Continuous intrusion miniature piezocone penetration test in quick soil deposits

Essai de pénétration en continu d'un piézocône miniature dans une argile sensible

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ABSTRACT: This paper presents the results of continuous intrusion miniature piezocone penetration test (CIMCPT) in quick saturated cohesive soil. The CIMCPT system consists of 2-cm^2 miniature piezocone penetrometer attached to a coiled stainless steel push rod 12.7 mm in diameter, which allows a continuous penetration of the cone without the need of segmental push rods. The coil is approximately 0.75 m in diameter and is mechanically straightened as the cone is pushed into the ground. Field tests were conducted at a test site of quick saturated clay deposit in Norway. Piezocone penetration tests, using the standard 10-cm^2 piezocone penetrometer, were performed previously by the Norwegian University of Science and Technology. Test results are analyzed to calibrate the miniature piezocone with respect to the standard piezocone penetrometer.

RÉSUMÉ: Cette communication présente les résultats d'un essai de pénétration en continu d'un piézocône miniature (CIMCPT) dans des soils mous cohérents et saturés. Le dispositif CIMCPT se compose d'une pointe piézocônique de 2 cm^2 de section fixée à une tige de fonçage enroulée, en acier inoxydable et 12,7 mm de diamètre, qui permet de réaliser un enfoncement continu du cône sans avoir recours aux éléments de tige discontinus. La bobine d'enroulement a un diamètre de 0,75 m environ et la tige est redressée mécaniquement au fur et à mesure de l 'enfoncement du cône dans le sol. Des essais ont été réalisés sur un site comportant un dépôt d'argile sensible en Norvège. Des essais de pénétration au piézocône utilisant la pointe standard de 10 cm^2 avaient déjà été réalisés auparavant sur ce site. Une analyse a été réalisée sur les résultats des essais pour étalonner le piézocône miniature par rapport au piézocône standard. Les résultats ont montré que le piézocône miniature permet de détecter une stratification plus fine du sol que le pénétromètre standard.

1 INTRODUCTION

The piezocone penetration test (PCPT) is a popular site characterization methodology in geotechnical engineering. This field test is appropriate for characterization of saturated soft and medium clay deposits. Figure 1 depicts a picture of a piezocone penetrometer. The PCPT is basically the intrusion of the piezocone into the soil deposit and the measurement of the soil tip/friction resistance and pore pressures generated from this intrusion. The soil resistance at the conical tip of the piezocone is the tip resistance (q_c) and the frictional resistance at the piezocone sleeve is the sleeve friction (f_s). The generated pore pressure (u) measured due to the piezocone intrusion depends on many factors including the location of the pore pressure element. The measured tip resistance, sleeve friction, and pore pressures are used to classify soils and estimate their properties such as the undrained shear strength (s_u), consolidation parameters and hydraulic conductivity characteristics of cohesive soils, and drained strength parameters and compressibility characteristics of cohesionless soils.

Louisiana Department of Transportation and Development (LA DOTD) depends on traditional subsurface exploration techniques in pavement and geotechnical engineering design. For example, undisturbed soil sampling and testing is conducted to obtain soil parameters necessary for design of driven piles and pavement layers. The cone penetration test (CPT) is also used by LA DOTD as a supplementary test to locate dense sand strata in design of end-bearing piles. Currently, efforts are made by LA DOTD to implement the penetration technology in different aspects of pavement and geotechnical design such as design of friction driven piles and prediction of resilient modulus of subgrade soils.

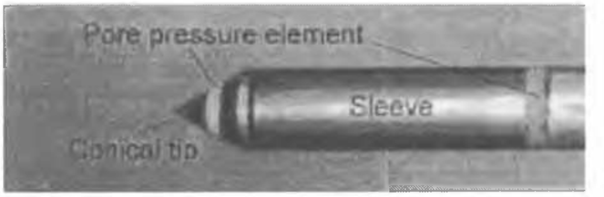

Figure 1. Picture of the piezocone penetrometer with dual pore pressure elements u_1 at the cone tip and u_3 behind the sleeve.

Efforts at the Louisiana Transportation Research Center (LTRC) resulted in the development, calibration, and implementation of the Continuous Intrusion Miniature Cone Penetration Test (CIMCPT) system (Tumay et al. 1998, Tumay & Titi 2000, Titi & Tumay 2000, Titi et al. 2000). The CIMCPT system continuously advances a miniature electric friction cone/piezocone with a 2-cm^2 projected cross-sectional area by uncoiling a stainless steel push rod. The system is designed to characterize the soil at shallow depths (15 m). The miniature cone/piezocone penetrometers proved to provide finer details of soil deposits and were able to recognize the thin layers/lenses of sand and silt within the clay deposits.

