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New method for estimation of soil shear strength parameters using results of piezocone

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ABSTRACT

Soil shear strength parameters, c and φ, can be determined by the use of laboratory tests and in situ testing data. In this study, a new method is presented for c and φ prediction using all quantities, q_c, u_2 and f_s from CPTu considering bearing capacity mechanism of failure at cone tip and direct shear failure along penetrometer sleeve. One of the advantages of this method is the improvement of accuracy in the case of erroneous data by using all three outputs of CPTu. Laboratory test results, two sets of non-linear equations by the proposed approach, and existing correlations of c and φ parameters were compared to data compiled from four other sources. In previous investigations, cohesive parameters are not considered in bearing capacity equation and they cause the failure loads to be transferred to the second part of the basic bearing capacity equation which is a function of the internal friction angel. It was observed that the internal friction angles which are obtained by current methods are relatively higher than the measured values. Furthermore, the comparison of predicted and measured c and φ values indicates appropriate consistency and less scattered for the proposed method in comparison to other approaches.

1. Introduction

The cone penetration test (CPTu) amongst different in situ tests is considered as a reputable procedure and is used in soft to medium deposits [1]. The laboratory measurements of soil shear strength parameters always shows difficulties such as: providing undistributed samples, size limitation, transportation and maintenance effects, actual stresses modeling and information discontinuity in depth. Hence, in situ and laboratory test results can only be used as a supplementary in geotechnical practice [2]. Geotechnical investigation by CPTu provides continuous vertical profile of cone tip resistance (q_c), sleeve friction (f_s) and pore water pressure (u_2) in every inch of the subsoil depth [3]. Therefore, soil profile and geotechnical properties of soil layers can be defined [4]. The penetrometer is a useful tool to identify thin layers where the traditional sampling procedures cannot be employed. So far, the relation results achieved through CPTu show that this test is considered as an appropriate tool to determine the density and shear strength of soil species. One of the most important parameters for fine-grained soils is undrained shear strength, Su, which is obtained in traditional ways from unconsolidated undrained triaxial (UU) or uniaxial unconfined compression tests [5]. Due to some weaknesses in undistributed sampling, inaccuracy of excess pore water pressure mobilization and overburden stress conditions in the laboratory, determination of undrained shear strength of cohesive soils by UU triaxial test, is accompanied with some difficulties. In alluvials containing gas, determination of undrained shear strength by traditional sampling procedures and using UU triaxial tests may lead to conservative

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results. In granular soils, determination of the friction angle (φ) as one of the major soil strength parameters by using direct shear or triaxial tests involves uncertainties due to sampling difficulties, confining pressure simulation and limitations of size effects [6]. The main advantages of CPTu versus other in situ test procedures are the elimination of undisturbed sampling, performance in real condition regarding stress level and geological aspects. Furthermore, by using the continuous data in one inch (25 mm) interval of depth, shear strength parameters (c, φ) can be obtained, and these parameters play a significant role in geotechnical designs.

2. Review of the proposed models to predict shear strength parameters using CPTu result

Some researchers have been developed various methods in order to determine the effective shear strength parameters in fine and coarse grained soils which will be briefly reviewed in following paragraphs.

Muromachi [7] assumed the slip surface as a logarithmic spiral during the cone penetration and proposed the following equation for non-cohesive soils:

$$q_c = 3/2P_0 \cos\varphi \cdot (e^{2\pi \tan\varphi} - 1) \tag{1}$$

in which P_0 is the effective surcharge stress. Trial and error method is required to determine the angle of internal friction. This equation estimates internal friction angle to the nearest one degree.

Meyerhof [8] presented the following equation for internal friction angle in cohesionless soils:

$$\varphi = \tan^{-1}\left(\frac{q_c}{0.5N_q}\right) \tag{2}$$

where q_c is the measured cone resistance and N_q is the bearing capacity factor.

Schmertmann [9] studied sandy soils behavior and suggested a correlation between φ and relative density, as follow (see Fig. 1):

$$\varphi = 28^\circ + 0.15D_r \tag{3}$$

where D_r is the relative density.

Mitchell and Durgunoglu [6] investigated the relationship between φ and q_c from CPT regarding bearing capacity failure. Based on bearing capacity theory, they proposed a relationship for φ, using q_c and effective overburden stress as illustrated in Fig. 2. Robertson and Campanella [10] focused on sandy soils in drained conditions and presented Eq. (4) to determine the internal friction angle as follows:

$$\varphi = \tan^{-1}\left[0.1 + 0.38\log\left(\frac{q_c}{\sigma'_{v0}}\right)\right] \tag{4}$$

in which σ'_{v0} is the effective vertical stress (effective overburden stress).

Moreover, Fig. 3 presents different recommended methods for the determination of N_q as a function of φ, which is commonly applied in pile design.

Senneset et al. [12] stipulated that in coarse grained soils, pore pressure is negligible during cone penetration.

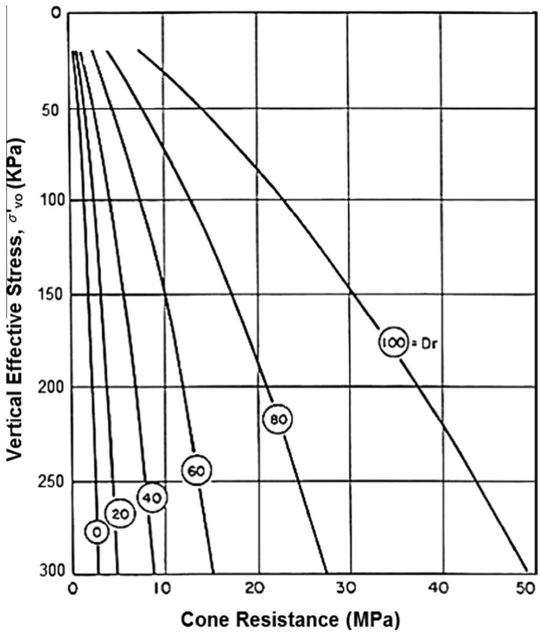

Fig. 1. Cone tip resistance changes with vertical effective stress graphic [9].

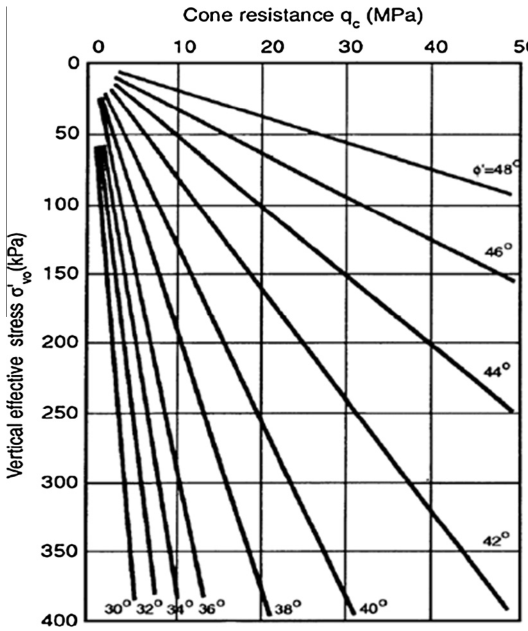

Fig. 2. Friction angle changes and cone tip resistance [6].

They presented the following correlation based on cone tip resistance:

$$q_c = \left[(N_q - 1)\left(\sigma'_{v0} + \frac{c'}{\tan\varphi'}\right)\right] + \sigma'_{v0} \tag{5}$$

where N_q is bearing capacity factor, φ', c' are the effective shearing strength parameters and σ_{v0} is the total vertical stress (total overburden stress).