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Use of retaining wall anchors as geothermal heat exchangers

Uso de anclajes en muros de retención como intercambiadores de calor

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A novel application of retaining wall anchors as heat exchangers is proposed as an alternative or complement to pile geothermal exchangers. A full-scale in-situ study using anchors and piles was performed. Thermal response tests (TRT) were carried out in both types of systems. The installation process of the heat exchanger anchor is shown and results of the in-situ tests are compared in terms of their thermal parameters and performance. We demonstrate that the installation of required pipes is possible in the anchors with no mechanical interference during its installation and after anchor tensioning. The results show that the use of heat exchanger anchors is a valid alternative, with thermal performance similar to more common energy piles.

Keywords: TRT, energy piles, energy anchors, ground source heat pumps

Una nueva aplicación de anclajes para muros de retención como intercambiadores de calor es propuesta como alternativa a intercambiadores de calor del tipo pilotes. Se realiza un estudio a escala real usando anclajes y pilotes. Ensayos de respuesta termal (conocido como TRT) se ejecutan en ambos sistemas. El proceso de instalación del intercambiador de calor en anclajes es mostrado junto con resultados de ensayos in situ para comparar los parámetros termales y funcionamiento obtenido. Se demuestra que la instalación de tuberías necesarias para ejecutar este tipo de anclajes es factible sin generar interferencia mecánica durante su instalación o posterior tensado. Los resultados obtenidos de esta investigación demuestran que el uso de anclajes como intercambiadores de calor son una alternativa válida, con un funcionamiento termal similar a los más comunes pilotes de intercambio de calor.

Palabras clave: TRT, pilotes de intercambio de calor, anclaje de energía, bomba de calor geotérmica

Introduction

In recent decades low enthalpy geothermal systems have emerged as a renewable and environmentally friendly alternative to supply all or part of the energy requirements in the built environment. These systems use the soil's ability to maintain a relatively stable temperature throughout the year, which depending on the location and altitude ranges between 7° and 13°C at 10 – 15 m deep (Busby *et al.*, 2009). The temperature difference between the air and the ground is used for heating or cooling purposes through heat exchanger systems such as Ground Source Heat Pumps (GSHP) (IGME, 2014).

Relatively recent developments suggest the use of geo-structures such us piles, walls, tunnel linings, concrete slabs and anchors as ground heat exchangers (Adam and Markiewicz, 2009; Pasquier and Marcotte, 2012; Mimouni *et al.*, 2014). Energy piles (or pile geothermal exchangers) have been used extensively by now in different projects around the world. Different authors have performed tests at full-scale piles in situ (You *et al.*, 2014; Hamada *et al.*, 2007) and numerical and analytical models have been implemented (Franco *et al.*, 2016; Ghasemi-Fare and Basu, 2013). The idea is to use the construction of a structural element (the pile) for an application different to its original function (vertical or lateral load capacity). Therefore, these elements are used to save energy for heating without spending much extra money on its construction and implementation. Previous research in the area has shown that thermal piles are a viable cost effective solution for building foundations (see Table 1, von der Hude and Sauerwein, 2007; Schroder and Hanscke, 2003; Amis *et* *al.*, 2008; Wood *et al.*, 2009). Additional research has been performed to determine the influence of the heat exchange system on the mechanical behavior of piles (Hamada *et al.*, 2007; Brandl, 1998).

Piles made of reinforced concrete are used as foundation systems in buildings on soft or loose soil and also as embedded retaining walls. These piles naturally have a large area of contact with the surrounding soil, so they can work as heat exchangers saving the time and expenses associated with the drilling and cementing of more traditional geothermal borehole systems. In order to use them as heat exchangers, pipes are installed to carry the working fluid within the piles during the construction process (de Moel *et al.*, 2010). Systems built in this way are known as Energy Piles (EP). When piles are used as retaining walls usually require the use of anchors that can be passive or active. Active anchors have a post-construction force applied on them to avoid horizontal displacements of the pile.

In recent years there has been an increasing interest in the study of EP systems by different research groups (de Moel *et al.*, 2010; Brandl, 2006; Olgun, 2013), but more research to optimize their design, construction and operation is still needed. Table 1 summarizes the main features of energy pile projects around the world (found in the scientific literature). Energy piles have an average length of 19.4 m and an average diameter of 0.74 m, being shallower and wider than regular geothermal borehole systems.

The use of anchors as heat exchangers for low enthalpy geothermal systems has not been tested yet. Numerical modeling has been carried out to estimate the potential of heat exchange anchors on tunnels (Mimouni *et al.*, 2014; Adam and Markiewicz, 2009). However, more research is needed to study the design and energy performance of anchoring systems. This paper describes the installation and Thermal Response Tests (TRT) performed on energy piles and pre-stressed energy anchors (EA) on gravely soil. A comparison between the in-situ responses of both types of systems is discussed.

