Discussion of "CPT-DMT Correlations" by P. K. Robertson

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Silvano Marchetti[1]

[1]Professor, L'Aquila Univ., Italy, and Director, Studio Prof. Marchetti, Via Bracciano 38, 00189 Roma, Italy. E-mail: silvano@marchetti-dmt.it

The ultimate scope of all soil characterization studies is the determination of reliable soil parameters that the engineer can use in design. Correlations interconnecting the cone penetration test (CPT) with the flat dilatometer test (DMT), such as Eqs. (28)–(30) developed by the author, while not serving directly this purpose, are useful in that translation formulas permit (1) the use of interpretation methods or charts developed for one test with the results of the other test; and (2) converting a database available for one test to a database for the other test.

The previously mentioned translations would, in practice, be possible if the conversion formulas were perfect. If this were the case, having run a CPT, it could be possible to obtain the DMT parameters, or vice versa, and it would be possible to unify advantageously an investigation to just one type of sounding.

The scope of this discussion is to emphasize that, while the developed correlations are, as noted by the author, a framework for future refinements, insuperable intrinsic limits to the accuracy and completeness of the CPT-DMT translations exist, which, despite future refinements, are bound to remain of an approximate and incomplete nature. This discussion also indicates the engineering applications for which the translation error is considered too high.

In particular, this discussion will make reference to Eqs. (28)–(30) developed by the author to obtain the DMT parameters I_D, K_D, and E_D from the CPT parameters q_t and f_s (or Q_{t1} and F_r).

One reason for the strong nonequivalence of CPT and DMT data is that, while DMT is a truly two-parameter test (p_o and p_1; or, say, E_D and K_D), with both parameters E_D and K_D connected with primary soil characteristics (stiffness and stress history, respectively), CPT is essentially a one parameter test (q_t or Q_{t1}) related to rupture characteristics. The sleeve friction f_s is generally considered a second-tier parameter [e.g., DeJong and Frost (2001): "underuse of f_s is related to the common sentiment that f_s is unreliable"; or Schnaid (2009): "sleeve resistances are less reliable and of lower resolution than tip resistance," to the point that "q_c alone is used for calculations of pile shaft resistance"] and is not easily linkable to fundamental soil properties. An indirect confirmation of the scarcely fundamental information content of f_s comes from the author's Eqs. (29) and (30), which, for inferring E_D and K_D, both use only q_t and do not use f_s.

Q_{t1} is first used in the author's Eq. (29) to estimate K_D, and then the same Q_{t1} is used in Eq. (30) to estimate E_D. It follows that Eqs. (29) and (30) are very approximate in nature because it is impossible to predict, from just one piece of information (i.e., Q_{t1}) two independent quantities (i.e., E_D and K_D). Eqs. (29)–(30) can be combined to eliminate Q_{t1}, obtaining a constant relationship K_D-E_D, which could be translated into a constant relationship p_o-p_1. Such a constant relationship would allow for the prediction of p_1 from p_o. Experience shows that, even in soil known to be claylike, it is impossible to predict p_1 from p_o—unless a very large error is permitted.

As pointed out by Mayne et al. (2009) today's trend is toward multiparameter in situ tests. The availability of more than one parameter may often help determine a particular design parameter. This is what is done, for example, when estimating the confined modulus M from E_D, K_D by using the basic DMT interpretation formulas. A satisfactory estimation of M would not be possible without K_D, which is used to select the factor for E_D. When only one parameter is available, such as q_c, no combination is possible (f_s does not help much). For example, approximate charts exist, providing factors (typically 2 to 20 in sand) to convert q_c to M. However, such charts contain curves for various overconsolidation ratios (OCRs). Hence, these charts require information about the stress history, which is not derivable from the parameter q_c, which is also the parameter needing to be factorized. The difficulty in selecting M on the basis of CPT was long ago signaled by Robertson et al. (1986): "Prediction of modulus from CPT can be rather poor…with a large potential error," or recently by Schnaid (2009): "Correlations between tip resistance and soil stiffness are unreliable." The primary reason for such difficulty was pointed out by Jamiolkowski et al. (1988): "without stress history, it is impossible to select reliable M from q_c," and by other writers (e.g., Leonards and Frost 1988; Schmertmann 1970; Terzaghi and Peck 1967).

