THE SECOND WORLD LANDSLIDE FORUM

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Use of the seismic dilatometer (SDMT) in landslide research and practice

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Abstract This paper shows the use of the seismic dilatometer (SDMT) testing (Marchetti, 1980, TC16, 2001, Marchetti et al. 2008) in landslide diagnosis and monitoring. The quick K_D-DMT method, developed by Totani et al. (1997) for detecting active or old slip surfaces, was recently applied in a research programme on stability conditions of natural slopes shaped in colluvial cover formations in Abruzzo region (Chieti, Teramo). The paper illustrates the capability of SDMT to identify remoulded zones, symptom of instability, and slip surfaces in the investigated slopes.

Moreover, the paper presents the possibility to use the DMT blade as a piezometer, to monitor rapidly the variation of the ground water level in relation to weather trend.

Keywords seismic dilatometer, horizontal stress index, colluvial cover formations

Introduction

The study presented in this paper refers to research aiming at quickly identifying the colluvial covers in Abruzzo (Central Italy) through the use of the seismic dilatometer (SDMT) testing (Marchetti et al. 2008), recently introduced to add the measure of the shear wave velocity to the flat dilatometer (Marchetti, 1980, TC16, 2001). In particular, this method allows the detection of very slow movements, that occur frequently on large areas, as a typical feature of the region, and to evaluate the thickness of these formations.

K_D – DMT method in the colluvial cover formations

As well documented by Totani et al. (1997) and then validated by Leroueil (2001), the K_D – DMT method quickly detects active or old slip surfaces in overconsolidated (OC) clay slopes, based on the inspection of the horizontal stress index K_D profiles. The K_D – DMT method can be summarized as follows:

a) the sequence of sliding, remolding and reconsolidation generally creates a remolded zone of nearly normally consolidated clay, with loss of structure, aging or cementation;
b) in NC clays $K_D \approx 2$, if an OC clay slope contains layers where $K_D \approx 2$, these layers are likely to be part of a slip surface (active or quiescent).

In Abruzzo the colluvial covers distributed over the marly clay bedrock (Teramo area) and over the OC clay (Chieti area) could generate both translational and rotational slip surfaces. Thus, the K_D – DMT method could be used to verify the slope stability in these situations, as illustrated in Figure 1.

In addition, K_D can identify the thickness of these colluvial covers, even if these formations don't generate a slip surface. In fact, the rapid change of K_D values in a vertical profile locates the contact between the colluvial cover and the layer below.

Use of the DMT in the Abruzzo colluvial covers

The case studies illustrated in the following paragraphs concern two different colluvial covers:

– silty clayey colluvial covers over marly clay bedrock that are potential translational slip surfaces, located in Teramo district;
– silty clayey colluvial cover over OC clay that are potential rotational slip surfaces, situated along Chieti hill.

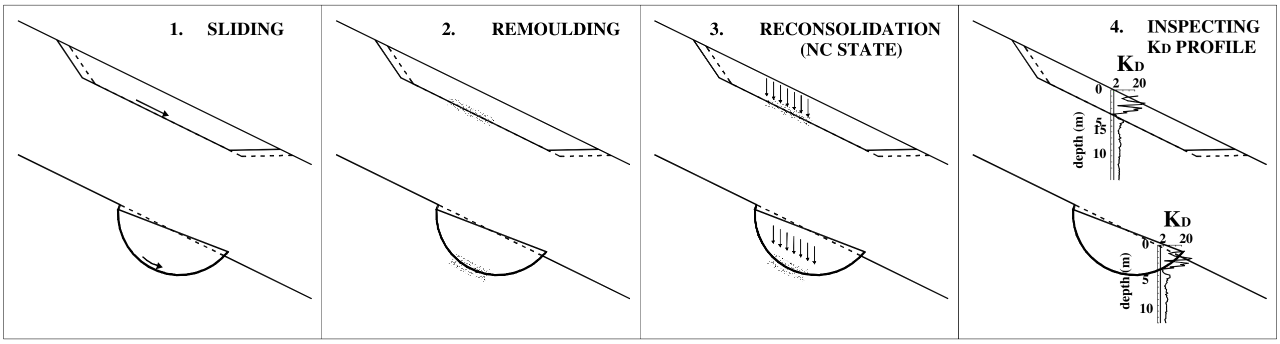

Figure 1 K_D – DMT method in colluvial covers with translational and rotational slip surfaces.

