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Applications of Geothermal Heat Exchange in Civil Engineering Infrastructure

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ABSTRACT

This paper focuses on design issues and key performance metrics for different applications of near-surface geothermal heat exchangers in civil engineering infrastructure, including energy foundations, landfills, and thermally active embankments. Incorporation of heat exchangers into civil engineering infrastructure has the positive aspects of decreasing the installation cost of geothermal heat exchangers, permitting access to novel heat sources, and potentially improving the primary function of the infrastructure. However, other issues must be considered in design to ensure that these systems are feasible from the perspectives of both heat exchange and serviceability.

1. INTRODUCTION

Commercial and residential buildings consume approximately 39% of the primary energy in the U.S., which corresponds to the generation of nearly 43% of the U.S. carbon emissions (EIA 2008). Development and characterization of new technologies to reduce building energy consumption are important goals for the U.S., as well as around the world, from both economic and environmental perspectives. Of the energy used by buildings, heating and cooling systems account for approximately 20%, emphasizing the need to improve their efficiency.

Ground-source heat pumps (GSHPs) are a commonly used technology to provide heating and cooling systems for buildings by using subsurface soil and rock as a heat source or sink. Conventional GSHP systems involve circulation of a heat exchange fluid through closed-loop heat exchange tubing installed in vertical boreholes or horizontal trenches outside of the building footprint. GSHPs have a relatively high efficiency compared to other heating and cooling technologies due to the relatively steady temperature of the subsurface (Preene and Powrie 2009). Their efficiency has been verified through field studies, and a wide set of tools has been developed for their design (Kavanaugh et al. 2007). However, their high up-front installation cost is a barrier to their implementation (Hughes 2008). To address this issue, ground-source heat exchangers are being incorporated into different civil engineering infrastructure. This approach reduces installation costs for GSHPs by using infrastructure for multiple purposes (Brandl 2006; Adam and Markiewicz 2009). The heat exchange elements of a GSHP system represent only a small fraction of the overall material cost in most civil engineering infrastructure. Although greater labour costs and construction site coordination efforts are expected for thermally-active civil engineering systems, the several successful installations to date indicate that these challenges can be overcome with proper planning.

Examples in which heat exchange elements have been incorporated into civil engineering infrastructure include building foundations, diaphragm walls, tunnel linings, pavements, and sewers (Brandl 1998; Laloui et al. 2003; Brandl 2006; Adam and Markiewicz 2009). Of these approaches, implementation of GSHPs into building foundations (i.e., energy foundations) has been widely adopted throughout the world, including both successful pilot test projects and implementation into buildings. Future opportunities to enhance the implementation of GSHPs include the exploitation of man-made heat sources which may provide greater thermal energy than the subsurface soil and rock. This includes waste-water treatment plants and municipal solid waste (MSW) landfills (Coccia et al. 2012; Grillo et al. 2012). Heat exchange may also be used to improve the processes in these systems. Other types of thermally-active civil engineering systems may use spurious heat to improve the primary function of the system. Examples include bridge-deck de-icing systems (Chiasson and Spitler 2001), thermally-active mechanically stabilized earth (MSE) retaining walls (McCartney 2012), or thermal drains (Abuel-Naga et al. 2006).

The objectives of this paper are to summarize design issues and key performance metrics from recent studies on geothermal heat exchange systems in energy foundations, MSW landfills and thermally active MSE walls. Information presented include typical ambient temperature profiles needed to characterize the thermal resource, thermal conductivity ranges for the different materials, thermo-mechanical design considerations (worst-case versus performance-based design), and geometrical configuration recommendations for heat exchangers.

2. ENERGY FOUNDATIONS

2.1 Overview

Energy foundations have been implemented in structures in Europe (Brandl 1998, 2006; Laloui et al. 2003, 2006; Adam and Markiewicz 2009; Bourne-Webb et al. 2009; Wood et al. 2009), Canada (ENR 2003), Japan (Morino and Oka 1994; Ooka et al. 2007), China (Gao et al. 2008); Australia (Bouazza et al. 2011) and most recently in the United States (Redmond Reporter 2010; McCartney and Murphy 2012). Brandl (2006) reported that there are currently over 25,000 energy foundations in Austria, with installations dating as early as the 1980's. There were approximately eight times more energy foundations installed in 2008 than in 2005 (Amis et al. 2008). One reason for this rise in production is the UK code for sustainable buildings that requires the construction of zero-carbon buildings by 2019 (Bourne-Webb et al. 2009). Similar targets are being set across the globe suggesting a continued increase in production of such systems throughout the world. Another reason is the long-term cost savings due to more efficient heat exchange (Hughes 2008).

The most common configuration of energy foundations consists of drilled shafts that feature embedded ground-source heat exchange elements used to transfer heat to or from the subsurface to the building (Bourne-Webb et al. 2009). Other types of foundations that have been adapted as energy foundations are auger-cast piles (Brettman and Amis 2011) and driven piles (Morino and Oka 1994; Lennon et al. 2009). Different configurations for energy foundations are shown in Figure 1.

