Basic soil properties from CPT in Bangkok clay for highway design

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ABSTRACT: Engineering soil parameters, such as soil type, strength, stiffness and stress history are important in the design and construction of highway embankments on soft clay. To quantify these engineering parameters, testing of soft clay samples in the laboratory may be required but is laborious and time consuming process. One way to estimate the engineering parameters is from in-situ tests. In Thailand, vane shear tests are widely used in estimating the basic engineering soil parameters. For the new Bangkok-Chonburi motorway construction, it is found that soil classification from cone penetration tests (CPT) coincides with those performed from laboratory tests. The cone factor for estimating the undrained shear strength (Su) of the Bangkok clay is found to be 16.6. However, for Bangkok clay, evaluation of the horizontal coefficient of consolidation by CPTs tends to underestimate, comparing with previous data.

1 INTRODUCTION

The soft Bangkok clay has been well known for high water content, low shear strength, and high compressibility, to geotechnical engineers for several decades. For constructing highway embankments on soft Bangkok clay, the main geotechnical concerns are excess settlement and potential stability failure. Thus, the Department of Highways (DOH), Thailand, applies several soil improvement techniques, such as, deep mixing cement column and vertical drains, to increase their highway serviceability, and lower their maintenance costs. In practice, designing highway embankments on soft Bangkok clay requires engineering properties such as coefficient of consolidation, soil classification, stress history, soil modulus and undrained shear strength. In the past decades, these engineering parameters are estimated from laboratory tests that are quite laborious and costly. At present, in-situ tests are widely used instead. For Bangkok clay, vane shear and standard penetration tests (SPT) are normally performed and then correlated to engineering soil properties by back-analysis techniques using geotechnical monitoring results such as those from pressuremeter, inclinometer, horizontal inclinometer, piezometer and so on. At present, correlations between engineering soil properties and in-situ test indices have been developed and available in many literatures (e.g., Kulhawy & Mayne, 1990); however, these correlations are site-by-site basis. Applying of these engineering correlations to a particular site shall be precautious especially for Bangkok vicinity called "soft Bangkok clay".

Road Research and Development Center, Department of Highways (DOH), Thailand, has initiated a pilot project to study an application of in-situ tests to the design of highway embankment on the soft Bangkok clay since 1995 at the construction site of the new Bangkok-Chonburi highway construction project at construction stations of 25+250 and 29+400. Geotechnical investigations on the construction sites are performed mainly by piezocone and vane shear tests. The objectives of this study are: a) to evaluate the possibility of applying the cone penetration test to the soft Bangkok clay, and b) to develop the suitable correlations of CPTs and their basic engineering properties of soft Bangkok clay and then compare the developed correlations with previous studies.

2 HIGHWAY CONSTRUCTION SITE

Tourist attractions, seaports, and industrial estates are located in the east of Thailand. With the second international airport as part of national logistics, the demand for highways is increased dramatically in the area. Thus, Department of Highway (DOH), Thailand, proposed the construction of the new Bangkok-Chonburi highway to connect the Bangkok and eastern part of Thailand and to alleviate the traffic congestion in the existing Bangna-Bangpakong highway. The new Bangkok-Chonburi highway is fully-controlled access with flyovers at intersections. Almost the entire highway route is found to be sitting on the well-known "soft Bangkok clay". The soft Bangkok clay layer is about 15 to 20 meters thick. Severe settlement of the highway embankment is anticipated if it is constructed on unimproved clay; thus, the prefabricated vertical drain (PVD) technique with preloading embankment is introduced to accelerate the primary consolidation settlement.

Soil profile along the construction route between stations 15+700 and 34+000 can be classified to four layers as follows: weathered crust, soft clay, medium stiff clay, and stiff clay, respectively, as shown in Table 1. Atterberg limit results are plotted in Casagrande's soil classification chart; moreover, the Bangkok clay is classified as CL or CH as shown in Figure 1. In addition, the undrained shear strength before and during PVD are shown in Figure 2. Vane shear tests (VST) were performed before and during PVD; Figure 2 indicates the effectiveness of the PVD to increase the undrained shear strength of the soft Bangkok clay.

Table 1: Basic engineering soil properties of the soil layers at the construction stations of 15+700 and 34+000 (after Lin, 1999).

