Bulgarian Chemical Communications, Volume 48, Special Issue E (pp. 115 - 119) 2016

Energy pile and ground temperature response to heating test: a case study in Brazil

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Geothermal energy piles have been used as space heating and cooling in residential and commercial buildings, as well as a sustainable and environmentally friendly alternative energy system. Brazil is currently the fifth largest buyer of air conditioner in the world, mainly due its tropical and subtropical climate. Seeing the need of studies about the use of energy piles in Brazil as a new solution for space conditioning and water heating, this paper presents some results of a preliminary investigation carried out in Brazil on the effect of the pile heating process on the ground temperatures, and the ground thermal recovery. For this study, a bored energy pile of 12 m length and 500 mm diameter was installed at the Geotechnical Experimental field of the University of São Paulo at São Carlos (Brazil). The experimental area is composed of an unsaturated tropical soil, including a lateritic superficial layer composed of colluvial clayey sand overlaying a residual sandstone soil, with average temperature of around 24°C. Temperature sensors were installed inside the pile and in the surrounding soil in order to provide the results of temperature variations during the heating loading-unloading. This paper presents the response of energy pile and ground temperatures to heating test at different depths.

Keywords: energy piles, unsaturated tropical soil, tropical and subtropical climate

INTRODUCTION

Ground-Coupled Heat Exchanger Systems have been used as acclimatization system for residential and commercial buildings [1]. This system was adapted to pile foundations in order to exchange thermal energy with the ground [2]. Energy pile systems have been implemented in many countries to replace an important part of electrical and other sources of energy.

Shallow geothermal resources have revealed a great potential of usable energy, especially in connection with pile foundations and by means of borehole heat exchangers [1]. Energy foundations are used for the environmental-friendly heating and cooling of the building. For this, the piles are installed with heat exchanger tubes [3].

The object of the design process of energy piles is to determine how much energy can be extracted or stored within the ground, or how many energy piles are required to achieve a certain energy demand. The energy attainable from the piles depends on the ground conditions and thermal properties [4]. Additionally, during heating and cooling cycles the energy pile expands and contracts, and this fact influences the pile-soil interactions [5] therefore, the thermal-mechanical response of energy piles should be evaluated in the design stage.

Brazil is the ninth largest consumer of electrical energy in the world [6], and much of this energy is used for air conditioning. Therefore, the present paper is part of an overall study proposed to investigate the use of energy piles in order to reduce the consumption of electricity in Brazil.

This paper explores: (i) the ground temperature response to heating (thermal loading condition that simulates operation of a geothermal pile during summer) by a pile heat exchanger; (ii) the radial heat transfer; and (iii) the ground recovery at a site in São Carlos, São Paulo state (Southeast Region of Brazil).

GROUND CONDITION AND PROPRIETIES

The key factor that motivates this study is that unsaturated tropical soils cover a significant part of the Brazilian territory, and the performance of heat exchanger piles in typical Brazilian soil and climate was not investigated before.

The pile heating test was conducted on a bored pile (12 m depth) installed in the Geotechnical Experimental field of the University of São Paulo at São Carlos (Brazil), consisted of unsaturated tropical lateritic soil, including a superficial layer composed of colluvial clayey sand (lateritic) overlaying a residual sandstone soil.

Fig.1 and Fig.2 shows the characterization of the soil at the site investigated and the results of the SPTs and CPTs. The mineralogical composition of the soil of this test site indicates that the fraction of quartz along the pile depth varies from 50 to 60%, and around 30% of the soil consists of aluminium and iron oxides, formed by lateralization process.

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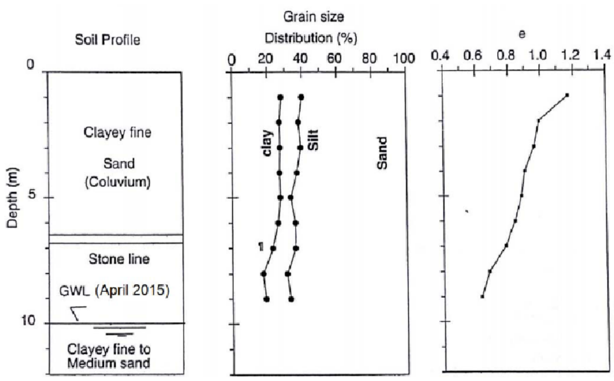

