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A Study on Piezocone Test using a Calibration Chamber

Calibration Chamber를 이용한 피에조콘 시험에 관한 실험연구

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요 지

피에조콘 관입 및 소산 시험이 Calibration Chamber 및 미니 피에조콘을 이용하여 수행되었다. 시험은 정규압밀 및 과압밀 점토에 대하여 정지토압 상태에서 실시되었으며 U1 (filter element at cone tip), U2 (filter element above cone base) 두 종류의 피에조콘이 사용되었고 0.3 cm/sec, 0.6 cm/sec의 관입속도가 적용되었다. 오실로스코프를 사용하여 소산시험 초기 간극수압의 급격한 변화를 측정하였다. 시험결과로부터 관입속도, filter element 위치, 과압밀비가 피에조콘 관입 및 소산시험의 결과에 미치는 영향을 고찰하였으며 입도분포시험을 실시하여 관입시험 전후의 입도분포 차이를 고찰하였다.

Abstract

Ten piezocone penetration and dissipation tests were conducted under Ko condition using LSU/CALCHAS (Louisiana State University Calibration Chamber System) and a miniature piezocone penetrometer. The chamber tests were conducted for normally consolidated and heavily overconsolidated specimens at the penetration rates of 0.3 cm/sec and 0.6 cm/sec. The U1 (filter element at the cone tip) and U2 (filter element above the cone base) configurations of the piezocone penetrometers were used. An oscilloscope was used to measure the rapid change of excess pore water pressure at the very initial part of dissipation test. From the chamber tests, the effects of penetration rate, filter element location, and OCR on the results of piezocone penetration and dissipation tests in cohesive soils were investigated. Gradation analysis was conducted before and after penetration test and the results were investigated.

Keywords : Calibration chamber, Piezocone, Penetration rate, Dissipation

1. Introduction

Calibration chamber test is performed to calibrate in-situ testing devices. In a calibration chamber test, the homogeneous, reproducible, and instrumented soil specimen can be prepared with a known stress history. Therefore, various parametric studies can be performed under well-controlled boundary conditions. The facts stated above present definite advantages of the calibration chamber.

The calibration chamber test for cohesive soils has the difficulties in the instrumentation for measuring pore water pressure, the saturation, and the preparation of large soil specimens. It is very time consuming and laborious process. So, the calibration chamber tests for large cohesive specimens are very few.

After the first calibration chamber for cohesive soils at Purdue University, the calibration chambers at University of Clarkson, at Cornell University, and at University of Sheffield, U.K. have been developed for cohesive soils.

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The chambers, however, have disadvantages in size and boundary conditions.

The computer-controlled LSU/CALCHAS (Louisiana State University Calibration Chamber System) was originally designed by de Lima (1990). It has a double-walled flexible calibration chamber to monitor various boundary conditions including Ko condition. The slurry consolidometer system was developed and added to LSU/CALCHAS by Kurup (1993) and Kurup, et al. (1994a) to prepare large cohesive specimens.

The piezocone penetration test (PCPT or CPTU) is widely used for the evaluation of in-situ soil properties and site characterization. Many in-situ soil properties are obtained from the interpretation of the results of piezocone penetration and subsequent dissipation tests. The interpretation of the piezocone test results is often complex as they are influenced by a number of variables (Voyiadjis, et al., 1994; Kurup, et al., 1994a, 1994b; Tumay, et al., 1995).

In this research, the influence of penetration rate, filter element location, and OCR (effective overburden pressure in this research) on the results of piezocone penetration and dissipation tests has been investigated through the calibration chamber test conducted using a miniature piezocone and the LSU/CALCHAS.

2. Experimental Equipment and Procedure

This section describes the experimental equipment and procedure of the piezocone penetration and dissipation tests performed using the LSU/CALCHAS and the slurry consolidometer system.

Soil slurry was prepared by mixing dry soil sample and deionized water at a water content of twice the liquid limit (40%) using a heavy duty chemical mixer. This water content has been found to be appropriate to minimize air entrapment in the slurry during mixing and placement in the consolidometer (Kurup, 1993). A mixture of 33% kaolin and 67% fine sand by dry weight was used to prepare the K33 soil specimen. The soil slurry was placed very carefully inside the consolidometer. The change of pore water pressure during the consolidation in the consolidometer could be monitored from the pore water pressure ducts instrumented inside the consolidometer and the data acquisition system (Fig. 1 and Fig. 2).

