# SOME GEOTECHNICAL PROPERTIES OF KLANG CLAY

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**ABSTRACT**

A series of subsurface investigation including in-situ and laboratory tests has been carefully planned and carried out for the residential and commercial development over soft Marine Clay at Bukit Tinggi, Klang, Malaysia. The approach taken in characterizing and developing a fundamental understanding of the Klang Clay is described in this paper. Some important correlations have been established for key engineering properties from good quality field and laboratory data including correlations between physical soil properties with undrained shear strength from field vane ($s_{uf}$) and laboratory consolidation tests. In addition, correlations involving the piezocone tests have also been systematically derived from high quality field data and presented in this paper.

**Keywords:** Clay; Consolidation; Shear Strength; Piezocone; Correlation

## 1. INTRODUCTION

The measurement and selection of soil parameters for geotechnical design is very important. Poorly determined parameters can have significant safety and economical consequences for a project with difficult subsoil condition. An approach in characterising and developing a fundamental understanding of the properties of soft alluvial clay had been carried out in Klang area, which underwent rapid development in the recent few years.

A residential and commercial development was carefully planned at a site of about 1200 acres at Bukit Tinggi, Klang, which is about 40km towards south west of Kuala Lumpur as shown in Figure 1. This development was constructed over soft silty clay, termed as Klang Clay in this paper. In particular, some important correlations have been established for key engineering properties namely undrained shear strength and compressibility parameters of Klang Clay. In addition, correlations involving the piezocone were also systematically derived from high quality field data. The major field and laboratory tests reported in this paper include 29 boreholes, 8 piezocone (CPTU), 1260 field vane shear tests, 70 oedometer tests and etc.

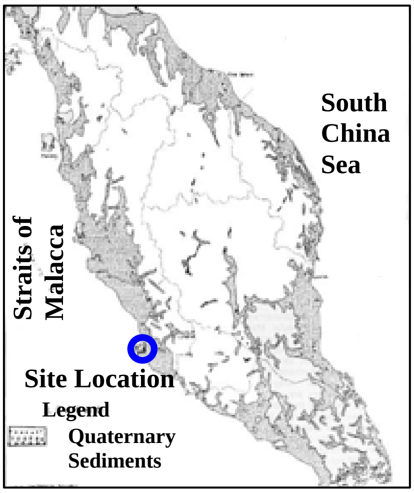


Figure 1 – Location of the Site.

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## 2. GEOLOGICAL FORMATION

The proposed site is located at the contact boundary of Quarternary Alluvium and Kenny Hill Formation as shown in Figure 2. The alluvial deposits are overlying the Kenny Hill Formation of weathered metasedimentary rock type.

The alluvial deposits generally consist of very soft to firm silty Clay up to a depth of 25m to 30m with presence of intermediate sandy layers. Beneath the silty Clay stratum generally consists of silty Sand. Residual soils (Grade VI) and completely weathered materials (Grade V) derived from the weathering of Quartzite were only encountered at depth of about 40m. The presence of quartzite rock-type was further confirmed from the observation of rock outcrop located about 2km from the site.

The behaviour of soft alluvial soils is influenced by the source of the parent material, depositional processes, erosion, redeposition, consolidation and fluctuations in groundwater levels. Alluvial soils in Klang area usually show pronounced stratification and sometimes organic matter, seashell and decayed wood are present in these deposits.

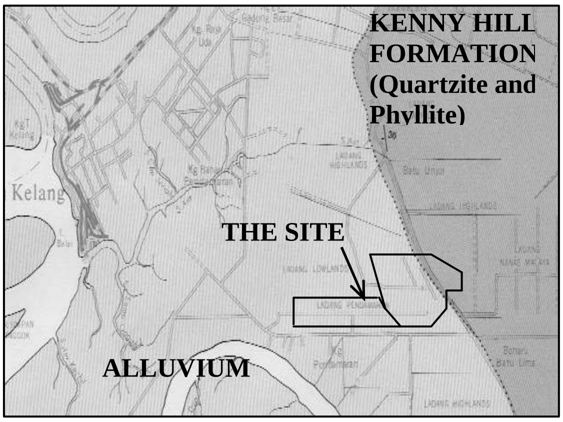


Figure 2 – Geological map of the Site (after Geological Survey Department, 1976)

## 3. GEOTECHNICAL PROPERTIES OF KLANG CLAY

### 3.1 Index Properties

In many circumstances, preliminary or conceptual design decisions have to be based on inadequate subsoil data particularly during the very initial stage of project development. A thorough study has been carried out to compile numerous geotechnical data in order to establish correlations between some important engineering parameters with the simple Atterberg Limits.