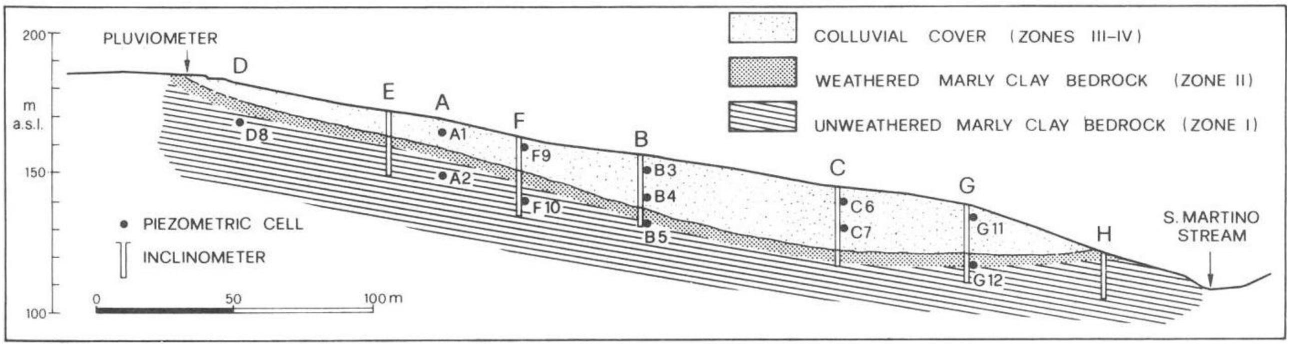

Figure 2 Geological cross section of a colluvial cover over a marly clay bedrock in Abruzzo (Bertini et al., 1984).

Teramo district

Very slow movements (a few cm/year) have been detected with site investigations (Bertini et al., 1980) as occurring on slopes shaped in Pliocenic marine marly clay formations in Teramo district, between Gran Sasso and Laga Mountains and the Adriatic Sea.

The slow translational movements involve the weathered part of these formations and the thick silty clayey colluvial covers overlying them on large portions of the slopes.

Geological and geotechnical setting

The region, referred to as the "hilly piedmont belt", is formed by a succession of layered marly clays which sedimented in Lower Pliocene ("Cellino" formation) and Middle-Upper Pliocene ("Argille grigio-azzure" formation).

Thick silty-clayey colluvial deposits suggestive of recent and very intense evolutional phases are widely distributed over marly clays. Due to their areal distribution and great thickness (until 30 m in depth), colluvial covers can be considered as a true geological formation.

Bertini et al. (1984) schematized a typical colluvial cover over a marly clay bedrock as follows (Figure 2):

- zone I: saturated overconsolidated very stiff marly clay bedrock;
- zone II: bedrock band formed by weathered marly clay. Weathering, softening and destructuring increase progressively from the bottom to the top;
- zone III: saturated slightly overconsolidated medium to stiff silty clayey colluvial cover with constant in depth geotechnical properties;
- zone IV: oxidized and highly fissured superficial crust of the colluvial cover subjected to drying and wetting cycles following the climatic variations.

A deep monitoring campaign (pluviometric stations, piezometers and inclinometers), realized by Bertini et al. (1984), shows that the equilibrium conditions of these slow translational movements are controlled by the seasonal variations of the pore pressure regime and that the slip surface is placed between the bottom of the colluvial cover (zone III) and the top of the weathered marly clay (zone II).