After the consolidation in the slurry consolidometer, the specimen was transferred into the calibration chamber using an overhead crane. Then reconsolidation of the specimen was performed under Ko condition using LSU/CALCHAS (Fig. 3 and Fig. 4). The value of Ko was recorded 0.42 for normally consolidated specimen and 1.58 for heavily over consolidated specimen (OCR=10) at the end of reconsolidation.

LSU/CALCHAS consists of a flexible double wall chamber that makes Ko condition possible, a piston cell, control panel, back pressure system, and data acquisition /control system. The control panel controls the vertical and lateral stresses automatically or manually. The change of pore water pressure during reconsolidation can be monitored from the data acquisition system.

After the reconsolidation in the calibration chamber, the miniature piezocone was saturated, then penetration and subsequent dissipation tests were conducted using the hydraulic and chucking system at the rates of 0.3 cm/sec and 0.6 cm/sec (Fig. 5). Cone tip resistance, sleeve friction, pore water pressure during penetration test, and the change

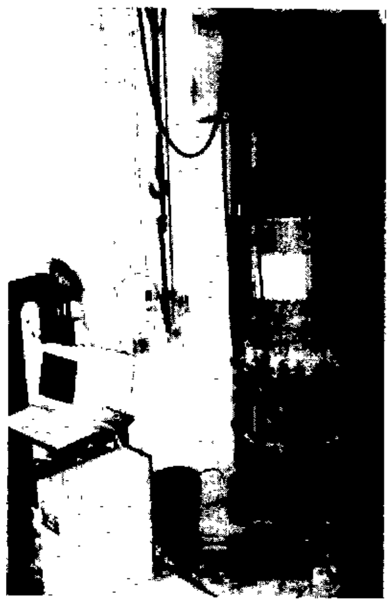

Fig. 1 Consolidation in the slurry consolidometer

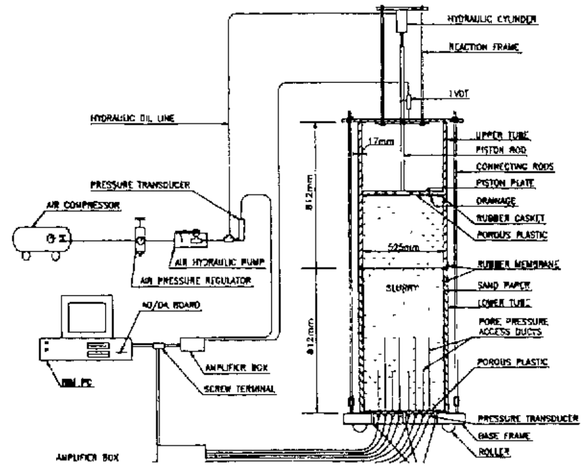

Fig. 2 Schematic of slurry consolidometer system (Kurup, 1993)

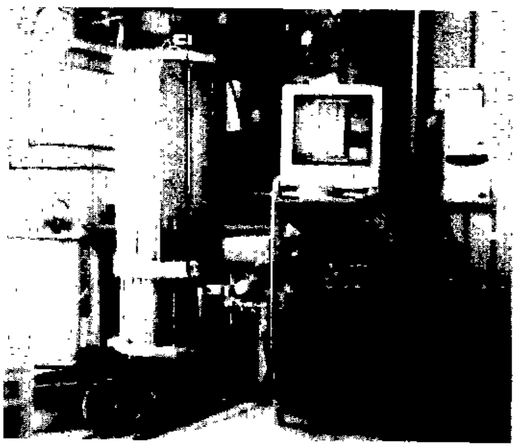

Fig. 3 LSU/CALCHAS

of pore water pressure during dissipation test were measured from the data acquisition system. In addition to the normal data acquisition system, an oscilloscope was used to measure the immediate and very rapid change of pore water pressure when the penetration stopped for dissipation test. Table 1 shows the piezocone penetration test program. The miniature piezocone penetrometer fabricated by Fugro B.V., the Netherlands, has a projected cone area of 100 mm^2, a cone apex angle of 60, a friction sleeve area of 1526 mm^2, and a slope sensor. The miniature piezocone penetrometer has two alternatives for the filter location. The filter can be located at the very cone tip (U1 configuration) or at 1 mm above the cone base (U2 configuration). Details regarding piezocone penetration test using LSU/CALCHAS are also described in Kurup (1993).

