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CPTU dissipation behavior of overconsolidated clay

L'action de la dissipation de CPTU dans l'argile surconsolidée

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ABSTRACT

In normally clays and silts, excess pore pressures due to piezocone penetration show a monotonically decreasing response with time, but dissipation tests performed in heavily overconsolidated soils show dilatory behavior. Therefore, available solutions proposed for normally consolidated soils do not adequately evaluate the response of pore water pressure in overconsolidated soils. In order to predict the coefficient of consolidation in non-standard dissipation curve, the distribution characteristics of individual excess pore pressure components (Δu_{oct} & Δu_{shear}) are studied. The influence zones of the octahedral and shear components due to penetration are estimated by theoretical framework and experimental method. In this study, the predicted distribution results at OCR=10 and OCR=20 are compared by the piezocone penetration results in Korea University Calibration Chamber.

RESUME

Normalement argiles et boues consolidées, les pressions de pore d'excès dû à la 'piezocone' pénétration montrent la réaction monotonement décroissante avec le temps, mais les tests effectués de la dissipation dans la terre lourdement surconsolidée montrent l'action lente. Alors la solution possible proposée pour la terre normalement consolidée n'éstime pas convenablement la réaction de pression de pore de l'eau dans la terre surconsolidée. Afin de prévoir le coefficient de consolidation (colmatage) dans la dissipation courbe de non-standard, les caractéristiques distributions des pièces individuels (Δu_{oct} & Δu_{shear}) de pression de pore d'excès sont étudiées. Les zones d'influences des pièces de l'octahedrale et des cisailles dû à la pénétration sont éstimées par la structure théorique et la méthode expérimentée. Dans ces études, les résultats de la distribution prévue de OCR=10 et OCR=20 sont comparés avec ceux de la 'piezocone' pénétration à l'Université de Corée de la chamber de calibration.

1 INTRODUCTION

Estimation of consolidation and flow characteristics in fine grained soils has received much attention in modern soil mechanics. In general, consolidation properties are estimated by oedometer test or back analyses of field performance. These methods have some limitations due to size effect, soil disturbance and so on. Therefore, in recent years, piezocone penetration and dissipation test has been widely used as an in-situ tool for determining the consolidation characteristics of cohesive soils. However, the interpretation of piezocone data is often complex, especially, when the dissipation curve in overconsolidated soils is non-standard. The dissipation tests preformed in heavily overconsolidated soils show the dilatory response, and the general solution for normally consolidated soils has not been used for non-standard dissipation curve. Although theoretical prediction methods have been proposed, these have not been verified by satisfactory field and laboratory calibration tests.

This paper presents a theoretical method based on cavity expansion theory and critical state concept to predict the pore water pressure behavior due to piezocone penetration. And the predicted values are corrected based on CPTU results in Korea University Calibration Chamber System.

2 CALIBRATION CHAMBER SYSTEM

In order to study in-situ test devices in cohesive soils, large calibration chamber system based on a two-stage consolidation technique was designed and fabricated at Korea University. KUCCS is composed of slurry consolidometer and calibration chamber system, and can simulate four types of boundary conditions by automatic or manual mode. The data acquisition and control software used in this chamber system was developed, based on Labview program.

The slurry consolidometer system was designed on the basis of LSU Calibration Chamber. The device was designed to produce uniform and repeatable cohesive soil deposit which simulates natural sedimentation by consolidating a slurry under K_0 conditions. Pore-water pressures of the specimen are monitored by pore pressure transducer installed on the base plate during the consolidation and CPTU dissipation. The calibration chamber system allows testing of different size of cone penetrometers under controlled boundary conditions. The double wall chamber is flexible and houses a specimen 1.2m in diameter and 1m high. Its operation is servo-controlled and is capable of consolidating soil specimens at a variety of stress paths including K_0 consolidation.

3 GEOTECHNICAL CHARACTERISTICS OF KU-50

Specimen which requires minimal consolidation time and maintains mechanical properties of cohesive soil was developed and named as KU-50. Its engineering properties of KU-50 specimen are summarized in Table 1. Specific gravity was determined by test method prescribed in ASTM D 854, and Atterberg limits were determined in accordance with ASTM D 4318 using soil specimens prepared from the dry, powdered constituent materials. Oedometer test was performed with specimen obtained from slurry consolidometer and calibration chamber.