An immediate and economic alternative is the use of flat dilatometer (DMT). Figure 3 illustrates the results of two seismic dilatometer (SDMT) tests (Marchetti et al.,2008) carried out in a representative area of Teramo district. Even if the profiles of K_D do not identify any layers with $K_D \approx 2$ (absence of slip surfaces), in these vertical profiles the rapid change of the horizontal stress index K_D, as well as the constrained modulus M, identifies different thickness of the colluvial cover (red arrows in Figure 3).

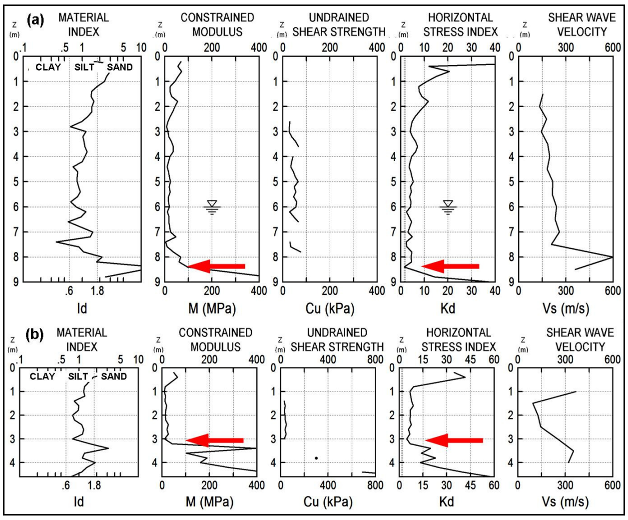

Figure 3. SDMT profiles of the colluvial cover in Abruzzo.

Even if less evidently than K_D and M, the shear wave velocity V_S feels the change of the profile between the colluvial cover and the below intact unweathered layer.

DMT testing in Atri

A series of three DMT tests, each 8-15 m in depth, and two boreholes, each 15 m in depth, were carried out in 2002 on Atri hill (Teramo district). The aim of this study was to investigate a building probably damaged by the slow translational movements of a colluvial cover.

An overall systematic description of the observed cracks showed that the structure was damaged only at the bottom, while the construction was safe at the top. The analysis of the surveys demonstrated that the building was realized in part on a stable area (at the top) and in part on an instable zone (at the bottom).

