The use of slot filter in piezocone tests for site characterization of tropical soils

L'utilisation de filtre à cavité en essai au piézocône pour la caractérisation des sols tropicaux

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ABSTRACT

The use of piezocone tests with a slot filter filled with automotive grease for site characterization of tropical soils is assessed. Laboratory tests using the slot filter filled with automotive grease as well as the conventional porous piezo-element saturated with glycerin were carried out to evaluate the pore pressure (u_2) transducer response. CPTu tests using piezo-elements saturated with glycerin and the slot filter filled with grease were pushed side by side in different research sites in Brazil. Estimates of mechanical and hydraulic soil parameters were made based on pore pressure dissipation curves from using both techniques. Laboratory test results indicate that the pore pressure response using the slot filter with grease was delayed when compared to the piezo-element saturated with glycerin, since grease has a higher viscosity. For tropical soils, the records of u_2 in piezocone tests using slot filter with grease presented larger peaks than with porous element saturated with glycerin. Records of u_2 using the slot filter above the groundwater table suggest the increase of the degree of saturation in unsaturated zone, where porous filter can be desaturated by suction. The slot filter can be used to help the interpretation of the soil profile with deep groundwater level as well as to help detecting its position for some studied soils. The results shown high repeatability for all study sites. This technique is much easier to handle, especially for tropical soils, where the groundwater table is usually deep and pre-drilling is expensive and time consuming.

RÉSUMÉ

L´utilisation d'un filtre à cavité rempli de graisse automobile est évaluée pour la characterization des sols tropicaux. Essais en laboratoire utilisant le filtre à cavité ainsi que les classiques piézo éléments poreux saturés d´eau et de glycérine ont été réalisés pour évaluer la réponse du transducteur à pression de pore (u_2). Essais de CPTu en utilisant des piézo-éléments saturés de glycérine et du filtre à cavité rempli de graisse ont été faits simultanément en différents sites de recherche au Brésil. Les estimations des paramètres mécaniques et hydrauliques des sols ont été obtenues en fonction des courbes de dissipation de la pression de pore à l'aide des deux types de techniques. Les résultats des tests en laboratoire indiquent que la réponse à la pression de pore en utilisant le filtre à cavité a été retardé par rapport au piézo-élément saturé d'eau ou de glycérine, puisque la graisse est plus visqueuse. Pour les sols tropicaux les registres de u_2 pour les tests au piezocone en utilizant le filtre à cavité ont présenté des valeurs plus élevées que les filtres saturés de glycérine. Valeurs de u_2 obtenus à l´aide du filtre à cavité au-dessus du niveau phréatique suggèrent l'augmentation du degré de saturation dans la zone non saturée, où le filtre poreux peut être désaturé par succion. Le filtre à cavité peut être utilisé pour faciliter l'interprétation du profil du sol avec la définition des niveaux phréatiques ainsi que pour aider à découvrir sa position pour quelques sols déjà étudiés. Les résultats ont indiqué répétabilité pour tous les sites d'étude. Cette technique est plus facile à manipuler, en particulier pour les sols tropicaux, où le niveau phréatique est généralmente profond et le pré-perçage est coûteux et lent.

Keywords: site characterization, tropical soils, piezocone, pore pressure, saturation.

1 INTRODUCTION

In piezocone penetration testing (CPTu), tip resistance (q_c), local friction (f_s) and pore pressure (u) are measured simultaneously. The quasi continuous data can be used for soil stratigraphic logging, to define groundwater levels and to estimate mechanical and hydraulic soil parameters based on appropriate correlations. Pore pressure records provide information about the response of the ground to the probe during the pushing and consequent migration of fluids, allowing an assessment of the drainage conditions. In tropical soils, the groundwater level is usually deep, and it is necessary to open a borehole to reach the groundwater before pushing the piezocone. This process is necessary to avoid desaturation of the porous element, and needs to be very carefully handled to provide reliable pore pressure response.