3. Cone Resistance

From this section, the results of the piezocone penetration and dissipation tests are presented. As shown in the piezocone penetration test program (Table 1), the penetration test no.2, no.4, no.6, and no.8 are the replications of the penetration test no.1, no3, no.5, and no.7, respectively. The maximum difference between the results of the tests and the results of the replications were less than 9 %, so only the averages are presented. The averages of penetration test no.1 and no.2 are expressed as 0.3 cm/sec (U1, NC), which means the penetration test conducted using U1 configuration and normally consolidated sample at the penetration rate of 0.3 cm/sec. Similarly, the averages of the penetration test no.3 and no.4, no.5 and no.6, and no.7 and no.8 are expressed as 0.3 cm/sec (U2, NC), 0.6 cm/sec (U1, NC), and 0.6 cm/sec (U2, NC), respectively. The 0.6 cm/sec (U2, OCR=10) indicates the penetration test no.9. The 0.6 cm/sec (U1, OCR=10) means the test no.10. Test no.9 and test no.10 have been conducted at the same location. After the penetration test of test no.9 (0.6 cm/sec, U2, OCR=10) to the depth of 220 mm, the dissipation test was performed at the depth of 220 mm and the piezocone was extracted. Then the penetration test of test no.10 (0.6 cm/sec, U1, OCR=10) was performed from 0 mm depth to 580 mm depth at the same location. So, the profile from 0 mm to 220 mm of test no.10 (dotted line portion of 0.6 cm/sec, U1, OCR=10 in Fig. 7 and Fig. 8) has no practical relevance and the profile below the depth of 220 mm (real line portion of 0.6 cm/sec, U1, OCR=10 in Fig. 7 and Fig. 8) was used for analysis.

The cone resistance was expressed as the corrected cone resistance, q_T, and back pressure, u0. As shown in Fig. 6, the corrected cone resistance was obtained from the measured cone resistance and the pore water pressure measured behind the cone tip (Kurup, 1993). The area ratio of the miniature piezocone used in this research was 0.62. Fig. 7 shows the cone resistance profiles from the piezocone penetration tests.

As shown in Fig. 7, the steady values of cone resistances for 0.6 cm/sec (U1, NC) and 0.6 cm/sec (U2, NC) were almost same (1.23 MPa), and the corresponding penetration

Table 1. Piezocone penetration test program

Test no	Filter location	σ_v (KPa)	σ_h (KPa)	Ko	OCR	Penetration Rate (cm/sec)
1	u1	262 01	110.04	0 42	1	0 3
2	u1	262 01	110.04	0 42	1	0 3
3	u2	262.01	110.04	0 42	1	0.3
4	u2	262.01	110.04	0.42	1	0.3
5	u1	262.01	110.04	0.42	1	0.6
6	u1	262 01	110.04	0 42	1	0 6
7	u2	262 01	110.04	0.42	1	0 6
8	u2	262 01	110.04	0.42	1	0.6
9	u2	26.20	41 40	1.58	10	0 6
10	u1	26.20	41 40	1.58	10	0.6

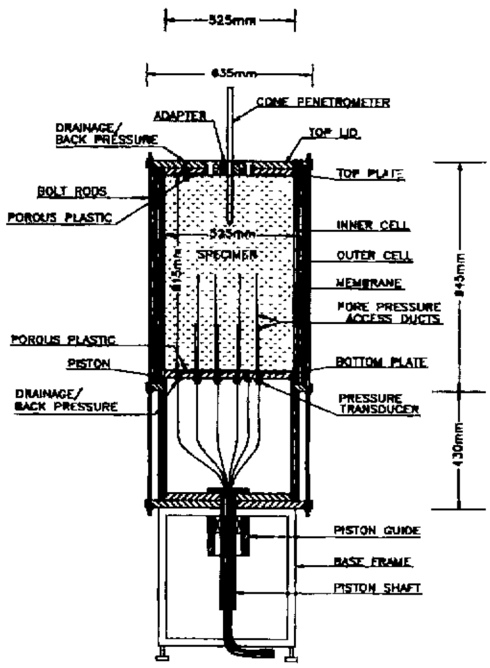

Fig. 4 Schematic of flexible double wall calibration chamber(Kurup, 1993)