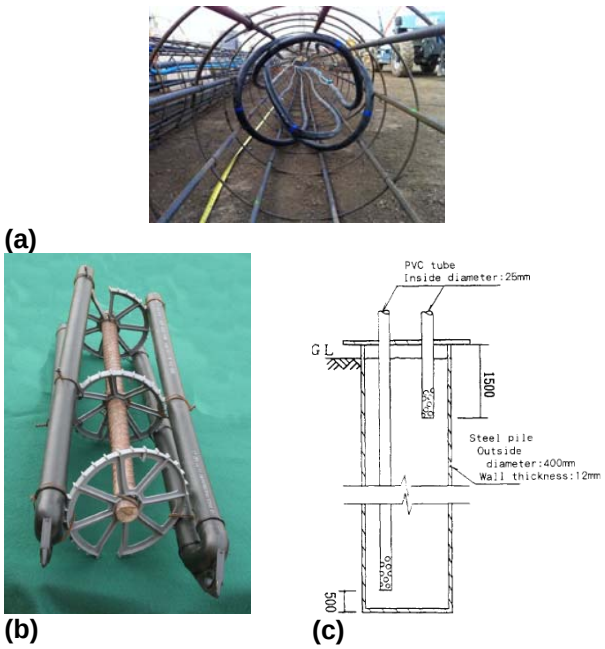


Figure 1: **Energy foundations: (a) Heat exchangers attached to inside of reinforcing cage (McCartney and Murphy 2012); (b) Heat exchangers attached to reinforcement for augercast pile (Brettmann and Amis 2011); (c) Steel pipe pile (Morino and Oka 1994)**

The length of energy foundations is typically shorter than that of vertical borehole-type GSHP heat exchangers: so they may be affected by changes in temperature. The depth limit (and cross-sectional area) of energy foundations is governed by the structural requirements. Nonetheless, energy foundations still are sufficient to take advantage of the thermal inertia of the subsurface. Typical profiles of temperature in energy foundations before operation of a heat pump are shown in Figure 1. The temperature is relatively stable at a depth of 3 m below the ground surface. McCartney and Murphy (2012) found that the temperature of the foundation reached a constant value after operation of the heat pump started, with a magnitude ranging from 10 to 20°C depending on the thermal load of the building .

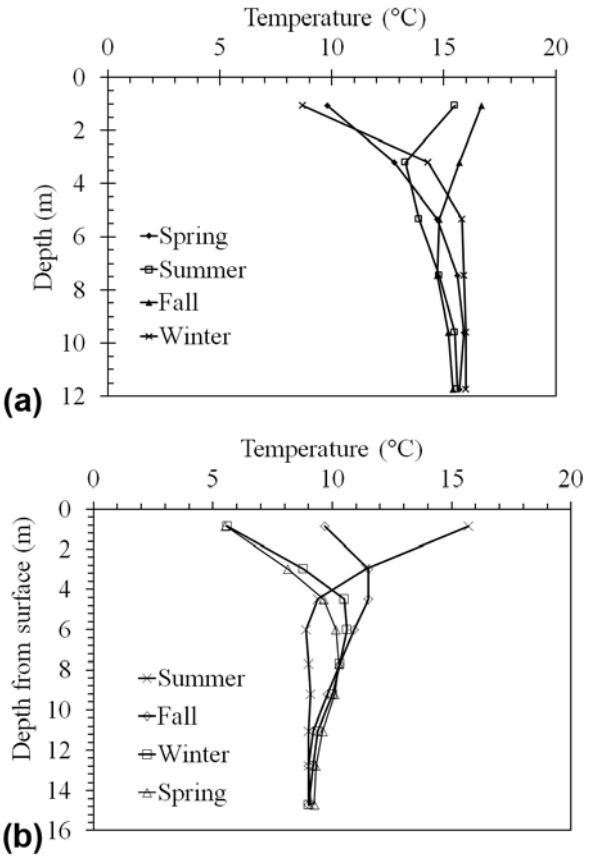


Figure 2: Ambient temperatures for energy foundations in different subsurface strata: (a) Sand and gravel in Denver, CO; (b) Sandstone in Colorado Springs, CO.

2.2 Characterization of Thermo-Mechanical Effects in Energy Foundations

An issue encountered is the potential for foundation movements due to thermal expansion and contraction of the foundation element or surrounding soil. Further, soil-structure interaction may restrain movement of the foundation, leading to generation of thermally induced stresses. Thermo-mechanical soil-structure interaction has been documented in several field-scale case histories (Laloui et al. 2006; Bourne-Webb et al. 2009; Amatya et al. 2012; McCartney and Murphy (2012). Although thermo-mechanical soil-structure

interaction analyses permit prediction of changes in axial stress or strain during heating and cooling operations (Knellwolf et al. 2011), they require empirical data for calibration of model parameters and verification of predictions. This is especially the case when considering the behaviour of energy piles in some soil deposits, such as soft clays or unsaturated soils. Different approaches have been used to obtain empirical data to characterize thermo-mechanical effects in energy foundations, including both centrifuge modelling and testing of full-scale foundations in the field.

