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Detecting the presence of cementation structures in soils, based in DMT interpreted charts

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ABSTRACT: Cemented soils usually don´t fit into the usual behaviour of transported soils in the light of classical Soil Mechanics theories, creating several problems on the interpretation of in situ test results. For this reason, the ability of discerning the presence of cemented structures in soils becomes fundamental in the interpretation of common in situ test results. Based in a large amount of sedimentary data, as well as in high quality experimental sites used in research programs on Porto and Guarda granitic residual soils (Viana da Fonseca 1996, Rodrigues 2003; Cruz & Viana da Fonseca 2006), interpretation diagrams based in DMT tests are proposed for detecting the presence of cemented structures. The results of a recent DMT calibration experiment performed in large artificially cemented block samples prepared in a large chamber (CemSoil box) were also used to calibrate these diagrams (Cruz 2010).

Keywords: residual soils, DMT, interpretation charts

1 INTRODUCTION

The continued actions resulting from weathering processes give raise to mechanical degradation, which starts from the unweathered more or less fractured massif, exhibiting its maximum strength and stiffness and moving towards a generalized soil mass, with no signs of the original macrofabric. In the extreme limits, assumed behaviours are quite different, with the first three weathering degrees of ISRM classification (unweathered, W_1, to medium weathered, W_3) being represented by rock mechanics principles and models, where macrofabric and rock matrix plays the fundamental role in strength and stiffness behaviours, while from this level on, chemical weathering is progressively extended to the whole massif and soil type behaviour arises. The mechanical evolution of massifs is mainly governed by an increasing porosity of rock material, the weakening of mineral grains and the existing bonding between grains is progressively loss, although a residual interparticle cementation always remain. In this sense, weathering degrees W_4 (weathered) and W_5 (decomposed) represent transition behaviour, where micro and macro fabrics have balanced influence, towards a residual soil-mass where the relic macrofabric is no longer present (Cruz 2010). Apart from residual soils and weak rocks, sedimentary soils (both soft to stiff clays and granular soils) can also be found structured in nature, with cementation being developed by agents like silica, hydro-silicates, iron oxides, carbonates and hydroxides deposited under various conditions (Clough et al. 1981, Leroueil & Vaughan 1990).

From the mechanical point of view, testing interpretation and deduction of geotechnical parameters are based in quite different laws, depending on the presence of a cementation structure. The main difference observed in the structured materials, with respect to classical sedimentary de-structured soils is the presence of a bonding structure, which generates a cohesive-frictional nature, eventual anisotropy derived from relic structures, highly variable fabric and mineralogy, destructuration under shear actions and low influence of stress history (Vaughan et al. 1988, Schnaid et al. 2004). From the strength strict point of view, bonding condition gives rise to tensile strength, explaining the cohesive-frictional nature generally exhibited by residual soils. It is generally accepted that for a given range of stresses, cemented soils may be adequately represented by Mohr-Coulomb envelope, typically showing a relatively stable angle of shearing resistance that seems to be fairly independent of cementation level, and a drained cohesive intercept directly related with the bonding structure strength (Clough et al. 1981, Viana da Fonseca 1996, 1998, Schnaid et al. 2004, Viana & Coutinho 2008, Cruz, 2010). This cohesive intercept is usually present, even when they show strong contraction during shear or when the same soil is in a remoulded state characterized by absence of tensile strength. As a consequence, the loss of strength with weathering can be represented by a reducing cohesion intercept, c', due to weakening of contact forces between particles, giving continuity to the behaviour evolution observed in rock materials. However, in these materials, cohesion intercept can be a result of many other contributions apart from cementation due to chemical bonding, such as electrostatic forces, adhesion of clay particles (clay bonding), contact cementation developed with time and pressure (ageing), interaction with organic matter and suction due to development of negative pore pressures in unsaturated conditions (Viana da Fonseca & Coutinho 2008). Despite this complexity, for most part of situations it is reasonable to assume that chemical bonding and suction give the main contributions for the overall strength.