Larsson (1995) and Elmgren (1995) have suggested the use of a slot filter filled with grease to replace the conventional procedure of saturating the porous element with water or glycerin. This technique was applied for soils with deep groundwater level, simplifying the piezocone saturation procedure and reducing the risk of filter damage. It allows the piezocone tests to be carried out directly from the surface, with no pre-drilling. There are just few publications about the use of the slot filter and its interpretation (Powell & Lunne 2005) and there exist many doubts about the pore pressure values measured using this technique. Elmgren (1995) carried out laboratory tests comparing different fluids and concluded that the slot filter filled with grease or oil can be acceptable, but that there is some hysteresis. Larsson (1995) also compared the porous and slot filter pore pressure response using field and laboratory data and concluded that the in situ u_2 values tends to be lower than in the laboratory, and the pore pressure velocity response depends on the grease type (lighter or softer). Mulabdic (1997) detected different u_2 values using both techniques and concluded that more studies are needed to understand the slot filter behaviour for its current use.

This paper presents and discusses piezocone testing data from tropical soils using the porous element saturated with glycerine and the slot filter filled with grease. Laboratory testing data are also presented to assess the pressure transducer response using both techniques. The results were interpreted to assess repeatability, stratigraphic logging and soil mechanical parameters estimation.

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2 MATERIAL AND METHODS

2.1 *Materials*

A standard piezocone was used. It has 10 cm^2 tip area, 150 cm^2 friction sleeve area, piezo-element located behind the tip (u_2) and 20 mm/s of penetration ratio. Figure 1 presents geometrical characteristics of the cone tip and of the slot filter. The data were recorded every 25 mm and transmitted wirelessly by sound. For the field tests, a 200 kN multi-function apparatus with a self-anchoring system was used to push the piezocone into the ground.

The slot filter filled with grease is much easier to prepare and handle than the porous piezo-element saturated with glycerin. The pore pressure measurement is done by a pressure transducer inside the piezocone, which is brought into stiff contact with the pore water in the soil by filling the inner cavity with water and pressing the grease into the cavities inside the cone tip. In this way, the pore pressure transducer becomes saturated when the tip is screwed on and the excess grease squeezes out through the slot (Figure 2).

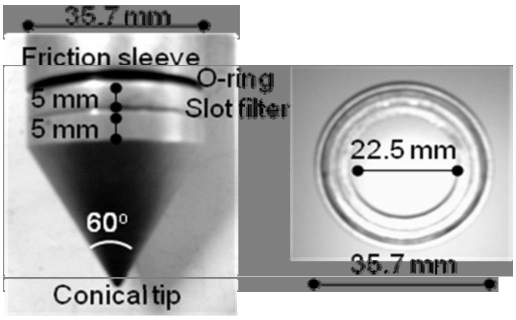


Figure 1. Detail of the piezocone tip and slot filter.

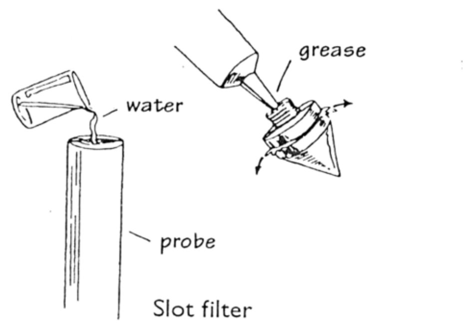


Figure 2. Piezocone saturation procedure using slot filter (SGI 1995).

2.2 *Laboratory tests*

A laboratory system was prepared using a triaxial chamber for pressure application into the piezocone pore pressure transducer, as indicated in Figure 3. Pressures were applied inside the chamber filled with water. This pressure was measured by a reference pore pressure transducer, and the readings were compared with those ones measured by the piezocone transducer. Glycerin was used to saturate the piezo-element and the pore pressure transducer and automotive grease was used to fill up the slot filter.

2.3 *Field tests*

The field tests were carried out in soils from the Guabirotuba Formation (Curitiba-PR), São Paulo Sedimentary Basin (São Paulo-SP) and in residual tropical soils from different sites in São Paulo State, Brazil.