Thermal Response Tests TRT are usually carried out in geothermal boreholes to determine the thermal conductivity λ of the system, and the thermal resistance between the carrier fluid and the borehole wall, R_b, which control the efficiency and long-term sustainability of low temperature geothermal systems (Gehlin, 2002; Eklof and Gehlin, 1996; Ochoa *et al.*, 2020). TRTs reject heat into the system through the circulation of a heated fluid, while recording inlet and outlet fluid temperatures as shown in Figure 1 (Gehlin, 2002). A constant temperature difference between the inlet and outlet is reached after some circulation time, which indicates the system is sustaining a constant heat extraction or injection rate. Recorded data interpretation of temperature versus time to obtain values of thermal conductivity is done based on the Line Heat Source (LHS) model (Ingersoll and Plass, 1948). Although the derivation of LHS solution involves several simplifications of the problem that are not always satisfied in practice, several studies have concluded that its interpretation of TRT data for Borehole Heat Exchanger (BHE) systems are fairly accurate for designing these types of systems (Signorelli *et al.*, 2007; Ozudogru *et al.*, 2012; Zhang *et al.*, 2014). Specifically, TRT tests are useful for determining the ground properties and evaluating the influence of key parameters such as soil heterogeneity, groundwater flow, installation depth or spacing between pipes (Ozudogru *et al.*, 2012; Gehlin, 2002; Gustafsson, 2006).

The same concept can be applied to energy anchors as proposed in this work and shown in Figure 2a. The use of the LHS model for interpreting TRT results in energy anchors is justified by the overall dimensions of these systems (*i.e.*, borehole diameter and length), which are similar to EPs and the depth of the anchors, guaranteeing that surrounding ground thermally behaves like an infinite medium.

This work compares results of TRTs performed in an experimental facility to study the performance of EP and EA systems built at a university campus in Chile (Muñoz, 2011; Guggisberg, 2012). The purpose of this study is to verify the feasibility of installation of the heat exchange system on anchors and compare its response with an EP in the same soil profile. This article will briefly discuss the mathematical theory used to obtain the estimate of thermal conductivity, and will then present the details of the EP and EA systems. The installation sequence is shown and TRT results are presented.

Table 1: Summary of energy pile projects found in the literature with their main features (L: pile length, Quantity: number of piles, D: borehole diameter, D_{pipe} pipe diameter, heating capacity)

Project	L m	Quantity -	D m	D_{pipe} mm	Heating Cap. kW	Other features
Main Tower, Germany (von der Hude and Sauerwein, 2007)	35	260	0.9	-	-	Energy piles
Hochhaus Galileo, Germany (von der Hude and Sauerwein, 2007)	26-30	47	1.5	40	-	Energy piles
IG-Metal, Germany (von der Hude and Sauerwein, 2007)	20	48	1.2	25	-	Energy piles
Business Center, Rostock, Germany (Schröder and Hanscke, 2003)	19	264	0.35	-	220	Energy piles
Columbus Centre, Austria (Adam and Markiewicz, 2009; Brandl, 2006)	7-20	300	1.2	-	1300	35 x 35 cm^2 Energy piles Diaphragm walls
Euros Office Centre, Austria (Adam and Markiewicz, 2009)	-	242	-	-	1300	Energy piles Bottom slab
Spa Hotel, Austria (Brandl, 2006)	30	-	-	-	1300	Auger piles 1.6 GWh (winter)
Arts Center, Bregenz, Austria (Brandl, 2006)	21	-	1.2	25	120	Energy piles
Hotel Hall, Austria (Brandl, 2006)	18	320	0.5	25	123	Energy piles
Lainzer Tunnel, Austria (Brandl, 2006)	17.1	59	-	25	150	Energy piles
Vienna Metro Station, Austria (Brandl, 2006)	14	6	-	20	-	Heat exch. only in the first 14 m
Rehabilitation Center, Austria (Brandl, 2006)	14	143	1.2	25	-	Energy piles
Paper Mill Plant, Austria (Brandl, 2006)	14	143	0.4	20	520	Energy piles
EPFL, Lausanne, Switzerland (de Moel *et al.*, 2010)	25.9	146	0.6	35	520	Energy piles
Lambeth College, New Sixth Form Center, UK (de Moel *et al.*, 2010; Amis *et al.*, 2008)	25	146	0.6	-	320 (heat.) 460 (cool.)	Energy piles
Lambeth College, UK (Amis *et al.*, 2008)	9-30	143	0.6	-	-	Energy piles
Residential building UK (Wood *et al.*, 2009)	10	21	0.3	32	-	Energy piles
Keble College, Oxford University, UK (Brandl, 2006; de Moel *et al.*, 2010)	9-15	53-115	0.45-0.75	- -	85 (heat.) 65 (cool.)	Energy piles
Building, China (Gao *et al.*, 2008)	25	-	0.6	20	-	Energy piles

