PREDICTING THE HYDRAULIC CONDUCTIVITY OF MAKASSAR MARINE CLAY USING FIELD PENETRATION TEST (CPTU) RESULTS

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Recently, the Cone Penetration testing (CPT) is a rapid method for determining the mechanical and transport properties of soils. The CPT provides continuous profiles of soil characteristics that are reliable, fast, and economical. Moreover, the estimation of the hydraulic conductivity from the CPT is traditionally made from the pore pressure dissipation test data. The Hydraulic conductivity for clay soil is primarily determined by the laboratory test. The main objective of this research is to develop correlation between CPTu (field-laboratory) test data and hydraulic conductivity, and the determination of the hydraulic conductivity that can overcome the drawbacks of the conventional dissipation test method. The method proposed here is based on the analysis of the steady-state pore pressure during the piezocone penetration test, so that the full interaction between the piezocone and the soil is considered. The study area was located in the coastal area of Makassar city, Indonesia. The results indicate that the cone resistance as well as the sleeve friction exhibits a very good linear relationship with the hydraulic conductivity value of marine clay. Furthermore, the exponential relationship was found between the friction ratio and pore water pressure. The relationship between the cone resistance and hydraulic conductivity was also found to be exponential. However, the dissipation of pore water pressure shown linear relationship. Finally, The comparison between results obtained this study shown that a good correlation obtained in order to predict the hydraulic conductivity based on the CPTu results and indicated that there is some potential of using this correlation value in engineering practice.

1. Introduction

A variety of penetrometer test developed for both geotechnical and geoenvironmental investigation. The most popular logging test for geotechnical
investigations in soil is the Cone Penetration Test (CPT). The CPT is rapid, repeatable, reliable and cost effective.

The CPT is widely known as an important in situ test for the characterization of soil where penetration is possible to conduct. The CPT provides continuous profiles of soil type and detailed stratigraphy. In the Cone Penetration Test with the measuring of pore liquid pressure (CPTU), improved stratigraphic detail can be obtained as well as important additional information on equilibrium groundwater conditions, consolidation and hydraulic conductivity. However, the CPT cannot identify the chemical composition of contaminants (Lunne et al. 2001).

Based on a simplified elastic solution, Vreughdenhil et al. (1994) provided some insight as to how to correct cone data for thin layer. The result shows that the error in the measured cone resistance within thin stiff layers is a function of the thickness of the layer as well as the stiffness of the layer relative to that of the surrounding soil. Rate of penetration effects can be caused to some extent by creep and particle crushing. In general, however, the pore pressure effects predominate and are most interest, especially when using the piezocone in fine grained soil. Normally a tenfold increase in rate causes 10-20% increase in cone resistance in stiff clays and 5-10% in soft clays (Powell and Quarteman, 1988).

For cone penetration into stiff, high OCR, fine grained soil, the measured \( q_c \) is generally large. The pore pressure measured on the cone (\( u_1 \)) generally large, but problems with filter compression can be encountered and pore pressures may be unreliable (Battaglio et al. 1986). Hence, the preferred measurement for use in interpretation in stiff, high OCR, fine-grained soil is the measured cone resistance, \( q_c \). From the above observation it is clear that there is no single location for pressure measurements that meets all requirements for all soil types. Hence, the preference is to record pore pressure at two or more locations simultaneously (to give \( u_1 \), \( u_2 \), and so on).

During the piezocone penetration from surface, the soil adjacent to the piezocone undergoes experience a large deformations with very high strains (>100%) (Kiousis et al. 1988; Abu-farsakh et al. 1998). Analysis of the cone penetration is quite difficult due to it involves large deformation and high nonlinear material and interface behavior. To accurately analyze the CPT, it is necessary to have a numerical method that takes into consideration the large deformation of the soil. Abu-Farsakh et al. (2003) reported that the values obtained from numerical method are in good agreement with the measured values. The shape of the dissipation curve is mainly dominated by the value of the horizontal hydraulic conductivity.