On its turn, the fundamental state-of-the-art points out that stiffness behaviour is typically represented by more than one yield point, represented by marked changes in stress-strain behaviour. The concept of more than one yield has been increasingly reported in literature (Vaughan et al. 1988, Jardine 1992, Malandraki & Toll 1994, Viana da Fonseca 1996, Cuccovillo & Coop 1997, Rodrigues 2003, among others), identifying the typical pattern as an initially stiff behaviour followed by progressive yields. The position of yield points differs according to the author. Globally, an initially stiff behaviour is identified, represented by more or less stable elastic behaviour until a certain point (at very low axial strain where conceptually the dynamic stiffness is coincident with elastic stiffness) when a first drop occurs (first yield), which was identified as the beginning of bonding breakage (Vaughan et al. 1988, Viana da Fonseca 1996 or Rodrigues 2003). Up to this point cementation contribution remains the same and only very small changes in stiffness occur. After the first yield, while stress and strain increase, the cementation strength decreases with a slight reduction in stiffness, and when the overall resistance (therefore the stress) drop, a major change in tangent modulus is observed (second yield). This yield is coincident for many authors, but shouldn't be confused with the Y_2 concept proposed by Jardine (1992), which is related with the end of an elastic non linear behaviour, much more difficult to determine. Beyond second yield, tangent modulus decrease with axial strain, progressively converging to the one observed in destructured equivalent soil, until both converge to failure (general yield).

As a consequence of these considerations, conventional Soil Mechanic Theories do not represent well the behaviour of these materials, creating important problems on the interpretation of in-situ and laboratory testing results. In recent years, many researchers have been concentrating their resources trying to develop specific models and methodologies to properly characterize mechanical behaviour of these non-textbook materials. Being so, it is important to define clear frameworks to detect the presence of cementation, in order to select the adequate methodologies for obtaining the best geotechnical approaches. Moreover, it is important that these criteria can be applied by common tests such as SPT, (S)CPTu, (S)DMT or PMT performed during routine campaigns. For this purpose, interpreted charts have been proposed by Schnaid et al. (2004) for the SPT and (S)CPTu parameters by defining influence zones in diagrams of G_0/N_{60} and G_0/q_c versus respectively normalized $(N_1)_{60}$ and q_{c1} test parameters. These charts were applied to results obtained in the experimental sites in granitic formations nearby the Portuguese cities of Porto and Guarda (CEFEUP and Av. França in Porto and IPG Guarda) and proved great adequacy for the residual soil profiles (Fig. 1).

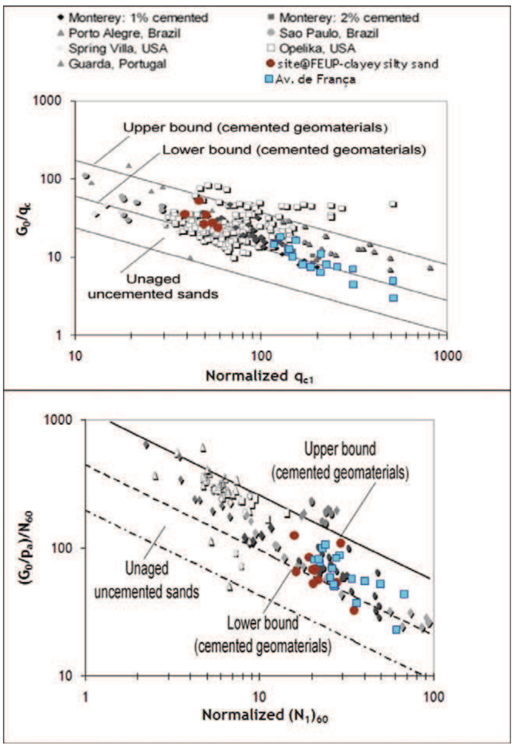

Figure 1. Relations between G_0 and SPT and CPTu parameters for structured soils (after Viana da Fonseca et al. 2007).

In the case of DMT tests, the earlier references (Marchetti 1980) pointed out the possibility of using the lateral stress index (K_D) for detecting cemented structures, since behaviours in normal transported soils exhibits stable OCR profiles and K_D values around two or decreasing OCR with depth towards a value of 2. On the other side, cemented soils with structural arrangement due to ageing will represent stable profiles in depth, with K_D values much higher than 2. Cruz et al. (2004) confirmed these criteria in Porto granitic residual soils, obtaining general K_D profiles stable with depth with values ranging from 5 to 15. However, this criteria is much dependent on the "lift-off" pressure, P_0, becoming quite sensitive to the effects of penetration. As a consequence, Cruz (2010) proposed new interpretations for the case of DMT tests, as discussed throughout this presentation.