In contrast to the large potential error when predicting settlements by CPT, there seems to be a general consensus on the ability of DMT to satisfactorily predict settlements (e.g., Lacasse and Lunne 1986; Failmezger and Bullock 2008; Monaco et al. 2006; Lehane and Fahey 2004; Mayne and Liao 2004; Tice and Knott 2000; Iwasaki et al. 1991; Schmertmann 1986, 1988; Steiner 1994; Leonards and Frost 1988; and numerous others). Such ability may be attributable not only to the possibility of combining E_D with the stress history parameter K_D, but also to the different nature of the test, in particular (1) E_D is a modulus from a miniload test rather than a penetration resistance test; (2) the distortions caused by the blade insertion are considerably lower than the distortions caused by a cone (Baligh and Scott 1975; Davidson and Boghrat 1983; Whittle and Aubeny 1993); and (3) the arching effect (Hughes and Robertson 1985), making $f_{s,\text{sleeve}}$ insensitive to σ_h (Huang and Ma 1994), is practically negligible for a flat probe.

The different abilities of CPT and DMT to predict settlements are proof that the correlations are far from perfect. If they were, it would be possible to use them to translate CPT data into E_D, K_D, and then use E_D, K_D to predict settlements. Although, had CPT data the potential for accurate settlement predictions, a direct methodology for converting CPT data to settlements would have been developed.

In short, the big difference between CPT and DMT is that DMT provides the parameter K_D related to the stress history (a fundamental piece of information and a protagonist in the DMT interpretation), whereas q_c is unaccompanied by a similar parameter containing information about stress history.

Another engineering application for which translation formulas (current or future) for estimating K_D from CPT data are believed to be too inaccurate, is the estimation of the sand liquefaction resistance [cyclic resistance ratio (CRR)] on the basis of K_D. A recent paper by Marchetti (2010) presents a compilation of data showing that K_D is considerably more sensitive than q_t (or Q_{t1}) to stress history and aging. No translation formula can reconstruct K_D values incorporating such sensitivity if the reconstruction is on the basis of q_t, which is "almost independent of past straining along the Ko-line" (Baldi et al. 1985) and "is not very sensitive to stress history" (Schnaid 2009). Yet, sensitivity to stress history is important for liquefaction. It is arduous to estimate liquefiability without stress history. See, for example, Baldi et al. (1985): "Reliable predictions of sand liquefiability…require some new in situ device [other than CPT or SPT], more sensitive to effects of past stress-strain histories." The fact that K_D is sensitive to aging, in addition to stress history, is also important. See, for example, Leon et al. (2006): "Ignoring aging and evaluating CRR from in situ tests insensitive to aging (SPT, CPT, Vs) underestimated CRR in South Carolina sands by a large 60%." Thus, when using K_D to evaluate CRR, it is important to use K_D measured by DMT—preserving the aging information—rather than use a reconstructed K_D. This because "disregarding aging is equivalent to omit a primary parameter in CRR correlations" (Monaco and Schmertmann 2007). Clearly the omission of a primary parameter causes dispersion in such correlations.

In the previously mentioned paper by Marchetti (2010), it is hypothesized that K_D, being correlated (Yu 2004) to the state parameter ψ, but, at the same time, incorporating stress history and aging effects, which are missing in ψ, could be uniquely well correlated with CRR. However, while on one hand, q_t is rather insensitive to stress history, on the other hand, the experimental information for estimating CRR is much more abundant for CPT than for DMT. One effective way for verifying the previously mentioned hypothesized capability of K_D could be to (1) convert the existing large CPT liquefaction database into first approximation K_D-CRR correlations by using the author's translation formulas; and (2) proceed to the fine-tuning of the obtained K_D-CRR correlations by accumulating real life liquefaction-nonliquefaction CRR-K_D data.

This discusser would like to conclude by noting that soil information is vital for the designer but is costly to obtain. Procedures and methods helpful for extracting as much information as possible from the field data, as done by the author, represent a precious contribution.

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