Use of in-situ flat dilatometer (DMT) for ground characterization in the stability analysis of slopes

Usage du dilatomètre plat (DMT) pour la caractérisation du terrain in-situ dans l'analyse de stabilité des pentes

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ABSTRACT: This paper shows the use of in situ dilatometer (DMT) testing in the analysis of the stability of clay slopes. In particular, a method is presented for detecting slip surfaces in overconsolidated (OC) clay slopes based on the inspection of the profiles of the horizontal stress index (K_D) from DMT. A number of case histories are presented where the slip surfaces signaled by the DMT-K_D method were confirmed by inclinometer measurements. The method provides a fast response in locating the position of active or quiescent slip surfaces.

RESUME: Cet article montre l'usage des preuves dilatomètriques (DMT) in situ dans les analyses de stabilité des pentes en argile. En particulier, on présente une méthode pour déterminer des superficies de glissement des pentes en argile surconsolidées (OC) sur la base de l'ispection des profiles de l'indice de poussée horizontale (K_D) du DMT. Des cas historiques sont présentés, où les superficies de glissement signalés de la méthode DMT-K_D ont été confirmés d'aprés les mesures inclinomètriques. La méthode fournit une réponse immédiate dans la localisation des positions des superficies de glissement actifs ou en repos.

1 INTRODUCTION

In the stability analysis of slopes, it is often important to be aware of the possible presence/location of past slip surfaces (active or quiescent).

Current methods for locating slip surfaces include examination of samples, inspection of cuts and inclinometer measurements over a period of time.

This paper shows the use of a quick method for detecting slip surfaces in overconsolidated (OC) clay slopes using in situ flat dilatometer (DMT) testing (Marchetti, 1980).

2 DMT-K_D METHOD FOR DETECTING SLIP SURFACES IN OC CLAY SLOPES

In many OC clay landslides the sequence of sliding, remoulding and reconsolidation (illustrated in Figs. 1 *a*, *b* and *c*) leaves the clay in the slip zone(s) in a normally consolidated (NC) or nearly NC state, with loss of structure, ageing or cementation effects.

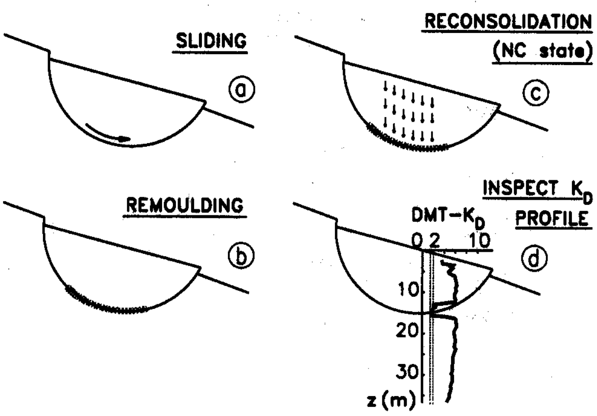

Fig. 1. Sequence of *a)* sliding, *b)* remoulding and *c)* reconsolidation in OC clay landslides. *d)* Principle of the DMT-K_D method for detecting slip surfaces.

Correlations established by several researchers (Fig. 2), based on field data from different clay sites in various geographical areas (Marchetti, 1980; Mayne, 1987; Lacasse & Lunne, 1988; Chang, 1991; Kamei & Iwasaki, 1995), have shown that in genuinely NC clays (no structure, ageing or cementation) the horizontal stress index K_D from the DMT is approximately equal to 2, while K_D values in OC clays are considerably higher, typically ranging from 5 up to 20.

Therefore, if an OC clay slope in a known or suspected slide area contains clay layers with $K_D \approx 2$ (Fig. 1 *d*), then these layers are highly likely to be part of a slip surface (active or quiescent).

