Temperature response of an energy pile and nearby piles during a thermal performance test

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Introduction

The use of shallow geothermal energy is a promising alternative for the thermal comfort of buildings under the current scenario of global climate changes. The use of GSHP systems through ground heat exchangers (GHE) is an energy-saving solution to satisfy the cooling and heating needs of buildings [1, 2, 3].

Building deep foundations, that are already in the ground for structural/geotechnical support, could be used as ground heat exchanger (known as energy piles) being a very cost-effective solution [4]. The present study analyses the thermal performance of a Continuous Flight Auger (CFA) energy pile installed at CICS Living Lab, a building designed to test advanced sustainable solutions at the Campus of University of São Paulo, Brazil. The current work presents the temperature variation along the tested energy pile and in nearby piles, during a thermal performance test (TPT) carried out at the studied site, for the use of energy foundations in Brazil, a country with a tropical climate condition, where the demand for cooling is predominantly. These energy piles (Fig.2) were constructed and evaluated in the thesis of [5].

Case Study Overview

SITE CHARACTERISTICS

Standard Penetration Tests performed at the test site revealed that the subsoil is predominantly composed of medium dense slightly clayey sand, interspersed by thin clayey layers, with emphasis on a layer of very soft silty sandy organic clay, located at a depth of about 3.10 m. It was possible to identify a groundwater table approximately 3 m ~ 3.5 m-deep. Fig. 1, adapted from [6], presents the soil profile, the results of SPT tests and the variation of ground temperature with depth, obtained by [5] through temperature sensors installed in CFA piles.

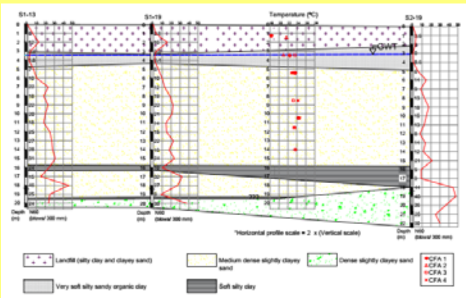

Fig. 1. Soil profile, SPT results and ground temperature variation along the depth (adapted from [6]).

ENERGY PILES AND INSTRUMENTATION

The TPT test was performed on a 15-m-long CFA heat exchanger pile, with active length of 10.5 m, diameter of 0.70 m and triple-U pipe configuration. This energy pile was instrumented with Pt-100 temperature sensors installed at different depths (1.3 m, 5.5 m, 8.0 m, 10.5 m, and 14.0 m). In Fig. 2, the tested pile is identified as TP.

Near the tested energy pile, other three energy piles were installed with similar characteristics, except for the configuration of the heat exchanger pipes (Tab. 1), identified as N1, N2 and N3 in Fig. 2.

Pipe configuration	Pile type	Radial distance from triple-U pile	Pt-100 sensors depths
N1	CFA	2.94D	at 3.5m, 5.5 m and 8.5 m depth
N2	CFA	2.87D	at 3.5 m, 5.5 m and 11.5 m depth
N3	CFA	3.22D	at 8.5 m and 11.5 m depth

Tab. 1. Characteristics of the surrounding energy piles (D = pile diameter).

The four energy piles were equipped with loops of high-density polyethylene (HDPE) heat exchanger pipes (inner diameter of 26 mm and outer diameter of 32 mm), attached to the reinforcement cage.

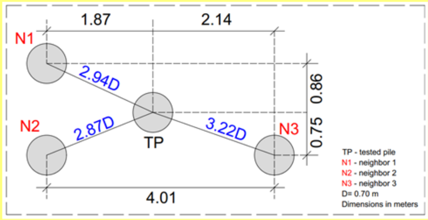

Fig. 2. Location of the energy piles (in meters).

THERMAL PERFORMANCE TEST

The TPT carried out in the present study was conducted during a period of 165 h with constant inlet fluid (water) temperature of 35ºC. Over the time, the heat was rejected in the ground, simulating a situation of demand for building cooling, as expected for São Paulo city. During the test, the flow rate was kept constant about at 13 L/min and the outlet fluid (water) temperature was monitored.