Centrifuge modelling is a useful approach to measure empirical parameters for soil-structure interaction analyses for energy foundations, as the properties of scale-model foundations and soil layers can be carefully controlled and different configurations can be considered for lower costs that full-scale field testing. An additional benefit of centrifuge modelling is that scale-model energy foundations can be loaded to failure to characterize the effects of temperature on the load-settlement curve. The back-calculated ultimate side shear distribution and end bearing are useful parameters for soil-structure interaction analyses (McCartney and Rosenberg 2011).

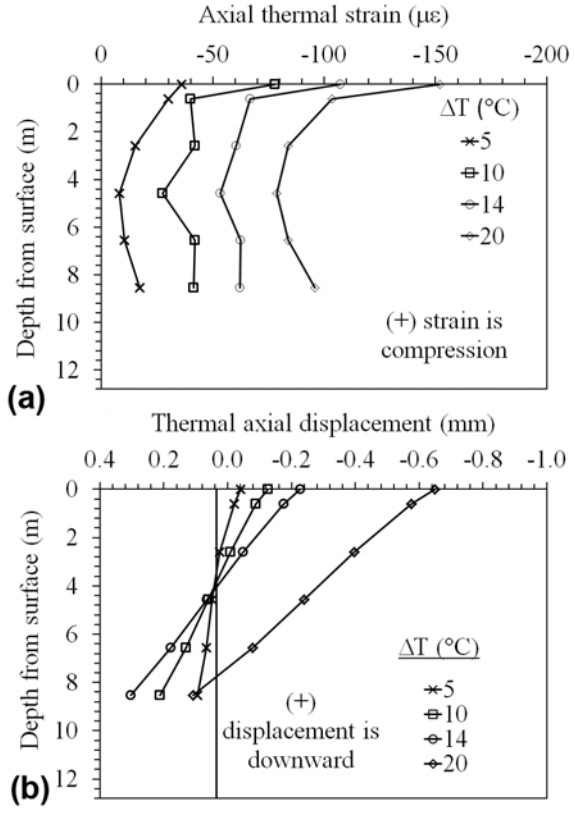


Figure 3: Typical results from centrifuge-scale tests on energy foundations (McCartney 2013): (a) Strain profiles; (b) Displacement profiles

Further, centrifuge tests on scale-model foundations with embedded instrumentation permit measurement of thermally induced strains in the foundation, which is useful for validation of soil-structure interaction analyses or finite element models (McCartney 2013; Stewart 2012). for example, the results in Figure 3(a) show strain profiles measured during heating of a scale-model energy foundation with semi-floating end-restrain boundary conditions. The foundation was permitted to expand upward freely at the head, and could expand into the underlying soil. The strain profiles can be integrated and subtracted from the measured head displacements during heating to characterize the displacement profiles of the foundation, shown in Figure 3(b). The point where the displacement profile signifies the null point, which is the point of thermal expansion. As the foundation is heated, the null point shifts downward as the soil at the toe of the foundation stiffens. This figure highlights an advantage of centrifuge testing in characterizing thermo-mechanical effects; the axial displacement of the head of the foundation could be tracked, something which is not possible for energy foundations installed beneath buildings.

Areas of thermo-mechanical soil-structure interaction analysis being explored in the centrifuge are the impact of thermally induced radial stresses on the side shear resistance, end-restraint boundary condition (foundation toe and head) effects, and the impact of temperature on the stress-strain curves for end bearing and side shear resistance.

Full-scale testing of energy foundations is also useful to characterize the thermo-mechanical and thermal behaviour of energy foundations. Regarding thermo-mechanical behaviour of energy foundations, full-scale tests permit evaluation of the effects of variable soil profiles and actual soil-foundation interaction phenomena resulting from the installation process of the foundation. Although loading of full-scale foundations may be difficult, the stiffness of the overlying structure may have important effects on the thermo-mechanical response of the energy foundation. Simulation of this stiffness is difficult in centrifuge modelling tests. Finally, full-scale energy foundations can be characterized under the range of thermal loads imposed by a heat pump.

Results from a full-scale energy foundation during typical operation of a heat pump are shown in Figure 4. The foundation is one of a pair of energy foundations installed as part of the construction of the new Denver Housing Authority senior residential facility in Denver Colorado. Although there were 60 drilled shafts under the building, only two were converted to energy foundations and connected to the conventional GSHP system already being incorporated into the building. The foundation is located below an interior column, and is 0.91 m in diameter and extends to a depth of 14.8 m. It is bearing in the Denver formation (claystone), and functions as a rock-socketed, end-bearing element in the bedrock. The foundation carries a load of 3.84 MN. The shaft contains a full-length reinforcing cage 0.76 m in diameter with nine #7 vertical reinforcing bars tied to #3 lateral reinforcing hoops spaced 0.36 m.