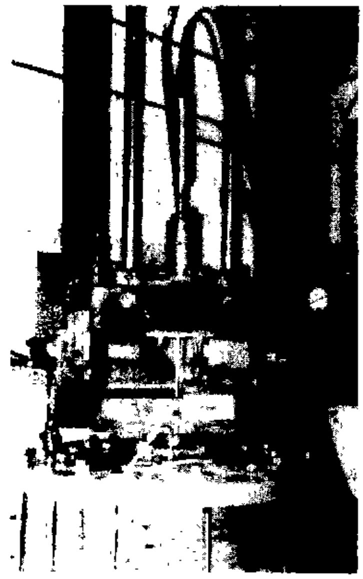

Fig. 5 Piezocone penetration test

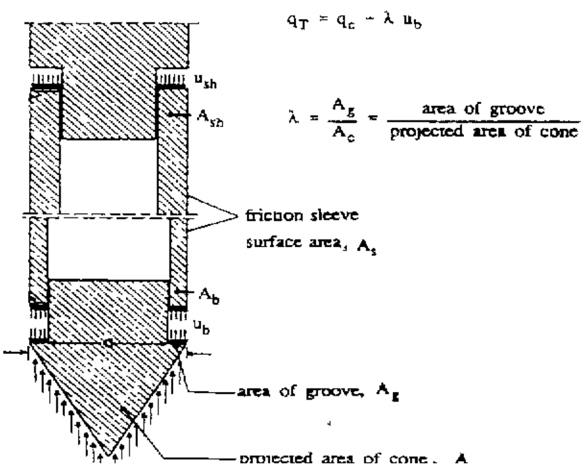

Fig. 6 Correction of cone resistance for unequal end area effects (Kurup, 1993)

depths were also almost same (140 mm). The steady values of cone resistance both for 0.3 cm/sec (U1, NC) and for 0.3 cm/sec (U2, NC) were 1.12 MPa, and the corresponding depths were 105 mm. Accordingly, it can be said that the steady value of cone resistance and the corresponding depth are regardless of the location of filter element. It is because the cone resistances were corrected using the pore water pressure measured behind the cone tip.

By comparing the steady values of 0.3 cm/sec (U1 and U2, NC) with those of 0.6 (U1 and U1, NC), it has been found that the cone resistance at higher penetration rate was larger than that at lower rate. In this research, more specifically, the steady value of cone resistance at 0.3cm/sec increased by 10 % with 100 % increase in

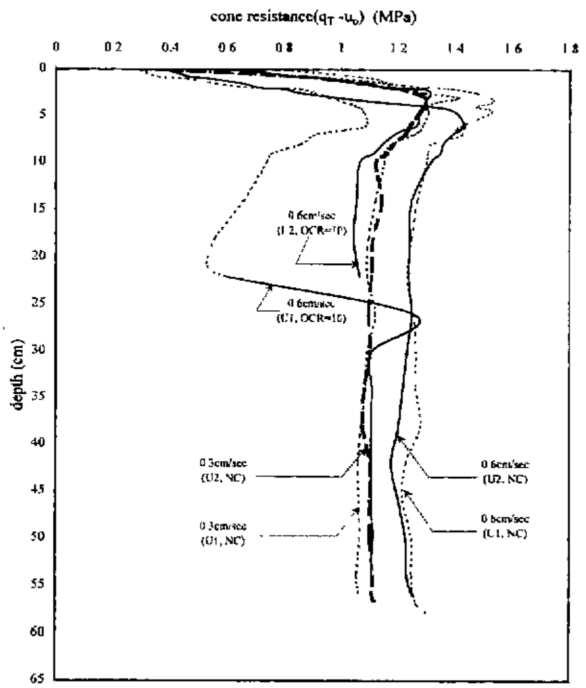

Fig. 7 Cone resistance profiles

penetration rate both for U1 and U2 configurations.

When the effective overburden pressure decreased, keeping the other conditions unchanged, namely, comparing the cone resistances of 0.6 cm/sec (U1 and U2, NC) with those of 0.6 cm/sec (U1 and U2, OCR=10), the steady value of cone resistance decreased to 13% with the increase of OCR from 1 to 10. The increase of OCR indicates the decrease of effective overburden pressure in this research (see Table 1).