In essence, the DMT-K_D method consists on identifying

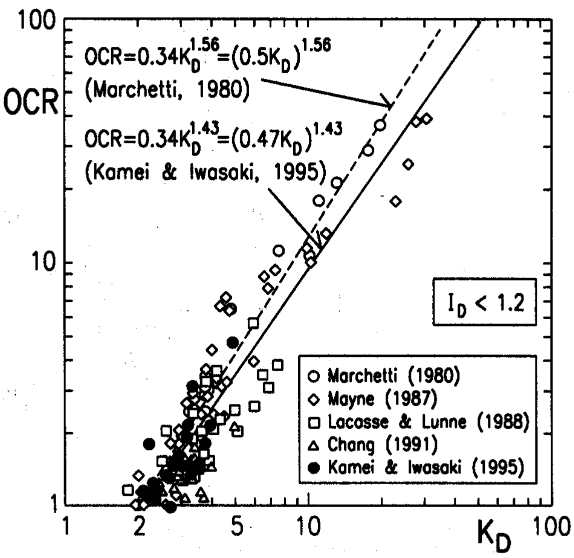

Fig. 2. Correlation between K_D and *OCR* for cohesive soils (after Kamei & Iwasaki, 1995)

zones of NC clay (i.e. $OCR = 1$) in a slope which, otherwise, exhibits an OC profile, using $K_D \approx 2$ as the identifier of the NC zones.

It is considered of significance that the method involves looking for a specific numerical value "$K_D \approx 2$" rather than simply searching for "weak/softened zones".

3 CASE HISTORIES

3.1 DMT testing in an unstable slope of Todi hill

A series of eight DMT soundings, each 45 m in depth, was performed in 1991 in an OC clay slope on a side of the hill of Todi (central Italy). The slope ("Fosso delle Lucrezie") is notorious for recurrent slips and has been extensively studied. Likely slip surfaces have been indicated by previous studies (Tonnetti, 1978), as shown in Fig. 3 *a*.

A comprehensive survey of the main features of the landslide and the results of previous investigations and measurements has been recently presented by Conversini et al. (1996).

The soil in the sliding area is a pliocenic heavily overconsolidated, intensely fissured lacustrine clay of medium plasticity. A wide literature is available, produced by several researchers (Calabresi & Scarpelli, 1985; Rampello, 1989; Burland, 1990 and others), showing the geotechnical properties and the mechanical behaviour of the Todi clay, mainly based on laboratory tests.

A series of inclinometers, installed some years before along the same cross section of the upper portion of the slope, investigated by DMT, had indicated sliding at a maximum depth of about 25 m. Three of these inclinometers are shown in Fig. 3 *b*.

The same Fig. 3 *b* also shows the K_D profiles obtained by the 8 DMT soundings. In such profiles K_D is generally in the range 4 to 8, with drops to $K_D \approx 2$ (hence $OCR \approx 1$) at several depths, indicating NC lenses interbedded in an OC clay mass.

From Fig. 3 *b* it can be seen that, at the same depths where the inclinometers had indicated sliding, $K_D \approx 2$.

The frequent presence of more than one depth with $K_D \approx 2$ in the DMT profiles suggests multiple sliding. This indication is in accordance with existing studies (Fig. 3 *a*).

It should be noted that the maximum depth of the possible slip surfaces signaled by $K_D \approx 2$ is about 40 m, that is *below* the maximum depth reached by the inclinometers.

Therefore, for these deep surfaces it is not possible a direct comparison between the DMT-K_D method and the inclinometer measurements.

