velocity V_S, the seismic dilatometer provides the usual DMT parameters by use of common correlations ([5], [10]).

The SDMT test procedure proves to be an effective, quick and cost-saving alternative to conventional Down-Hole tests in soft to firm soils (no need of holes with pipes to be grouted, operations requiring a few days pause for the cement to set up before testing). A disadvantage of the SDMT, similar to the SCPT, is the impossibility of penetrating very hard soils. However a procedure for obtaining SDMT V_S profiles – but not the other DMT parameters – in non-penetrable soils (e.g. gravel, or even in rock) has been devised in [11]. The procedure is the following: (1) A borehole is drilled to the required test depth. (2) The borehole is backfilled with sand. (3) The SDMT is inserted and advanced into the backfilled borehole in the usual way (e.g. by use of a penetrometer rig) and V_S measurements are carried out every 0.50 m of depth. No DMT measurements – meaningless in the backfill soil – are taken in this case.

The possibility of such measurement descends from the fact that the path of the shear wave from the surface to the upper and lower receiver includes a short path in the backfill of very similar length for both receivers. Comparative tests at various sites where both the usual penetration procedure and the backfilling procedure were adoptable, reported in [11], indicate that the values of V_S obtained in a backfilled borehole are essentially coincident with the V_S obtained by penetrating the "virgin" soil.

3 IDENTIFICATION OF GROUND TYPES USING SDMT RESULTS

3.1 SDMT investigations in the area of L'Aquila following the April 6, 2009 earthquake

This section presents a selection of results obtained by seismic dilatometer tests executed at various sites in the area of L'Aquila (Italy) in the period 2009-2011. Some of these tests were carried out in the first months following the April 6, 2009 earthquake, as part of site investigations planned at a number of sites selected for the location of new temporary houses (C.A.S.E. Project). SDMT results were also used in the seismic microzonation project of the area of L'Aquila promoted by the Italian Department of Civil Protection [12]. Other seismic dilatometer tests were executed, both in the historic city centre and in the suburban area of L'Aquila, as part of investigations aimed at site characterization for design of restoration/retrofitting of important buildings severely damaged by the earthquake. A comprehensive review of SDMT results obtained in the area of L'Aquila following the April 6, 2009 earthquake can be found in [13]. Additional information and comparisons between V_S obtained by SDMT and by other techniques in post-earthquake investigations are reported in [14].

Whenever possible, in soils ranging from clay to silty sand (silt in the majority of the cases), the seismic dilatometer tests were executed by the normal penetration procedure. However, due to the characteristics of the soils commonly encountered in this area (mostly coarse-grained, non-penetrable), SDMT measurements (V_S-only) were generally executed in backfilled boreholes, according to the procedure described in [11].

Comparisons of parallel profiles of $V_S - c_u$ and $V_S - N_{SPT}$ at various sites investigated by SDMT are illustrated in the next paragraphs.

3.2 Identification of ground types based on V_S vs. c_u in fine-grained soils

Figures 3 to 6 show SDMT results obtained in mostly fine-grained soils at various sites investigated by the penetration procedure. The SDMT results in Figures 3 and 4 were obtained at two sites of the C.A.S.E. Project (Cese di Preturo, Roio Piano). The V_S profile obtained by SDMT at Roio Piano was found in reasonable agreement with V_S profiles obtained by parallel surface waves tests (MASW) and Down-Hole tests [14]. SDMT results obtained at other sites investigated by the penetration procedure are shown in Figure 5 (Santa Rufina) and in Figure 6 (Ponte Rasarolo – Aterno River, a site where liquefaction and lateral spreading phenomena were triggered by the April 6, 2009 earthquake).

The typical graphical SDMT output in Figures 3 to 6 displays the profile of V_S as well as the profiles of four basic DMT parameters: the material index I_D (indicating soil type), the constrained modulus M, the undrained shear strength c_u and the horizontal stress index K_D (related to OCR), calculated with usual DMT interpretation formulae, as in [5] and [10].

The available experience, summarized in [10], indicates that the undrained shear strength c_u obtained from DMT using the original Marchetti 1980 [5] correlation is generally accurate and dependable for design practice. Moreover no c_u values determined from laboratory tests on undisturbed samples were available at the examined sites. To note also that the availability of continuous profiles of c_u obtained from DMT (or e.g. from CPT) proves generally advantageous for the identification of ground types, compared to the typically "discontinuous" laboratory c_u profiles. The values of c_u obtained from DMT interpretation where then used for the identification of ground types according to the EC8 [1] – Table 3.1.