A reinforced slab on grade with a thickness of 150 mm was cast at grade level. The foundation contains a

total of 82.3 linear meters of tubing configured into three loops running the length of the reinforcing cage. The heat exchanger tubing was attached to the interior of the reinforcing cage using wire ties connected at every other hoop along the length of the reinforcing cage. The heat exchanger tubing was routed along the inside perimeter of the reinforcing cage to avoid crossing the diameter of the cage, which could block concrete flow or cause segregation of concrete. Equal angular spacing of the tubing was maintained to ensure relatively uniform temperature along the circumference of the shafts. The tubing was installed away from the vertical reinforcement to ensure an adequate bond between the concrete and reinforcement and to ensure good contact between the concrete and the tubing itself. The supply and return lines for each loop were arranged on opposite sides of the reinforcing cage to reduce thermal short-circuiting, which occurs when heat flows directly from the inlet of the tube to the outlet of the tube before the fluid has circulated through the entire foundation.

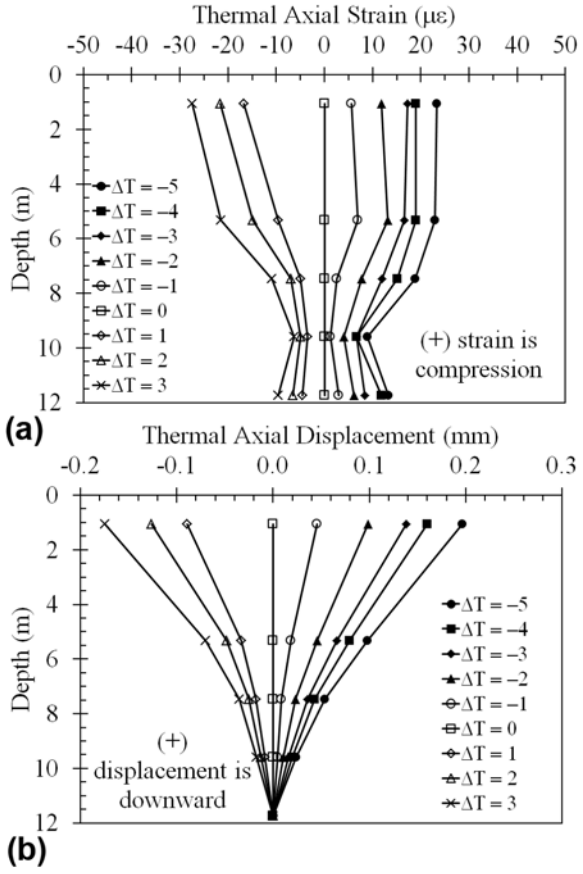


Figure 4: Typical results from full-scale tests on energy foundations: (a) Strain profiles; (b) Displacement profiles

The thermal axial strains shown in Figure 4(a) indicate that greater fluctuations in strain are observed near the top of the foundation than at the bottom of the foundation. This behaviour results from the greater side shear restraint of the soil and rock near the bottom of the foundation. Assuming that the toe of the foundation does not move (i.e., rigid end restraint), the thermal axial displacements of the foundation are shown in Figure 4(b). These results indicate that the movement of the foundation increases with height of the foundation, even though the stiffness of the overlying superstructure provides some restraint. McCartney and Murphy (2013) note that the changes in axial stresses in the foundation induced by heating and cooling are within 10% of those induced by mechanical loading of the building. This information, together with the relatively small thermal axial displacements, indicate that heat exchange operations are not expected to lead to significant issues in end-bearing type energy foundations. The results in Figure 3(b) for a semi-floating foundation indicate that this may not be a general trend for all energy foundations, especially for those installed in soft clay layers.

2.3 Key Design Issues in Energy Foundations

The thermal response of energy foundations is critical to predicting the amount of energy that can be extracted from these elements Field tests have also been performed to characterize the thermal response of energy foundations (Ooka et al. 2007; Adam and Markiewicz 2009; Wood et al. 2009; Ozudogru et al. 2012; Wang et al. 2012). These studies have confirmed that heat pumps attached to the energy foundations have similar coefficients of performance (COPs) to conventional ground-source heat pumps. The thermal conductivity of the soil-energy foundation system is being investigated using thermal response tests where the temperatures of the fluids entering and exiting the heat exchange tubing are monitored during application of a constant heat energy input to the fluid (Brettmann and Amis 2011; Ozudogru et al. 2012). The thermal conductivity values of the foundation-soil system calculated using the line source equation range from 2.44 to 2.66 W/mK for pressure grouted augercast energy foundations (Brettmann and Amis 2011). These values are higher than the components of energy foundation-soil systems (soil, polyethylene tubing, concrete). Similar high values were also recently measured using the line source equation for an energy foundation installed at the Air Force Academy by the author.