Fig.1. Grain size distribution and average void ratio of soil at the test site [7]

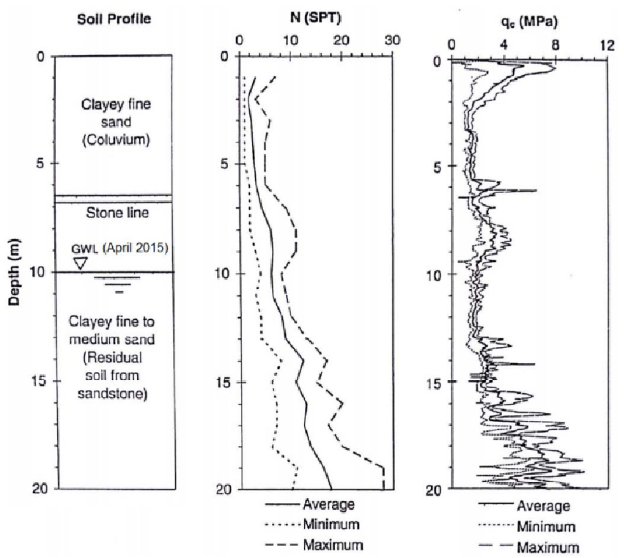

Fig.2. Results of SPT and CPT tests in the test site [7]

EXPERIMENTAL SYSTEM

The pile heating test was carried out using a thermal response test unit (Fig.3) built in Brazil for the current research. The unit consists of a 100-L water heater reservoir tank and a pump, two heating elements (two 1000 W independent resistances), a data logger, a turbine flowmeter and one inlet and one outlet for the heating fluid. The data logger monitored and recorded inflow and outflow heat-exchange fluid (pure water in the current case) temperatures, and the flow rate.

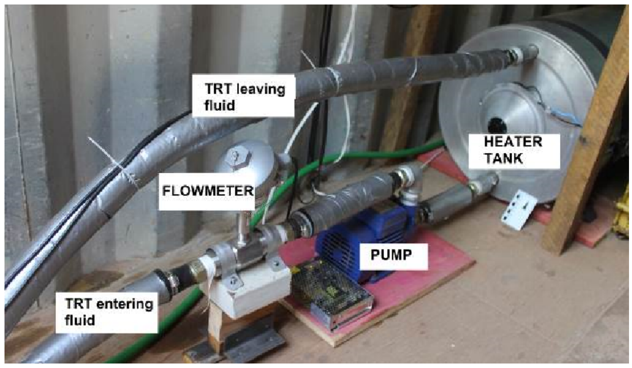

Fig.3. Thermal response test unit (water heater reservoir tank, water pump, and the turbine flowmeter)

For this investigation, a bored pile with 0.50 m diameter and 12 m depth was used as heat exchanger pile. As illustrated in Fig.4 and Fig.5, a polyethylene piping system (32 x 3,0 mm) was fixed to the reinforcement cage of the energy pile. Before the concrete filling, the cage with a double "U" loop was installed inside the pile in the borehole (Fig.5a).

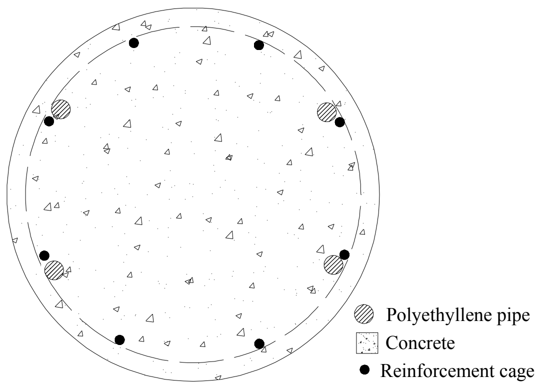

Fig.4. Cross-cutting section of energy pile

Fig.5. Installation of Pt100 temperature sensors (a) in the pile cage and (b) in the ground

The energy pile was instrumented with strain and temperature sensors placed at different depths. The thermistors (PT 100) were installed inside the pile and into the ground in two boreholes close to the pile (BH1 and BH2) at different depths: 3.5, 7.5, and 11.5 m, as described in Fig.6.

