Equivalent CPT Method for Calculating Shallow Foundation Settlements in the Piedmont Residual Soils Based on the DMT Constrained Modulus Approach.

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ABSTRACT: The flat plate dilatometer test (DMT) is well-recognized for its ability to calculate settlements of shallow foundations in a practical manner in soil types ranging from sand to silt to clay. Within the Piedmont physiographic province, an equivalent method has been developed for the CPT to obtain constrained moduli for use in the same procedure as the DMT.

INTRODUCTION

Over 2 decades of calibration between the DMT and measured foundation performance records have shown its value & reliability in settlement computations (e.g., Schmertmann, 1986; Mayne & Frost, 1988; Marchetti, et al. 2001). The measured dilatometer modulus (E_D) is converted to a constrained modulus (M') per the procedures established by Marchetti (1980). For each sublayer, the uniaxial strain can be calculated as $\varepsilon = \Delta\sigma_v/M'$ and the resulting settlement in that sublayer is simply $\rho = \varepsilon\,\Delta z$. The change in stress at each sublayer can be obtained from classical elastic theory solutions (e.g., Poulos & Davis, 1970; Mayne & Poulos, 1999). Settlements from all sublayers are summed to find the total foundation settlement:

$$\rho_{Total} = \Sigma \frac{\Delta\sigma_v}{M'} \cdot \Delta z$$

An earlier & well-received method for foundation settlement calculations (Schmertmann, 1970) related the settlement modulus directly to the measured cone tip resistance (q_c), particularly in fine sandy soils (e.g., $M' = 2\ q_c$). This too utililized elastic theory solutions, but combined the influence of the modulus and stress distribution to form a simplified strain influence diagram, known as the 0.6-2B triangle. At that time (circa 1970), it was necessary to approximate the distributions because engineers relied on slide rules for their calculations. With programmable calculations and Pentium IV computer notebooks, there is no need for approximate distributions any longer.

Another clarification that needs address is the use of a one-dimensional modulus (M'), that corresponds to consolidation or oedometer testing, versus the three-dimensional problem associated with footings & mats that require an elastic modulus (E'). In fact, the two moduli are related via elastic theory:

$$E' = \frac{(1+\nu')(1-2\nu')}{(1-\nu')} \cdot M'$$

where ν' is the drained Poisson's ratio. For $\nu' = 0$, in fact, E' = M', and for the normal case where $\nu' = 0.2$, the elastic E' is 90 percent of M', so in practical circles they are used somewhat interchangeably.

It is of interest to revisit both approaches and develop a methodology by which the advantages of the CPT can be appreciated for foundation settlement evaluations. In this case, the Piedmont geology comprised of silty residuum will be addressed.

PIEDMONT DATA

The Piedmont geology is comprised of residual silty sands, clayey silts, and sandy silts derived from the weathering of old gneiss, schist, and granite. Details on the formation and characteristics have been discussed elsewhere (e.g., Sowers & Richardson, 1983; Sowers, 1994; Martin, 1977; Mayne, 1999). At several well-documented sites, data from both DMT and CPT have been collected and provide an opportunity to interrelate the measurements. For example, extensive testing has been reported for the National Geotechnical Experimentation Site (NGES) in Piedmont soils near Opelika, Alabama (Vinson & Brown, 1997; Brown & Vinson, 1998; Scheider, et al. 1999; Mayne, et al. 2000; Finke, et al., 2001). Similar data sets in the Piedmont have been reported for a test site at the Georgia Tech campus (Mayne & Harris, 1993; Harris & Mayne, 1994). Additional unpublished and published data are also available in Piedmont soils in North Carolina (e.g., Wang & Borden, 1996).

Three sets of CPT-DMT data have been compiled for an intracorrelative derivation of relationships. The tests were conducted in accordance with ASTM D 5778 and D 6635 standards for the CPT and DMT, respectively. From the cross-comparative analyses, Figure 1 shows that the DMT modulus correlates well with the cone tip stress.