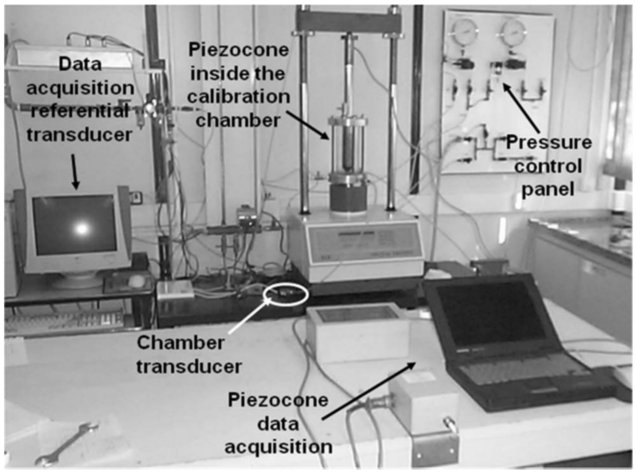


Figure 3. System for piezocone testing in laboratory.

Several piezocone tests were carried out at each site using the traditional porous element saturated with glycerin and the slot filter filled with automotive grease. For the first case, pre-drilling was executed down to the groundwater level in Curitiba-PR site and for one of two tests in São Paulo Site. Pore pressure dissipation data were recorded in São Paulo-SP (Sedimentary Basin) and Bauru-SP (residual tropical soil) sites.

3 RESULTS

3.1 *Laboratory tests*

Figures 4 and 5 present typical pore pressure response data using glycerin and grease, respectively. It can be seem in these figures that there is some delay in pore pressure transducer response using the slot filter with grease.

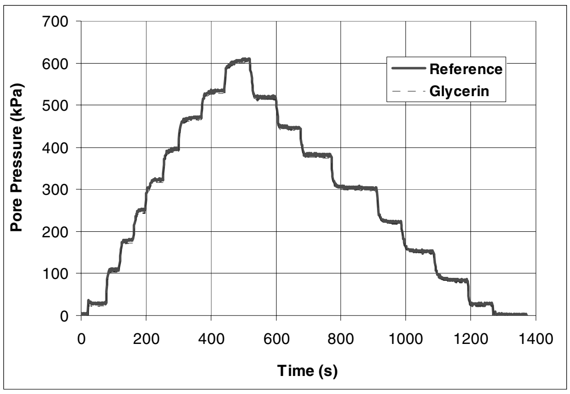


Figure 4. Pore pressure versus time curves using porous element with glycerin.

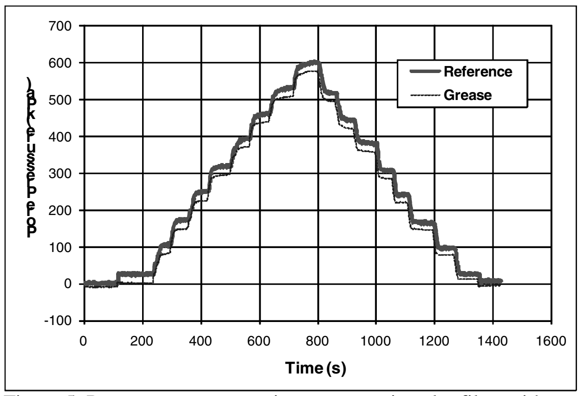


Figure 5. Pore pressure versus time curves using slot filter with grease.

3.2 *Field tests*

Figures 6 to 9 present pore pressure logs obtained during the piezocone tests carried out in Curitiba-PR, Campinas-SP, São Carlos-SP and São Paulo-SP sites, respectively. The pore pressure values were measured using the traditional piezo-element saturated with glycerin and the slot filter filled with automotive grease. The stratigraphic logging based on Standard Penetration Tests (SPT) carried out nearby the piezocone tests are also presented for the study sites.