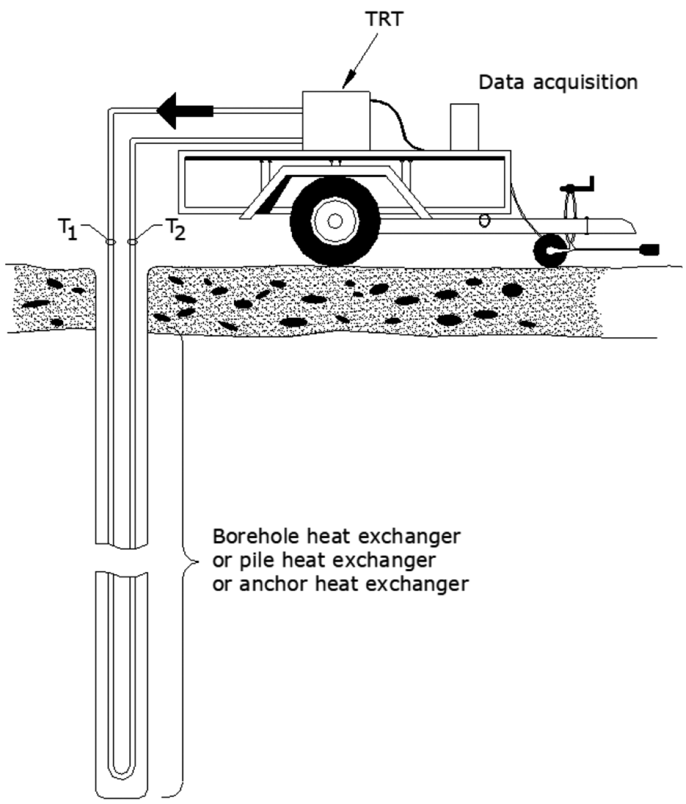

Figure 1: Schematic illustration of the setup for a thermal response test TRT (Gehlin, 2002), T_{in1}: inlet temperature, T_{out2}: outlet temperature.

Line heat source model

It is assumed that geothermal heat exchangers (in our case EP and EA) behave as a line heat source in an infinite, homogeneous and isotropic domain with a uniform initial temperature. Furthermore, we assume that the system instantly transfers a finite amount of uniform heat flow in the radial direction due to the temperature difference between the inlet and outlet sections on the pipe. Under these assumptions, it is possible to find an analytical solution to estimate the temperature variation versus time during the transient regime. This conceptual and mathematical model, known as the Line Heat Source (LHS) model, is based on Kelvin's line source theory and has been for a long time the method of choice to interpret the behavior of BHE system (Ingersoll and Plass, 1948; Morgensen, 1983). Then, the temperature around the BHE system as a function of time t, and radial distance r from the borehole axis, can be calculated as:

$$T(r,t) - T_{surr} = \frac{\dot{q}'}{4\pi\lambda} Ei\left[\frac{r^2}{4\alpha t}\right] \quad (1)$$

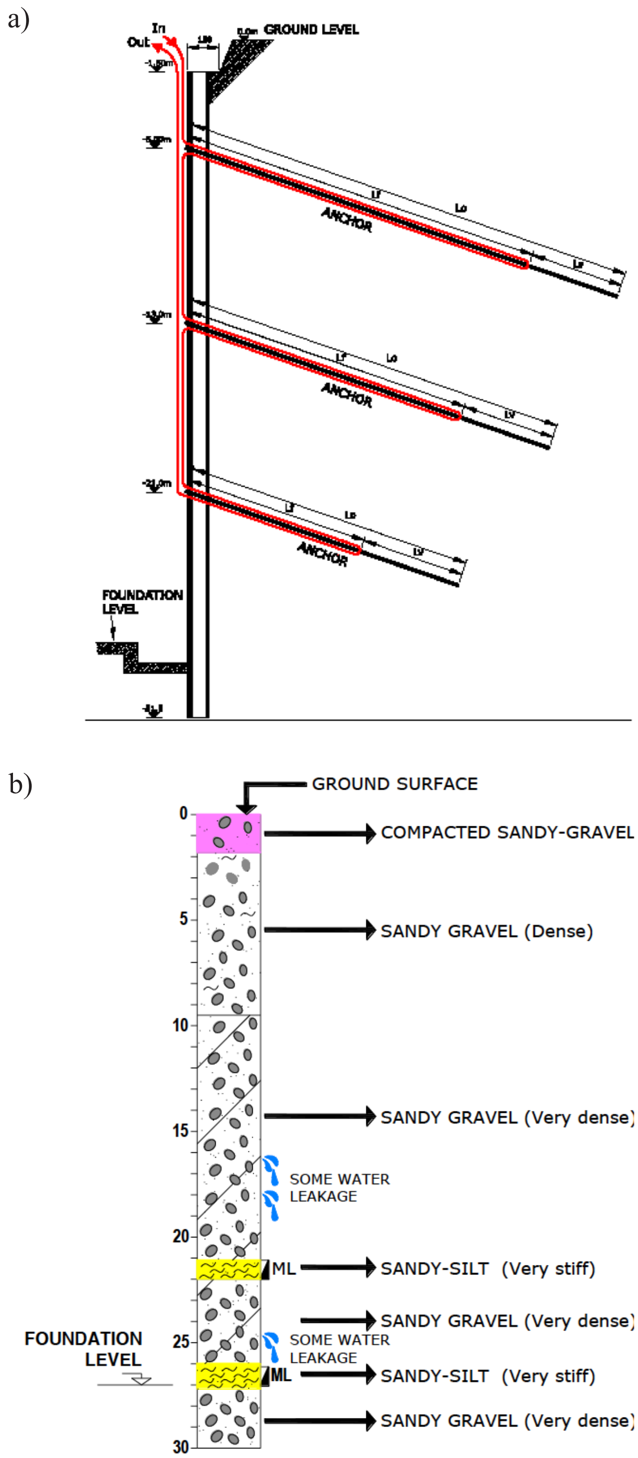

Figure 2: Schematic illustration of: (a) piles with anchors, and (b) soil stratigraphy

