Evaluating Undrained Shear Strength of Klang Clay from Cone Penetration Test

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ABSTRACT: The undrained shear strength (Su) of clay is generally obtained from the laboratory test on undisturbed soil sample or direct measure using the field vane shear test. As cone penetration test (CPT) has become a popular method for exploring the subsoil stratification, it will be useful for practising engineers to evaluate the Su of clay based on the CPT results if correlation between the Su and the cone resistance (qc) has been established. In this paper, the Su from vane shear tests and cone resistance, qc, of CPT tests from three sites located on Klang Clay are presented. These results are compared and correlated so as to establish an empirical relationship between the Su and qc. An empirical cone factor (Nk) in the range of 5 to 12 is obtained. This Nk value can be used to evaluate the Su of Klang Clay. The obtained Nk values are compared with Nk values of other known soft clays. It was found that in general the Nk value of Klang clay is at the lower boundary of the published Nk vlaues.

1 INTRODUCTION

In the past day when the static cone penetration test (CPT) has not gained acceptance to many countries, the undrained shear strength (Su) of soft clay is generally obtained from the results of laboratory test on undisturbed soil samples or results of field vane shear test. As CPT has proved its valuable for soil profiling, effectiveness in both time and cost as compare with conventional exploratory holes, the use of CPT has increased. As more and more results of CPT are available, many attempts have been performed to evaluate the Su of clay from the results of CPT. These attempts including theoretical methods such as bearing capacity solution (Terzaghi, 1943, Meyerhof, 1951), cavity expansion approach (Ladanyi, 1963, Vesic, 1972), strain path approach (Baligh, 1985), and empirical correlation approach. All the theories have the following relationship between the Su and the cone penetration resistance, qc:

$$qc = Nk \bullet Su + \sigma$$

where Nk is cone factor and σ is overburden pressure.

The findings by Lunne et al., (1976) from five sites in Scandinavia show that the Nk values are in the range of 15 to 19 for marine clay and 11 to 13 for soft clay. Schmertmann (1975), Lunne and Eide

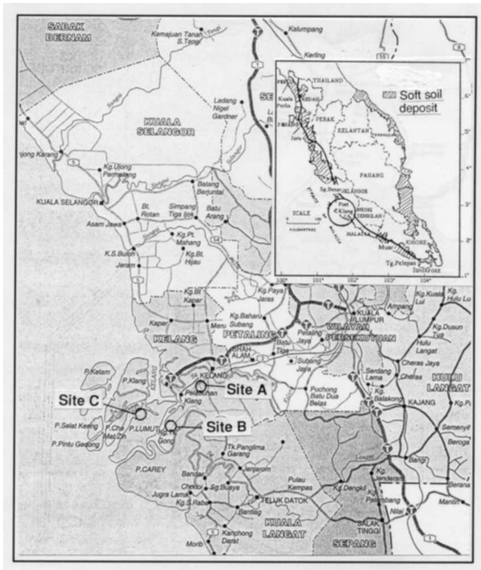

Figure 1. Locations of test sites

(1978) also recommended that the Nk value for various type of soil should be correlated locally.

This paper attempts to correlate the undrained shear strength of Klang clay from field vane shear test to the qc of CPT test and establish an empirical relationship.

Results of both vane shear tests and CPT tests from three sites located on the Klang clay deposit as shown in Figure 1 are presented. The equipment used and the physical properties of Klang clay at the three site will also be presented.

2 DESCRIPTION OF EQUIPMENT USED

2.1 *Vane Shear Test Apparatus*

Geonor Vane apparatus were used in all the three sites. After the blades of the vane were pushed to the level where the soil strength was to be determined, the vane was then rotated in a rate of about 0.1°/sec and the corresponding torque was measured. The Su of soil was calculated from the maximum torque and the dimension of blades used.

2.2 *Cone Penetration Test Apparatus*

The cone penetrometer used for the three sites has a 10 cm^2 base area cone with an apex angle of 60 degree. Above the cone there is a 13.4cm long straight cylindrical shaft having the same diameter as the cone. The cone has transducers to measure cone resistance, local friction and water pressure. The jacking unit was a 100kN twin cylinder hydraulic ram. All these jack, data acquisition equipment and necessary accessories are mounted on a self propelled crawler chassis. The total weight of the unit is about 25kN. Before conducting the test, 4 numbers of screw anchors will be installed to provide reaction to the apply thrust in order to advance the penetrometer. The penetration rate will be maintained at 20mm/sec and the measured data will be recorded every 25mm.

