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Evaluation of effective cohesive intercept on residual soils by DMT and CPT

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ABSTRACT: Residual soils show by nature important deviations towards to the behaviour detected in transported soils modelled by the classical theories of Soils Mechanics. Such deviations are, to a great extent, due to a structural cementation inherited from the original rock mass and are, in terms of strength, essentially characterized by the existence of a effective cohesive intercept (c') and the development of a yielding evolution related to the break of the cementation structure, apart from the one corresponding to the plastification of the soil matrix component. The quantification of the cohesive parcel (c') has been achieved mainly by triaxial tests and, less often, by back-analysis of load tests with different plate or footing sizes. Getting undisturbed samples on these soils is extremely difficult, usually implying the partial or even complete loss of the cemented natural structure. This paper presents an experimental conceptual approach, aiming at quantifying the effective cohesive component (c') of strength by means of Marchetti's Dilatometer test, DMT, alone or combined with Cone Penetration Test, CPT, thus attempting to contribute to establish a correlation for its common quantification.

1 INTRODUCTION

The north region of Portugal is largely dominated by residual soils, from different nature, namely granitic. These soils behave differently from transported ones well modelled by Classical Soil Mechanics, mainly because of the existence of a cemented structure, whose effects are felt both at strength level as well as stiffness.

Marchetti's dilatometer test (DMT) has been increasingly used and seems to be very useful for the characterisation of loose to medium compacted granular soils and soft to medium clays. The use of this test on residual soils has not been very much exploited, with the exception of a few singular cases. In the last five years, the authors have studied the efficiency of these test results on such soils, thus trying to define specific correlations that may explain their mechanical behaviour. In this context, one of the goals of this paper is to establish correlations for deriving the strength parameters due to cemented structure, revealed by the presence of an effective cohesive intercept, c', by the Mohr-Coulomb criterion.

Since the test allows the determination of two basic parameters (P_0 and P_1), it generates the possibility of evaluating both the angle of shear resistance and cohesive intercept. The main goal of the methodology that will be presented in this study is the establishment of correlations that will allow the evaluation of the increment of resistance resulting from the cemented structure, represented by effective cohesion.

In what follows we will describe the application of this methodology on residual soils of granitic nature in five experimental sites located nearby the city of Porto.

2 IDENTIFICATION AND PHYSICAL CHARACTERIZATION

From the point of view of identification and physical characterization, the tested soils correspond to silty sands or eventually sandy silts, being systematically classified as SM (ASTM). They are non-plastic soils, with fines content ranging from 15% to 35%, void ratio between 0.5 and 0.8 and saturation degrees between 50% and 100%. The identification of these soils from DMT (Marchetti, 1980) and CPTU (Robertson, 1990) tests results is very consistent with this information.

3 MECHANICAL CHARACTERIZATION

The mechanical characterization of the studied soils was based on “in situ” (DMT, CPT/CPTU and PLT) tests and laboratory (triaxial, CK_0D and CID) tests over undisturbed samples. The determination of reference effective cohesive intercept, c’, was established based on triaxial tests and, in one of the cases, through the performance of a set of three plate load tests up to failure under different loading areas (Viana da Fonseca et al., 1998). A summary of the results obtained, which are relevant for this paper is presented in Tables 2 and 3.

Table 1 – Results of triaxial and PLT tests

Site tests	σ'_3 (kPa)	$\sigma'_1 - \sigma'_3$ (kPa)	ε_a (%)	c’ (kPa)	ϕ' (º)
Maia 1 CID	19	85.1	5.8	5	37
	23	90.1	4.5		
	33	120.1	7.7		
	40	119.6	9.6		
	58	200.4	6.8		
Maia 2 CID	30	125	0.3	10.3	36.3
	77	289	4.6		
	90	297	6.3		
	125	381	8.0		
	150	490	7.0		
Maia 3 CK0D	18	106	4.5	11.9	42.1
	23	146	5.8		
	33	150	7.7		
	40	190	5.9		
	58	288	6.8		
Porto CK0D	8	109	3.2	24.3	32
	15	114	3.5		
	30	156	3.7		
V. Conde CK0D	9	48	4.6	10.8	35.4
	12	67	3.0		
	30	96	5.1		
Mat. PLT	-	-	-	9 - 12	37

Table 2 – Results of DMT and CPT tests

Site	I_D	K_D	vOCR[1] (DMT)	M/q_c	ϕ' (º)[2] (DMT)	ϕ'(º)[3] (CPT)
Maia 1	1.5–2.5	4.5–7.5	5–20	5–15	37–39	35–36
Maia 2	1.8–2.0	3.5–5.0	5–10	10–15	35–40	35–39
Maia 3	2.0–3.5	7.5–11.0	10–25	10–15	39–40	37–40
V. Conde	1.8–2.0	11.0–15.0	20–50	10–15	39–41	44
Porto	1.8–2.1	7.5–15.0	50–100	10–15	42	38–41
Mat.	1.5–2.0	7.0–11.0	10–25	10–20	39–41	42–44

(1) Virtual Over Consolidation Ratio (presented in paragraph 4.3);
(2) Marchetti’s (1997); (3) Robertson and Campanella’s (1983)

4 DISCUSSION OF RESULTS

4.1 *The purpose*

The attempt to evaluate the effects of cementation structure was based on the results of DMT and DMT+CPT tests, namely from the lateral stress index, K_D, “virtual overconsolidation ratio”, vOCR (DMT) and the ratio of DMT and CPT parameters, M / q_c. These results were then compared with the cohesive intercept obtained from triaxial and PLT tests.