4 INTERPRETATION

4.1 *Stratigraphic logging*

In Figure 6, the pore pressure records for Curitiba-PR site using the slot filter filled with grease helped identify the groundwater level at 4 m depth. The pore pressure log also reflected changes in soil profile, with higher or lesser intensity, as shown by tip resistance (q_c) and friction ratio (R_f) (Figure 6.a and 6.b). The records using grease is delayed every rod break. This effect is recovered right after re-starting the test. These delays also occurred in the tests carried out with glycerin, but with lesser intensity. It depends on the rod break interval and soil permeability. This behavior can be observed in the residual soil between 4 and 8 m depth (Figure 6.c).

Another aspect observed in Figure 6.c is that the pore pressure records using grease has similar trends to those recorded with glycerin for both side by side tests. However, the pore pressure values recorded with grease show significantly larger peaks than those registered with glycerin. It is not in accordance with the results presented by Larsson (1995), where pore pressure values recorded with grease were approximately 25 kPa lower than those recorded with the glycerin.

The pore pressure registers for Campinas-SP site presented in Figure 7 increase with depth showing excess of pore pressure before reaching the groundwater table, between 13 and 15 m depth. The excess pore pressure started between 7 and 10 m depth, when the slot filter was used. For the porous filter it just started at 10 m depth. This fact can be related to the suction in the unsaturated zone, causing desaturation of the porous filter, since no pre-drillings were done is this site.

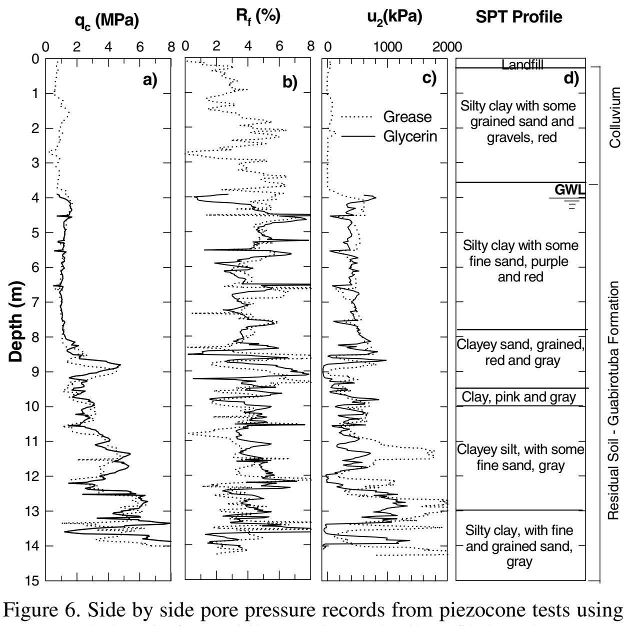


Figure 6. Side by side pore pressure records from piezocone tests using grease and glycerin for Curitiba-PR site, and soil profile based on SPT.

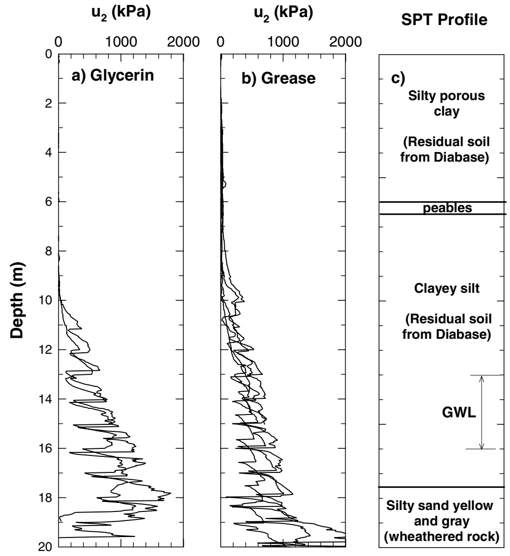


Figure 7. Pore pressure records from piezocone tests using grease and glycerin for Campinas-SP site.