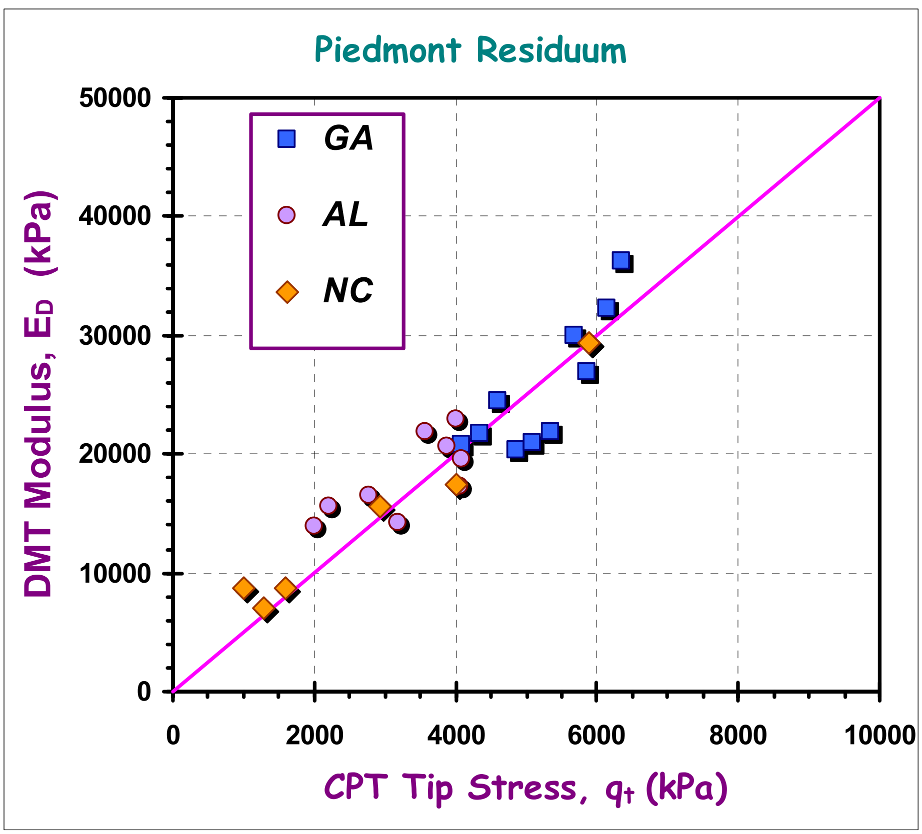

Figure 1. Relationship between the DMT Elastic Modulus and CPT Tip Stress in Piedmont Soils.

In the Marchetti procedure (1980, 2001) for obtaining a constrained modulus, the dilatometer material index (I_D) and horizontal stress index (K_D) are also required in order to attain the modulus ratio (R_M = M'/E_D). The DMT material index relates to the grain size of the soil, as does the CPT friction ratio, FR = $f_s/(q_t-\sigma_{vo})$. Figure 2 shows that an approximate trend is evident between these two data sets in the Piedmont.

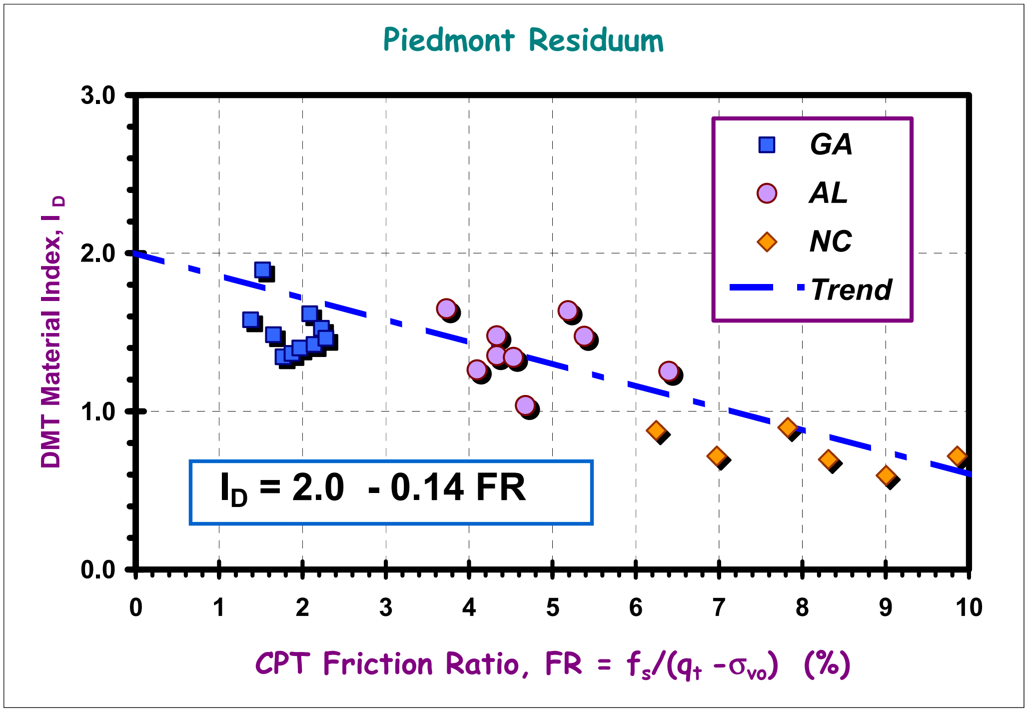

Figure 2. Relationship between DMT material index and CPT friction ratio in Piedmont residuum.