The values of bulk unit weights and Atterberg Limits of Klang Clay are shown in Figure 3. As observed from Figure 3, the subsoil is generally soft, inorganic, possess medium to extremely high plasticity, compressible with high Liquidity Index. The material can also be divided into two distinct layers at depth of 15m namely upper Klang Clay and lower Klang Clay.

### 3.2 Compressibility Properties

There are two main geotechnical problems in soft clay engineering, namely settlement and stability. However, many practising engineers tend to forget about the importance of settlement problem. Therefore, more effort should be emphasized in the interpretation of compressibility parameters for settlement analysis.

Some of the compressibility parameters of Klang Clay are presented in Figure 4 and these parameters always play a vital role in the settlement analyses. Many research works have been carried out in order to have more understanding on these parameters. However, the reported literature of different region has given the different solutions. Hence, the authors will discuss the compression index of Klang Clay of Malaysia with some empirical correlations in the following section.

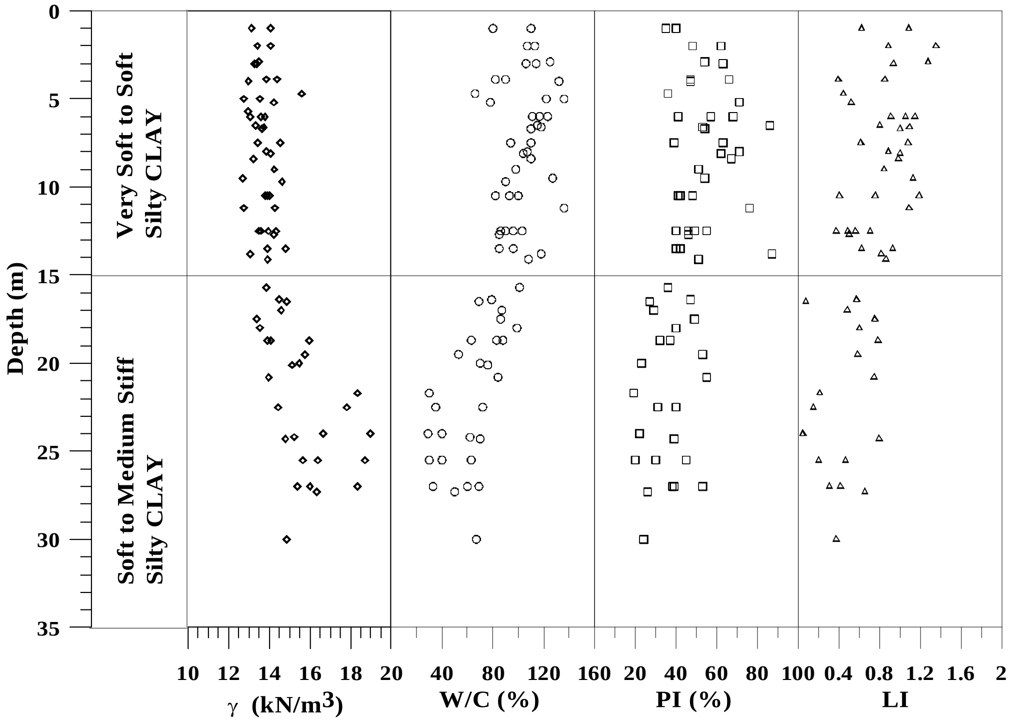


Figure 3 – Basic Soil Properties

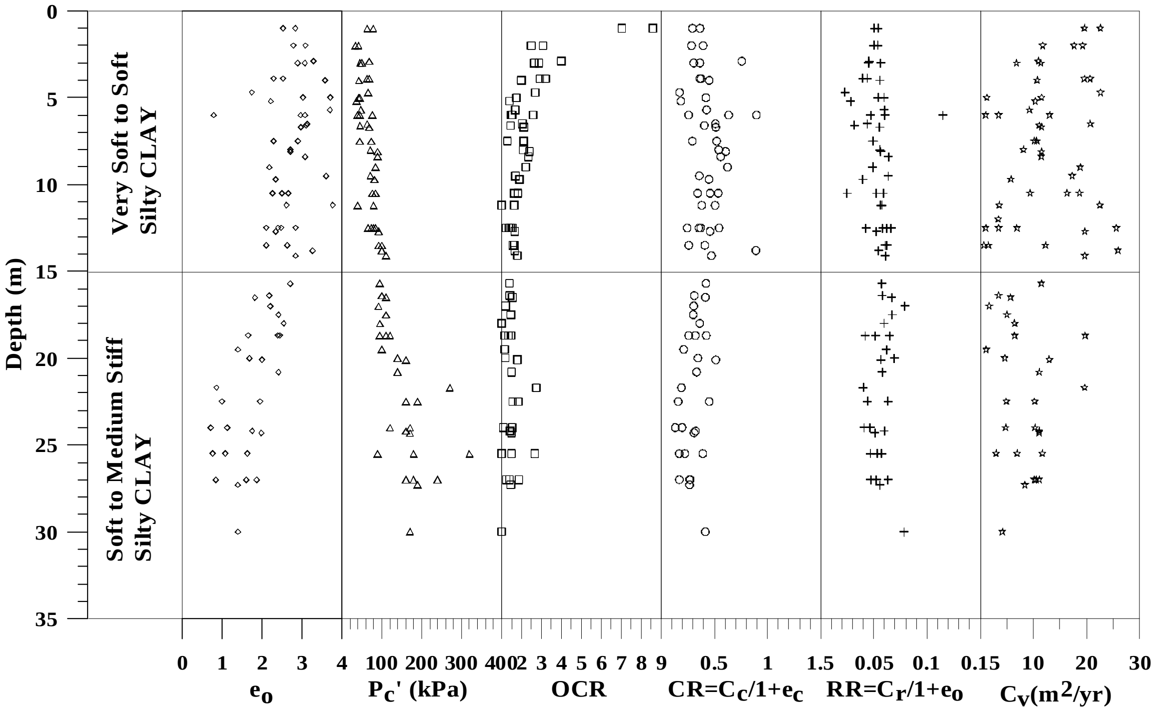


Figure 4 – Compressibility Parameters for Klang Clay

Compression index, $C_c$ is the slope of the linear portion of the e – log σ′ plot and is dimensionless. Many attempts also have been carried out to correlate $C_c$ with the basic index properties of soil, especially with the liquid limit, LL. Figure 5 shows the relationship between the compression index of Klang Clay and its liquid limit and the equation is as below:-

$$C_c = 0.02LL - 0.87 \qquad (1)$$

As compression index, $C_c$ is influenced by the sensitivity of natural clays, it can generally be related to void ratio and sensitivity (Leroueil et al., 1983). Figure 6 shows the relationship between $C_c$ and natural void ratio, $e_o$ by equation below:-

$$C_c = 0.61e_o - 0.17 \qquad (2)$$

In additional to this, Figure 7 shows the relationship between $C_c$ and natural water content, $w_n$ and represented by the equation below:-