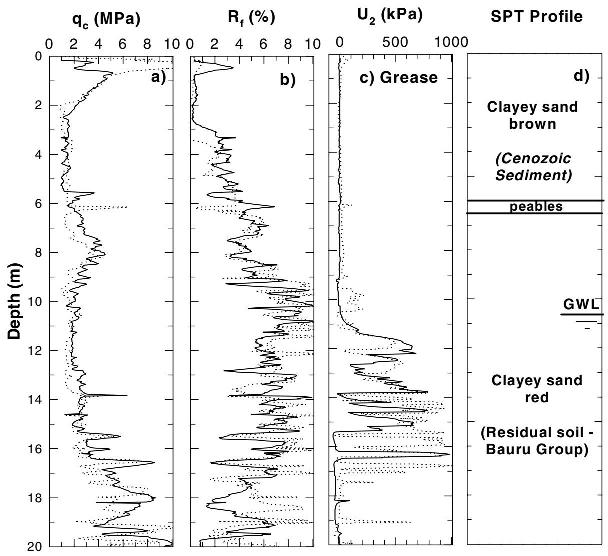


Figure 8. Pore pressure records from piezocone tests using grease for São Carlos-SP site and soil profile based on SPT.

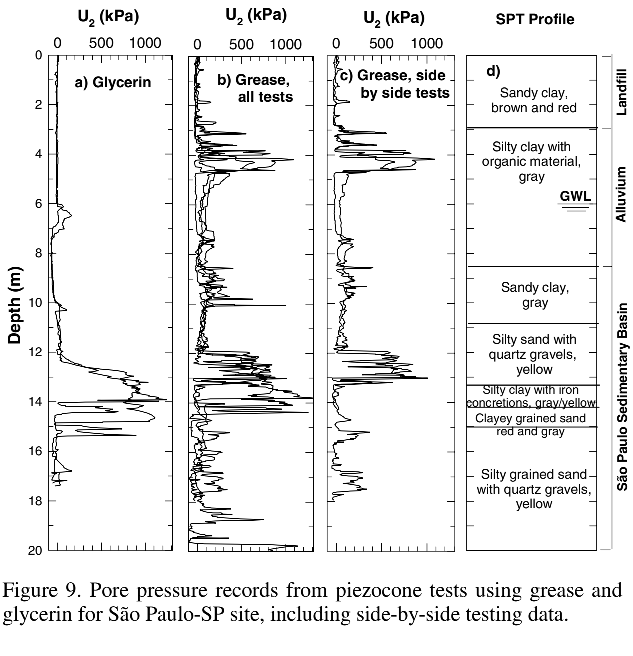


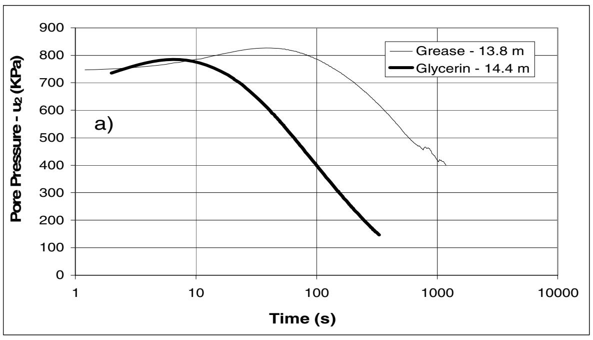
Figure 9. Pore pressure records from piezocone tests using grease and glycerin for São Paulo-SP site, including side-by-side testing data.

Figure 8 presents São Carlos-SP site piezocone tests results. The pore pressure records helped identification of the groundwater table, like for the Curitiba-PR site (Figure 6). The cone penetration is undrained or partially drained in the layer between about 11 to 16 m depth (Figure 8.c). This particular layer cannot be identified based on just q_c and R_f values and pore pressure records were useful for detailing soil profile.

Pore pressure data from piezocone tests using the slot filter with grease and porous element saturated with glycerin are presented in Figure 9 for São Paulo Sedimentary Basin. For this particular site, pore pressure records cannot be used to help identify the groundwater table position, at 6 m depth. High peaks of pore pressure (Figures 9.b and 9.c) appear above the groundwater table, been difficult to explain if they were caused by water retention or infiltration, or due to the heterogeneous soil profile, with presence of organic material at this depth. In the other hand, pore pressure log was additional information for soil logging and changes on pore pressure data were in accordance with q_c and R_f values. Piezocone tests using the slot filter with grease are consistent (Figure 9.b) and repeatable, as show in Figure 9.c, where it can be seem pore pressure data recorded by two side by side tests just 1 m apart.