2 OBTAINED RESULTS AND DISCUSSION

To obtain sustainable interpretation modes it is important to have considerable amount of quality data in both residual and sedimentary soils to properly study the characteristics that differentiate them. This was achieved by using the available data in sedimentary and residual Portuguese soils collected and analyzed during more than 15 years, completed with important publications on local materials and the access to G_0 obtained by seismic dilatometer tests, SDMT, kindly granted by Professor Silvano Marchetti. The global data set used in this study can be summarized as follows:

a. Sedimentary data obtained in the Tagus and Mondego (clayey to sandy) alluvial deposits (Cruz et al. 2006), validated by $G_{0\ DMT}$ sedimentary data, kindly granted by Prof. Silvano Marchetti in the course of a PhD research program (Cruz 2010).
b. Referenced granitic residual soil experimental sites where cross-hole testing was available—IPG in Guarda (Rodrigues, 2003), CEFEUP/ISC2 and Av. França/Casa da Musica Metro station in Porto (Viana da Fonseca et al. 2009). Other experimental sites around the city of Porto were used for checking the solution, such as CICCOPN (Cruz et al. 2004), and Matosinhos (Viana da Fonseca 1996) sites, as well as Porto Geotechnical Map (COBA 2003).
c. Physical modeling in laboratory controlled conditions, by using artificially cemented samples in triaxial testing and in a calibration apparatus (CemSoil box) where pushed-in and pre-inserted DMT blades were installed (Cruz 2010).

The ratios between a stiffness modulus and a specific stress-strain in-situ test parameter is a promising possibility for the present purpose, since they usually appear to be higher in overconsolidated and cemented soils than in remoulded or normally consolidated ones, because this modulus have a wider sensitivity to stress history and cementation (Cruz 2010). If the correlation is made with small strain shear modulus (G_0), as used by Schnaid et al. (2004), it depends exclusively on the combination of the void ratio and the average effective stress, represented by the State Parameter, ψ (Viana da Fonseca 1996, Cruz et al. 1997). The selection of G_0 as reference parameter makes use of the concept of an almost "intact" parameter, which is known to be very sensitive to cementation influence (Cruz 2010). In fact, the expected cementation breakage during penetration will highly affect the basic test parameters in structured than sedimentary soils, and thus the ratios G_0/N_{60} and G_0/q_c will tend to be as high as the cementation level increases. Although this implies obtaining an extra parameter (shear wave velocity), late technology made its application very practical with the availability of Seismic Dilatometer (SDMT) or Seismic Cones (SCPTu).

Particularly, DMT provides high level of precision for displacement measurements and its response can be explained by semi-spherical expansion theories, and thus the respective results usually represent high level of accuracy. The earlier works on the subject (Jamiolkowski et al. 1985, Lunne et al. 1989, Baldi 1991, Tanaka & Tanaka 1998) pointed out some discernable behaviours (in sands and clays) using the ratio G_0/E_D, which were confirmed by the sedimentary Portuguese results in Portuguese soils (Cruz et al. 2006). Furthermore, Cruz et al. (2006) introduced I_D in the correlations for sedimentary Portuguese soils and concluded that R_G (G_0/E_D) globally decreases with increasing I_D, marked by a significant drop as the soil goes from clay to silty clay, later confirmed by DMT international database, kindly granted by Prof. Marchetti. As for the residual data obtained in the referred experimental sites, there is an obvious increase of the ratio when compared to the grain size equivalent sedimentary soil revealing its potential to be used in detecting cementation, as shown in Figure 2.

The whole set of results obtained both in Portuguese and international sedimentary soils data, as well as in Portuguese residual soils, show the convergence of the curves as I_D increases, overlapping for values around 5, which seems logical since for those values the percentage of fine content is too small to display a cohesive factor. The representation of G_0/E_D versus I_D in a bi-logarithmic scale seems to be more appropriate to deal with data (Fig. 3), allowing for the definition of a frontier line (the central line in the figure), which can be described by the following equation:

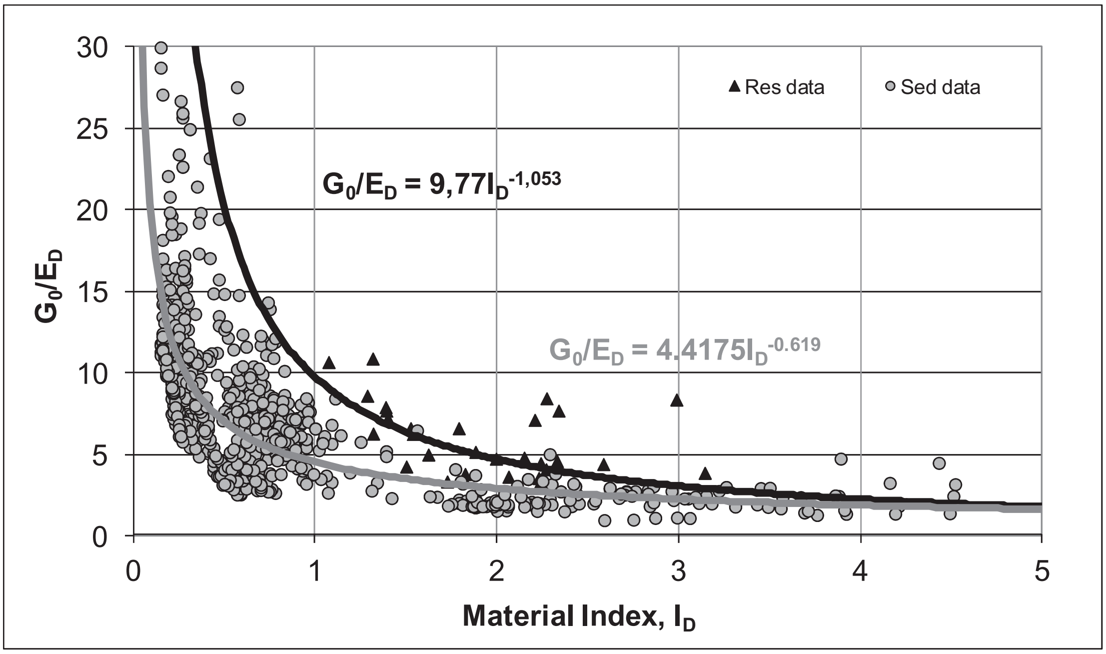

Figure 2. Relations between G_0/E_D vs I_D in sedimentary and residual soils.

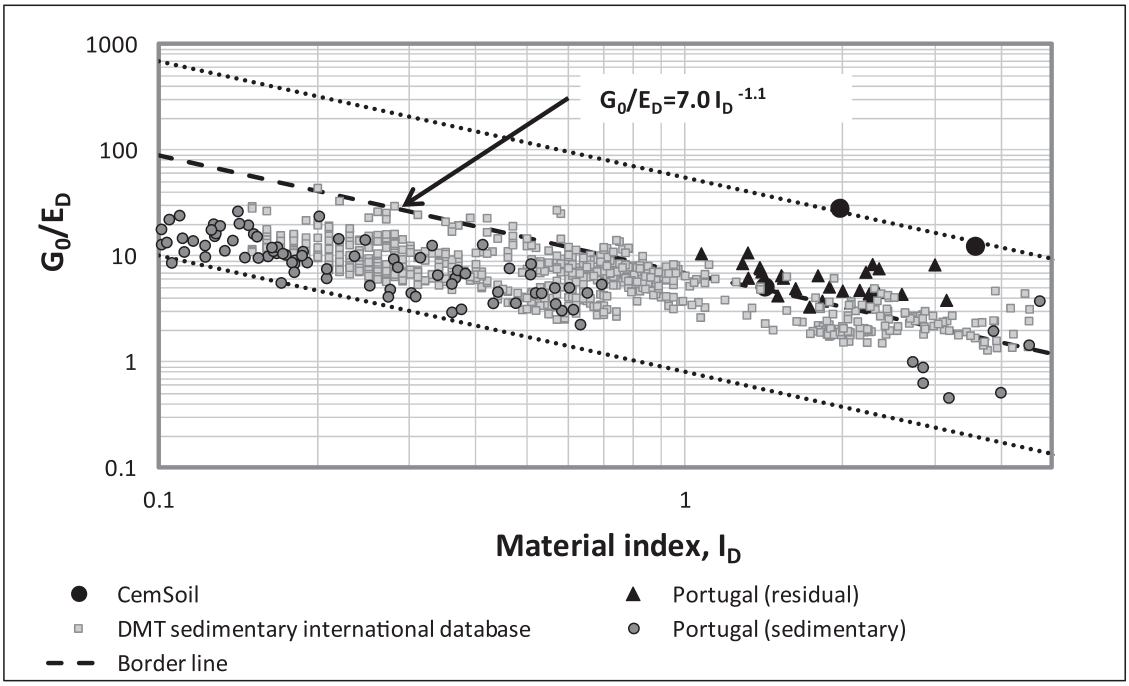

Figure 3. Residual and sedimentary sandy soils, in G_0/E_D vs I_D plot.