In this paper, the CIMCPT system was used to conduct miniature piezocone penetration tests in soft saturated sensitive soils in Norway. The purpose of the field-testing program is to evaluate the reliability and repeatability of the miniature piezocone penetrometer and to determine its comparability with standard 10 cm^2 piezocone penetrometer. The field calibration and verification of the miniature piezocone penetrometer with respect to the standard penetrometers is necessary before the miniature penetrometer can be implemented in shallow depth site characterization to obtain the fine details of the soil deposits.

2 CONTINUOUS INTRUSION MINIATURE CPT SYSTEM

The CIMCPT, shown in Figure 2, consists of a thrust device, coiling mechanism, hydraulic motor, miniature cone and piezocone penetrometers, and a data acquisition system. A coiled stainless steel push rod 12.7-mm in diameter is attached to the miniature cone to allow for continuous penetration. The coil is approximately 0.75 m in diameter and is mechanically straightened as the cone is pushed into the ground. The miniature electric piezocone penetrometer (fabricated by SAGE Engineering, Inc., Houston, Texas) is a subtraction type probe with a projected cross-sectional area of 2 cm^2, friction sleeve area of 40 cm^2, and

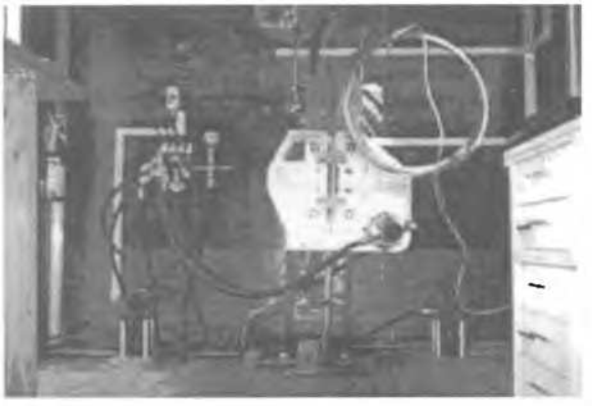

Figure 2a. Continuous intrusion miniature piezocone penetration test system.

Figure 2b. Continuous intrusion miniature piezocone penetration test system mounted on NTNU drill rig.

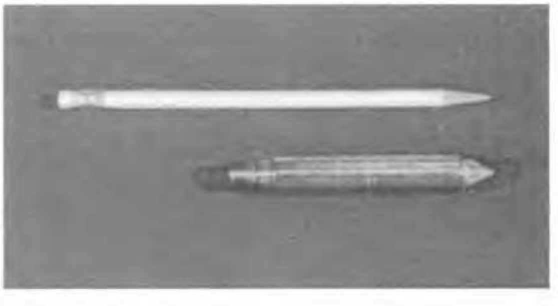

Figure 3. 2-cm^2 miniature penetrometer.

cone apex angle of 60 degrees. The net area ratio of the miniature cone is 0.65. The miniature piezocone penetrometer can be configured to measure pore pressures generated at the cone tip (u_1) or behind the cone tip (u_2). Figure 3 shows a picture of the miniature penetrometer.

3 MINIATURE PIEZOCONE PENETRATION TESTS

The test site is located at Tiller, approximately 10 Km southeast of Trondheim, Norway. This test site is well characterized due to many laboratory and field investigations carried out by Norwegian University of Science and Technology (Norges Teknisk – Naturvitenskapelige University, NTNU) researchers (e.g., Sandven 1990, Black 1997). The site consists of 2-m of top crusted clay layer, 6m silty low sensitive marine clay, and 10-m quick clay. Tiller clay is described as medium stiff to stiff, overconsolidated and partly quick clay with sensitivity range of 5-1000. The clay also possesses a low plasticity index (PI range = 2 to 8). The moisture content varies between 35 and 45% and is usually higher than the liquid limit (Sandven 1990).