4.2 *Dissipation tests*

The dissipation of the excess pore pressure generated during the piezocone pushing can be recorded when the penetration is stopped. Figure 10 shows two dissipation curves recorded for São Paulo-SP site, using slot filter filled with grease and the traditional piezo-element saturated with glycerin. These dissipation tests were performed in two adjacent tests, in a clay layer, located at 13.8 m and 14.4 m depth. The groundwater level was at 6.0 m depth and a pre-drilling was opened for the test using the piezo-element saturated with glycerin.



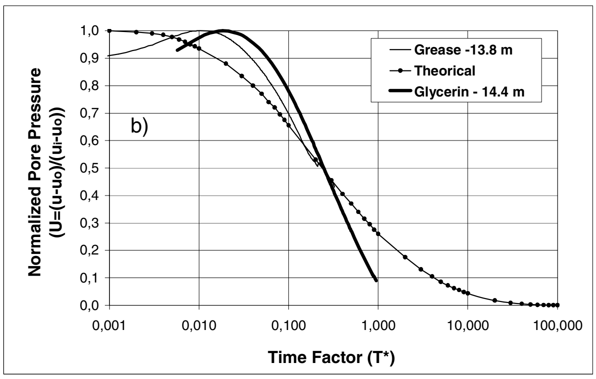


Figure 10. Pore pressure dissipation curves for São Paulo-SP site using glycerin and grease. Side by side tests.

In Figure 10.a, the dissipation curve recorded using slot filter with grease shows a delay comparing to the curve obtained with the glycerin, caused by the high viscosity of the grease. However, both experimental dissipation curves fitted reasonably well to Houlsby & The (1988) theoretical curve (Figure 10.b), with an elevation of the pore pressure in the beginning of the dissipation test. Since the time for fifty percent of dissipation (t_{50}) was higher for the grease, the horizontal consolidation coefficient (c_h) estimated using this technique was lower than for the glycerin results. This fact caused a decreasing of the time factor (T*) calculated for grease test results when compared with the glycerin test results (Figure 10.b).

The hydraulic conductivity (k) was estimated based on the data presented in Figure 10 and c_h values. Hydraulic conductivity values obtained using both techniques have the same order of magnitude: $k = 6x10^{-9}$ m/s for glycerin test and $k = 2x10^{-9}$ m/s for grease. Despite the restrictions of using the slot filter in a piezocone dissipation test, because there is no continuity between the water from the soil and from the pore pressure transducers, determined k values are in accordance with those expected for clayey soils.

5 CONCLUSIONS

Laboratory testing data showed a delay on pore pressure response when the slot filter filled with grease was used. However, the readings have the same pattern and order of magnitude.

The slot filter filled with grease was very useful to get additional information for stratigraphic logging, as well as to assist the definition of the groundwater table for Curitiba-PR site (Figure 6). The results obtained shown u_2 loggings very reproducible for all study sites. This technique offers significant advantages since it is much easier to handle, especially for tropical soils, where the groundwater table is usually deep and pre-drilling is expensive and time consuming.

The pore pressure records during the field tests carried out at clayey soils from Campinas-SP (Figure 7) and from São Paulo-SP (Figure 9) sites shown peaks even above the groundwater table using the slot filter technique. This fact shows the pre-drilling importance when the traditional porous filter is used to assess pore pressure loggings in tropical soils, since it can be desaturated by suction in unsaturated soil layers.

The pore pressure dissipation curves fitted reasonably well to theoretical for the studied soils and there is potential for estimating the horizontal coefficient of consolidation (C_h) and hydraulic conductivity (k) using the slot filter filled with grease. More field and laboratory tests are recommended for better understanding the behavior of the slot filter filled with grease or other kind of viscous materials, like vaseline, for example.

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