In order to evaluate undrained shear strength property, undisturbed specimens were consolidated to known vertical effective stress and rebounded to the expected OCR. Following the SHANSEP method, the variation of s_u/σ_{vc}' with OCR was established from the results obtained by anisotropically consolidated triaxial compression tests. Equation (1) is a relationship between s_u/σ_{vc}' and OCR, for KU-50.

Table 1. Properties of KU-50 specimen

Property	Value
Liquid limit	33.5%
Plastic limit	14.6%
Specific gravity	2.62
Percent by weight of clay size particles	50%
Coefficient of consolidation	0.0013 ㎠/sec

$$\frac{s_u}{\sigma_{vc}'} = 0.35(OCR)^{0.84} \tag{1}$$

For many natural clays, a numerical index of OCR in Equation (1) has been found to be within the range of 0.75 ~ 0.85(Ladd et al. 1977), and the value of numerical index of KU-50 specimen is within this range.

4 EXCESS PORE PRESSURES DUE TO PENETRATION

The insertion of a piezocone into a soil deposit causes changes in pore water pressure. This alternation results from a combination of the changes in the octahedral and shear stresses. While the octahedral component is always positive, the shear component can be either positive or negative in the U2 type Piezocone. Therefore, in order to interpret the non-standard dissipation curve in overconsolidated soils, the excess pore pressure has to be decoupled. And, the influence zone by each component must be determined by adequate prediction method.

The estimation method in this study is the hybrid cavity expansion-modified Cam clay model suggested originally by Burns & Mayne (1998) to evaluate excess pore pressures. However, Burns & Mayne (1998) neglected the effect of initial anisotropic stress state. Because this approximation incorrectly represented the initial stress state in overconsolidated soils, the shear induced component of excess pore pressure can be underestimated.

Based on the concepts of undrained cavity expansion, the octahedral component was assumed with shear modulus at 50% peak shear stress and 2% axial strain as follows (Vesic, 1972; Torstensson, 1977)

$$\Delta u_{oct} = s_u \ln(I_r)\text{; cylindrical cavity} \tag{2}$$

And, the shear component was expressed with considering the anisotropic stress by the following;

$$\Delta u_{shear} = p_o'[1-(OCR/2)^{\Lambda}] \tag{3}$$

where, Λ is the plastic volumetric strain ratio= $1-c_s/c_c$, where c_s is the swelling index and c_c is the compression index.

The soil affected by the cone penetration can be divided according to the strength or stiffness characteristic of zone. Therefore, the size of influence zones was predicted by a combination of critical state concept and cavity expansion theory. In this study, the shear zone and plastic zone are represented as follow;

$$r_{plasitc} = r_o(G_{\tan}/s_u)^{0.33} \tag{4}$$

$$r_{shear} = r_o(G_{\sec}/s_u)^{0.5} \tag{5}$$

Where, r_o is cone radius, G_{tan} is the initial tangent modulus, and G_{sec} is the secant modulus at peak state.

5 CPTU RESULTS IN KUCCS

In order to analysis the dissipation characteristics of non-standard curve in overconsolidated clay, piezocone penetration tests were conducted under various overconsolidation ratio (OCR=1,5,10,20) on large instrumented cohesive soil specimens in calibration chamber system. The piezometers were located around the penetration hole in order to verify the size of influence zones and the value of induced excess pore pressure.

5.1 *Initial excess pore pressures*

Initial excess pore pressure were predicted by hybrid cavity expansion theory, and the predicted values were compared with the measured ones by CPTU tests in KUCCS. It can be seen in Figure 1 that excess pore pressures predicted by spherical cavity expansion theory are larger than the measured values, while the predicted values by cylindrical cavity expansion theory with $G_{2\%}$ are similar to measured values. It is also noted that the magnitude of initial excess pore pressure decreases with increasing OCR. And, this result is generally consistent with the previous results in which the octahedral component around the cone base was shown to be better represented by the cylindrical cavity expansion.