The boreholes were installed at distances of 1.0 m (BH1) and 2.0 m (BH2) from the pile center axis (Fig.6). These temperature sensors were attached to steel bars (Fig.5b), and after that the boreholes were filled with grout.

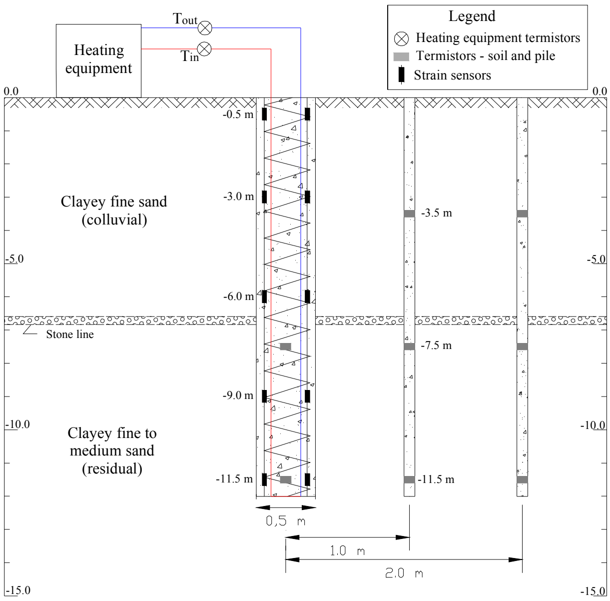

Fig.6. Scheme of the energy pile and instrumented soil boreholes (BH1 and BH2)

Fig.7 shows the temperature distribution of the underground soil at different depths (in BH2) and at the soil surface in a period started after 30 days after the heating test is completed. This figure illustrates that the soil surface temperature oscillates periodically, and at the depth of 3.5m the temperature is reduced compared to the results measured at 7.5 and 11.5mm depth. Probably the temperature of the soil at 3.5m is more affected by ambient air temperature.

HEATING TEST

The pipes of the heating test equipment were connected to the pipes inside the energy pile, and the system was filled with fluid (water in this case).

The heating test consists in circulating fluid thought an energy pile while supplying a constant amount of power to the fluid. The current heating test was conducted during a period of 8.5 days. Inflow and outflow temperature of the heat-exchange fluid, and the temperatures of the pile, the ground and the atmosphere were recorded continuously during and after the heating period.

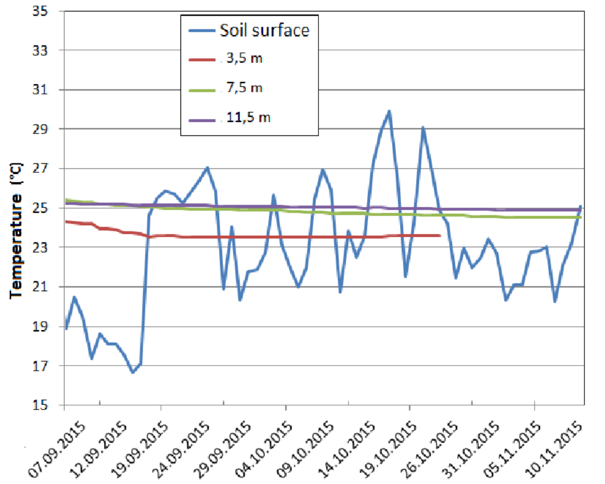

Fig.7. Ground temperature fluctuations measured at the borehole BH2 30 days after the end of heating test

After the end of the heating test, the pile and the ground were cooled by stopping the fluid circulation and letting the induced heat dissipate into the surrounding soil. Further details on the heating tests and the ground thermal properties are presented in Morais et al. [8].

The heating fluid temperatures measured within the pipes entering and leaving the pile during the heating period are presented in Fig.8.