Depth (m)	Unit Weight (g/cm^3)	Water Content (%)	Liquid Limit (%)	Plastic Limit (%)
0 to 1	1.6 to 1.8	40 to 60	60 to 80	25 to 30
1 to 16	1.4 to 1.5	70 to 160	90 to 140	30 to 60
16 to 20	1.6 to 1.8	40 to 60	60 to 80	30
20 to 22	1.8 to 2.0	-	-	-

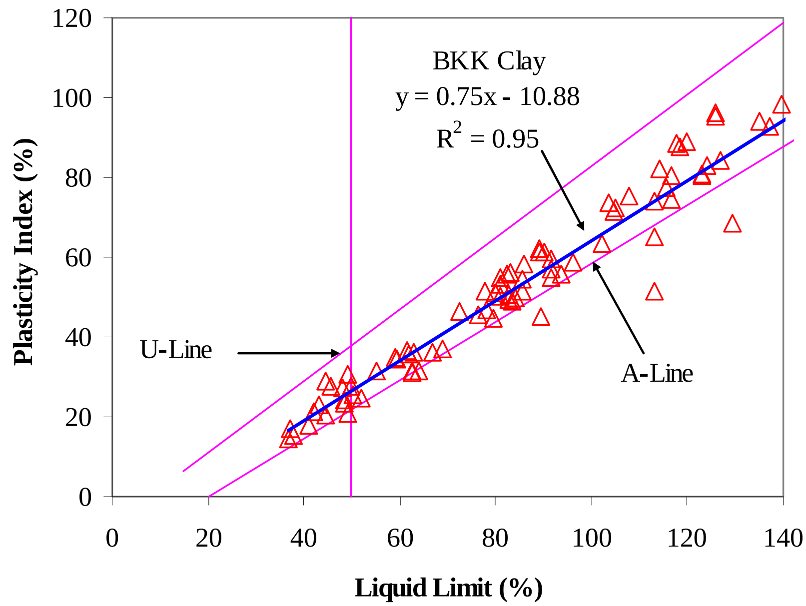

Figure 1: Atterberg limit test results of the soft Bangkok clay in soil classification chart.

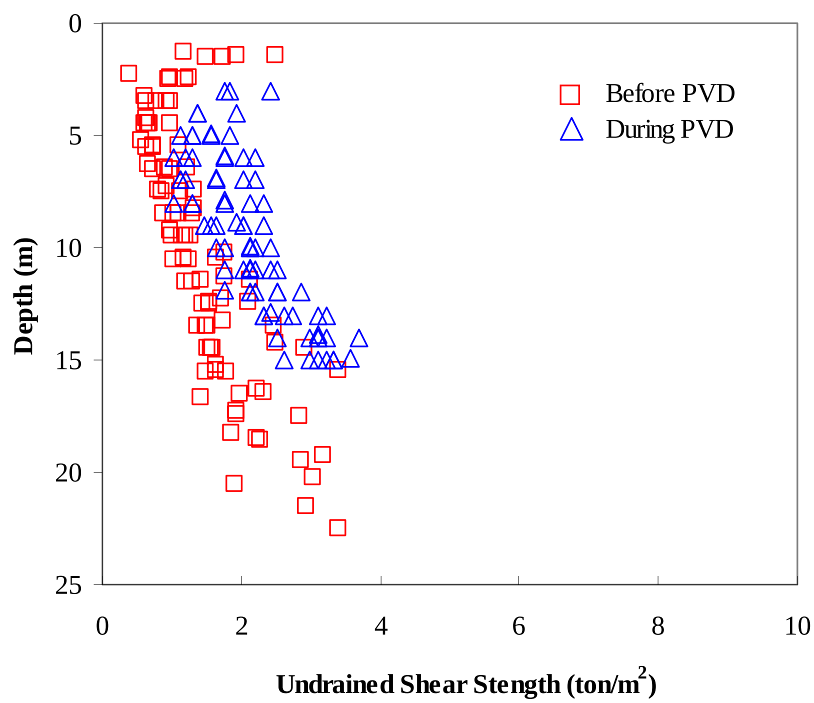

Figure 2: Undrained shear strength of the soft Bangkok clay before and during PVD (after Lin, 1999; Apimeteetamrong et al., 2007).

3 IN-SITU TEST

The Cone Penetration Test (CPT) has been one of the most widely use in-situ tests to evaluate soil profile and parameters throughout the world. The advantages of the CPT over conventional geotechnical investigations are fast and continuously soil profile. The first cone penetrometer model can measure only the tip resistance; recent development of cone penetrometer is to measure pore water pressure during cone penetrating. The porous element for pore water pressure measurement used in this study is located immediately above the cone tip. In order to perform the CPT, a conical cone, with apex angle of 60 degrees, a sleeve friction area of 150 cm^2 and cross-sectional area of 10 cm^2, is hydraulically pushed into the soil layer at the rate of 2 cm/sec; sleeve friction, tip resistance, and pore water pressure are continuously measured during advancing cone. The measurement of cone sleeve friction data makes the soil classification in terms of soil type possible (Robertson, 1990). In addition, many geotechnical engineers have proposed correlations between engineering soil properties, coefficient of consolidation, undrained shear strength and stress history, and in-situ test parameters (Baligh & Levadoux, 1986; Kulhawy & Mayne, 1990; Robertson et al., 1992; Sabatini et al., 2002; 1999; Teh & Houlsby, 1991).