$$C_c = 0.02\, w_n - 0.37 \qquad (3)$$

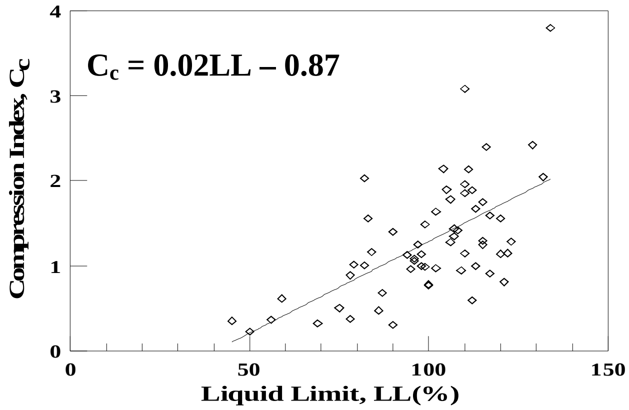


Figure 5 – Relationship between $C_c$ and liquid limit of Klang Clay

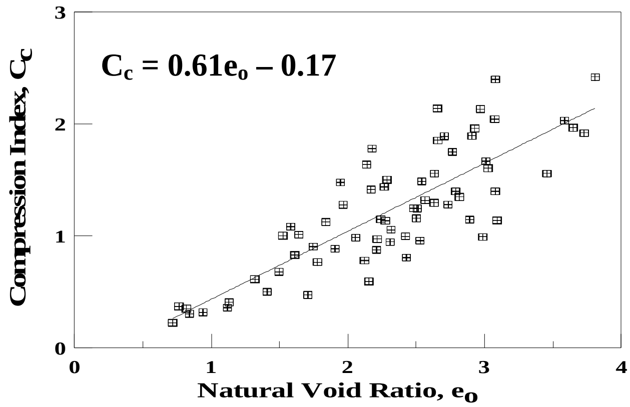


Figure 6 – Relationship between $C_c$ and natural void ratio of Klang Clay

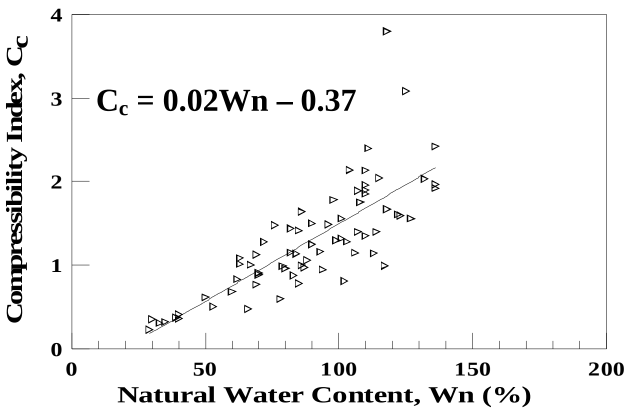


Figure 7 – Relationship between $C_c$ and natural water content, $w_n$ of Klang Clay

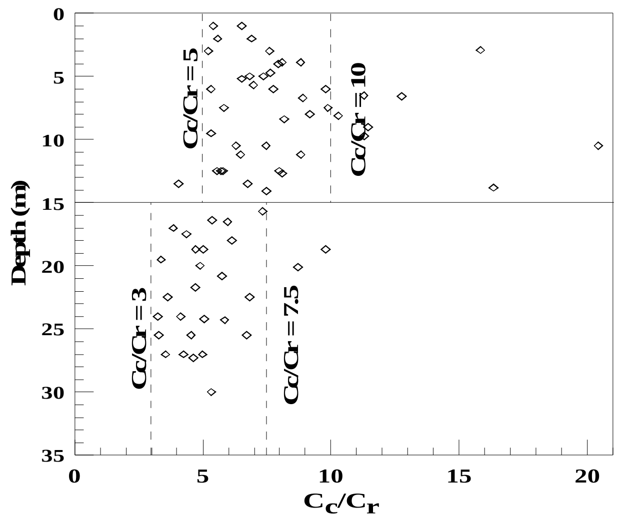


Figure 8 – Ratio $C_c$ and $C_r$ of Klang Clay.

The recompression index, $C_r$ is also an important parameter for soft compressible ground settlement analysis. $C_r$ is defined in the same way as $C_c$ except that it applies to the unloading-reloading phase of the oedometer test. Figure 8 shows that the ratio of $C_c/C_r$ of Klang Clay is in the range of 5 to 10 for the first 15m and ranges from 3 to 7.5 for the subsequent depth with evidence of two distinct layers.

### 3.3 Undrained Shear Strength

Undrained shear strength is a soil parameter essential for the analysis of embankment stability (total stress) and bearing capacity of foundation in saturated clay. Shear strength of soil can be measured directly or indirectly with different apparatus, including laboratory and in-situ tests. The results of laboratory tests are usually subjected to uncertainties primarily due to the inevitable sample disturbance particularly for very soft to soft clay. In this paper, only the undrained shear strength, $s_u$ obtained from in-situ strength tests such as field vane (FV) and piezocones will be discussed. Figure 9 shows the undrained shear strength (undisturbed field vane) of Klang Clay increases almost linearly with depth after the overconsolidated top crust. The penetration field vane shear test results show that the sensitivity of Klang Clay ranges from 2 to 5.

Empirical correlations are commonly used to interpret undrained shear strength from the piezocone results as the theoretical solutions (e.g. classical bearing capacity theory etc.) have limitations in modeling the real soil behaviour under conditions of varying stress history, anisotropy, sensitivity ageing and macrofabric. The commonly used empirical correlations for undrained shear strength are presented in this paper. Figures 10 to 12 show the correlations obtained from the interpretation of the piezocone results and the correlation factors for different type of empirical approaches are tabulated in Table 1. The undrained shear strength values, $s_{u(fv)}$ used in the correlations were obtained from the field penetration vane shear tests before Bjerrum's correction factor to represent the peak strength.