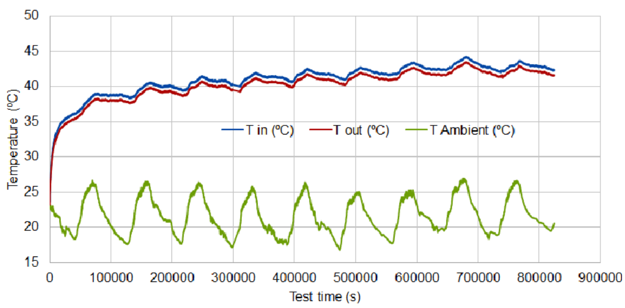

Fig.8. Fluid temperatures registered during the heating period

During the heating test, the temperatures inside the pile and in the two boreholes around the pile (1m and 2m distance from pile axis) were registered. The temperature sensor installed at 3.5m depth inside the pile was damaged; therefore, the measurements of temperature at 3.5m depth were obtained only inside the boreholes around the pile.

Fig.9 presents the pile transient temperature in response to the heat test. The temperature was found to increase within the pile during the heating test and decrease progressively after the test was stopped. This figure shows that the temperature inside the pile increased during the test, mainly at -7.5m depth (compared to the bottom part of the pile at -11.5m). During the heating test the temperatures kept rising as the days passed, however the rate of increase tended to stabilize. The temperature decreases rapidly and uniformly in the first 5 days after the heating test is completed.

Fig.9 shows an almost full thermal recovery after around 30 days. The pile takes around three times the amount of time used for the heating test to have full thermal recovery. After around 60 days cooling the pile returned fully to the temperature levels recorded before the heating test.

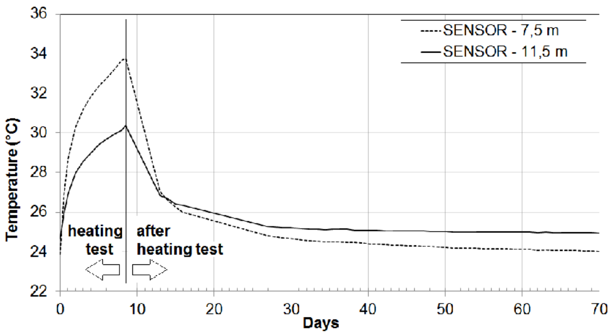

Fig.9. Energy pile temperature response to heating test

Fig.10 shows the ground temperature variation of BH1 (at a distance of 1.0 m from the pile axis) during the heating test. The maximum temperature of 27.5ºC was observed at 7.5 m depth at the end of the heating test. The minimum temperature was observed at 3.5 m depth, however, the amount of temperature increase during the test are similar at these both depths, and smaller at the pile base (-11.5 m depth). This figure also illustrates that, as observed inside the pile, the ground temperatures started to decrease as soon as the heating test was stopped. This shows the immediate ground thermal response during and after the heating test. The shape of thermal profiles is similar at all the selected time periods; therefore the ground thermal response to the heat test is uniform at all tested depths.

The heat test has increased 3.2ºC of the ground temperature, in distance of 1.0 m from the pile axis, at 3.5 m and 7.5 m. Therefore, it could be concluded from this observation that the heat moved in radial direction. Lower temperature increase was observed at 11.5 m depth, probably because in the vicinity of pile head and base the radial heat transfer are reduced.

Fig.10 indicates that the temperature drop is higher in the first 20 days after the end of the heating test. Heat dissipated faster in the beginning after the heating is stopped. The ground recovery took around three times of the heating test duration as observed earlier within the pile. Full thermal recovery took around 60 days to complete, however, at 3.5 m depth the recovery time is smaller (around 30 days) due to the influence of the ambient air temperature.

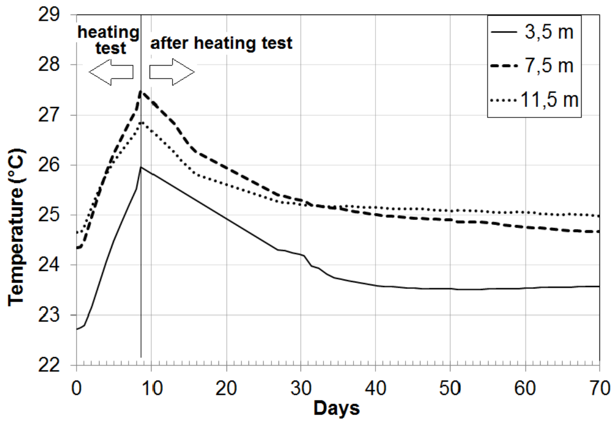

Fig.10. Ground temperature response of BH1 (at a distance of 1.0 m from the pile axis) to heating test

The ground temperature response in BH2 (at a distance of 2.0 m from the pile axis) is shown in Fig.11. This figure shows that the temperature increase immediately following the start of the heating test, and continues to increase after the end of the heating test.