At all the above sites (Figures 3 to 6) the maximum test depth, limited by the push capacity of the penetrometer rig, was ≈ 17 to 23 m. Therefore it was not possible to calculate the values of $V_{S,30}$ in the top 30 m according strictly to the EC8 formulation. However, since the purpose of this study was to compare ground type identifications provided by V_S and c_u in the same deposit/layer, an equivalent shear wave velocity $V_{S,test\ depth}$ over the investigated depth was then calculated by adapting the EC8 formulation for $V_{S,30}$ to the maximum test depth (< 30 m), instead of the conventional 30 m depth.

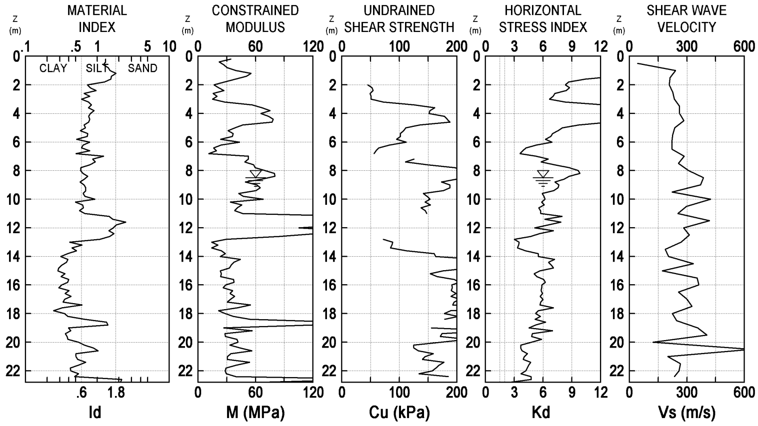

Figure 3. SDMT results at the site of Cese di Preturo – C.A.S.E. Project (L'Aquila)

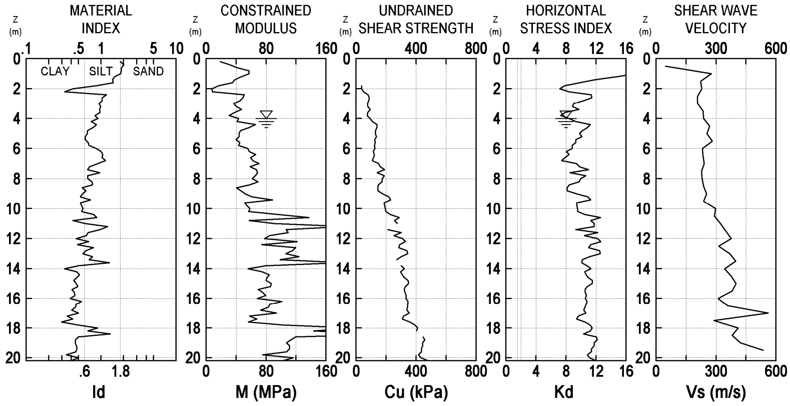

Figure 4. SDMT results at the site of Roio Piano – C.A.S.E. Project (L'Aquila)

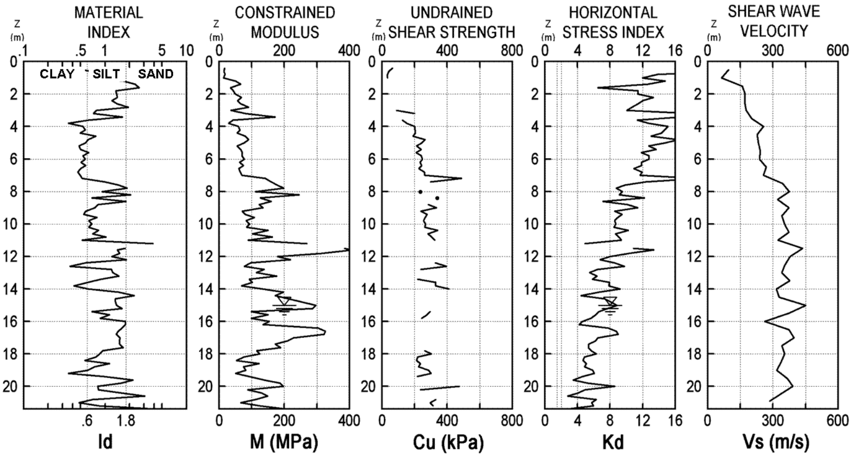

Figure 5. SDMT results at the site of Santa Rufina (L'Aquila)