Upper sedimentary/lower residual bound:

$$G_0/E_D = 7.0\ I_D^{-1.1} \qquad (1)$$

A similar approach was followed using the ratio G_0/M_{DMT} plotted against K_D proposed by Marchetti et al. (2008), which revealed an expected similar potential given the sensitivity of K_D to cementation effects. In fact, the plot G_0/M_{DMT} versus K_D (Fig. 4) reveals that cemented soils assume higher rates when compared with remoulded conditions in sedimentary de-structured soils for the same granulometric range (I_D higher than 1.2),

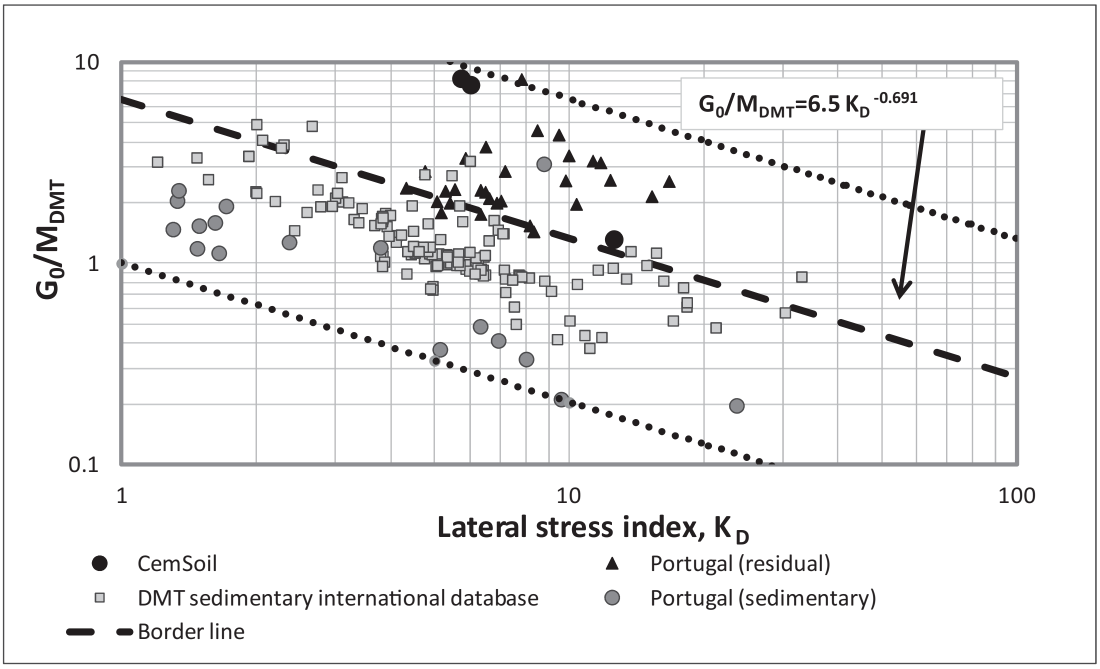

Figure 4. Residual and sedimentary sandy soils, in G_0/M_{DMT} vs K_D plot.

which is also confirmed by CemSoil pushed-in data (Cruz 2010). The equation defining this border line can be represented by:

Upper sedimentary/lower residual bound:

$$G_0/M_{DMT} = 6.5\ K_D^{0.691} \tag{2}$$

3 CONCLUSIONS

A large amount of quality data obtained from an international database (including portuguese) of sedimentary soils was analyzed and used as comparing reference for high quality granitic residual soil experimental sites calibrated by data from Porto Geotechnical Map (COBA 2003) and a specific calibration experiment (Cruz 2010). The obtained results highlight the possibility of introducing a (double) methodology based inseismic flat dilatometer (SDMT) test results for discerning non-cemented from cemented soils, very similar to the interpretation charts proposed by Schnaid et al. (2004) related with seismic piezocone (SCPTu) and SPT tests. In this case, either the ratio G_0/E_D versus I_D or G_0/M_{DMT} versus K_D can be used to detect the presence of cementation. Even though they can be used separately, it is suggested to combine them use to have a redundant classification with the required input data coming from similar test origins, although G_0/E_D versus I_D correlation reveals higher precision in the border line.

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