where $T(r, t)$ is the ground temperature at a location r and time t, T_{surr} is the initial ground temperature, $\dot{q}'$ is the heat injection rate per meter of borehole length, λ is the thermal conductivity, α is the thermal diffusivity of the ground, and Ei denotes the exponential integral function. For small values of the argument of the exponential integral function, *i.e.* large times or short distances from the source, the solution can be approximated by (Ingersoll and Plass, 1948, Carslaw and Jaeger, 1959, Roth *et al.*, 2004):

$$T(r,t) - T_{surr} = \frac{\dot{q}'}{4\pi\lambda}\left[\ln\left(\frac{4\alpha t}{r^2}\right) - \gamma\right] \quad (2)$$

where γ is Euler's constant. The error of this simplification is less than 2% for times greater than $5r^2/\alpha$. Assuming steady-state heat injection to the ground, the thermal resistance between the carrier fluid and the borehole wall R_b is defined as (Eklof and Gehlin, 1996):

$$R_b = \frac{T_f(t) - T(r,t)}{\dot{q}'} \quad (3)$$

In equation (3), T_f (t) corresponds to the local carrier fluid temperature. T_f will vary along the length of borehole, but it has been demonstrated that using a mean fluid temperature yields good results (Eklof and Gehlin, 1996). Let *T*(t) be the average fluid temperature of circulation fluid, given by:

$$\bar{T}\,(t) = \frac{T_{in} + T_{out}}{2} \quad (4)$$

T_{in} and T_{out} are the inlet and outlet temperature of fluid, respectively. Then, by combining equations (2) and (3), $\bar{T}(t)$ can be expressed as a simple linear relation (Eklof and Gehlin, 1996; Roth *et al.*, 2004), evaluating the ground temperature at $r = r_b$, where r_b is the borehole wall radius:

$$\bar{T}\,(t) = k\ln(t) + m \quad (5)$$

k and *m* are, respectively,

$$k = \frac{\dot{q}'}{4\pi\lambda}Ei \quad (6)$$

$$m = \frac{\dot{q}'}{4\pi\lambda}\left[\ln\left(\frac{4\alpha}{r_b^2}\right) - \gamma\right] + T_{surr} + R_b\dot{q}' \quad (7)$$

Equation (5) is often used in the interpretation of TRT results by representing $\bar{T}(t)$ versus the natural logarithm of time. The curve slope is compared to (6) to obtain an estimated value of soil thermal conductivity, λ. In this last expression and according to the LHS model, $\dot{q}'$, heat injection per unit borehole length, is assumed constant and equal to

$$\dot{q}' = \frac{\dot{m}c(T_{in} - T_{out})}{L} \quad (8)$$

where $\dot{m}$ is the fluid mass flow rate through the pipe, *c* is the fluid specific heat, and *L* is the depth (length) of the borehole. Once the thermal conductivity is obtained, the thermal resistance R_b can be estimated from (5) with knowledge of T_{surr} and $\dot{q}'$:

$$R_B = \frac{\bar{T}(t) - T_{surr}}{\dot{q}'} - \frac{1}{4\pi\lambda}\left[\ln\left(\frac{4\alpha t}{r_b^2}\right) - \gamma\right] \quad (9)$$

Energy anchor design and construction

A retaining wall was designed to be able to construct a vertical excavation of approximately 30 m deep as part of a new building (see Figures 2a and 3). The chosen wall retaining system for this project consists of 1 m diameter bored piles made of reinforced concrete. Each pile is restrained by 3 anchors at different levels (Figure 2a). The anchor diameter is 12 cm. The subsoil consists on medium-dense to dense sandy gravel from fluvial origin as it is shown in Figure 2b. The water table is located deeper than the bottom of the excavation, so no influence is expected. Moisture content varies on the subsoil mainly due to old pipes with water leakage.

The heat exchange system in the pre-tensioned anchors consists of 3 different branches: 17.5 m, 14.5 m, and 9.5 m long HDPE pipes with a diameter equal to 22 mm. The three branches are installed from top to bottom, with the 17.5 m branch being in the top of the system and the 9.5 m branch at the bottom. The total piping length in the EA system is 83 m, while the total borehole length (comprising three anchors) is 41.5 m (Figure 2a). In the case of EP there are two configurations used as shown in Figure 4a. The energy piles with a triple U system shown on the left side of Figure 4a and in Figure 4b are reported in this paper. The EP pipes are 32 mm in diameter, with a total pipe length of 170 m for both configurations. The total borehole depth for the EP system is 30 m. Similar results were obtained with the second EP configuration. Smaller diameter pipes (22 mm) were used in the EA system because of lack of free space between the cable (from the mechanical anchor) and the borehole constructed.