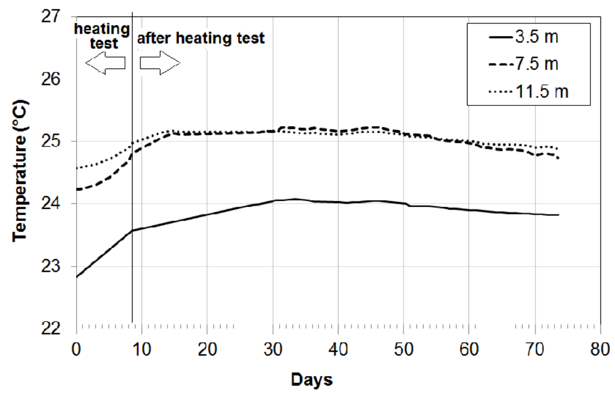

Fig.11. Ground temperature response of BH2 (at a distance of 2.0 m from the pile axis) to heating test

Fig.11 shows that at the horizontal distance of 2.0 m from the pile axis, there is little increase in ground temperature during the heating test. The maximum increase in temperature at 7.5 m and 11.5 m occurred 6 days after the completion of the heating test, and at 3.5 m depth occurred after 25 days (due to the influence of the ambient air temperature). The ground temperature started to decrease around 40 days after the heating test was stopped. The ground thermal recovery in BH2 is slower compared to the pile and in BH1.

Similar response of pile and ground temperatures of the current investigation was observed in the experimental work of Singh et al. [9].

Fig.12 shows the temperature distribution in a horizontal section at 7.5 m depth around the pile. The pile temperature increases from 23.9°C to 33.7°C during the heating test. The temperature 2 m from the pile center increased approximately 0.8°C compared the original soil temperature (24.2°C). Therefore, the temperature influence radius of the single pile after 8.5 days of heating should be slightly greater than 2 m (8 times the pile radius).

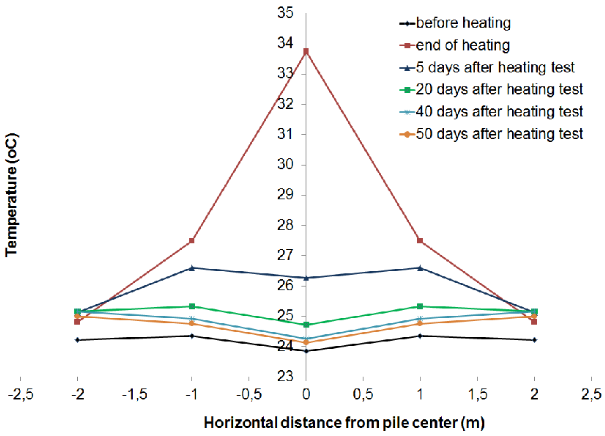

Fig.12. Temperature distribution around the pile in the horizontal direction at 7.5 m depth

A superposition effect may occur due to the thermal interaction of the close spacing residential energy piles [10]. The temperature influence zones for the grouped piles under the test conditions overlap. Therefore, the suggested spacing for the current case of energy pile should be larger than 2 m (8 times the pile radius).

Ghasemi-Fare & Basu [11] showed that the thermal influence zone around the heat exchanger pile extends approximately up to a radius of 11 times the pile radius after 60 days of heat rejection from the pile to the ground. These authors commented that the thermal influence zone continuously grows with time after heat rejection starts.

CONCLUSION

This paper describes the temperature response of a bored geothermal energy pile installed in an unsaturated tropical soil in Brazil with two observation boreholes.

The preliminary results obtained for a short heating period of 8.5 days showed that: (a) the energy pile subjected to a heating test was allowed to recover through natural heat dissipation; (b) the heat moved in radial direction; (c) the measurements of the temperature distribution around the pile in the horizontal direction indicate that the temperature influence radius of a single pile exceeds 2 m. The thermal interaction effects due to cooling of more than one pile should be evaluated in a latter study.

ACKNOWLEDGEMENTS

The authors are thankful to the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), for financial support by project Nº. 2014/14496-0.

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