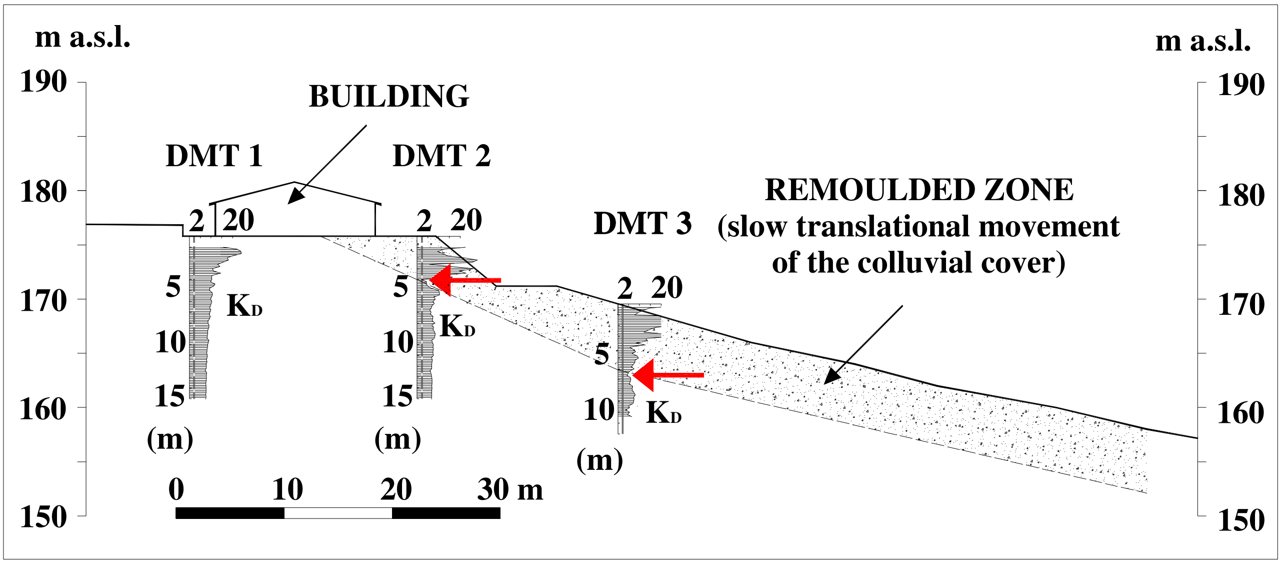

Figure 4. Horizontal stress index K_D profiles on Atri hill.

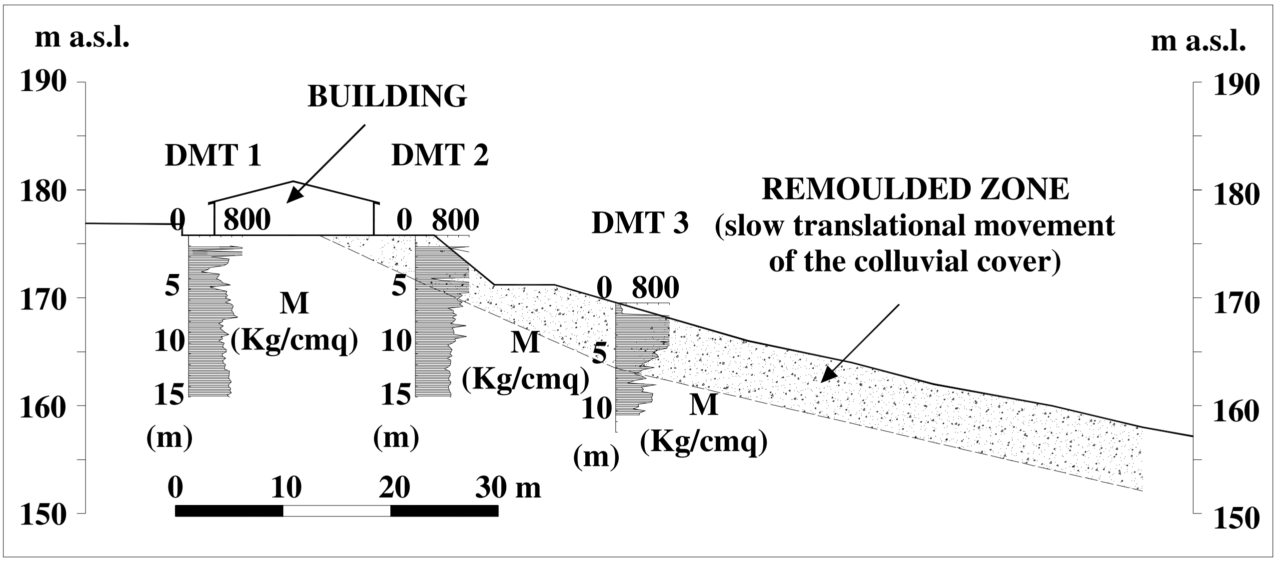

Figure 5. Constrained modulus M profiles on Atri hill.

In fact, DMT2 and DMT3 soundings, performed at the bottom of the construction, highlighted layers where $K_D \approx 2$ (red arrows in Figure 4), respectively at 4 m and 6 m in depth. Thus, these layers detected a NC zone constituted by a colluvial cover (K_D decreases gradually with the depth until values $K_D \approx 2$) over a marly clay formation (K_D assumes constant values until 15 m in depth, $K_D \approx$ 8-10). Moreover, the high value of K_D in the first few meters of the probe justified the presence of a superficial crust of colluvial cover.