As the DMT obtains 2 independent measurements (p_0 and p_1), the third index is readily obtained from the first two indices. The horizontal stress index is found from:

$$K_D = \frac{E_D}{34.7 \cdot I_D \cdot \sigma_{vo}'}$$

Thus, in summary, the CPT data can be converted to equivalent DMT indices via the following expressions:

Dilatometer Modulus, E_D = 5 q_t

Material Index, I_D = 2.0 - 0.14 (FR)

Standard DMT data reduction procedures are then employed to obtain the constrained modulus (D' = M' = $1/m_v$):

$$M' = R_M \; E_D$$

where R_M = fctn (I_D, K_D), as detailed in the following table (Marchetti, 1980; Schmertmann, 1986; Mayne & Martin, 1998; Marchetti, et al. 2001):

Table D-1. Constrained Modulus Parameter (R_M) for Settlement Calculations

Conditions	Relationship for R_M = M'/E_D	Notes
If $I_D < 0.6$	$R_M = 0.14 + 2.36 \log K_D$	Clay soils
If $I_D > 3$	$R_M = 0.50 + 2.0 \log K_D$	Clean (quartz) Sands
If $0.6 < I_D < 3$	$R_M = R_{M0} + (2.5 - R_{M0}) \log K_D$ where $R_{M0} = 0.14 + 0.15(I_D - 0.6)$	Silts to silty Sands
If $K_D > 10$	$R_M = 0.32 + 2.18 \log K_D$	
If $R_M < 0.85$	Set $R_M = 0.85$	

The forward evaluation of M' from CPT data in the Piedmont is seen to compare very well with the DMT values of M' in Figure 3, thus validating the proposed approach.

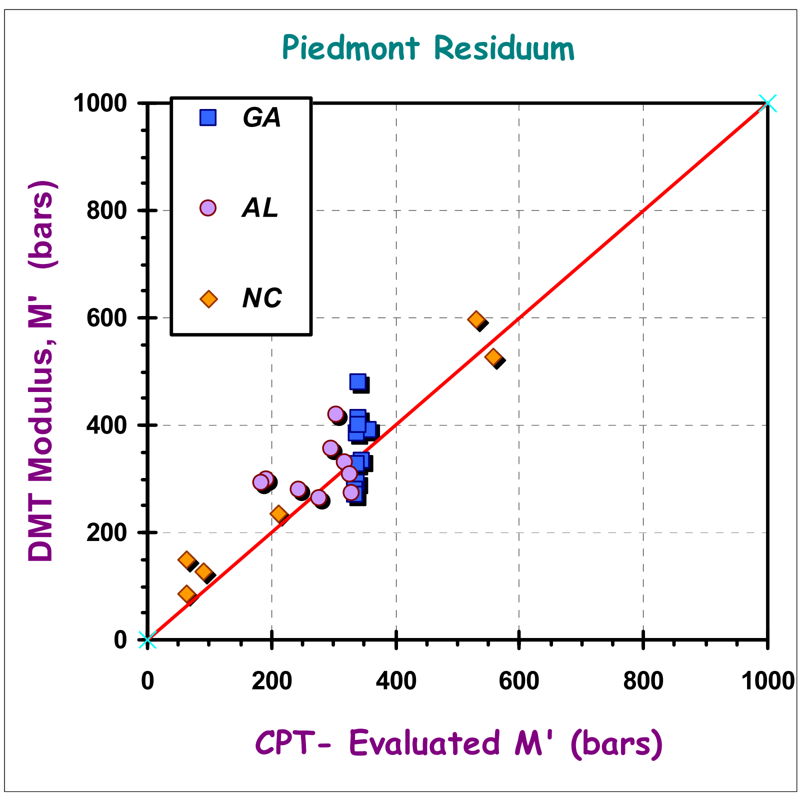

Figure 3. Validation of CPT Method for Evaluating DMT Constrained Modulus in Piedmont Soils.

REFERENCES:

ASTM (2002). Standard for Flat Dilatometer Test, ASTM D 6635, American Society for Testing & Materials, West Conshohocken, PA.