3 DESCRIPTION OF SUBSOIL AND RESULTS OF TESTS

3.1 *Site A*

Site A as shown in Figure 1 is generally a flat ground approximately 2km away from the coast with very soft clay at the top 20m. The Standard Penetration Test Results (SPT) in this very soft clay is equal to or less than 1. Disturbed samples were obtained after the SPT tests. Undisturbed samples were also obtained at designated depth. The Plasticity Indices (PI) of this soft clay at varies depths are as shown in Figure 2 which is in the range of about 25%to 50%. The average of bulk density is about 14 kN/m3 as shown in Figure 2.

Four numbers of field vane shear tests were carried out inside the boreholes at 1m to 1.5m intervals. The direct measured Su shows a increasing trend with depth as shown in Figure 2. In general, the Su of soft clay is about 8 kPa to 10 kPa at 2m below the ground surface and increases to about 40 to 70 kPa at 18m depth.

The results of CPT carried out are also shown in Figure 2. A similar trend of increasing in soil strength (qc value) with depth is also observed.

Nk values were computed based on the average Su and qc values. The computed results are as shown in Figure 2. Wide range of Nk value was obtained within the top 5m. However, the Nk values become more consistent, in the range of 7 to 12, as the depth increases.

3.2 *Site B*

Site B is located near to the coastal area as shown in Figure 1. The subsoil condition is as shown in Figure 3. In general, about 2m thick silty fine sand layer can be encountered near the ground surface. Underneath this sand layer is a approximately 2m thick clayey silt with sand and followed by thick layer of silty clay. At about 11m below the ground surface, sand layers could be encountered. The PI of the silty clay layer is in the range of 70% to 90% as shown in

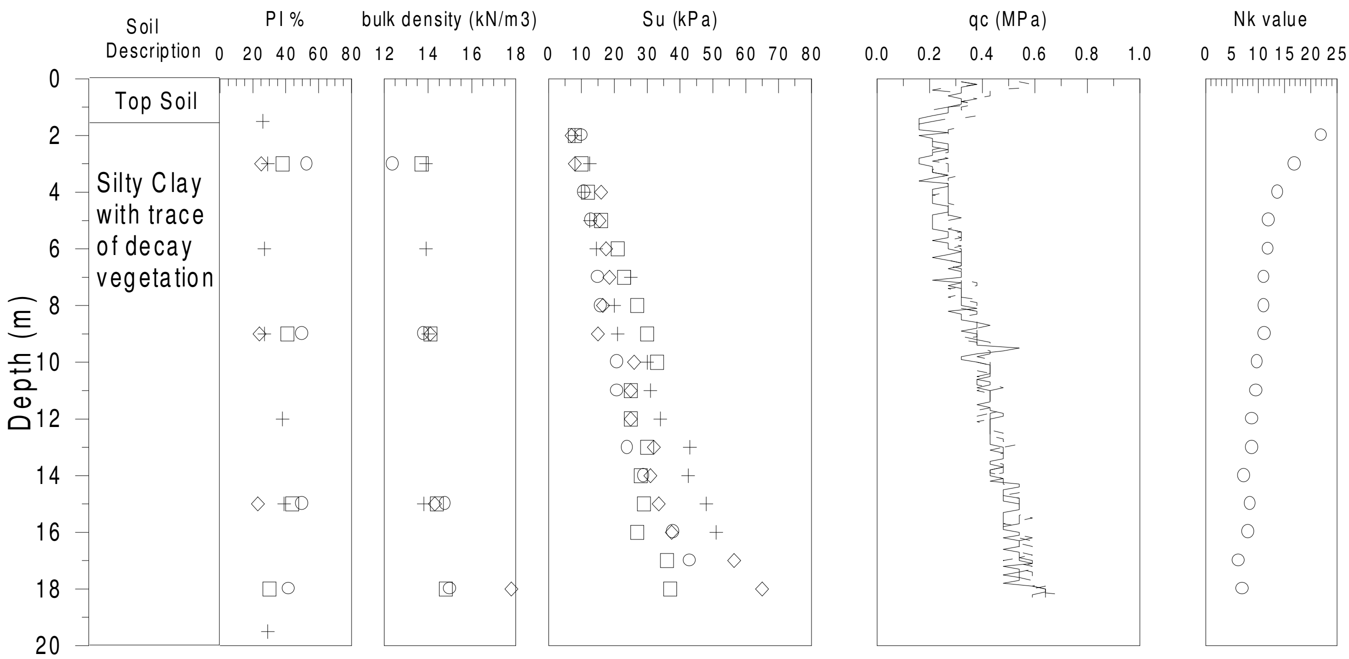

Figure 2. Soil properties, test results and Nk values of Site A

Figure 3. Average bulk density is about 14.5 kN/m3.