One of the reasons for the high thermal conductivity may be that, different from vertical boreholes, the line source equation may not be suitable due to the geometrical configuration of heat exchangers (arrayed around the inside perimeter of the foundation), and because the foundation has a relatively high heat storage capacity which must be overcome before heating the surrounding soil. Nonetheless, Ozudogru et al. (2012) evaluated these thermal conductivity values using finite element modelling and constituent material thermal properties, and concluded that these thermal conductivity values may be reasonable (at least for the constituent thermal properties assumed). Other thermal conductivity approaches, similar to that proposed by Shonder and Beck (1997) may be more suitable for thermal conductivity calculation than the line source equation.

Regarding the design issues for the thermo-mechanical foundations, two approaches can be considered. The first approach involves characterization of the expected soil-structure interaction during the temperature changes of the foundation. Design tools have been developed for this purpose (Peron et al. 2011; Knellwolf et al. 2011). This is the recommended approach, as it permits consideration of the impact of soil behaviour on the thermo-mechanical response of the energy foundation. However, this approach requires several parameters that require time to measure making it difficult to use for quick design decisions.

The second approach, which may be suitable for preliminary design checks, involves characterization of the worst-case scenario. Regarding thermal axial displacements, the worst-case scenarios would involve an upward or downward movement of the foundation head corresponding to the free expansion of the foundation during an extreme change in temperature (maximum of 20 °C). This may be useful information for structural engineers to design the reinforcement for the connection between the foundation and grade beam. Regarding thermal axial stresses, the worst-case scenario for compressive stresses during foundation heating would be full constraint of the foundation along with dragdown from thermal contraction of the surrounding soil. Based on published thermal stress values this is expected to be a conservative value. The worst case scenario for tensile stresses during foundation cooling would be full constraint of the foundation without soil interaction. Most studies indicate that the zone for the greatest potential for tensile stresses during heating is near the toe (Bourne-Webb et al. 2009), so designers can use the worst case tensile stresses and this location to modify the reinforcement pattern if necessary.

3. GEOTHERMAL SYSTEMS IN LANDFILLS

On average, the encapsulated waste mass in municipal solid waste (MSW) landfills has sustained temperatures which are up to 35 °C higher than that of the surrounding subsurface due to the exothermic decomposition of organic materials (Tchobanoglous et al. 1993; Yesiller and Hanson 2003; Yoshida and Rowe 2003; Yesiller et al. 2005; Hanson et al. 2005). Leachate, gas, and heat are the three most common by-products of organic waste decomposition in landfills. The decomposition of organic wastes occurs in three phases: an aerobic phase, a transient phase, and an anaerobic phase (Tchobanoglous et al. 1993). The initial decomposition of organic wastes occurs under aerobic conditions. However, shortly after waste is buried in the landfill, oxygen availability becomes limited and anaerobic generation of methane and carbon dioxide, the two main components of landfill gas, begins to increase as degradation enters the transient phase. After a peak value of approximately 70% by volume, carbon dioxide concentrations begin to decrease to a stabilized level of approximately 40% by volume as anaerobic conditions are established. Over a similar timeframe, the methane concentration gradually increases and stabilizes at around 60%. Heat generation is observed to occur during all three phases with the greatest gain in temperature occurring during the onset of anaerobic decomposition. Hanson et al. (2005) monitored a landfill in Michigan, USA during the placement and storage of new municipal waste. During the study, the aerobic phase was observed to last from two weeks to three months among various cells at the landfill site. The transient phase occurred from two to five months, followed by the anaerobic phase, after which the average waste temperature remained constant. The temperatures in MSW as a function of depth in this landfill was presented by Yesiller et al. (2003), and is shown in Figure 5(a). Below a depth of 8 m in the MSW, the temperature was relatively steady with time and ranged from 30 to 55 °C, or 10 to °60 above that of the transient outside air temperature. The trend of temperature with depth at several landfills throughout North America are shown in Figure 5(b). Although not all of the landfills reach the temperatures observed in Figure 5(a), the waste is generally 20 °C greater than the average outside air temperature in all of the locations. Coccia et al. (2012) summarized results from other studies focused on the different variables that affected the heat content of landfills. They also evaluated the impact of temperature on the settlement and methane gas generation of MSW, and found that if lower temperatures are maintained, the