Table 1: Correlation factor to determine $s_{u(fv)}$ from piezocone

| Empirical Approaches | Empirical Equation | Obtained Correlation Factor |
|---|---|---|
| Total cone resistance | $s_{u(fv)} = \dfrac{q_t - u_2}{N_{ke}}$  $s_{u(fv)} = \dfrac{q_t - \sigma_{vo}}{N_{kt}}$ | $N_k$= 5 to 15 , $N_{kt}$ =10 to 20 |
| Effective cone resistance | $s_{u(fv)} = \dfrac{q_c - \sigma_{vo}}{N_k}$ | $N_{ke}$ = 5 to 11 |

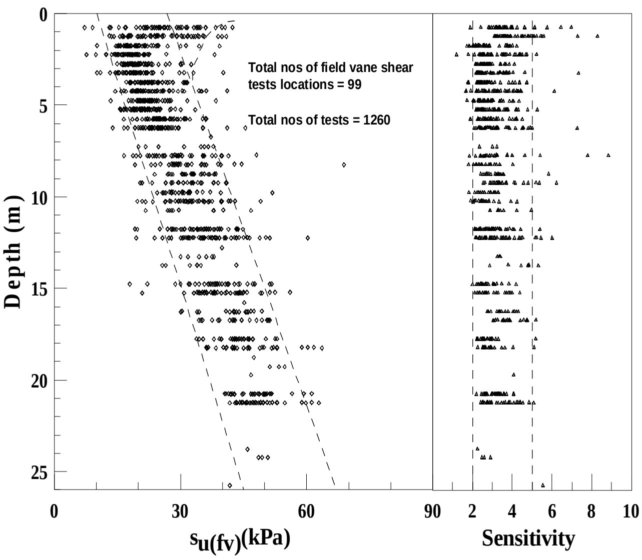


Figure 9 – Undrained Shear Strength and Sensitivity of Klang Clay

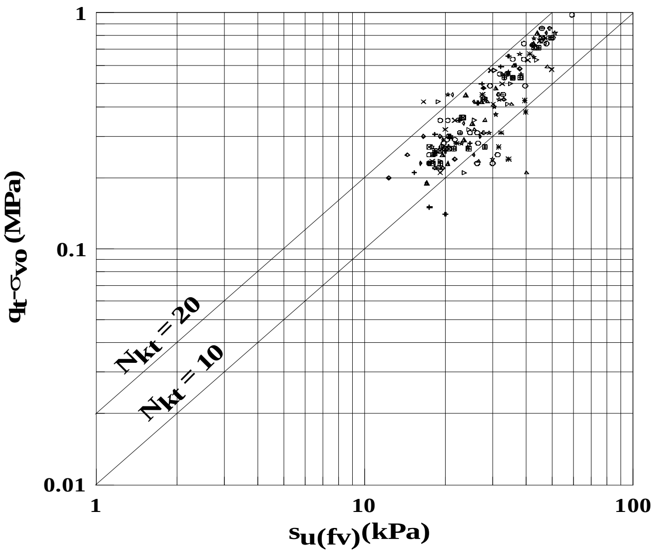


Figure 10 – Relationship Between Corrected Total Cone Resistance And Uncorrected Field Vane Shear Strength

In general, corrected total cone resistance ($q_t$) is the most frequent used empirical approach to estimate the undrained shear strength of saturated clay. Gue and Tan (2000) recommend using $N_{kt}$ value of 15 to estimate a lower bound for the undrained shear strength at new site. The test results indicate that it is reasonable to use average value of $N_{kt}$ = 15 to estimate the undrained shear strength for Klang Clay.

Normalized undrained shear strength with the preconsolidation pressure, $P_c'$ is an important index to evaluate the undrained shear strength of saturated clay. Figure 13 shows the $s_{u(fv)}/P_c'$ ratio of Klang Clay is relatively high with ratio of $s_{u(fv)}/P_c'$ = 0.4 compared to other type of clays in Southeast Asia that ranges from 0.19 – 0.33 (Tanaka et al. 2000). In addition, Figure 14 shows that the $s_u/P_c'$ ratio is independent of the plasticity index.