Miniature piezocone penetration tests (MPCPT), using the 2-cm^2 penetrometer, were conducted on Tiller quick clay, Norway. During penetration test, continuous measurements of the cone tip resistance (q_c), sleeve friction (f_s), and pore water pressures (u_2) were recorded with depth. During each test, the cone penetrometer was advanced into the ground at the standard penetration rate of 2 cm/sec. Miniature piezocone penetration tests on Norwegian clays were conducted during cold weather conditions with temperature approximately equal to 8 °C. Under these conditions, the filter element of miniature piezocone penetrometer was saturated using the liquid Paraffin, which holds well inside the porous stone at low temperatures. The length of the coil rod attached to the penetrometers allows penetration down to about 20 m for the miniature piezocone penetrometer.

The results of the miniature piezocone penetration tests on Tiller quick clay are shown in Figure 4. The total tip resistance (q_c) was corrected for the unequal area effect and the corrected total tip resistance (q_t) versus depth is shown in Figure 5. The results of the previous standard 10 cm^2 piezocone penetration testing conducted at the same site by NTNU are also presented in the same figure for comparison. The PCPT testing was conducted using 10 cm^2 modified Fugro piezocone with continuous records of cone tip resistance and pore water pressure. The PCPT testing by NTNU was performed according to the ISSMGE recommended procedure. The tip resistance (q_t) profiles recorded by the miniature piezocone and cone penetrometers are consistent and show similar pattern below the crusted clay layer (2 m deep). The sleeve friction (f_s) below 2 m depth is zero due the fact that quick clay liquefies upon disturbance caused by the advancing conical tip. The pressure transducer recorded the generated positive excess pore pressures below 5 m of depth.

Figures 4 and 5 show the compliance and consistency between the measurements of the miniature and the standard piezocone penetrometers. Both penetrometers captured similar and consistent profiles. The tip resistance and pore pressures recorded by the miniature piezocone is slightly higher than those measured by the standard piezocone. Figures 4 and 5 demonstrate the repeatability of the miniature piezocone penetration tests (MPCPT) and their consistency with the standard piezocone results. Inspection of Figure 5 shows that the part of the quick clay deposit (9-14 m) can be considered a homogeneous for the purpose of calibrating/evaluating the performance of the miniature piezocone with respect to the standard piezocone penetrometer. For this deposit, the average corrected tip resistance recorded by the miniature piezocone is $q_t(MCPT)$ = 0.636 MPa while the average corrected tip resistance measured by the standard piezocone is $q_t(CPT)$ = 0.573 MPa. The miniature piezocone recorded the tip resistance, under similar penetration rate of 2 cm/sec, approximately 11% higher compared to tip resistance recorded by the 10 cm^2 standard

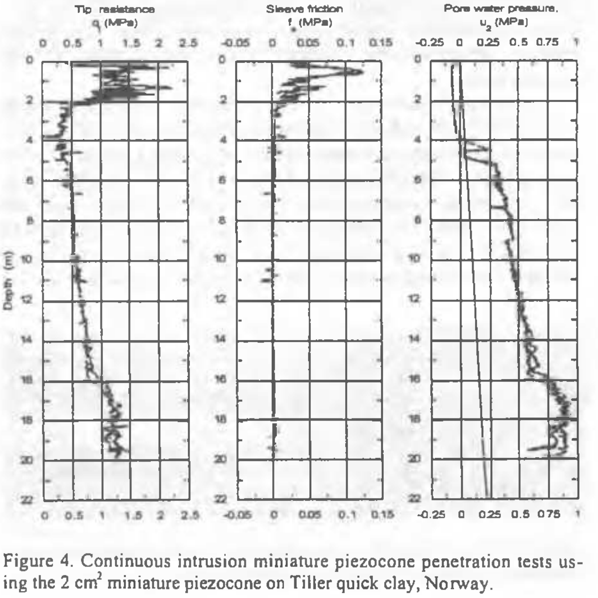

Figure 4. Continuous intrusion miniature piezocone penetration tests using the 2 cm^2 miniature piezocone on Tiller quick clay, Norway.

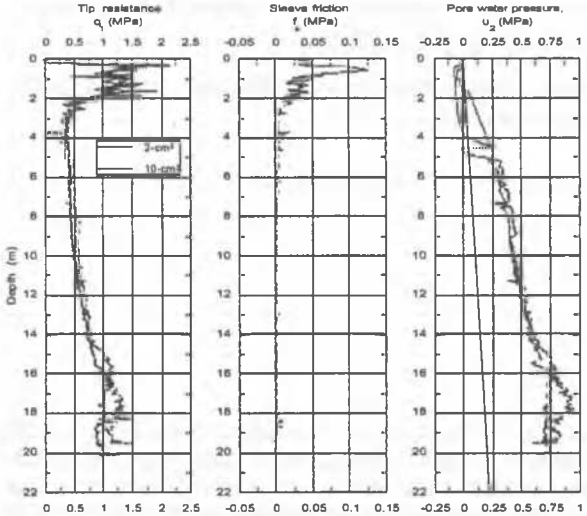

Figure 5. Continuous intrusion miniature piezocone penetration test vs. standard piezocone test on Tiller quick clay, Norway.

piezocone. This compares well with previous research on the miniature friction cone penetrometer by Tumay et al. (1998).