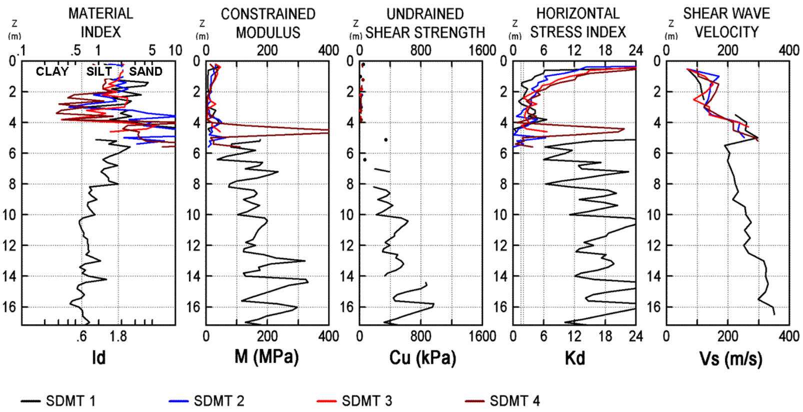

Figure 6. SDMT results at the liquefaction site of Ponte Rasarolo – Aterno River (L'Aquila)

At three of the four examined sites (Cese di Preturo, Roio Piano and Santa Rufina, Figures 3, 4 and 5) the calculated values of $V_{S,\text{test depth}}$ are generally in the range ≈ 230 to 270 m/s. According to the EC8 [1] – Table 3.1 these values indicate "ground type C" ($V_{S,30}$ = 180-360 m/s, c_u = 70-250 kPa). The same ground type identification is obtained using the equivalent c_u calculated over the same test depth, generally ≈ 120 to 180 kPa (in the form similar to $c_{u,30}$ specified in the Italian building code [2]), or even using simply an average value of c_u ≈ 150 to 250 kPa, accounting for the generic designation provided by the EC8.

At the site of Ponte Rasarolo – Aterno River (Figure 6), in the clay layer between ≈ 7 and 17 m depth, below a shallow loose sand layer (where liquefaction occurred during the April 6, 2009 earthquake), the equivalent V_S ≈ 270 m/s indicates "ground type C", while the equivalent c_u ≈ 420 kPa, or the average c_u ≈ 490 kPa, indicate "ground type B" ($V_{S,30}$ = 360-800 m/s, c_u > 250 kPa).

To note that the silty clayey soils at the four examined sites basically belong to the same geological formation (lacustrine Pleistocene deposits). However, the overconsolidation ratio OCR of these deposits is known to be rather variable over the L'Aquila basin, due to a very complex depositional history. Compared to the other three examined sites, the clay deposit at Ponte Rasarolo – Aterno River exhibits much higher values of OCR (and c_u), as inferred from the DMT horizontal stress index K_D, but similar V_S. This suggests that the increase in c_u due to overconsolidation is much higher than the increase in V_S, which appears substantially unaffected OCR. Since OCR seems to have a different influence on V_S and c_u – i.e. the two alternative parameters used for ground type identification according to the EC8, in highly OC clays the identification of ground type based on c_u rather than on V_S may lead to a contradictory evaluation, possibly resulting in an underestimate of the seismic action.

3.3 *Identification of ground types based on V_S vs. N_{SPT} in coarse-grained soils*

Figures 7 to 11 show SDMT results (in terms of V_S profile only – no DMT parameters) obtained by the backfilling procedure at various sites in the area of L'Aquila.

Figure 7 shows the profiles of V_S obtained by SDMT in five backfilled boreholes, superimposed to V_S obtained by Down-Hole, at the site of Palazzo Camponeschi, typical of the subsoil conditions in L'Aquila city centre. In this case the backfilling procedure permitted to obtain V_S measurements by SDMT down to 74 m depth. (V_S measurements by SDMT to 133 m depth at the site of Fontana 99 Cannelle are reported in [13]). The values of N_{SPT} measured at various depths are also shown in Figure 7.