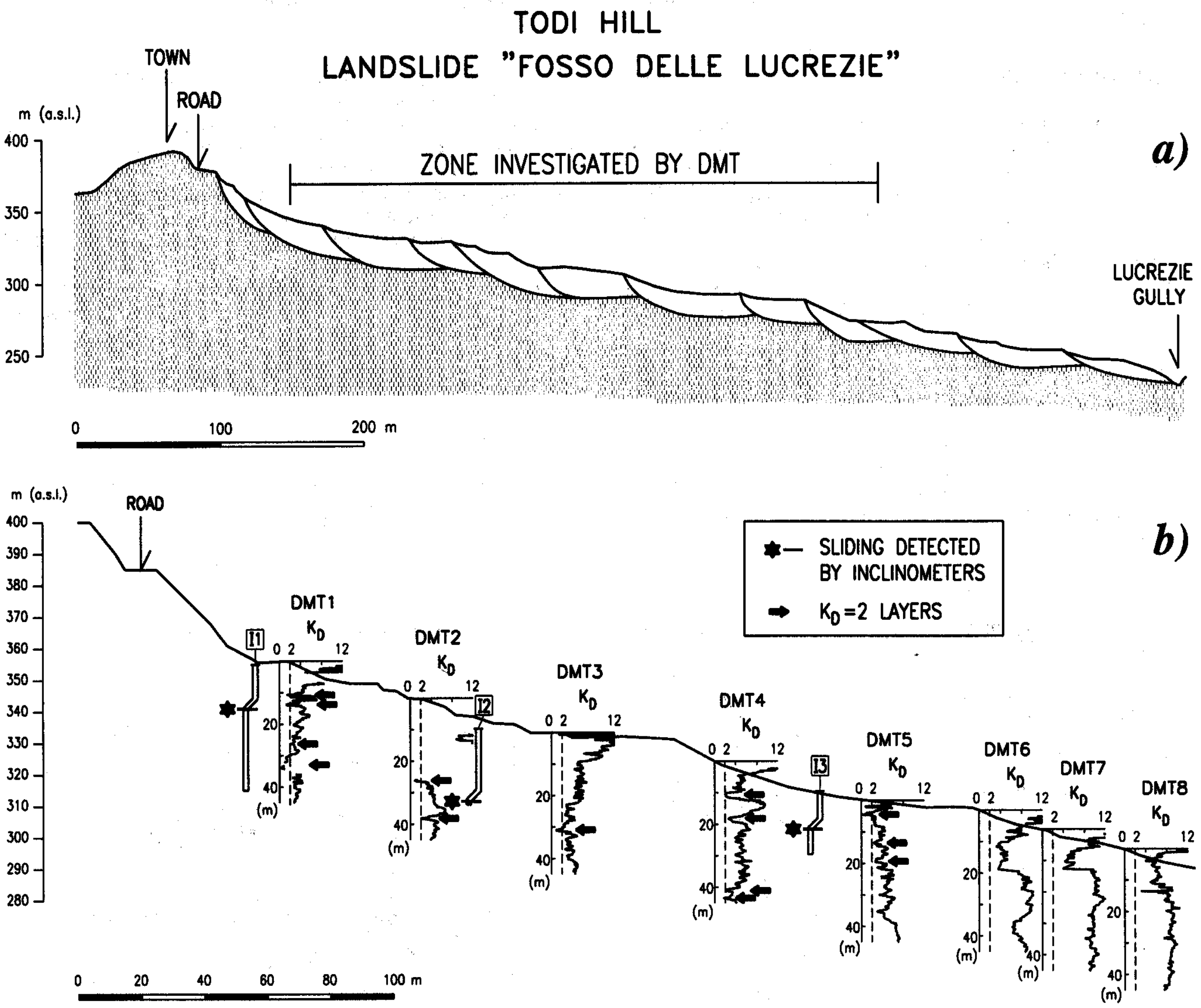

Fig. 3. Todi hill - Fosso delle Lucrezie. Cross section of the studied slope with: *a)* indication of possible slip surfaces obtained by previous studies (after Tonnetti, 1978); *b)* K_D profiles with indication of $K_D \approx 2$ layers and sliding planes detected by inclinometers.

