Modeling the Relationship between Shear Strength and Texas Cone Penetrometer value N_{TCP} in Clay Soils: Energy Method

Minsu Kim, M.S. and C. Vipulanandan, Ph.D., P.E.
Center for Innovative Grouting Materials and Technology (CIGMAT)
Department of Civil and Environmental Engineering
University of Houston, Houston, TX 77204-4003
Tel: 713-743-4291; email: rc0206@hotmail.com

Abstract: The relationship between undrained shear strength (C_u) and Texas Cone Penetrometer (TCP) value N_{TCP} in clay Soils was investigated using the energy method supported by the Finite Element Method (FEM) and compared to the current TxDOT relationship.

1. Introduction

The TCP is used by the Texas Department of Transportation (TxDOT) for site investigation [Tex-132-E]. From the test, blow count (N_{TCP}) (number of blows of the hammer for 12 inches (300 mm) of penetration) is obtained and is related to the undrained shear strength of the soil. The blow count (N_{TCP}) will be affected by number of factors including the soil properties, depth, geology and hammer efficiency. Hence it is of interest to investigate the effects of some of these parameters on predicting the undrained shear strength of the soil. In this study the energy concept is used and the average penetration per blow is used in the analysis (pseudo-static problem). The energy delivered by the hammer per blow is used to overcome the soil resistance with a loss factor (a lumped parameter accounting for all the losses in the system) incorporated into the relationship.

2. Objectives

The objective of this study was to determine the relationship between undrained shear strength (Cu) and N_{TCP} using the energy method with FEM and identity the important soil and driving system parameters.

3. Finite Element Method (FEM)

FEM is used to quantify the work done against soil resistance. PLAXIS was used and Fig. 1 shows the FEM model. The cone was pre-embedded to a depth of 30 ft. For the preliminary study, the soil was idealized as a homogeneous elastic-perfectly plastic material with Mohr-Coulomb yield criterion. A parametric study was undertaken to quantify the influence of the ratio of modulus (E) to Cu. Three E/C_u ratios were examined (250, 500 and 1000). The average unit end bearing (q)-displacement (δ) relationships for the TCP are shown in Fig 2.

4. The Relation between Undrained Shear Strength (*Cu*) and TCP N-value (N_{TCP})

TxDOT Model: The following relationship is used to determine the shear strength (C_u) of CH soils from N_{TCP} (TxDOT (2000)):

$$C_u = 2\left(N_{TCP}/50\right) tsf = N_{TCP}/25\, tsf = (0.556)\cdot N_{TCP}\ (psi)\ \text{(for CH soil)} \quad (1)$$

Energy Method: the average energy per blow effectively used for driving the TCP is represented as follows:

$$Energy/Blow\ effective\ in\ driving\ the\ TCP = \alpha \cdot E_N \quad (2)$$

Where α is the efficiency factor and E_N is the energy delivered by the hammer.
The resistance to driving the TCP can be represented as follows:

$$\text{Work done to overcome soil resistance} = A_c \cdot \int_0^{\Delta Z} q\, d\delta \quad (3)$$

Where A_c is the cross section area of cone, q is the unit resistance and δ is the deflection.
Hence the governing relationship for TCP driving is as follows:

$$A_c \cdot \int_0^{\Delta Z} q\, d\delta = \alpha \cdot E_N \quad (4)$$

The $q-\delta$ relationship for various Cu and E/C_u obtained from the FEM is shown in Fig.2 and be approximated by a hyperbolic relationship as follows:

$$q = \frac{\delta}{a(Cu) + b(Cu)\delta} \quad \text{-- (5)}$$

In which *a(Cu)* and *b(Cu)* are soil parameters.
Combining Eq. (4) and Eq. (5) will result in the following relationship.

$$\int_0^{\Delta Z} \frac{\delta}{a(Cu) + b(Cu)\delta} d\delta = \frac{\alpha \cdot E_N}{A_c} \quad \text{-- (6)}$$

$$\frac{\Delta Z}{b(Cu)} - \frac{a(Cu)}{b(Cu)} \left\{ \ln \frac{a(Cu) + b(Cu) \cdot \Delta Z}{a(Cu)} \right\} = \frac{\alpha \cdot E_N}{A_c} \quad \text{-- (7)}$$

In addition, the penetration depth per blow ΔZ is related to the N_{TCP} by using the following relationship.

$$\Delta Z = {}^{1\,ft}\!/_{N_{TCP}} \quad \text{-- (8)}$$

Eq. (7) can be solved to determine ΔZ for various Cu, E/C_u and α. Once ΔZ is determined, N_{TCP} is determined using Eq. (8). Consequently, the relationship between *Cu* and N_{TCP} using the energy method with FEM is compared to the TxDOT method and field test data in Fig.3. The energy method predictions captured the field data with the varibles investigated in this study.

5. Conclusions

The energy method was used to develop the relationship between undrained shear strength (*Cu*) and N_{TCP}. Using this approach, it was possible to quantify the effects of soil parameters and hammer efficiency in predicting the shear strength of soil using the TCP.

6. Acknowledgement

This work is supported by the Center for Innovative Grouting Materials and Technology (CIGMAT) with funding from TxDOT. The funding agency is not responsible for any of the conclusions.

7. References

[1] TxDOT Geotechnical Manual (2000) - Texas Department of Transportation (TxDOT), Austin, Texas.

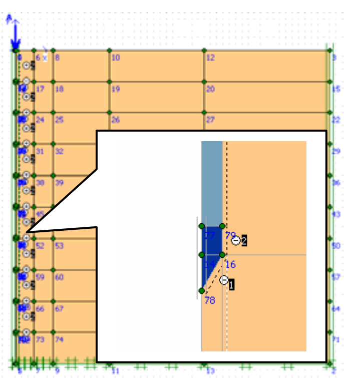


Figure 1. Finite element model

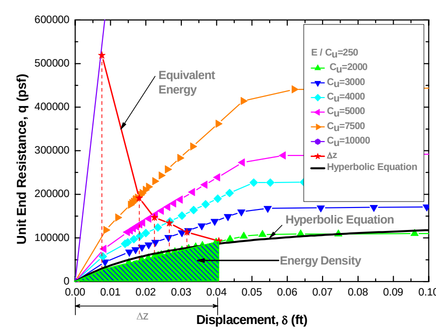
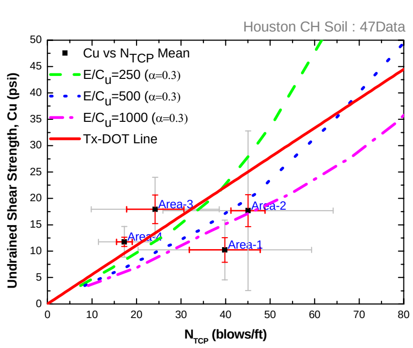
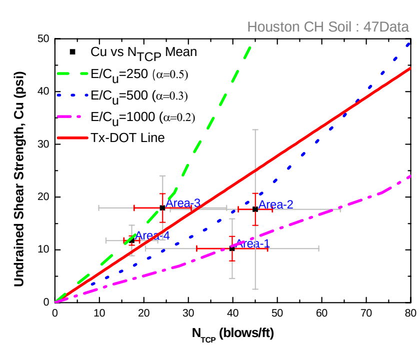


Figure 2. $q-\delta$ **relationship for various Cu and** E/C_u **and Hyperbola model**



(a) α **=0.3 and various** E/C_u



(b) various α **and** E/C_u

Figure 3. Relationship between undrained shear strength (Cu) and N_{TCP} for the varying α and E/C_u