The Vane Shear Test (VST) is considered to be the most reliable tool to estimate undrained shear strength (Su). To perform the vane shear test, a vane is pushed directly into a soil layer and rotated until the soil fails. The torque required to fail the soil along the vertical and horizontal edges of the vane is a relatively direct measurement of the shear strength. On this study the field vane shear tests were performed using the Geonor vane equipment. Because of vane shear time loading, a correction factor is required to evaluate the undrained shear strength. Bjerrum (1974) evaluated the undrained shear strength from case histories of embankment failures and proposed the correction factor versus plasticity index as shown in Equation 1 (as cited by Das, 2002).

$$\mu = 1.7 - 0.54\log(PI) \qquad (1)$$

where μ is the correction factor and PI is the plasticity index.

4 IN-SITU TEST RESULTS AND EVALUATIONS

4.1 *Soil Classification*

A soil classification method proposed by Robertson (1990) has been adopted on this study. CPT test results are plotted on the Robertson's chart as shown in Figure 3. Following CPT data in Figure 3, soil materials at the construction station number 25+250 and 29+400 are classified as clayey silt, silty clay or clay, which are coincided with the soil classification in laboratory.

4.2 *Stress History*

The CPT has been used to evaluate the stress history in clays. Kulhawy & Mayne (1990) intensively collected the CPT and consolidation test results. The relationship between the cone tip resistance and preconsolidation stress correlates well as shown in Figure 4. In addition, Kulhawy & Mayne (1990) notified that this correlation is not applicable to fissured clays. Before soil improvement by preloading with PVD, the soft Bangkok clay on this construction site at the depth between 3 and 12 meters from the surface is believed to be slightly overly consolidated; therefore, the preconsolidation stresses should approximately be or slightly over the overburden pressure. Two cone penetration tests were performed outside the preloaded area. With the parameter introduced by Kulhawy & Mayne (1990), the preconsolidation stresses from the cone penetration tests are overestimated. For the soft Bangkok clay in this study, this parameter should be around 0.21 and 0.24 instead of 0.29 (see Figure 5).

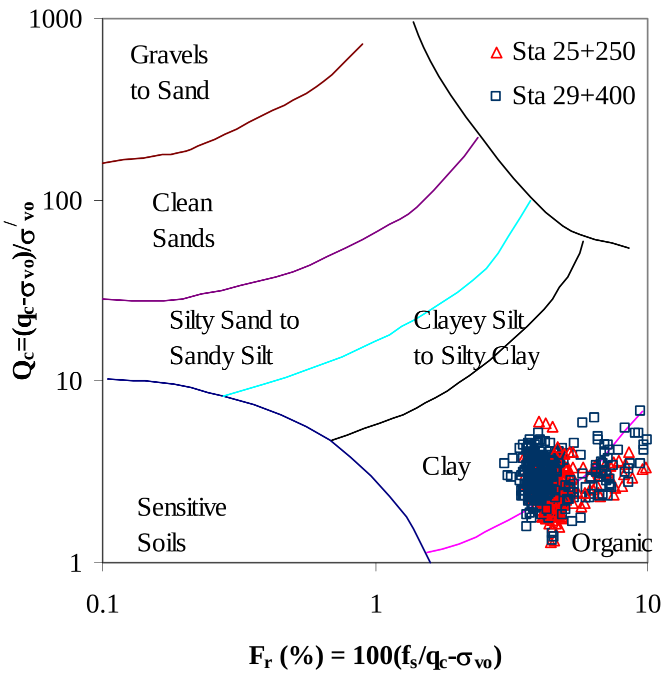

Figure 3: Soil classification by the cone penetration test (after Robertson, 1990)

4.3 *Undrained Shear Strength*

Based on the bearing capacity theory, the theoretical relationship of undrained shear strength from CPT is followed using equation 2. According to literature reviews, the N_{KT} depends on soil types and field as well as laboratory tests to determine Su, in which its value is between 7 and 20. To make the estimation of undrained shear strength from CPT simpler, the decision was made to evaluate undrained shear strength as Equation 3. On this study, undrained shear strength is estimated from vane shear tests with the Bjerrum's correction factor. The results are well correlated as shown in Figure 6; thus, the decision to omit the effect of the total overburden pressure is justified. Following in-situ test data shown in figure 6, the N_{KT} for the soft Bangkok clay is 15.6.

$$S_U = (q_t - \sigma_{VO}) / N_{KT} \tag{2}$$

$$S_U = q_t / N_{KT} - \sigma_{VO} / N_{KT} \tag{3}$$

where σ_{vo} is total overburden pressure and N_{KT} is the cone factor.