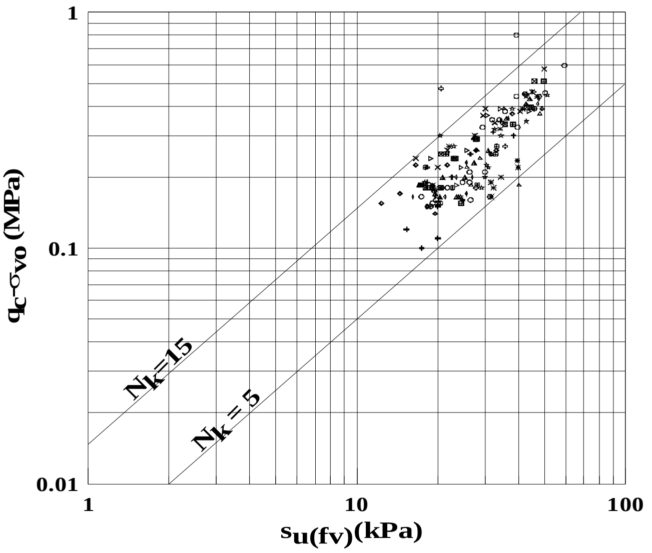


Figure 11 – Relationship Between Uncorrected Total Cone Resistance And Uncorrected Field Vane Shear Strength

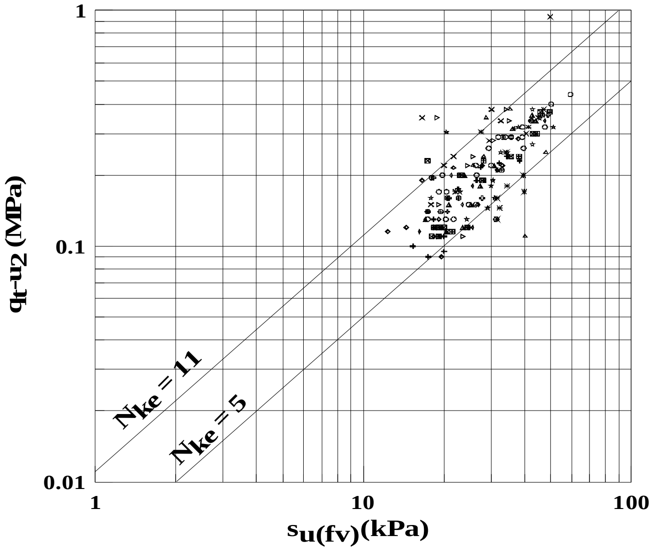


Figure 12 – Relationship Between Effective Cone Resistance And Uncorrected Field Vane Shear Strength

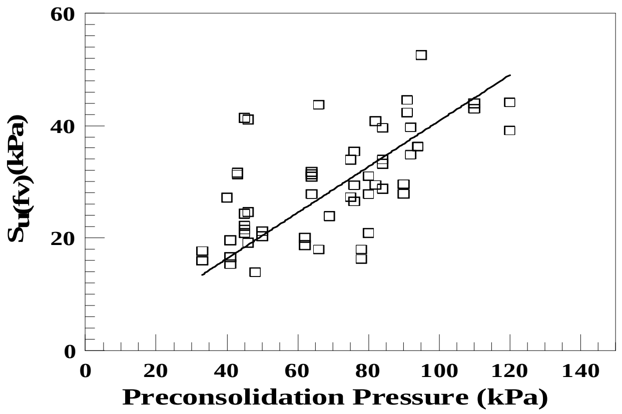


Figure 13 – $s_{u(fv)}/P_c'$ ratio of Klang Clay.

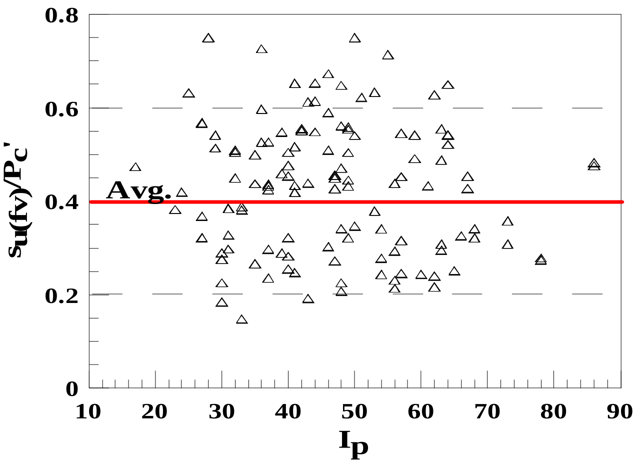


Figure 14 – $s_{u(fv)}/P_c'$ ratio Klang Clay is independent on its Plasticity Index

### 3.4 Overconsolidation Ratio (OCR)

In ground settlement analysis, one of the important parameters for geotechnical design over soft clay is overconsolidation ratio (OCR). Underestimating OCR will cause overestimation of consolidation settlement magnitude and thus lead to expensive and time-consuming geotechnical solutions. Hence, it is extremely useful if reliable correlations on OCR can be obtained from piezocone data.