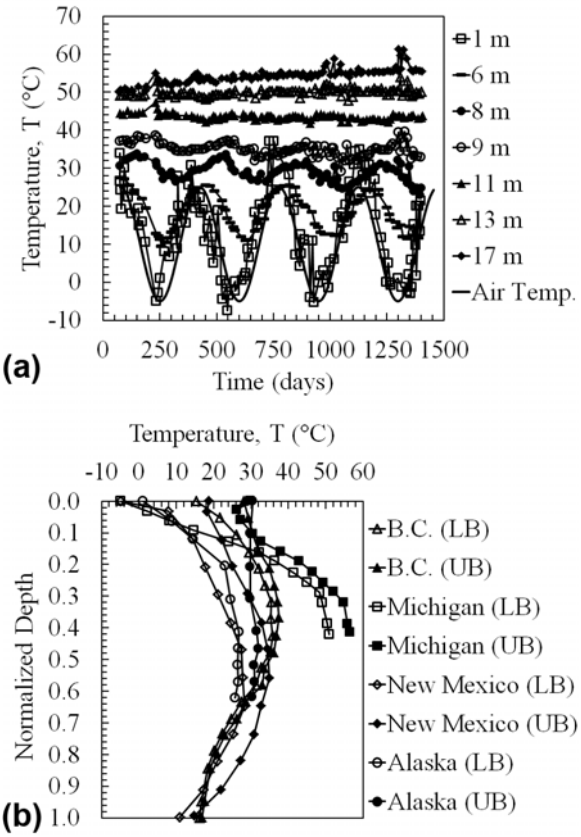
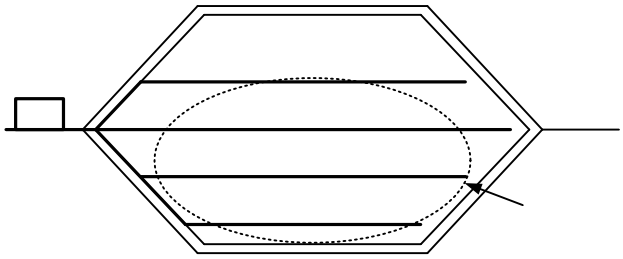


Figure 5: Typical temperature conditions in MSW landfills: (a) Time series (Yesiller et al. 2003); (b) Temperature profiles (Yesiller and Hanson 2003; Yoshida and Rowe 2003; Yesiller et al. 2005; Hanson et al. 2005)

Modern landfills already incorporate complex plumbing systems to collect leachate, detect leaks, vent landfill gas, or recirculate leachate to accelerate methane production in bioreactor landfills, so the inclusion of additional plumbing for heat exchange would not lead to a significant increase in cost or complexity. There are different options for the design of thermally active landfills, depending on the goals of the heat exchange process. Two possible design alternatives for landfill are shown in Figure 6. The configuration shown in Figure 6(a) involves heat exchangers embedded in the daily cover material placed between waste lifts. Coccia et al. (2012) observed that the waste near the bottom of the landfill has a combination of both high temperature and high water content, indicating that the thermal conductivity of this material may be optimal for heat exchange operations. Hanson et al. (2008) found that the thermal conductivity of MSW ranges from 0.3 to 1.5 W/mk depending on density and water content, and the specific heat ranges from 1000-2200 kJ/m^{3}K. Accordingly, the approach in Figure 6(a) may be optimal for collecting the maximum amount of heat from the MSW, and also for modifying the rate of settlement or gas generation in MSW. An issue with this approach is potential effects of differential settlement on the heat exchanger integrity, but more research is necessary to evaluate if this will occur.



(a)



(b)

Figure 6: Potential designs for landfill heat exchangers: (a) Optimized for heat content (Coccia et al. 2012); (b) Optimized for ease of installation and thermal protection of hydraulic barrier (Grillo et al. 2012)

The configuration shown in Figure 6(b) involves heat exchangers placed above the hydraulic barrier at the base of the landfill, within the leachate collection system. This approach has the advantage that the leachate collection system is fluid-saturated, and is simple to construct. Further, this approach may be useful to protect the hydraulic barrier from desiccation under high thermal gradients, an issue which has been identified as a risk for base liner integrity (Southen and Rowe 2005). The geothermal heat exchanger has the advantage that a constant temperature will be maintained during the heat extraction processes.

The only source of cost data for a geothermal system in a landfill was reported by Grillo et al. (2012). This project involved heating of a maintenance garage adjacent to a landfill located in northern New Hampshire. Although performance data has not been collected from the project, the authors report that the installation costs ranging from $40,000 (direct heat exchange) to $50,000 (heat exchange with a heat pump) can be recovered after 3.9 to 6.9 years by avoiding the costs associated with fuel oil required to heat the garage. This study is promising evidence regarding the practical application of this concept.