Figure 3: View of vertical excavation and instrumented energy piles (indicated by an arrow)

a)

b)

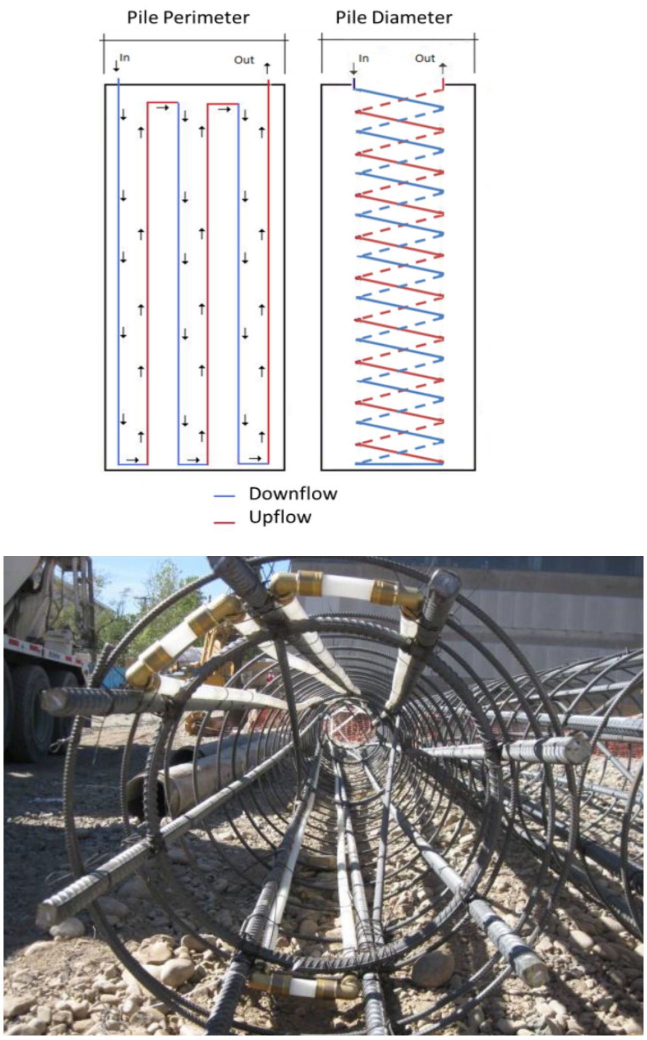

Figure 4: (a) Configuration of HDPE pipes in the energy piles and (b) energy pile being assembled on the field

In situ soil temperature profiles (before construction of the retaining wall) were measured at different times of the year and are presented in Figure 5 for three months. The months of June and September correspond to the beginning and end of the Austral winter season, respectively. March corresponds to the end of the summer season in the Southern Hemisphere. The results indicate that at depths greater than 5 m the ground temperature remains at a constant value in the range of 14 – 17°C, independent of the season in the year.

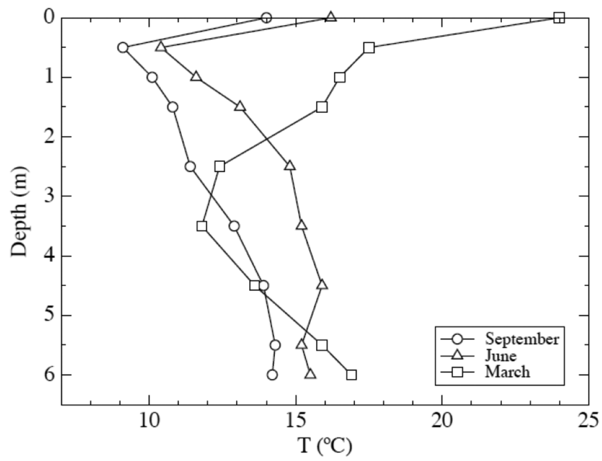

Figure 5: Ground in-depth temperature measurements for winter (June - September) and summer (March) months

As it is a common application, no details are given for the heat exchangers used in the piles. In the case of the anchors, it was necessary to modify the outside end of the anchor to pass the heat exchangers piping. Figures 6 and 7 show the necessary steps to install the mechanical anchor and its corresponding heat exchange system. The first step is to drill the borehole (Figure 6a). Once the required length is reached the heat exchanger tubes and steel cables are installed together (Figure 6b). Finally, the cables pass through a metallic beam and are post-tensed to the required load according to the geotechnical design (cf. Figure 7). HDPE pipes are located behind the beam and then connected to new pipes that reach the TRT equipment. The difference between a standard anchor and the anchor with the heat exchange system is shown in Figure 7. Once the excavation advances deeper the anchors are stressed. When the construction of the wall of the building is finished, the anchors are de-stressed. Installation of energy anchors has proven to be feasible and therefore can be implemented in pile supporting anchors in future projects.