The upper portion of the subsoil in L'Aquila city centre is generally constituted by the deposit known as "Brecce dell'Aquila", about 80-100 m thick, composed of fine to coarse calcareous fragments of variable size (mostly of some centimetres) embedded in sandy or silty matrix, having generally $V_S \approx$ 600-1000 m/s. The breccias are superimposed to fine- to medium-grained, mostly silty lacustrine deposits, having $V_S \approx$ 400 to 600-700 m/s, placed on the calcareous bedrock located below 300 m depth. (To note that in this case, in presence of an inversion of V_S with depth, the use of $V_{S,30}$ appears inappropriate to describe the site effects on the seismic action).

At the site of Palazzo Camponeschi the values of V_S in the breccias are generally ≈ 600-800 m/s or higher, increasing with depth. The observed dispersion of the V_S values possibly reflects some variability in grain size distribution, cementation and mechanical properties typical of this material. The lower values ($V_S \approx$ 260 m/s) measured in the upper 3 to 9 m, particularly in the Down-Hole test (DH 4), were obtained in a shallow fill material layer. The values of N_{SPT} in the breccias are generally very high, typically resulting in penetration refusal in presence of gravel, cobbles or boulders. (The use of SPT in these soils is often meaningless). By contrast N_{SPT} values less than 10-15 blows/30 cm were measured in the shallow fill material.

The values of $V_{S,30}$ calculated from each SDMT profile are in the range 660 to 890 m/s, indicating "ground type B" ($V_{S,30}$ = 360-800 m/s, N_{SPT} > 50 blows/30 cm) or even "A" ($V_{S,30}$ > 800 m/s) according to the EC8 [1] – Table 3.1. The site classification based on N_{SPT} would result as "ground type B" even in case of penetration refusal, since the EC8 does not allow to indentify "ground type A" based on N_{SPT} or c_u, but only based on V_S (a rational choice).

In the shallow fill material, the shear wave velocity $V_S \approx$ 260 m/s would indicate "ground type C" ($V_{S,30}$ = 180-360 m/s, N_{SPT} = 15-50 blows/30 cm), while N_{SPT} would identify the soil as "ground type C" or "ground type D" ($V_{S,30}$ < 180 m/s, N_{SPT} < 15 blows/30 cm).

Figures 8 to 11 show the profiles of V_S obtained by SDMT in backfilled boreholes at various sites located in the densely populated suburban districts of Coppito, Pile, Cansatessa and Pettino. These sites are mostly characterized by the presence of coarse-grained soils (calcareous gravel in sandy-silty matrix or sand), where generally $V_S \approx$ 600-1000 m/s, increasing with depth.