4. THERMAL SOIL IMPROVEMENT

Incorporation of geothermal systems into civil engineering infrastructure has several opportunities to improve the performance of the system. This is the case for thermally active MSE wall systems (McCartney 2011; McCartney and Stewart 2012; McCartney et al. 2013). Because the performance of near-surface geotechnical systems is closely related to water flow arising from environmental interactions, most geotechnical design guides for fill-type systems attempt to minimize the impact of water by using free-draining backfill soils. However, this can lead to high construction costs, especially in areas where such backfills are not available. In addition to poor drainage, compacted backfills with high clay content are avoided in geotechnical systems because their strength and stiffness tend to decrease with increasing water content (or decreasing suction) during environmental interactions (Zornberg et al. 1994; Mitchell and Zornberg 1995). Silts are avoided for similar reasons and because of their susceptibility to frost heave. However, if these soils remain in unsaturated conditions, these detrimental impacts on the performance of fill-type geotechnical systems with poorly draining backfills may be minimized. It is well known in unsaturated soil mechanics that suction plays an important role in the effective stress state. An increase in effective stress in unsaturated soils can lead to significant improvements in their engineering properties including shear strength and stiffness. A novel way of maintaining unsaturated conditions in poorly draining backfills is to engineer the mechanically stabilized earth (MSE) wall so that thermally induced water flow away from embedded heat exchangers causes drying of the backfill.

An example of a thermally active MSE wall is shown in Figure 7(a), where heat exchangers are placed in the unsaturated compacted backfill. The heat exchangers can be placed at intermediate lifts between the reinforcements, so that the geosynthetics may serve as permeable pathways for thermally induced water flow. To serve this purpose, the geosynthetic reinforcements may be either permeable woven geogrids or nonwoven

geotextiles. In this case, the geosynthetics will not only serve their conventional, passive roles (reinforcement, separation, drainage), but will also serve an active role by providing a boundary condition for thermally induced water flow. The spacing and location of heat exchangers is not only important for uniform soil-geosynthetic composite improvement, but also to create a thermal gradient between the backfill and atmosphere, which will in turn drive water from the system. A strategy for routing of heat exchange tubing is shown in Figure 7(b).

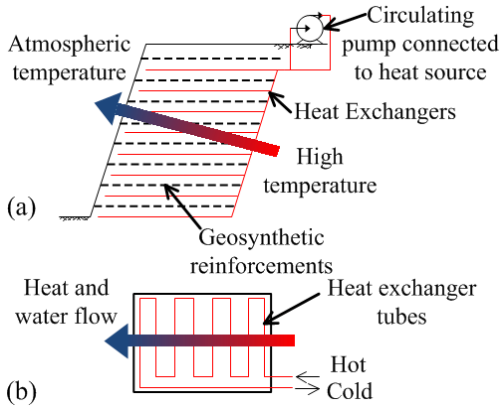


Figure 7: Thermally active MSE wall (McCartney et al. 2013): (a) Elevation view; (b) Plan view

Coccia and McCartney (2012) studied the zone of influence of thermally induced water flow in unsaturated soil layers. They found that the affected zone and magnitude of thermally induced water flow are functions of the initial degree of saturation (S), hydraulic conductivity for saturated conditions (k_s), thermal conductivity (λ), and porosity (n). They used Vadose/W to study the heat and water flow processes in a compacted soil layer having a thickness of 5 m, with heat exchangers embedded at the base of the layer and at 3 m above the base of the layer. The upper surface of the soil layer was simulated as an atmospheric boundary layer with constant relative humidity of 50% and temperature of 25 °C. The transient heat flow process is shown in Figure 8(a) for a temperature of 60 °C applied to the heat exchangers. The change in saturation of the soil layer near the vicinity of the upper heat exchanger is shown in Figure 8(b). A greater decrease in saturation at the location of a heat exchanger was observed for silt with lower initial S. Other simulations indicate that soils with lower k_s tended to have a smaller zone of drying.

Thermally induced water flow is also affected by coupled changes in the thermal conductivity of soil, which may decrease by a factor of about 10 as S approaches zero, with a lower limit of 0.25 to 0.5 W/m°C depending on density and mineralogy. However, Smits et al. (2012) observed nonlinear changes in apparent thermal conductivity for sands during drying under temperatures above 55 °C, with a peak value at a saturation of 0.1. This behaviour was attributed to the development of a heat pipe effect in the unsaturated soil layer, leading to greater heat transfer than due to conduction alone. Accordingly the apparent thermal conductivity in dry conditions around the heat exchangers in thermally active MSE walls may still have appreciable levels of heat transfer.