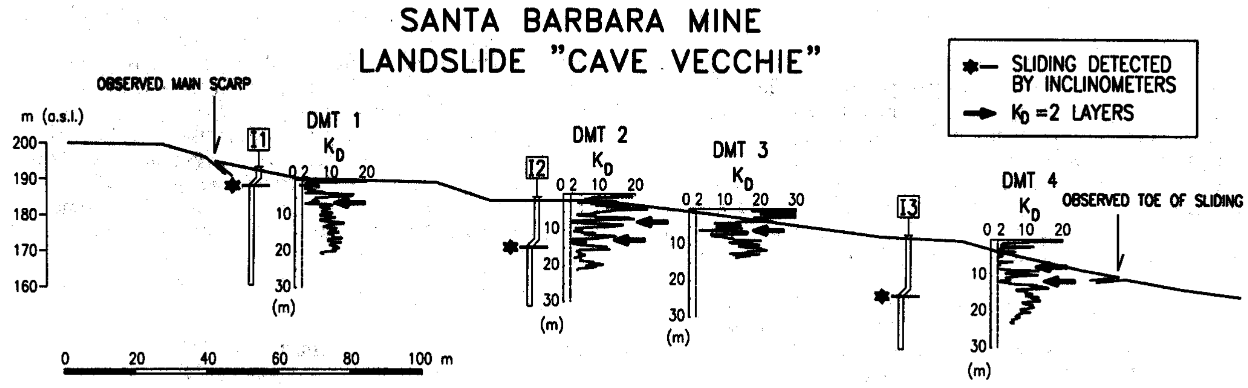

Fig. 4. Santa Barbara mine - Cave Vecchie. Cross section of the studied slope. K_D profiles with indication of $K_D \approx 2$ layers and sliding planes detected by inclinometers.

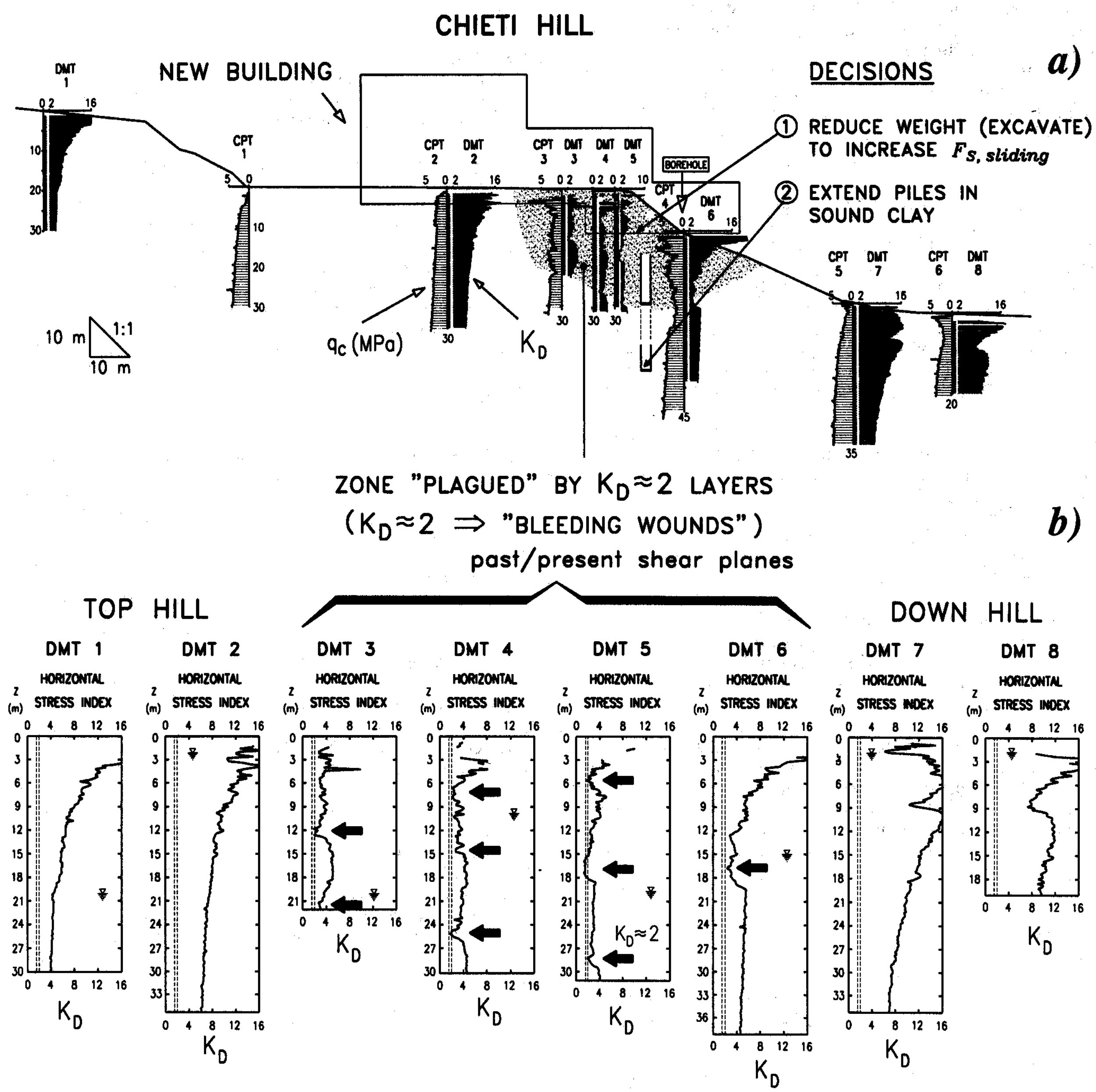

Fig. 5. Chieti hill. *a)* Cross section of the studied slope with DMT-K_D and CPT-q_c profiles. *b)* DMT-K_D profiles with indication of $K_D \approx 2$ layers.