In Fig. 7, it is also shown that the peak values of cone resistance have the same trends as the steady values with respect to the changes of penetration rate and OCR. The peak regions, that occur before the steady state, can be thought as the influence of the thin sand layer at the top of the specimen and to occur to initiate the penetrations.

4. Excess Pore Water Pressure

Fig. 8 shows the excess pore water pressure profiles of the piezocone penetration tests. As shown in Fig. 8, the steady values of excess pore water pressures for 0.6 cm/sec (U1, NC), 0.6 cm/sec (U2, NC), 0.3 cm/sec (U1, NC), 0.3 cm/sec (U2, NC), 0.6 cm/sec (U1, OCR=10), and 0.6 cm/sec (U2, OCR=10) were 0.086 MPa, 0.081 MPa, 0.067 MPa, 0.064 MPa, 0.063Mpa, and 0.053 MPa, respectively.

In all cases tested under the same stress condition (NC or OCR=10) and at the same penetration rate (0.3 cm/sec or 0.6 cm/sec), it was clearly observed that the excess pore water pressures measured at the cone tip (U1) were greater than those measured above the cone base (U2) unlike in the cone resistance profiles. This can be explained by that the soil below the cone tip is subjected to predominantly normal stress, on the other hand, the soil above the cone base mainly experiences shear stress (Kurup, et al., 1994b). The differences between the excess pore water pressures of U1 and those of U2 for 0.3 cm/sec (NC), 0.6 cm/sec (NC), and 0.6 cm/sec (OCR=10) were 4.5 %, 5.8 %, and 15.9 %, respectively. So, it can be said that the difference of the excess pore water pressures between U1 and U2 increases with the increase of penetration rate and it also increases with the increase of OCR (decrease of effective overburden pressure in this research).

With respect to U1, 22 % increase of excess pore water pressure has been found with the increase of penetration rate from 0.3 cm/sec to 0.6 cm/sec by comparing the excess pore water pressure for 0.3 cm/sec (U1 or U2, NC) with that for 0.6 cm/sec (U1 or U2, NC), with respect to U2, 21 % increase of excess pore water pressure has been found with the increase of penetration rate from 0.3 cm/sec to 0.6 cm/sec. This means that excess pore water pressures measured both at the cone tip and above the cone base increase with the increase of penetration rate at a very similar rate.

By comparing the results of 0.6 cm/sec (U1 and U2, NC) with those of 0.6 cm/sec (U1 and U2, OCR=10), 27 % and 33 % decreases of excess pore water pressures have been found with the increase of OCR from 1 to 10 (decrease of effective overburden pressure in this research) for U1 and U2. respectively, which means the decrease of excess pore water pressure in U2 is greater than that in U1 with the increase of OCR (decrease of effective overburden pressure in this research). The peak regions occurred like in the cone resistance profiles, which are the influence of the thin sand layer at the top of the specimen and are needed to initiate penetrations.