The results of vane shear tests are as shown in Figure 3. An increase in Su values with depth is observed. The Su results at the same depth are quite consistent except when there are existence of sand layers.

Results of CPTs as shown in Figure 3 clearly demonstrate its value for soil profiling especially when there are existence of sand layers. The qc values also show the increasing trend as observed from the vane shear tests.

The calculated Nk values at various depths are also shown in Figure 3. Except at locations where sandy layer may be encountered, the Nk values are generally in the range of 6 to 10 which is similar to that from Site A.

3.3 *Site C*

Location of Site C is as shown in Figure 1 which is also at the coastal area. The subsoil condition is as shown in Figure 4. In general, there is a 1m thick top soil mainly consists of sandy silt. Underlying is a thick layer of silty clay with localised silty sand layer could be found between 3 to 6m below the ground surface. Below this silty clay layer, sandy silt or silty sand layer could be encountered. The PI of the silty clay layer is shown in Figure 4. Except at depths where localised sand layer could be found, the PI values are in the range of 40% to 60%. Average bulk density is about 16 kN/m3.

The Su as obtained from vane shear test are as shown in Figure 4. Apparently the soil strength remains constant at the top 4m and begins to show an increasing trend like the other sites after 4m below ground surface.

Results of CPT are presented in Figure 4. Localised sand layers were found within 3m to 6m below ground surface.

The computed Nk values are in the range of 5 to 9 as shown in Figure 4.

3.4 *Summary of Test Results*

Table 1 summarizes the results of vane shear tests and CPT tests from the three sites.

Table 1. Summary of test results

Site	Depth (m)	PI %	Su kPa	Nk
A	5-18	25-50	10-70	7-12
B	4-18	70-90	10-70	6-10
C	1-13	40-60	7-50	5-9

4 COMPARISON OF DERIVED CONE FACTORS WITH PUBLISHED VALUES

The derived empirical cone factors, Nk, from the three sites indicate that the Nk for the Klang clay is in the range of 5 to 12 or average of about 8. The plasticity indices of the Klang clay from these three sites are in the range of 25 to 90.

A comparison of Nk value of Klang clay with other known Nk values for various types of soft clay is as shown in Figure 5. By superimposed the Nk of Klang clay into Figure 5 abstracted from Lunne and Kleven (1981), it is clear that the Nk of Klang clay is generally at the lower bound of published Nk values.