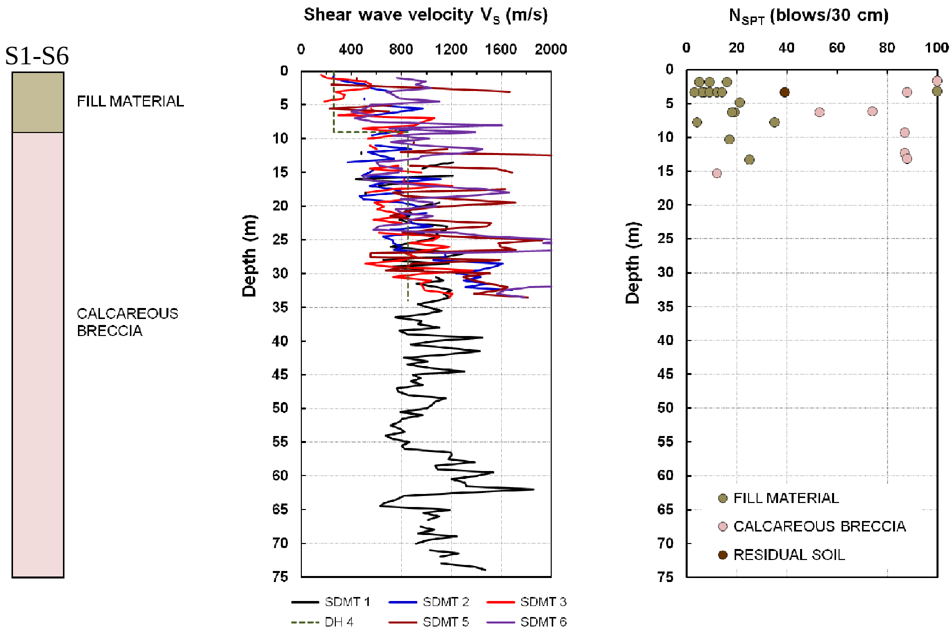

Figure 7. Schematic soil profile, profiles of V_S measured by SDMT (in 5 backfilled boreholes) and by Down-Hole, and values of N_{SPT} measured in 6 boreholes at the site of Palazzo Camponeschi (L'Aquila)

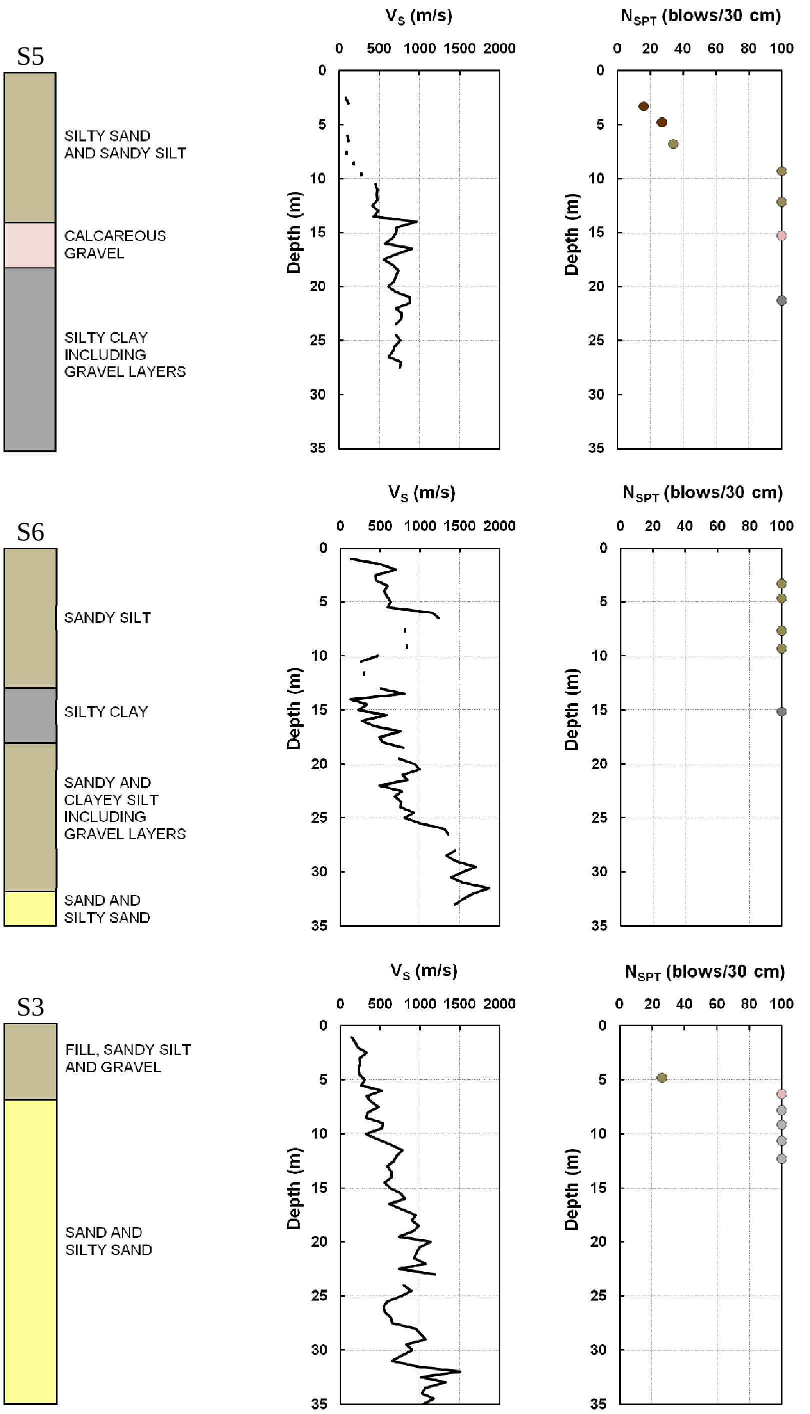

Figure 8. Schematic soil profile, profiles of V_S measured by SDMT in 3 backfilled boreholes and values of N_{SPT} measured in the same boreholes at the site of Coppito – San Salvatore Hospital (L'Aquila)