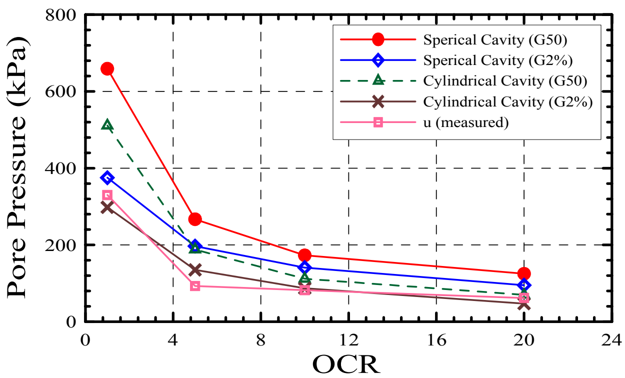

Figure 1. Comparison of predicted and measured values

5.2 *Influence zone*

In general, it has been known that the evaluation of shear zone is more difficult than plastic zone. According to Vesic (1972), the shear zone was assumed equal to that of plastic zone by cavity expansion theory, and Gupta (1983) assumed that the shear zone is about three or four times of piezocone radius. Burns and Mayne (1998) proposed that the size of shear zone is 1-10mm regardless of overconsolidation ration of soils. But, in order to develop an interpretation method of the non-standard dissipation curve, the information about the influence zones by the cone penetration is required because the negative excess pore pressure in the shear zone influences the dilatory response of overconsolidated soils.

In this study, the sizes of influence zone were evaluated by the cylindrical (for plastice zone) or spherical (for shear zone) cavity expansion for each OCR with shear moduli obtained from triaxial tests on KU-50 soil. Initial distribution of Δu_{oct} around the cone base was assumed to be logarithmic, while the initial distribution of Δu_{shear} in the shear zone was assumed to be linear from the cone surface. And, the distribution curves of Δu for OCR=10 and OCR=20 are shown in Fig. 2 and Fig.3. From the results shown in figure, it can be found that the distribution of initial excess pore pressure is non-standard for moderately and heavily overconsolidated clays, and that the shear zones with different pore pressure responses are occurred by the piezocone penetration. And, the size of plastic zone predicted by cylindrical cavity expansion is smaller than the measured one. Though peak values of Δui were measured at $1.8r_o$ and $1.5r_o$ for OCR=10 and OCR=20, respectively, actual position of Δu_{max} at OCR=20 is likely to be at the distance of $(1.5\sim2.0)r_o$.

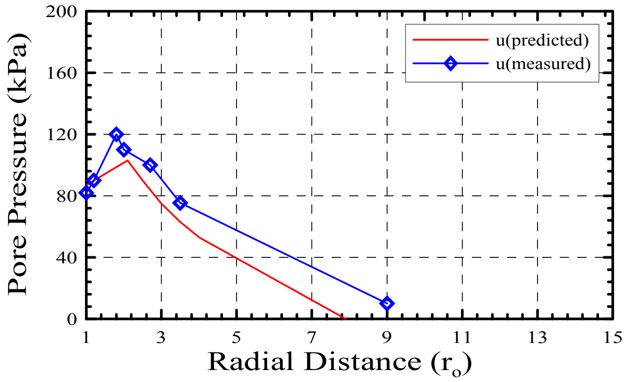

Figure 2. Initial distribution of Δu around piezocone (OCR=10)

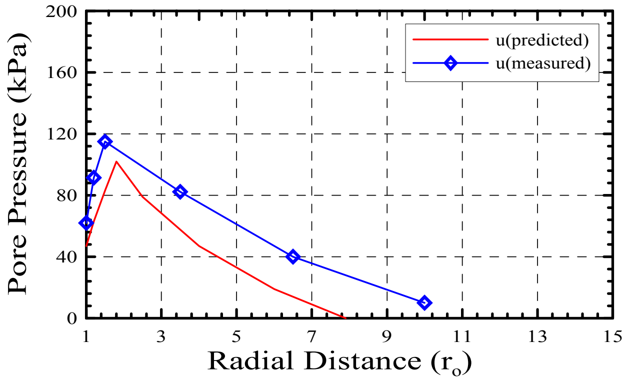

Figure 3. Initial distribution of Δu around piezocone (OCR=20)

6 SUMMARY AND CONCLUSIONS

From the piezocone and piezometer results in KUCCS, it was found that the shear and plastic zones exist around the piezocone, and that the size of influence zones is related to the shear modulus corresponding to the degree of deformation. The sizes of influence zones are dependent on the accuracy in the estimation of undrained shear strength and shear modulus. It was also shown that the size of shear zone by each method is similar, for the plastic zone, the measured size is larger than the predicted one.

Also, the initial excess pore pressure distribution predicted by theoretical method showed a slight underprediction, compared with the measured values, but these distribution trends are almost alike. And, it could be concluded that Δu_i by cylindrical cavity with $G_{2\%}$ is similar to the measured one with increasing OCR.

ACKNOWLEDGMENTS

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