Instead, DMT1 test, carried out at the top of the slope, next to the building, showed a typical profile of an OC clay (K_D decreases gradually with the depth until values $K_D \approx$ 8-10).

The profiles of the constrained modulus M (Figure 5) gave high values, substantially uniform from the colluvial cover to the marly clay formation. Therefore M cannot supply clearly information on the position of the NC zone.

Hence, considering the previous geological and geotechnical studies (Bertini et al., 1984) the DMT investigations, through K_D, provided rapidly the slip surface (the remoulded zone with $K_D \approx 2$) at 4-6 m in depth, typical for the slow translational movements of the colluvial covers in Teramo district.

Chieti hill

Chieti hill, located between Majella Mountain and the Adriatic Sea, is characterized by Plio-Pleistocenic marine formation and recent continental deposits that could create localized rotational slip surface.

Geological and geotechnical setting

The periadriatic region is formed by a Plio-Pleistocenic succession ("Mutignano" formation). It includes silty clays ("Argille grigio-azzurre" formation) that change gradually in sandy clays, sands and arenaria on the top of Chieti hill.

Recent continental deposits are widely distributed over the previous mentioned OC clays. They are constituted by silty-clayey colluvial covers and they reach until 20 m in depth, as maximum thickness.

Instability phenomena of localized soil mass are controlled by the seasonal variations of the pore pressure regime, as documented by several monitoring activities concerning the hydrogeologic risk of the Chieti hill.

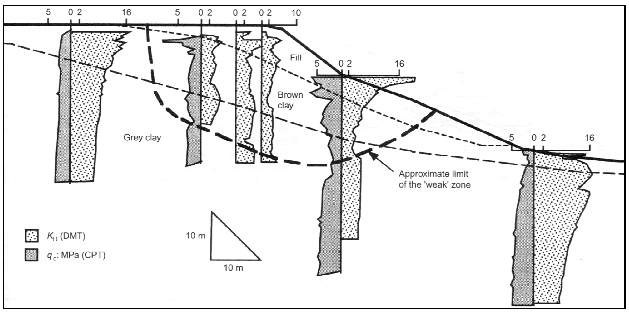

Figure 6. CPT (q_c) and DMT (K_D) profiles at Chieti, Italy (Lerouil, 2001).

As well as in the Teramo district, the flat dilatometer can quickly solve the problem of slope stability. In particular, a case history on Chieti hill was examined by Totani et al. (1997) and then validated by Lerouil (2001), using the profiles of the horizontal stress index K_D from the flat dilatometer (DMT) and of the cone resistance q_c from the cone penetration test (CPT). The inspection of K_D profiles clearly highlighted the presence of several layers with $K_D \approx 2$, suggesting that an approximate limit of the "weak" zone (Figure 6).

DMT testing in Fosso S. Chiara

A detailed investigation of six SDMT tests, each 10 m (on the top of the hill) and 20 m in depth (on the bottom of the hill) and six boreholes, each 30-50 m in depth, were performed in 2011 on Chieti hill to restore an historical building, damaged by the April 6, 2009 L'Aquila earthquake.

The soundings allowed the construction of a geotechnical cross section of the slope in the area of Fosso S. Chiara (Figure 7). The historical centre was built on sandy and arenaria deposits (45 m in depth), while moving towards the bottom of the slope the colluvial cover start to emerge over the OC silty clay, as well interpreted by the flat dilatometer. In fact, the SDMT1 profiles (Figure 8) clearly indicated the contact surface between the colluvial cover and the OC silty clay at 15 m in depth. The constrained modulus M, the undrained shear strength c_u and the horizontal stress index K_D increase rapidly moving from superficial deposits to the OC formation (red arrows in Figure 8), while the shear wave velocity V_S appears to not recognize this contact surface. In particular, K_D decreases gradually until values $K_D \approx 4$ (15 m in depth) and then the parameter increases quickly in correspondence of this contact surface and it becomes constant ($K_D \approx 6\text{-}8$) in the OC silty clayey formation.