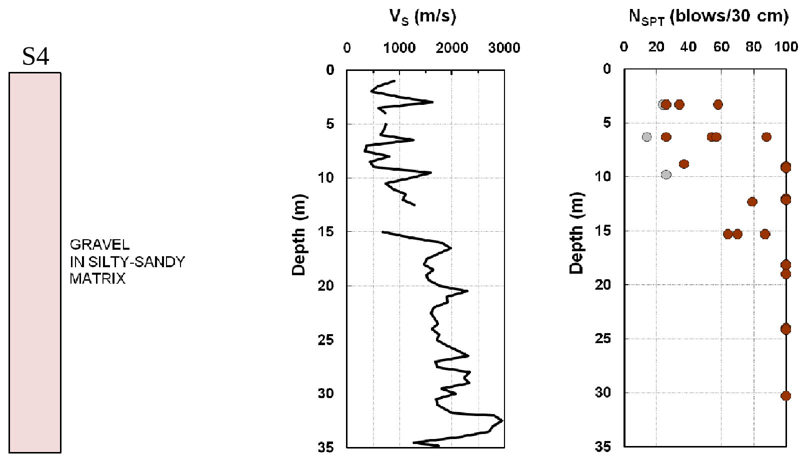

Figure 9. Schematic soil profile, profiles of V_S measured by SDMT in a backfilled borehole and values of N_{SPT} measured in 5 boreholes at the site of Pile – Via Salaria Antica Est (L'Aquila)

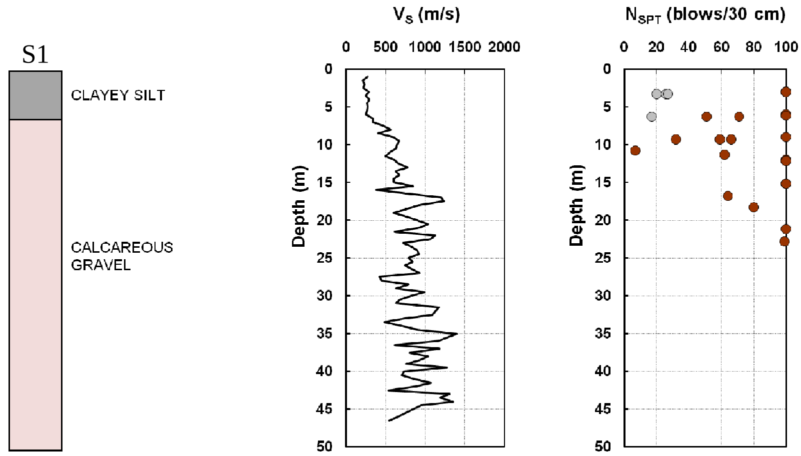

Figure 10. Schematic soil profile, profiles of V_S measured by SDMT in a backfilled borehole and values of N_{SPT} measured in 6 boreholes at the site of Cansatessa – Via Solaria (L'Aquila)

Figure 8 shows the profiles of V_S obtained by SDMT in three backfilled boreholes and the corresponding N_{SPT} values measured in the same boreholes at the site of Coppito – San Salvatore Hospital (mostly in sand). In this case $V_{S,30}$ and $N_{SPT,30}$ are generally in agreement, both indicating "ground type B" ($V_{S,30}$ = 360-800 m/s, N_{SPT} > 50 blows/30 cm). However it can be noted in Figure 8 that the N_{SPT} values, frequently resulting in penetration refusal, reflect very poorly the soil variability indicated by the V_S profiles.

At the site of Pile – Via Salaria Antica Est (Figure 9) the soil is identified as "ground type A" based on $V_{S,30} \approx 1000$ m/s, while N_{SPT} indicates generally "ground type B" or even "C", also depending on the use of $N_{SPT,30}$, as specified in the Italian building code [2], or of an average N_{SPT}, as generically indicated in the EC8 [1].