4.2 *Lateral stress index, K_D*

According to basic DMT reference (Marchetti, 1980), the KD profiles present typical patterns revealing the following behaviours:

a) the K_D profile tends to follow the classical shape of the OCR profile;
b) normally-consolidated (NC) soils tend to present values of K_D around 2;
c) over-consolidated (OC) soils tend to show values of K_D above 2, decreasing with depth and converging to the values of NC;
d) Normally consolidated soils affected by a cementation or ageing structure show values of K_D higher than 2, remaining fairly stable with depth.

The K_D profiles within the present study show a general tendency to remain stable with depth, showing values significantly higher than 2, namely ranging from 5 to 15. Thus, following the above mentioned assumptions, these values clearly reflect the effects of cementation.

4.3 *Virtual Overconsoladation Ratio, vOCR*

Even tough the concept of overconsolidation ratios does not have the same meaning for sedimentary and residual soils, the presence of a naturally cemented structure gives rise to similar behaviour. Preconsolidation stress is now represented by the second yield (y_2). This stress is called virtual preconsolidation stress and the relation between this and the vertical rest stress is called ‘virtual overconsolidation degree (vOCR)’, thus differentiating it from the one physically sustained in the process of sedimentary soils generation with ‘stress memory’.

This concept, here designated as previously, has the same meaning as the established terminology: "vertical yield stress = σ'_{vy}"; which corresponds to other established more general concept: "yield stress ratio = YSR. Thus, the OCR derived from the DMT test on residual soils (vOCR) reflects the strength resulting from the cementation structure, normalised in relation to the effective vertical stress. It is important to note that OCR evaluation is I_D and K_D dependent (that is P_0 and P_1 dependent), allowing to be confident on the determination of both angle of shear resistance and effective cohesive intercept.

The results obtained by derivation of the cohesion, following the methodology presented in this paper, have revealed a parallelism with K_D reflecting the relation between them. On the other hand, OCR shows higher sensitivity to variations, which is related of OCR dependency on I_D, in addition to K_D (Marchetti & Crapps, 1981). This proves to be a useful tool for the evaluation of cohesion.

4.4 *M (DMT) versus q_c (CPT)*

The M/q_c relation for sandy soils has been emphasised by Marchetti (1997) as a useful tool for the definition of OCR on granular soils, given the greater sensitivity of the M parameter to variations in compaction, when compared to the tip resistance, q_c. Marchetti (1997), synthesising the work of different authors, suggests that values of M/q_c between 5 and 10 correspond to normally consolidated soils, whereas values of M/q_c between 12 and 24 correspond to overconsolidated soils.

Again, it is important to note that M is based on I_D, E_D and K_D, and thus incorporating P_0 and P_1. Cruz et al. (2004), in a wider study including the experimental sites upon which this work is based, have detected the following trends in these soils:

a) M/q_c relation tends to show values situated in the frontier NC/OC (10 to 12, according to Marchetti, 1997) frequently showing OC peaks; part of these peaks are mainly due to decreases of q_c, which may be related with the higher disturbance caused by the CPT insertion (Baligh & Scott, 1975)
b) It is clear that M (DMT) increases with depth at higher ratio than q_c;
c) K_D profiles are typical of normally consolidated soils, but with values varying from 2 to 25; since the reference value for sedimentary soils is around 2, it reveals the presence of cementation-conditionated soils, according to Marchetti's (1980) conclusions on the development of K_D profiles;
d) The K_D value corresponding to the NC/OC frontier of M/q_c (10-12) is between 5 and 6, i.e. about half; since K_D reflects the low K_0 values which characterise these soils, K_D is not a good indicator of the vOCR indexation and the level of cementation.

Figure 1 illustrates a representative situation of the evolution of K_D, vOCR, and M / q_c with depth, obtained in the present study. The results clearly show the sensitivity of vOCR and M/q_c to variations in soil condition and the sensitiveness of K_D.