a)

b)

Figure 6: Installation of Energy Anchors: a) ground drilling, and b) cable and HDPE pipes are inserted.

a)

b)

Figure 7: Detail of anchor head; a) Energy Anchor and b) standard anchor

The installation of the heat exchange system was fast, with no major inconvenient found. The metallic beam has an additional cost, however as long as the building is being constructed from bottom to top and the anchor loads are released, this beam can be removed from the site and used for another similar project. Therefore, the cost of installation is related to the heat exchange system itself and an approximate 10 to 20% in increase of installation time with respect to anchors without the system. No interference was detected with the operation of the mechanical anchor, and once the anchor load was released the heat exchange system was able to continue functioning properly.

Thermal response testing

Figure 8 shows the Thermal Response Test TRT equipment designed and built for this research and details of its main components. Mobile TRT equipment has been used for more than 20 years now. Good reviews of the test equipment can be read in Sanner *et al.* (2005) and Gehlin (2002). The available electrical heater has a maximum power of 4500 W at a maximum water flow rate of 10 l/min, and is driven by a 2 HP centrifugal pump. The system can deliver a maximum of 300 kPa water pressures and it has a tank with a 400 l capacity. The system is used at flow rates of 6 and 10 l/min (turbulent flow), with an outlet pressure of 135 kPa, to replicate the operating conditions for the energy anchor and energy pile systems, respectively. The TRT unit measures the temperature at the exit of the equipment, which corresponds to the circuit inlet temperature (T_{in}), and the outlet temperature before the water enters the TRT unit (T_{out}) using a data acquisition system connected to a computer. Based on the operational experience, the current prototype has been improved, and includes a deaerator, an activated charcoal filter, a rotameter for flow measurement and a manometer for pressure control. To avoid the influence of ambient conditions on thermal response tests, the unit was isolated with a 50 mm thick glass wool layer throughout all its exterior walls.

Figure 8: TRT equipment built for this research

It is known that part of the power of a water pump is converted to heat. The amount of heat contributed by the pump operation was quantified through measurements using a swimming pool filled with tap water, and operating the TRT equipment with the heater off. These temperature measurements (inlet and outlet) on the circuit are shown in Figure 9. With knowledge of the thermophysical properties of water, the results show that water pump delivers an additional 225 W of heat to the water in the heating circuit. This amount was considered in the analysis of the thermal performance of the energy piles and energy anchors, incorporating this power to the heater power considered in each case.

The test procedure first involves the filling of piping circuits in the circuit to be tested (*i.e.* energy pile or energy anchor), by opening the valve to the main water tank and activating the centrifugal pump. It has been determined that the EP systems reported in this study require 127 l to be filled, while the EA systems require 55 l. Once the circuit is filled, the main water tank valve closes and the test begins.

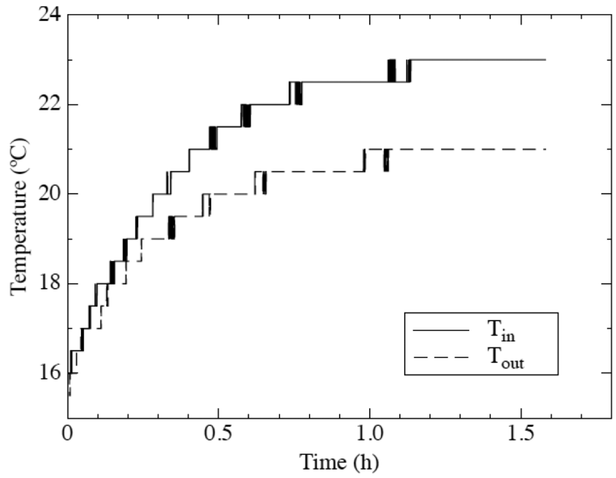

Figure 9: Measurements performed on a swimming pool to estimate heat contribution of the water pump in

Experimental results and discussion

All the thermal response tests were carried out in winter, during the month of August. Ambient temperature fluctuated in the range of ~10° and 20°C during the testing, as can be seen in Figures 10, 11, and 12. TRT test results in the EP monitored on site are shown in Figure 10.

These results are used to deduce the system thermal conductivity, as it will be discussed later. TRT tests were carried out in two anchor systems, which are composed of multiple anchors (EA1 and EA2). For both systems tests were performed in different days with only minor differences attributed to changes in the soil moisture content due to water leakage observed in old pipes.

