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Determination of Thermal Conductivity of Soil Using Standard Cone Penetration Test

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Abstract

The thermal cone dissipation test is a newly-developed method for determining thermal conductivity *in situ* based on temperature dissipation over time. The standard cone penetration test with pore pressure measurement (CPTu) is used. The cone heats up as it is pushed through the soil, due to the build-up of friction on the cone and rods. The dissipation of this heat can then be measured when penetration of the cone is stopped at intervals, and the thermal conductivity of the soil over that test interval determined. Three thermal cone dissipation tests (TCT) were conducted, the first test in soft clay with a high moisture content, and the second and third tests in clay containing a stiff sandy clay layer. The stiff sandy clay layer showed the more significant temperature increase on cone penetration. Using a previously developed correlation, the thermal conductivity was then calculated for each TCT. The temperature increase of the cone for the duration of each CPTu test was also recorded. While the TCT is a promising new test, it is suggested that further research is necessary to develop and refine the method.

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Keywords: Standard cone penetration, thermal testing, thermal conductivity

1. Introduction

Demand for clean energy has increased in recent decades, coinciding with raising energy costs, price fluctuations [1], and the need to reduce carbon emissions due to their proven link to global warming [2]. These factors have seen a rise in geothermal applications worldwide, with direct utilisation of geothermal energy seeing an increase of up to

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7.7% annually. Ground-source heat pumps represent the most common method of utilising low temperature geothermal energy [3]. The primary reason for the increasing use of geothermal resources is the increasing efficiency of geothermal energy capture, in addition to the environmental benefits. As the use of energy becomes more prominent, the need for rapid and reliable testing of the thermal parameters and response of the ground increases. Current state-of-the-art methods include the thermal response test (TRT). This test involves circulating a fluid through pipes embedded in the ground for a period of 48 to 72 hours. Under constant flow and power, the measured change in the temperature of the fluid over time enables the thermal parameters of both the vertical borehole and the surrounding ground to be determined [4]. As a result of the need for a borehole, the long duration of the test, and necessity for constant power over the test duration, the costs associated with a TRT can be significant. There has been significant research carried out exploring the TRT method and its different applications [5] to [9]. In addition, the results obtained using the TRT are only considered accurate to within 10% due to numerous uncertainties that cannot be fully accounted for [10]. Advantages of the TRT are that the ground is tested *in situ*, and the properties of the grout or concrete are included in the interpretation of the test, making it reasonably rigorous. An alternative method to the TRT for determining the thermal parameters of soils is by borehole sampling and laboratory measurements. However, a borehole is still required, samples will likely suffer disturbance, laboratory testing can be expensive, and the effect of the borehole, grout or pile cannot be accounted for. Hence both the TRT, and borehole sampling and laboratory testing have their drawbacks.

In this study, a newly-developed test, the thermal cone dissipation test (TCT) was used to measure the thermal parameters and response of the ground [11]. The test involves using the cone penetration test with pre pressure measurement (CPTu), with the addition of a soil moisture probe (SMP). The thermal cone dissipation test overcomes most of the drawbacks associated with the previously mentioned test methods in that it is rapid and less expensive. However, the TCT will not obtain thermal information for the borehole, grout or pile. This paper aims to increase awareness and knowledge of the TCT method for estimating the thermal parameters and response of different soil profiles, and to extend its application to other soil profiles and improve its reliability.

2. Test apparatus and procedure

The CPTu is a common test method used to determine soil profiles and to estimate soil parameters such as shear strength, deformation and permeability, among others. To adapt this test to the estimation of the thermal parameters of soils is straightforward, based on the temperature of the cone during testing and its dissipation when penetration is stopped at intervals. The measured dissipation of heat is then used to determine the thermal parameters of the soil over the test interval. Being a common *in situ* testing procedure, the use of the CPTu for determining thermal parameters may readily be implemented in most soil profiles. The purpose of this research was to evaluate the use of the standard CPTu test, with the addition of a SMP for the purpose of measuring temperature. The SMP used was from Geomil, and was capable of measuring temperature to within 0.04°C. The probe was mounted above a S15 (15 cm^2) piezocone allowing for the conventional CPTu data to be recorded from the same test. It was pushed at the standard rate of 2 cm/s and a number of temperature dissipation tests were undertaken at varying depths and within different soil layers. The piezocone was stopped at the desired locations for a period of 16 to 20 min, during which the temperature was recorded. In addition to recording the temperature decrease, the temperature increase per metre was recorded to allow an estimation of the expected increase resulting from friction on the cone and rods. The location of the SMP was approximately 900 mm behind the tip (see Fig. 1).

3. Field tests

Three CPTu tests were carried out at two different sites. The first two CPTu tests were carried out to a depth of 20 m with temperature dissipation testing at 5 m intervals, and the third test was carried out to a depth of 9 m with the temperature dissipation testing at 3.5 m, 7 m and 9 m depth. The first CPTu test was in soft clay with a high moisture content, while the second and third CPTu tests encountered a layer of stiff sandy clay overlying softer clay. The sites were located in Brisbane, Australia, which has a ground temperature potentially well-suited to low enthalpy geothermal energy for the heating and cooling of buildings. The thermal parameters of the ground would be a requirement for the design of geothermal energy systems, making the locations and test depths selected ideal for implementation of the TCT.