These observations are attributed to the scale effects of the miniature piezocone penetrometer (de Lima and Tumay 1991). Therefore, the results obtained by the miniature piezocone can be used directly, after scale corrections, to characterize the soil using the available methods/approaches, since these methods were developed based on test results using the standard penetrometers. Calibration of the miniature piezocone based on penetration tests in different soil types will help in establishing a correlation with the cones commonly used in the industry.

The results of the miniature piezocone tests were used to classify the soil at Tiller test site using the soil classification method developed by Senneset et al. (1989). The parameter B_q is defined as (Senneset et al. 1989):

$$B_q = \frac{u_T - u_o}{q_t - \sigma_{vo}} \tag{1}$$

where u_T is the pore pressure measured behind the cone, u_o is the hydrostatic pore pressure, q_t is the corrected tip resistance, and σ_{vo} , is the total vertical overburden pressure.

The results are presented in Figure 6. Soil classification using the 2 cm^2 miniature piezocone data is consistent with soil classification obtained by the standard 10 cm^2 piezocone penetrometer. The miniature piezocone profiles showed more detailed classification of the sediments (seams) encountered.

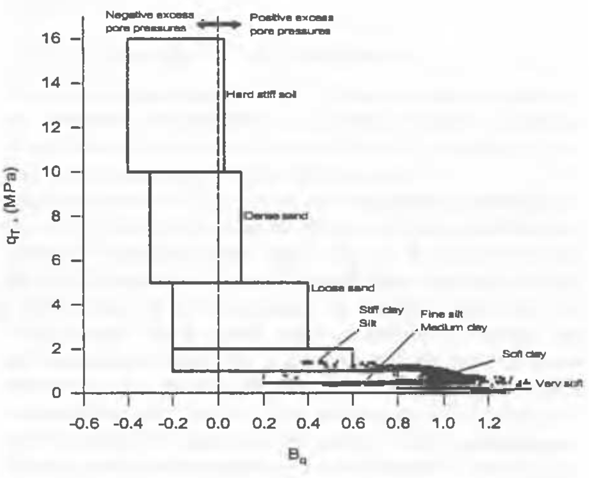

Figure 6a. Soil classification for Tiller soil from 5-20 m obtained from the results of the 2-cm^2 miniature piezocone penetration test.

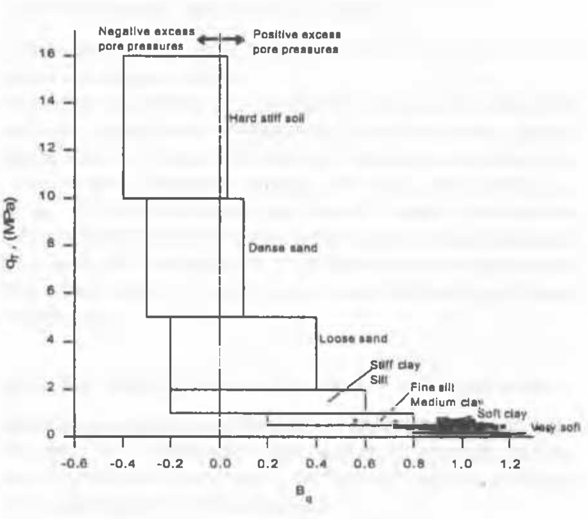

Figure 6b. Soil classification for Tiller soil from 5-20 m obtained from the results of the standard 10-cm^2 piezocone penetration test.

4 CONCLUSIONS

A Continuous intrusion miniature piezocone penetration test system was developed, calibrated, and implemented in shallow-depth site characterization. Field tests in saturated sensitive clay showed that the 2-cm^2 miniature piezocone penetrometer test results are consistent with those obtained from the standard 10-cm^2 piezocone penetrometer. The 2-cm^2 miniature piezocone penetrometer recorded 11% higher tip resistance compared to the standard 10 cm^2 piezocone penetrometer and was able to better identify the thin seams encountered.

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