Figures 11 and 12 show examples of the test results performed in these anchor systems. The time to reach steady-state conditions was between 6 and 10 h, and it is believed to be dependent on the natural moisture content on site (Bravo, 2014). TRTs were developed to measure the thermal performance of boreholes, where homogeneous soil conditions around the geothermal exchanger are assumed. In the case of this experimental installation, the energy anchors (EA) system has certain

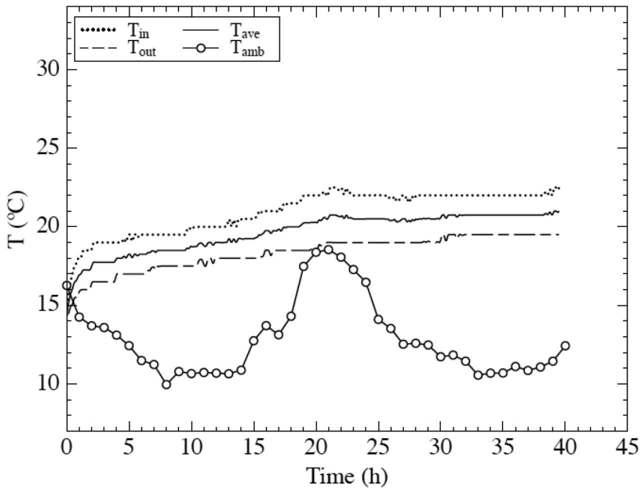

Figure 10: TRT test performed on an Energy Pile during the winter season, with a flow rate of 10 l/min.

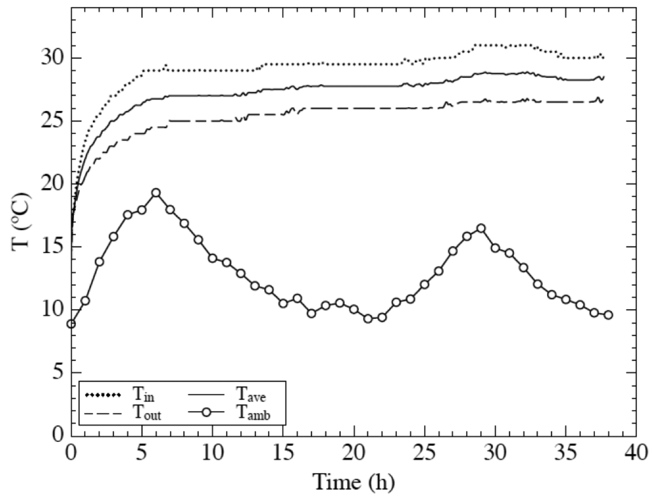

Figure 11: TRT test performed on an Energy Anchor 1 system (EAl) during the winter season, with a flow rate of 6 l/min.

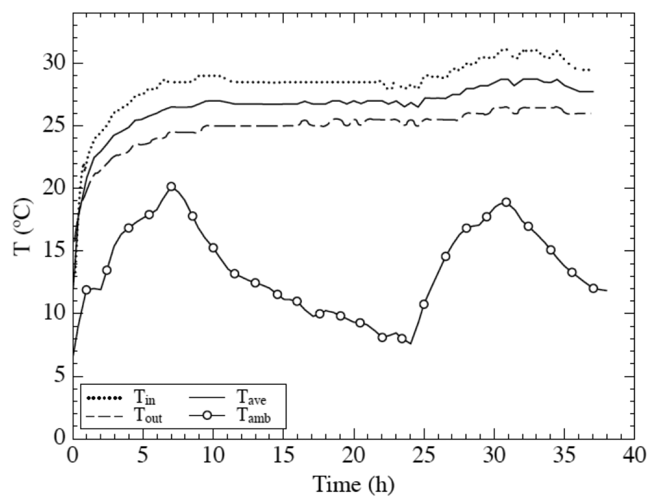

Figure 12: TRT test performed on an Energy Anchor 2 system (EA2) during the winter season, with a flow rate of 6 l/min.

peculiarities that make thermal losses and gains inevitable as a result of daily thermal oscillations. The vertical pipe that connects the inlet and outlet to each section of the EA system is exposed to environmental conditions as shown in Figure 2a, since it is only covered by a layer of thermal insulation provided by a polyurethane foam tube. Figure 12 shows the stabilization of the temperature in the first 6 to 10 h and then a thermal gain that coincides with the variation in ambient temperature (from approximately 25 h onwards). The undisturbed soil measurements made in the EA circuits are 16.2°C for winter measurements and 16.7°C for late winter (Bravo, 2014).

Estimation of ground thermal properties

Figure 13 shows a sample plot of $\overline{T}(t)$ versus $\ln(t)$ used to obtain the soil thermal conductivity λ (equation (5)). A critical time t_c of less than 7.8 h was not considered for the determination of λ of the EA according to Signorelli *et al.* (2007) and Bravo (2014). Table 2 shows a summary of the results obtained on the field. Five TRT tests were conducted between August and September (end of winter). The average thermal conductivity obtained in the two tests involving EA1 is 2.19 W/m·K. This value is 18% greater than the average value obtained for two tests on EA1 (1.86 W/m·K). The test on the EA2 system shows a higher thermal conductivity than EA1 due to the presence of higher moisture content in the ground as discussed previously (8% increase). The results are in good agreement with published data for gravel soils, which states that thermal conductivity in the temperature range of 0° to 20°C is 2.0 W/m·K (Farouki, 1981).