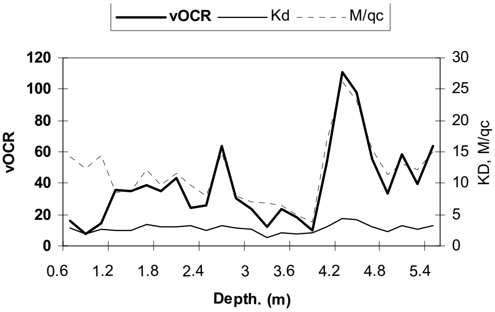

Figure 1. Representative K_D, vOCR, and M/q_c profiles.

4.5 *Parametric relations*

The comparison between c' obtained from reference tests and K_D, vOCR, and M/q_c are presented in Figures 2, 3 and 4. The convergence with c' is clearly greater with vOCR (DMT) and M/q_c than with K_D. Nonetheless, vOCR shows a tendency to adjust better to variations, since it incorporates I_D, i.e. the type of soil.

In the same figures it is also represented the correlations with c'/σ'_{v0} . The true values of this latter are multiplied by 100 to be represented in the same scale. As it can be seen the correlating factors generally decrease, but tend to show the same tendencies.

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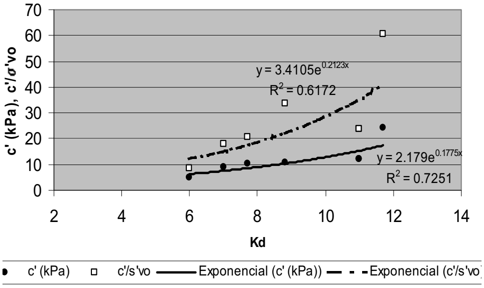

Figure 2. c' and 100.c'/σ'vo - K_D correlations

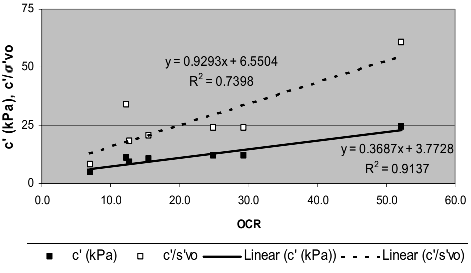

Figure 3. c' and 100.c'/σ'vo - vOCR correlations

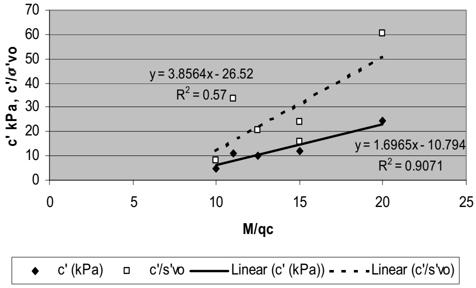

Figure 4. c' and 100.c'/σ'vo – M/q_c correlations

Figure 5 shows another interesting detail that reinforces the quality of results. In fact, it seems that the difference between the angles of shear resistance obtained by means of DMT and triaxial tests is consistent with the variation of c'.

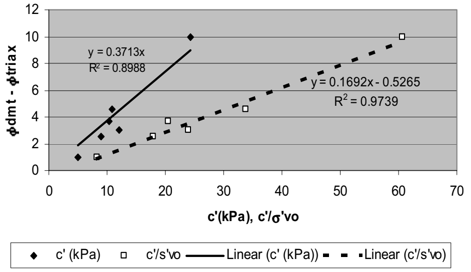

Figure 5. Trends between (ϕ'_{DMT}-ϕ'_{triax}) and c', 100.c'/σ'vo

On the other hand, comparing c' with preconsolidation pressure, σ'_p, obtained via DMT, the relation between them is represented by 0,011, which is lower of those pointed out by Mayne & Stewart (1988) and Mesri et al (1993), for overconsolidated clays (0,03 to 0,06 and 0,024, respectively), which could be explained by a stronger overconsolidation effect. Again, it seems to point out the ability of the test to feel the cementation structure. The regression is presented in Figure 6.

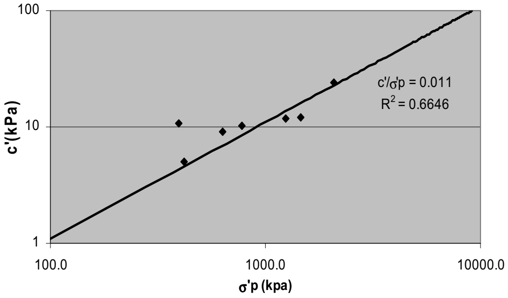

Figure 6. Relation between c' and σ'_p

5 CONCLUSIONS

The study performed allowed the authors to confirm the adequacy of the DMT test, whether or not together with the CPT test, for the evaluation of a dual component strength of cemented residual soils, by mean of parameters K_D, OCR (DMT) or M/q_c. However, OCR (DMT) and M/q_c seem to possess a higher potentiality for this evaluation.

Considering the narrow range of this study and the limited number of tests any extrapolation of these results to other locations should be tested. However, it seems reasonable to admit that the methodology followed may be successfully applied in other geological environments.

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