Therefore, on the Chieti hill the seismic dilatometer provided to identify the thickness of this colluvial covers, even if this formation doesn't generate a slip surface. In fact, the rapid change of K_D values, as well as M and c_u, in a vertical profile locates the contact between the colluvial cover and the layer below.

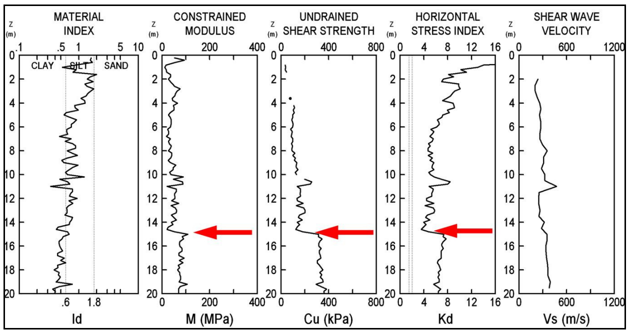

Figure 8. Fosso S. Chiara: DMT1 profiles.

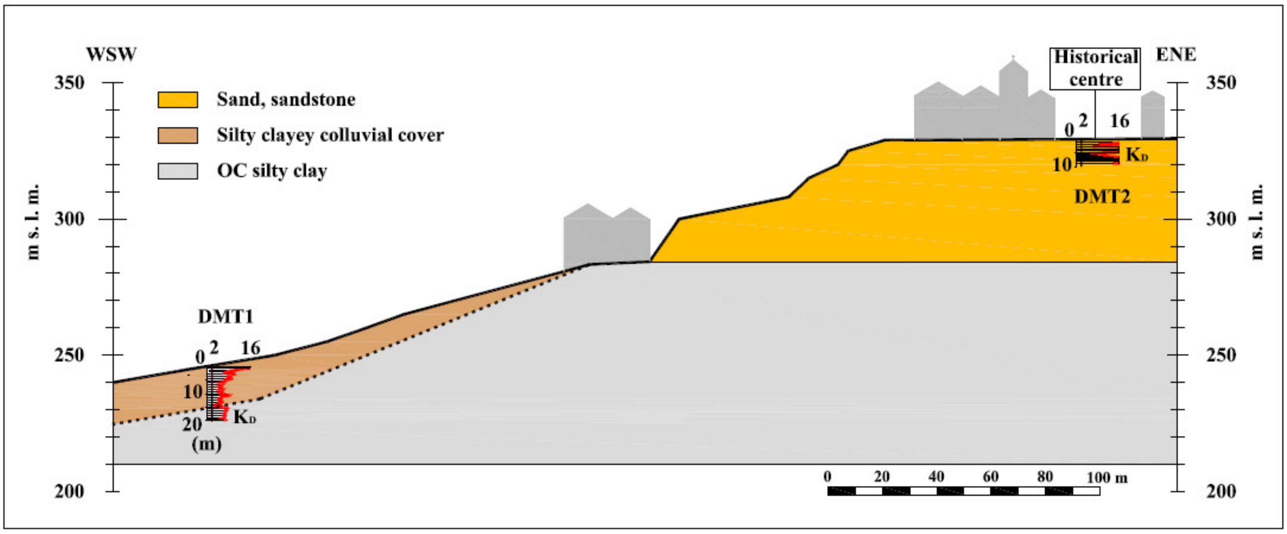

Figure 7. Fosso S. Chiara: geotechnical cross section with K_D profiles.

Concluding remarks

The examined case study demonstrated the ability of the seismic dilatometer to detect rapidly and economically the thickness of the colluvial covers.

The rapid change in K_D, M and c_u profile discriminate these formations from the intact unweathered OC clay.

In the Abruzzo colluvial covers, the K_D-DMT method identifies slip surface signalled by layers with $K_D = 2$, as well documented for Atri hill.

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