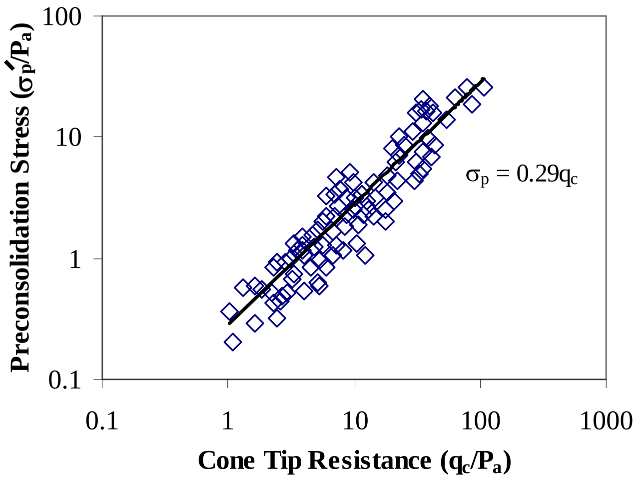

Figure 4: The relationship between cone tip resistance and preconsolidation stress (after Kulhawy & Mayne, 1990)

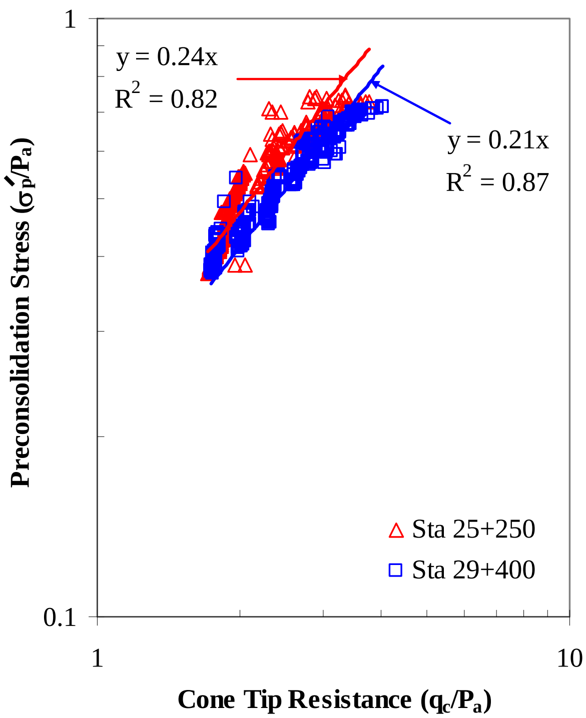

Figure 5: The relationship between cone tip resistance and preconsolidation stress at the construction stations of 25+250 and 29+400.

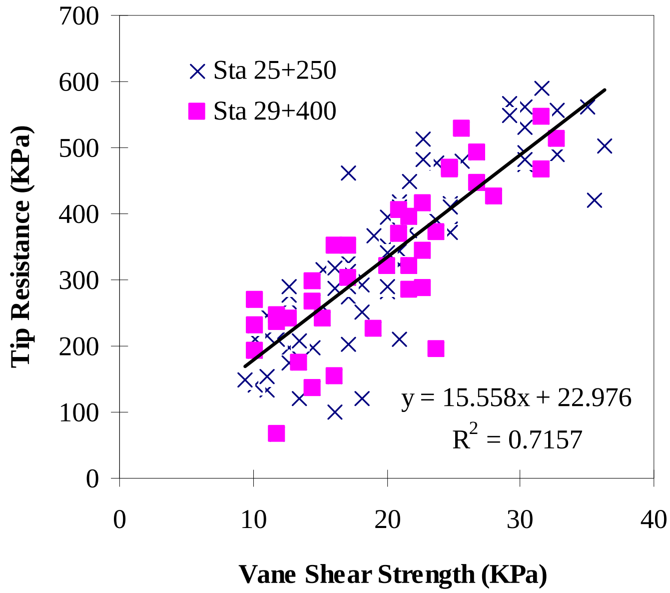

Figure 6: Undrained shear strength evaluation by the cone penetration tests at the construction stations of 25+250 and 29+400.

5 CONCLUSIONS

The correlations of basic engineering properties and cone penetration tests are presented. It is shown that the soils can be classified by using CPTu's results. For this study, the soil materials are classified as clayey silt, silty clay or clay, which are coincided with the soil classification in laboratory testing results. The relationship between cone tip resistance and preconsolidation stress from this study in founded to underestimate when compare with the previous correlation because it is site-by-site basis. The cone factor (N_{KT}) for estimating the undrained shear strength (S_u) of the soft Bangkok clay is found to be 15.6 in which tends to underestimate when compares with previous data.

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