At the site of Cansatessa – Via Solaria (Figure 10) the soil is identified as "ground type B" both using $V_{S,30}$ ($\approx$ 500 m/s) and N_{SPT}.

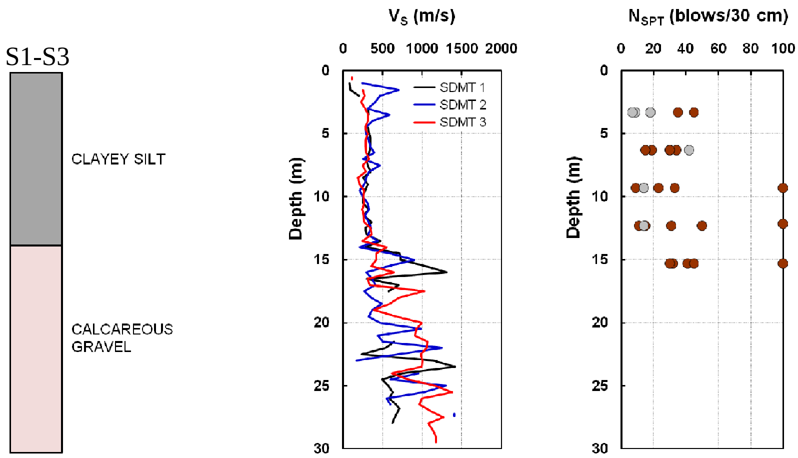

Figure 11. Schematic soil profile, profiles of V_S measured by SDMT in 3 backfilled boreholes and values of N_{SPT} measured in 8 boreholes at the site of Pettino – Via Via Sila Persichelli (L'Aquila)

The subsoil at the site of Pettino – Via Sila Persichelli (Figure 11), typical of this area, is characterized by the presence of an upper layer of soft silty-clayey sediments of variable thickness (maximum ≈ 10-15 m) overlying a stiff gravel deposit. The profiles of V_S obtained by SDMT in three backfilled boreholes clearly identify a contrast of shear wave velocity between the upper ≈ 13 m thick soft clay layer ($V_S \approx 300$ m/s) and the lower gravel layer ($V_S \approx 600$-900 m/s). The values of N_{SPT} with depth show the same trend, however the contrast of V_S is much more evident. In this case the site should be classified as "ground type E".

4 CONSIDERATIONS BASED ON THE EXPERIMENTAL INTERRELATIONSHIP BETWEEN G_0 AND M_{DMT}

The evidence emerging from the above direct comparisons is indirectly reinforced by recent research on the experimental interrelationship between *small strain* and *working strain* stiffness using SDMT results.

Previous papers [4], [15] presented experimental diagrams constructed using same-depth values of the *small strain* shear modulus G_0 (obtained from V_S as $G_0 = \rho\, V_S^{\,2}$) and the *working strain* constrained modulus M_{DMT} (obtained from the usual DMT interpretation – see [4]) determined by SDMT at 34 different sites, in a variety of soil types.

In Figure 12 the ratio G_0 /M is plotted as a function of the DMT horizontal stress index K_D (stress history) for clay (having material index I_D < 0.6), silt ($0.6 < I_D < 1.8$) and sand ($I_D > 1.8$). Best fit equations are indicated for each soil type.

Recognizable trends in Figure 12 are:

- The data points tend to group according to their I_D (soil type).
- The ratio G_0 /M varies in a wide range (≈ 0.5 to 20 for all soils), hence it is far from being a

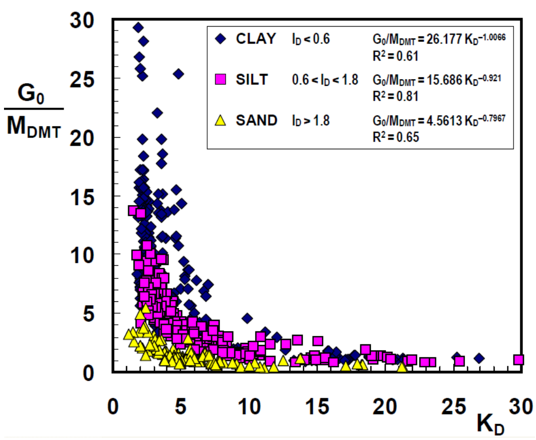

Figure 12. Ratio G_0/M_{DMT} vs. K_D (OCR) for various soil types [15]

constant, especially in clays and silts. Its value is strongly dependent on multiple information, e.g. soil type and stress history. (As a consequence, it appears next to impossible to estimate the operative modulus M by dividing G_0 by a constant, as suggested by various Authors).