Moreover, the purpose of this study is to predict and develop correlation between CPTu (field-laboratory) test data and the determination of the hydraulic conductivity that can overcome the drawbacks of the conventional dissipation test method.
2. Location and Methods

Field investigation was conducted in the coastal region of Makassar city, South Sulawesi Province, Indonesia (119° 24’ 24.76” S and 5° 08’ 58.48” E) as shown in Figure 1.

The CPTu was conducted according to the ASTM D-5778-95 and measure the mechanical response of the ground or material to the penetration process through cone penetration resistance \( q_u \), sleeve friction \( f_s \) and the pore liquid pressure \( u \). In the piezocone, penetrometer, pore pressure is measured typically at one, two or three locations as shown in Figure 2. These pore pressures are known as: on the cone \( (u_1) \), behind the cone \( (u_2) \) and behind the friction sleeve \( (u_3) \). The measurement of equilibrium pore pressures can be an important part of an investigation to evaluate the direction of ground water flow and vertical pressure head distribution and hence the hydrogeologic regime.

The device is pushed into the ground at a rate of 2 cm/s. At the required depth, cone penetration is stopped and a pressuremeter test is performed. A cone penetrometer with a 10 cm² base area cone with an apex angle of 60 degrees is attached into device.
Baligh and Levadoux (1980) recommended that the horizontal coefficient of permeability can be estimated from the expression:

\[ k_h = \frac{\gamma_c \times RR \times c_s}{2.3 \times \sigma'_{vo}} \]  

(1)

where \( RR \) is the compression ratio in the overconsolidated range. It represents the strain per log cycle of effective stress during recompression and can be determined from laboratory consolidation test (\( 0.5 \times 10^{-2} < RR < 2 \times 10^{-2} \) was recommended by Baligh and Levadoux).

3. Results and Discussion

The location of CPTu was distributed on the 3 locations namely CPTu-01, CPTu-02 and CPTu-03. For CPTu-01, the depth of hard soil (\( q_c > 15 \) MPa) was found at 18.4m below the ground level. The pore pressure was read at the depth of 1.4m from surface which indicates the water level. The dissipation test was conducted up to 13.9m below the ground level. Moreover, the calculation of the hydraulic conductivity at each depth can be obtained by using eq.(1) as shown in Figure 3.

For CPTu-02, the depth of hard soil (\( q_c > 15 \) MPa) was found at 18.8m below the ground level. The pore pressure was read at the beginning of measurement which indicates the water level near the surface. The dissipation
test was conducted up to 16.7m below the ground level. The calculation of the hydraulic conductivity at each depth can be obtained by using eq.(1) as shown in Figure 4.

Figure 4. CPTu profile and hydraulic conductivity value at CPTu-02

Figure 5. CPTu profile and hydraulic conductivity value at CPTu-03
For CPTu-03, the depth of hard soil (qc > 15 MPa) was found at 19.3m below the ground level. The pore pressure was read at the depth of 1.4m from surface which indicates the water level. The dissipation test was conducted up to 16.8m below the ground level. The calculation of the hydraulic conductivity at each depth can be obtained by using eq.(1) as shown in Figure 5.

Moreover, at the early stages of dissipation, the excess pore pressure behind the cone base tends to increase slightly before initiation of dissipation stage as shown in Figure 6-8. This phenomenon is mainly due to the redistribution of pore pressure around the piezocone, immediately after penetration stops, resulting from the presence of high pore pressure gradient around the cone base (Abu-Farsakh et al. 2003). In heavily overconsolidated clay, in which a negative pore pressure can be generated near the cone base there is a possibility that the pore pressure increases initially to positive territories before it starts to dissipate. In all cases, the excess pore pressure at the tip dissipates at a faster rate than behind the base, especially at the early stages of dissipation.

![Figure 6. Dissipation of excess pore pressure for CPTU-01](image)

![Figure 7. Dissipation of excess pore pressure for CPTU-02](image)
4. Conclusions

Pore pressure redistribution around the piezocone can be described that initially the excess pore pressure near the cone base tends to slightly increase before the initiation of dissipation stage. Excess pore pressure at the tip usually dissipates at a faster rate than that behind the base.

According to this study results, the hydraulic conductivity can be determined by using CPTu data. The shape of dissipation curves is mainly dominated by the value of the horizontal hydraulic conductivity.

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