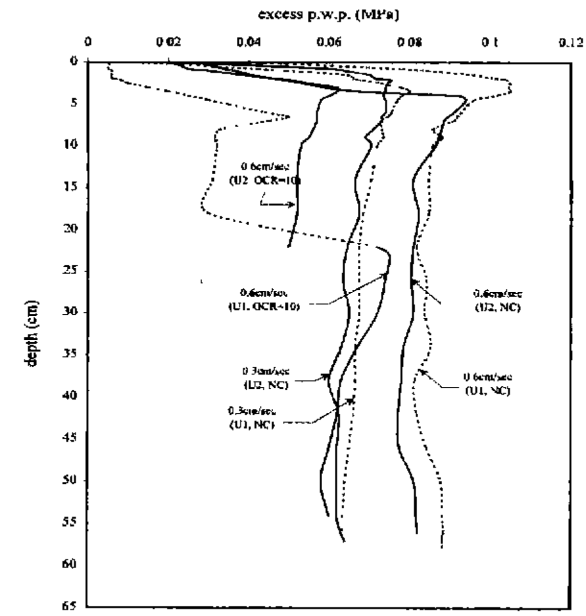

Fig. 8 Excess pore water pressure profiles

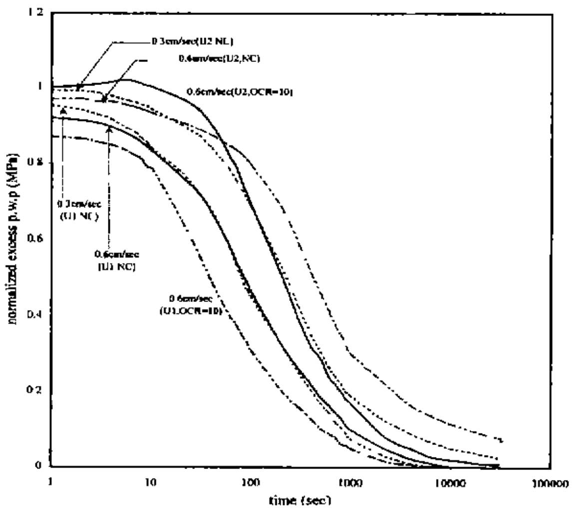

Fig. 9 Dissipation of excess pore water pressure

5. Dissipation of Excess Pore Water Pressure

Fig. 9 shows the dissipations of the excess pore water pressures. These experimental data have been measured during the dissipation tests that were subsequently conducted after the penetration tests. The excess pore water pressures were normalized by their initial excess pore water pressures, that are the excess pore water pressures measured at the filter element of the piezocone when the penetrations stopped for the dissipation tests.

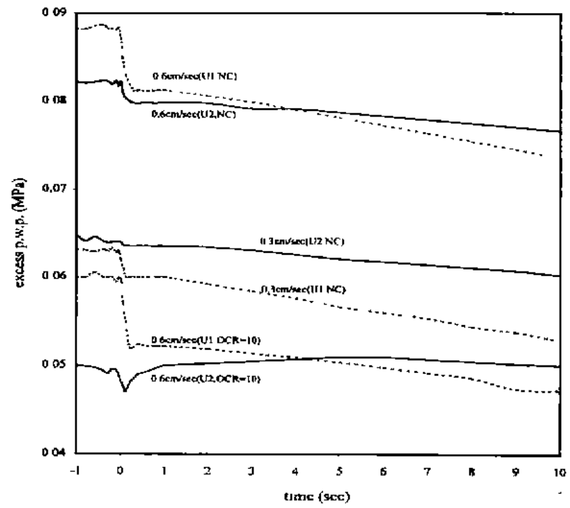

Fig. 10 Initial part of dissipation test (measured using oscilloscope)

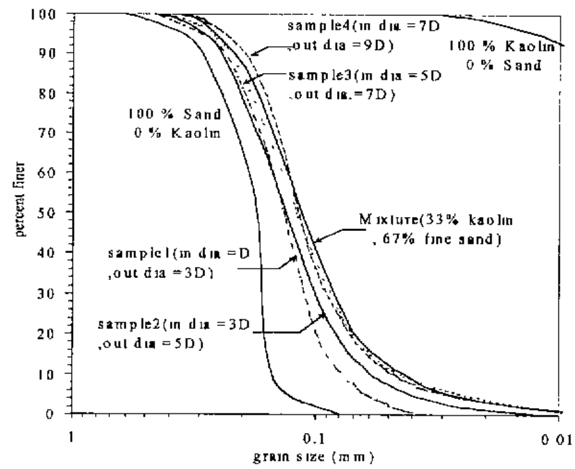

Fig. 11 Grain size distribution before and after penetration test

As shown in Fig. 9, the dissipations of excess pore water pressures in NC cases took longer time than those in OCR=10 cases both for the U1 and U2. However, the biggest difference of all dissipation curves is their initial values. Fig. 10 shows the initial parts of the dissipation data measured using an oscilloscope. These initial drops were higher for the pore water pressures measured at the cone tip (U1) than those measured above the cone base (U2). It is due to the redistribution of pore water pressure and the normal stress reduction that occur when the penetration ceases (Kurup, et al., 1994b; Tumay, et al., 1995).

It has been also found that the magnitude of the initial drop increased with the increase of the penetration rate, and that the excess pore water pressure increased, a little bit, immediately after the initial drop for the case of 0.6 cm/sec (U2, OCR=10).