3.2 *DMT testing in an unstable cut of Santa Barbara open-pit mine*

The slopes of Santa Barbara open-pit mine (central Italy), constituted by a heavily OC jointed lacustrine clay of pliocenic age, have been affected, during the exploitation, by a series of slides, sometimes involving very large volumes of soil. Some of these unstable slopes, extensively instrumented by inclinometers, have been monitored and studied over a long period (Calabresi & Manfredini, 1973; Esu, 1966; Esu & Calabresi, 1969; Esu & D'Elia, 1976; Esu et al., 1984; D'Elia et al., 1996).

Some years ago, a number of inclinometers were installed in order to define the geometry of one of the major slides ("Cave Vecchie"), where clear marks of instability were easily detectable on the ground surface (Fig. 4).

Four DMT soundings were performed in 1994 within the landslide area along a cross section of the slope. Three DMT tests were performed just close to three previously installed inclinometers which had indicated sliding.

The inspection of the K_D profiles, shown in Fig. 4, indicates that, at the same depths where the inclinometers had indicated sliding, $K_D \approx 2$.

The presence of other layers where $K_D \approx 2$ above the depths of sliding indicated by the inclinometers suggests remoulding/disarticulation of the soil mass comprised within the sliding volume.

3.3 *DMT testing in a building slope area of Chieti hill*

A new massive public building had to be constructed on a slope of Chieti hill (central Italy). In particular, the owner was concerned about the general stability of the slope.

Several investigations performed earlier (boreholes, trial pits and laboratory tests on samples) had indicated a rather uniform (horizontally) OC silty clay of medium plasticity.

In an attempt to obtain more detailed indications concerning the health of the slope, it was decided to use the DMT-K_D method.

Eight DMT tests were performed along the longitudinal section of the slope, in combination with six cone penetration tests (CPT) and one borehole. The profiles of DMT-K_D and CPT-q_c (cone penetration resistance) are shown in Fig. 5 *a*.

The inspection of the DMT-K_D profiles clearly highligths the presence of several layers where $K_D \approx 2$ (pointed out by arrows in Fig. 5 *b*), concentrated in a soil volume located just across the slope where the new building is to be constructed (hatched zone in Fig. 5 *a*).

It should be noted that the K_D values outside the zone "plagued" by $K_D \approx 2$ layers (remoulded soil mass) are considerably higher, suggesting quite better stability conditions outside this "weak zone".

In this case, the assumption of the presence of layers where $K_D \approx 2$ as an indicator of past/present shear surfaces could not be confirmed by inclinometer measurements or historical information. However, based on these indications and on the results of the stability analyses carried out (where residual shear strength parameters were assumed for the "weak zone"), it was decided to improve the stability of the slope in correspondence of the new building.

4 CONCLUSIONS

- A method has been illustrated for detecting slip surfaces in overconsolidated clay slopes based on DMT-K_D.
- A number of case histories have been presented where the slip surfaces signaled by $K_D \approx 2$ were confirmed by inclinometer measurements.
- The proposed method involves looking for a specific numerical value ($K_D \approx 2$) rather than simply searching for "weak zones", which could be located just as easily by means of other in situ tests.
- The method provides a faster response than inclinometers in locating the position of the slip surfaces.
- The method enables to quickly detect even quiescent slip surfaces (not revealed by inclinometers), which may be reactivated by fresh activity.
- On the other hand, the proposed method itself cannot establish if a slope is presently moving and what the movements are, while inclinometers can.
- In many cases, DMT testing and inclinometer measurements could be helpfully used in combination.

ACKNOWLEDGEMENTS

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