- For all soils G_0 / M_{DMT} decreases as K_D (OCR) increases.

As a general rule it is by large preferable to measure V_S directly, as recommended by the EC8. However Figure 12 might turn out helpful to obtain rough estimates of V_S (via G_0) at sites where V_S has not been measured and only mechanical DMT results from past investigations are available. Comparisons presented in [13] indicate a good agreement between profiles of V_S measured by SDMT and V_S estimated from mechanical DMT data obtained in the same SDMT sounding (by the penetration procedure).

The experimental diagram G_0 / M_{DMT} vs. K_D in Figure 12 offers some elements of discussion on the feasibility of using c_u or N_{SPT} as a substitute for V_S – when V_S has not been measured – for ground type identification to define the seismic action, as allowed by the EC8.

Figure 12 highlights the dominant influence of K_D (OCR) on the ratio G_0 / M. In case of non availability of K_D, all the experimental data points would cluster on the vertical axis. In absence of K_D – which reflects the stress history – the selection of the ratio G_0 / M would be hopelessly uncertain. Hence as many as *three* informations, i.e. I_D, K_D, M (though only two independent), are needed to formulate rough estimates of G_0 and V_S.

In view of the above consideration, the use of N_{SPT} or c_u alone as a substitute of V_S (when not measured) for the seismic classification of a site does not appear founded on a firm basis. In fact, if V_S is assumed to be the primary parameter for the classification of the site, then the possible substitute of V_S must be reasonably correlated to V_S. If three parameters (I_D, K_D, M) are barely sufficient to obtain rough estimates of V_S, then the possibility to estimate V_S from only one parameter appears remote.

5 CONCLUSIONS

The paper illustrates some examples of direct comparisons of parallel profiles of $V_S - N_{SPT}$ and $V_S - c_u$ at various sites investigated by seismic dilatometer (SDMT) in the area of L'Aquila following the April 6, 2009 earthquake.

In general the use of N_{SPT} or c_u provided the same broad identification of ground type as V_S. However in some cases the identification of ground types based on N_{SPT} or c_u vs. V_S proved to be inconsistent or ambiguous. In particular, in highly OC clays the identification of ground type based on c_u rather than on V_S may lead to a less conservative evaluation, possibly resulting in an underestimate of the seismic action. In coarse-grained soils including gravel, cobbles or boulders the identification of ground type based on N_{SPT}, often resulting in penetration refusal, may be ambiguous or meaningless.

The evidence emerging from such direct comparisons is indirectly reinforced by recent research on the experimental interrelationship between *small strain* stiffness (G_0 from V_S) and *working strain* stiffness (constrained modulus M from current DMT interpretation) using SDMT. Experimental diagrams G_0 / M vs. K_D constructed using same-depth values of G_0 and M determined by SDMT at 34 different sites, in a variety of soil types [5], indicate that the ratio G_0 / M varies in a wide range (≈ 0.5 to 20), hence it is far from being a constant, especially in clays and silts. Its value is strongly dependent on multiple information, e.g. soil type and stress history. The stress history, reflected by the DMT horizontal stress index K_D, has a dominant influence on the ratio G_0 / M.

Since as many as *three* informations (I_D, K_D, M) are barely sufficient to obtain rough estimates of G_0 and V_S, the possibility to estimate V_S from only one parameter appears remote. In fact, if V_S is assumed to be the primary parameter for the classification of the site, then the possible surrogate of V_S must be reasonably correlated to V_S. Hence the use of N_{SPT} or c_u alone as a substitute of V_S (when not measured) for the seismic classification of a site appears of dubious validity.

In conclusion, considering that several reliable and cost-effective in situ techniques are available today for the direct measurement of V_S, the possibility of identifying the ground type to determine the seismic action based on N_{SPT} or c_u rather than directly on V_S should possibly be abandoned, or at least explicitly restricted to design of minor constructions (e.g. buildings of importance class I) or low-risk projects.

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