6. Grain Size Distribution after Piezocone Penetration

Fig. 11 shows the grain size distributions of the samples obtained after extracting the piezocone penetrometer. The samples were carefully obtained at certain radial distances away from the center of the piezocone penetrometer, and sieve analyses and hydrometer tests were performed using the samples. Sample 1, sample 2, sample 3, and sample 4 were obtained between D (diameter of piezocone penetrometer) and 3D, between 3D and 5D, between 5D and 7D, and between 7D and 9D, respectively, around the penetration hole. In Fig. 11, the mixture (33 % kaolin, 67 % fine sand) indicates the original mixture used for the piezocone penetration tests.

It was observed that sample 3 and sample 4 had almost same grain size distributions as the original mixture, but sample 1 and sample 2 were clearly on the left side (coarser) of the original mixture, which meant sample 1 and sample 2 contained less clay particles than the original mixture. Also, sample 1 had less clay particles than sample 2. It may be concluded, therefore, that the closer to the piezocone penetrometer the sample is, the less clay particles it contains. This can be explained by the fact that the clay particles migrate radially from the piezocone penetrometer axis along the penetration path since the clay particles are lighter than the sand particles and are carried by the water pressure generated in soil pores.

7. Conclusions

The corrected cone resistance, q_T, at the steady state and the required depth were not influenced by the location of the filter element. The cone resistances increased with the increase in penetration rate but decreased with the increase of OCR (decrease of effective overburden pressure in this research).

The excess pore water pressures measured at the cone tip (U1) were greater than those measured above the cone base (U2). The difference of the excess pore water pressures between U1 and U2 increased with the increase of penetration rate and with the increase of OCR (decrease of effective overburden pressure in this research). The excess pore water pressures measured both at the cone tip and above the cone base increased with the increase of penetration rate at a very similar rate. The decrease of excess pore water pressure for U1 was greater than that for U2 with the increase of OCR (decrease of effective overburden pressure in this research). The excess pore water pressures at the cone tip and above the cone base were quite different, furthermore, the excess pore water pressure above the cone base changed very rapidly for all cases, which produced a large pore pressure gradient. In that sense, the importance of location of the filter element for measuring pore water pressure needs to be emphasized again.

The dissipations of excess pore water pressures for normally consolidated cases took longer time than those for OCR=10 case both for U1 and U2. The immediate initial drop in excess pore water pressure was observed in all cases. The initial drop was higher for U1 than for U2 and its magnitude increased with the increase of penetration rate.

Investigating the grain size distributions of the samples before and after penetration test, it has been observed that the soil which was closer radially to the piezocone contained less clay particles than the soil which was farther from the piezocone. This can be explained by the migration of clay particles in a radial direction mobilized by the water pressure generated in soil pores.

Acknowledgments

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References

1. de Lima, D. C. (1990), "Development, Fabrication and Verification of the LSU In-Situ Testing Calibration Chamber," Ph.D. Dissertation, Louisiana State University, Baton Rouge, LA.

2 Kurup, P. U. (1993), "Calibration Chamber Studies of Miniature Piezocone Penetration Tests in Cohesive Soil Specimens," Ph. D. Dissertation, Department of Civil and Environmental Engineering, Louisiana State University, Baton Rouge, LA.

3 Kurup, P. U., Voyiadjis, G. Z., and Tumay, M T (1994a), "Calibration Chamber Studies of Piezocone Test in Cohesive Soils," ASCE, Journal of Geotechnical Engineering, Vol. 120, No. 1, pp. 81-107

4 Kurup, P. U , Voyiadjis, G. Z., and Tumay, M. T. (1994b), "Excess Pore Pressure Dissipation after Piezocone Penetration," Computer Methods and Advances in Geomechanics, Siriwardane & Zaman (eds), pp. 1751-1756

5. Tumay, M T., Kurup, P. U., and Voyiadjis, G. Z. (1995), "Profiling OCR and Ko from Piezocone Penetration Tests," International Symposium on Cone Penetration Testing, Sweden, pp. 337-342.

6 Voyiadjis, G Z., Kurup, P. U., and Tumay, M. T. (1994), "Determination of Soil Properties from Laboratory Piezocone Penetration Tests," XIII ICSMFE, India, pp. 303-308

(received on May., 10, 2000)