Many attempts have been carried out to estimate OCR from piezocone data. OCR of soft marine clay can be estimated with the following simple formula:

$$OCR = k\,\frac{q_t - \sigma_{vo}}{\sigma_{vo}'} \qquad (4)$$

Figure 15 shows that an average value of $k$=0.23 can be used to estimate the OCR value of Klang Clay and the estimated values indicate good agreement with the oedometer tests results as shown in Figure 16.

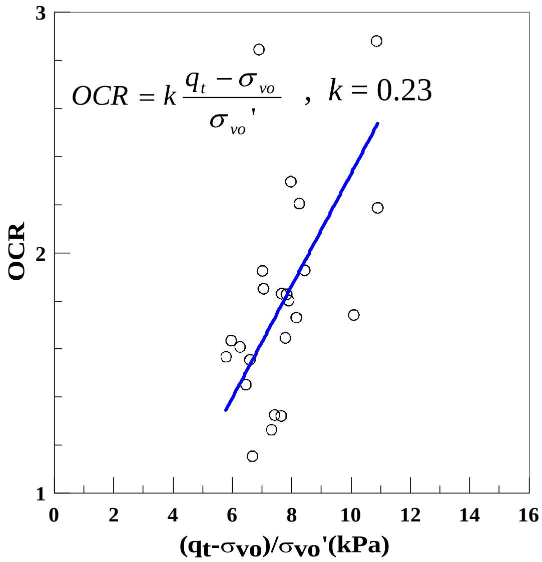


Figure 15 – Relationship Between OCR and Piezocone Data

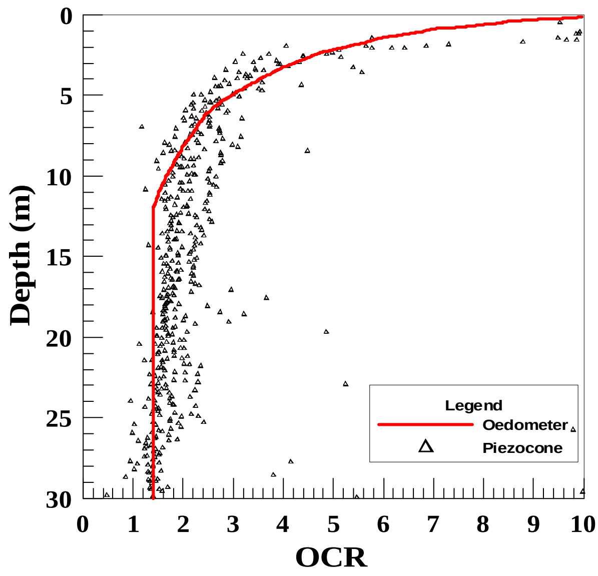


Figure 16 – Estimated Value of OCR from Piezocone Data

## 4. DISCUSSION AND CONCLUSIONS

Klang Clay can be divided into two distinct layers at depth of 15m. A series of correlation of compressibility index of Klang Clay was presented in the paper. The results show compressibility index can be correlated well with the liquid limit, natural void ratio and natural water content. The ratio of $C_c/C_r$ of Klang Clay is in the range of 5 to 10 for the first 15m and ranges from 3 to 7.5 for the subsequent depth with evidence of two distinct layers.

The undrained shear strength of Klang Clay increases almost linearly with depth and shows relatively high value for the first 3m with the existence of overconsolidated crust. The correlation between undrained shear strength and parameters from piezocone show an acceptable scatter. Generally, it is reasonable to use average correlation factor of $N_{kt}$ = 15 to estimate the undrained shear strength for Klang Clay. The $s_{u(fv)}/P_c'$ ratio of Klang Clay is about 0.4 and it is also clearly independent of plasticity index. In addition, an average value of *k*=0.23 can be use to estimate the OCR value of Klang Clay from the piezocone data.

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