Using thermophysical data for sand and gravel from Farouki (1981), estimation of the thermal resistance between the fluid in the ground heat exchanger and the borehole wall was carried out. In the calculations a value for the specific heat of the soil of c_p = 1100 J/kg·K was used, while the soil density was taken as ρ = 2850 kg/m^3. The thermal diffusivity of the soil was calculated using the thermal conductivity values obtained with the TRT test analysis. The thermal resistance for the EA and the EP are, 0.180 K·m/W and 0.0757 K·m/W, respectively. These values are similar to previously published values (Eklof and Gehlin, 1996; Gehlin, 2002).

Table 2: Summary of TRT measurements for energy piles and energy anchors conducted in this work and estimated soil thermal conductivity

System	Soil thermal conductivity λ_{LS}, W/m·K
Energy Pile 1 - Triple U (Test 1)	2.27
Energy Pile 1 - Triple U (Test 2)	2.10
Energy Anchor 1 (Test 1)	1.89
Energy Anchor 1 (Test 2)	1.83
Energy Anchor 2 (Test 1)	1.98

Comparison of EA versus EP performance

The average power output for the energy piles tested on the field was equal to 1395 W (1.4 kW), corresponding to a fluid flow rate of 10 l/min. This value is similar to previously tested EP, as for example You *et al.* (2014). For the case of EA the average output power value was 1380 W (1.4 kW) for a fluid flow rate of 6 l/min. These power outputs yield a linear heat injection rate $\dot{q}' = 42.47$ W/m for the energy piles and $\dot{q}' = 74.52$ W/m for the energy anchors. The power output obtained on the energy anchors is similar to the energy piles, but the EAs have a higher heat injection per unit depth of borehole. Due to the fact that in the case of EA the water flow rate was lower, it can be argued that its performance is better, and therefore for higher flow rates a higher power output is expected, as previously shown by Xia *et al.* (2012). Note, however that a limit is reached because the temperature difference between the inlet and the outlet of the heat exchanger is inversely proportional to the flow rate, $\Delta T \sim Q^{-0.2}$, where Q is the volumetric flow rate (Cecinato and Loveridge, 2015).

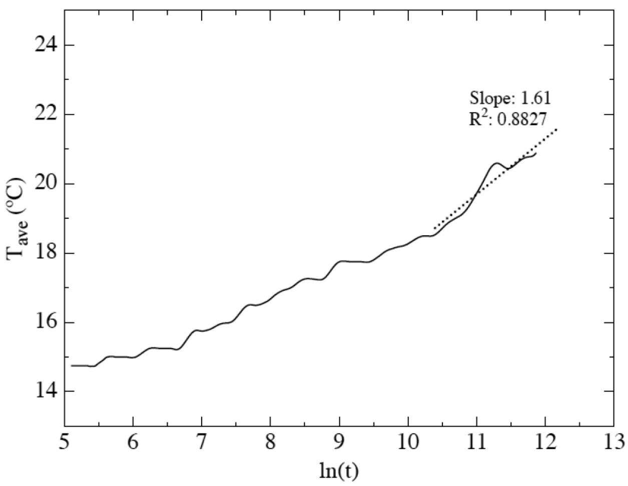

Figure 13: Plot of the average temperature versus ln(t) for the EA test, for the ground thermal conductivity estimation

The results show that installing energy anchors on a GSHP is a good alternative to increase the installed system capacity. Although the fact that the boreholes in the retaining anchors are shallower means that the energy anchors will be subject to greater variations in the ground temperatures caused by seasonal temperature changes, the tests show a very similar performance. Further testing is required to prove whether the thermal performance of an EA system is maintained throughout the year or only during the cold season (Figure 5) and to determine the minimum depth to attain an acceptable performance in these systems.

Conclusions

A novel installation of a heat exchange system, whose main purpose is to transfer load from retaining wall to the soil in order to maintain stability, was designed and implemented in this project. Details of the installation of this system on the field and its performance during testing were reported. The results indicate that energy anchors EA can be a feasible and convenient heat exchange system that could be used separately or together with energy piles EP to increase the installed capacity of a GSHP system. As the building industry tends to build larger and higher structures, the increased energy demand of these buildings can be supplied to a greater extent using combined EP and EA systems.

The experience on building and installing a GSHP system consisting of both energy piles and energy anchors has shown that the installation of a heat exchange system on retaining anchors is possible and does not create a large increase in installation time with respect to more traditional borehole heat exchange systems. This results in no significant increments in construction times or costs. Furthermore, we observed no negative effects during installation or during the heat injection phases on the anchors.

Thermal response tests were successfully performed on both the energy pile and energy anchors, using a custom built TRT apparatus. The thermal performance of the EA system tested in this study proved to be similar to the performance of EP system under similar ground conditions. The power output of both systems was similar, although the water flow rate for the EA system was lower, indicating that higher heat injection rates could be achieved by increasing the flow rate. The test results also show that EAs are dependent on the soil moisture content, showing a similar behavior to EP. However, further tests are required to characterize the thermal and operational performance of EA systems with respect to energy piles, including longer test periods to quantify the performance over different seasons and in different types of soils, different from the sandy gravel that existed in the site of the reported tests.

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