Fig. 3. shows the test equipment, that is composed by: a heater reservoir, with 0.1 m³ of capacity and two electrical resistors with 1500 W of power; a circulation pump; a turbine type flowmeter; Pt-100 sensors; and a high-resolution data acquisition system. Pipes and temperature sensors were insulated to avoid interferences of ambient temperature.

Fig. 3. Test equipment: (a) heater reservoir, (b) electrical resistor, (c) circulation pump, (d) turbine type flowmeter, (e) data acquisition system, and (f) insulated pipes connected to the piles.

Results

During the test, ambient temperature, inlet and outlet fluid temperatures were monitored. As expected, the inlet temperature was maintained approximately constant, after the desired fluid temperature has been reached. Furthermore, the flow rate also remained stable during the test, and it was possible to notice that, despite the large fluctuations in ambient temperature, the inlet and outlet temperatures were not affected, due to the good insulation.

The temperature variation along the tested triple-U pile (TP) was registered for all depths where there are sensors installed. As possible to see in Fig. 4, the temperature distribution along the pile depth was non-uniform. At the depth of 14.0 m, where no heat exchange pipes were installed, after 150h of pile heating the temperature did not change.

The influence of an energy pile operation (simulated by the TPT test) on the surrounding soil and on nearby piles was studied through measurements of temperature by Pt-100 sensors installed in the nearby piles N1, N2 and N3 (Fig. 5). After 150 h of pile heating, the temperature of the pile N3, located 3.22D distant from the test pile, almost did not change.

The nearby piles N1 and N2, located approximately 2.9D distant from the test pile, showed a slight increase in temperature after 150h of heating test, compared to the initial temperatures (after 15h of test), specially at the depth of 5.5 m, in soil layer with higher thermal and hydraulic conductivity of soil and groundwater flow velocity. On the other hand, the temperature registered in the nearby piles at the depth of 3.5 m (clay layer), practically no temperature change was observed, probably due to the low thermal conductivity of the clay layer.

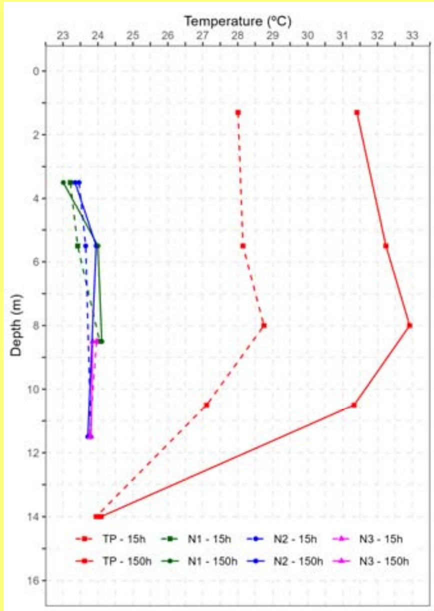

Fig. 4. Temperature in the tested pile – TP - and in the neighboring piles – N1, N2 and N3 - at horizontal distances of 2.94 D; 2.87 D and 3.22D, respectively, from the TP, after 15h and 150h of a heating test.

Conclusions

The main findings obtained in this work are present bellow:

- During the heating test under constant fluid temperature, the pile temperature varies non-uniformly along the depth, and practically did not vary in the zone without heat exchanger pipes.
- The temperature variation of the N3 pile section from -8.0 m to 11.5m depth, located at ~ 3.22D distant from the heated pile, was practically insignificant.
- The temperatures of the nearby piles N1 and N2, were slightly affected by the 150hs of heating test, specially at the depth of 5.5 m, pile zone in a layer with higher thermal and hydraulic conductivity of soil and groundwater flow velocity.;
- After approximately 40 hours of pile heating (fluid inlet temperature of 35ºC), the rate of pile temperature increase decreases considerably and become constant.

References

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