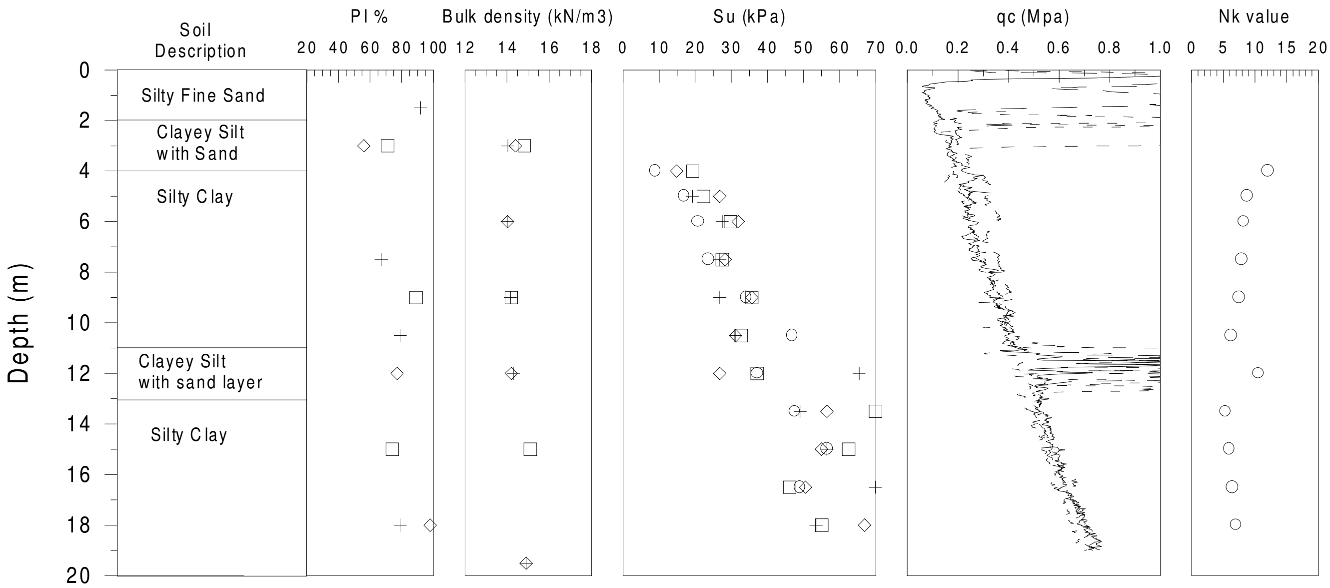

Figure 3. Soil properties, test results and Nk values of Site B

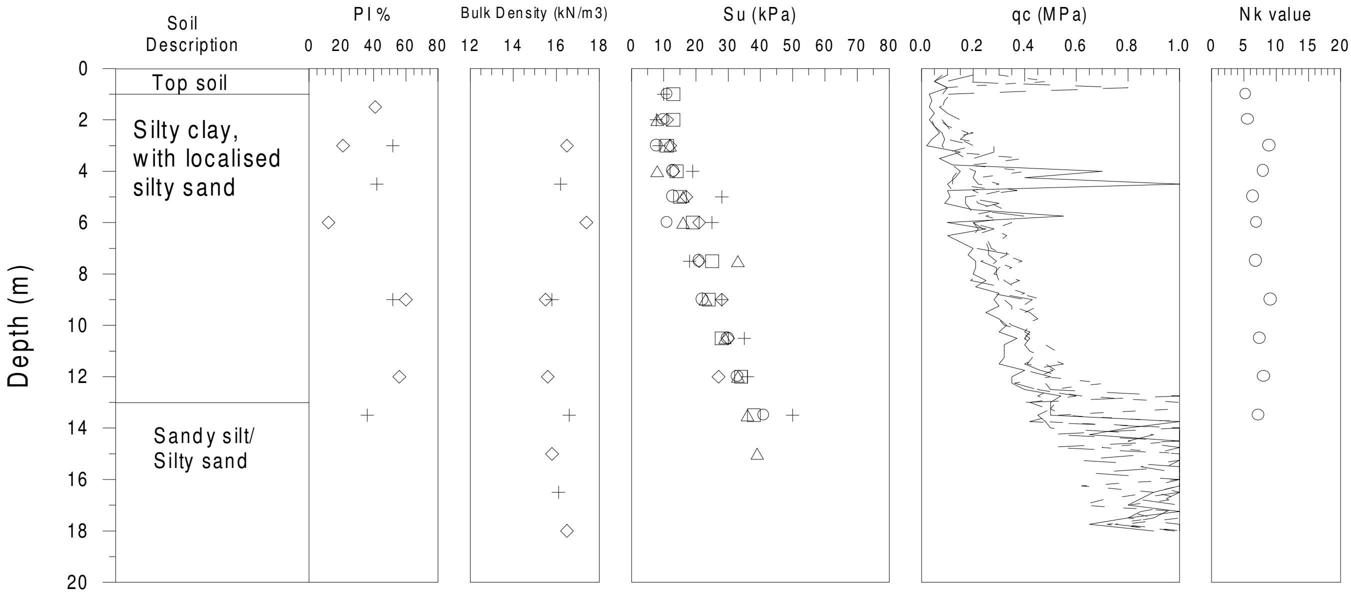

Figure 4. Soil properties, test results and Nk values of Site C

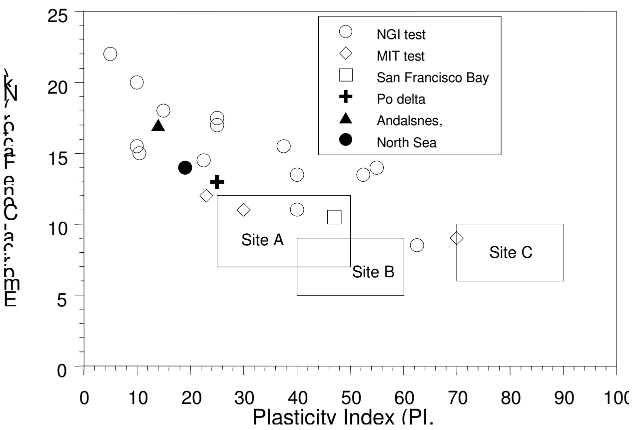

Figure 5. Comparison of obtained Nk values

5 CONCLUSIONS

An attempt has been performed to correlate the cone resistance, qc, from cone penetration test to the undrained shear strength, Su, of Klang clay obtained from field vane shear test. These tests have been carried out in three sites. An empirical cone factor, Nk, was derived from the correlation and the values are in the range of 5 to 12 or average of 8. From this exercise, it is suggested that a Nk of 8 can be used for the evaluation of undrained shear strength of Klang clay from cone penetration test.

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