Brown, D.A. & Vinson, J.(1998). Comparison of strength and stiffness parameters for a Piedmont residual soil, Geotechnical Site Characterization, Vol. 2, Balkema, Rotterdam, 1229-1234.

Finke, K.A., Mayne, P.W. & Klopp, R.A. (2001). Piezocone penetration testing in Atlantic Piedmont residuum. Journal of Geotechnical & Geoenvironmental Engineering 127 (1), 48-54.

Harris, D.E., & Mayne, P.W. (1994). Axial compression behavior of two drilled shafts in Piedmont residual soils, Proceedings, International Conference on Design and Construction of Deep Foundations, Vol. 2, Federal Highway Administration, Washington, D.C., 352-367.

Marchetti, S. (1980). In-situ tests by flat dilatometer. Journal of Geotechnical Engineering 106 (GT3), 299-321.

Marchetti, S., Monaco, P., Totani, G. & Calabrese, M. (2001). The flat dilatometer test (DMT) in soil investigations. A report by the ISSMGE Committee TC 16. Proceedings, International Conference on In-Situ Measurement of Soil Properties & Case Histories, Bali, Indonesia, 95-131.

Martin, R.E. (1977). Estimating foundation settlements in residual soils, Journal of the Geotechnical Engineering Division (ASCE) 103 (GT3), 197-212.

Mayne, P.W. (1999). Site characterization aspects of Piedmont residual soils in eastern US. Proceedings, 14th International Conference on Soil Mechanics & Foundation Engineering, Vol. 4, Balkema, Rotterdam, 2191-2195.

Mayne, P.W. & Frost, D.D. (1988). Dilatometer experience in Washington, D.C. Transportation Research Record 1169, National Academy Press, Washington, D.C., 16-23.

Mayne, P.W. & Harris, D.E. (1993). Axial load-displacement behavior of drilled shaft foundations in Piedmont residuum. Research Report No. E-20-X19 submitted to Federal Highway Administration by Georgia Tech Research Corp, 162 p. (available from Association of Drilled Shaft Contractors, Dallas).

Mayne, P.W. and Martin, G.K. (1998). Commentary on Marchetti flat dilatometer correlations in soils. ASTM Geotechnical Testing Journal 21 (3), 222-239.

Mayne, P.W. and Poulos, H.G. (1999). Approximate displacement influence factors for elastic shallow foundations. Journal of Geotechnical & GeoEnvironmental Engineering 125 (6), 453-460.

Mayne, P.W., Brown, D.A., Vinson, J., Schneider, J.A. and Finke, K.A. (2000). Site characterization of Piedmont residual soils at Opelika, Alabama. National Geotechnical Experimentation Sites, GSP No. 93, ASCE, Reston, Virginia, 160-185.

Poulos, H.G. and Davis, E.H. (1974). Elastic Solutions for Soil & Rock Mechanics, Wiley & Sons, New York; now available from University of Sydney Press.

Schmertmann, J.H. (1970). Static cone to compute static settlement over sand. ASCE Journal of Soil Mechanics & Foundations Division 96 (3), 1011-1043.

Schmertmann, J.H. (1986). Dilatometer to compute foundation settlement. Use of In-Situ Tests in Geotechnical Engineering, GSP 6, ASCE, Reston/VA, 303-321.

Schneider, J.A., Hoyos, L., Mayne, P.W., Macari, E.J., & Rix, G.J. (1999). Field and lab measurements of dynamic shear modulus of Piedmont residual soils. Behavioral Characteristics of Residual Soils (GSP 92), ASCE, Reston, 12-25.

Sowers, G.F. (1994). Residual soil settlement related to the weathering profile. Vertical and Horizontal Deformations of Foundations and Embankments, GSP No. 40, Vol. 2, ASCE, Reston, Virginia, 1689-1702.

Sowers, G.F. & Richardson, T.L. (1983). Residual soils of the Piedmont and Blue Ridge, Transportation Research Record No. 919, National Academy Press, Washington, D.C., 10-16.

Vinson, J.L & Brown, D.A. (1997). Site characterization of the Spring Villa geotechnical test site and a comparison of strength and stiffness parameters for a Piedmont residual soil, Report No. IR-97-04, Highway Research Center, Harbert Engineering Center, Auburn University, AL, 385 p.

Wang, C.E. & Borden, R.H. (1996). Deformation characteristics of Piedmont residual soils. Journal of Geotechnical Engineering 122 (10), 822-830.