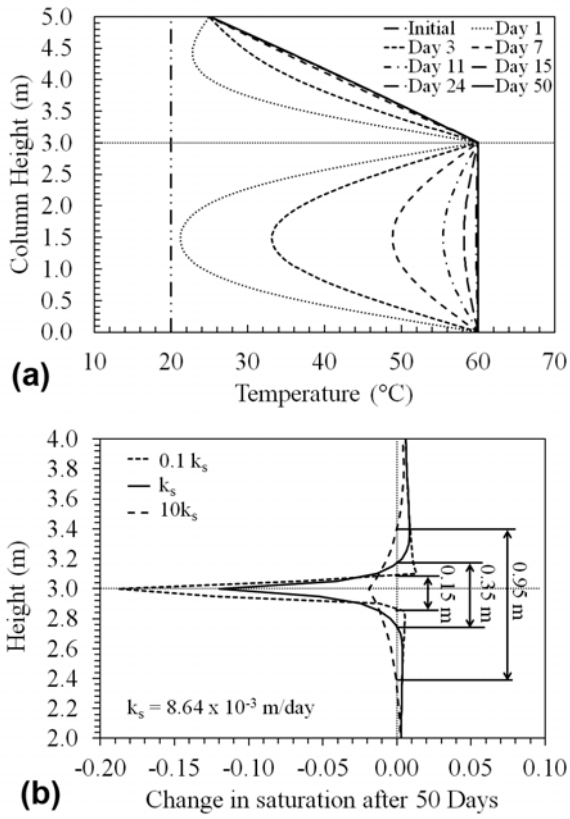


Figure 8: Thermally induced water flow results (Coccia and McCartney 2013): (a) Transient temperature profiles; (b) Changes in saturation for soils with different hydraulic conductivity values

Coccia et al. (2013) performed a physical modelling experiment to characterize the mechanical response of the soil layer corresponding to a heat exchange processes such as that observed in Figure 8. They embedded a heat exchanger a mid-height of a compacted silt layer, as shown in the pictures in Figure 9. The compacted soil layer represents the upper heat exchanger in a thermally active MSE wall. A heat pump was used to bring the heat exchanger to different temperatures, after which time was permitted for heat transfer and water flow to occur. After reaching steady-state conditions, plate loading tests were performed to evaluate changes in the plate load stiffness of the soil layer.

The steady-state temperature profiles in the soil layer after different stages of heating are shown in Figure 10(a). The plate load versus settlement curves performed after the heat exchanger reached different steady-state temperatures are shown in Figure 10(b). It is clear that a slight decrease in the soil layer thickness occurred after each heating stage, which indicates that the unsaturated soil contracts during heating. The mechanisms behind this thermal contraction are currently under investigation. The stiffness measured

from the load-settlement curves after reaching different temperatures at the heat exchanger are shown in Figure 10(c). A clear increase in stiffness of the soil layer is observed with heating, likely due to the permanent densification of the soil layer due to thermal consolidation. As thermally induced volume changes may not be desired during long-term operation of a MSE wall, the wall can be heated after construction to induce the settlements observed in Figure 10(b), after which no further permanent changes in volume are expected. However, the wall will continue to serve as a thermal mass to reject heat, and the elevated temperatures will serve to drive water from the unsaturated backfill soil.

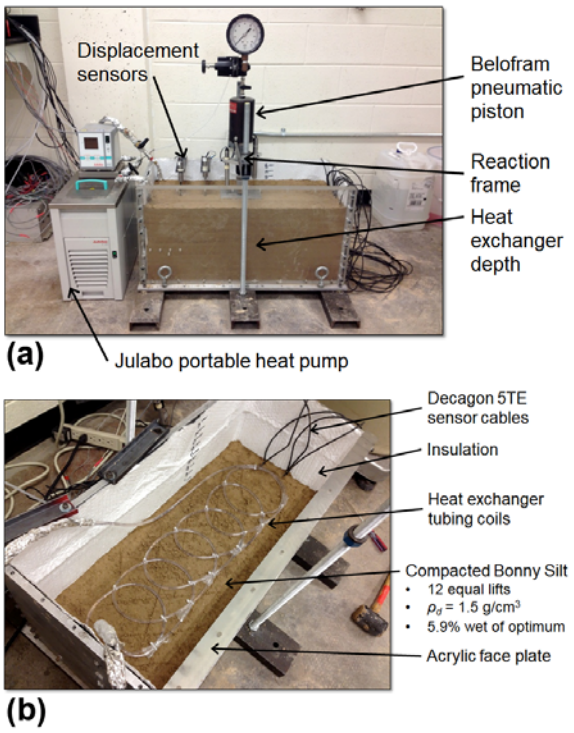


Figure 9: Physical modelling experiment for thermo-mechanical characterization of unsaturated soil layers (Coccia et al. 2013): (a) Elevation view; (b) Picture of the heat exchanger at mid-height of the soil layer

Thermally active MSE walls can be used to enhance the energy efficiency of heat pump systems for cooling of buildings similar to conventional GSHPs. However, they can also be used in dry cooling operations to reject spurious heat generated by power plants or industrial facilities. Cooling needs are typically defined in terms of equivalent tons of cooling, defined as the heat rejection in cooling 12 liters/minute by 5 °C. Buildings typically require 0.82 tons of cooling (4396 W) per 100 m^2 of floor area while a 700 MW power plant can require as much as 100,000 tons of cooling (Drbal et al. . As heat is rejected through conduction, the inlet fluid temperatures, heat exchanger lengths/spacing, and fluid circulation rates are the important design variables that can be varied to reach a heat rejection goal. The entering water temperature typically ranges from 50 to 80 °C in typical cooling applications.

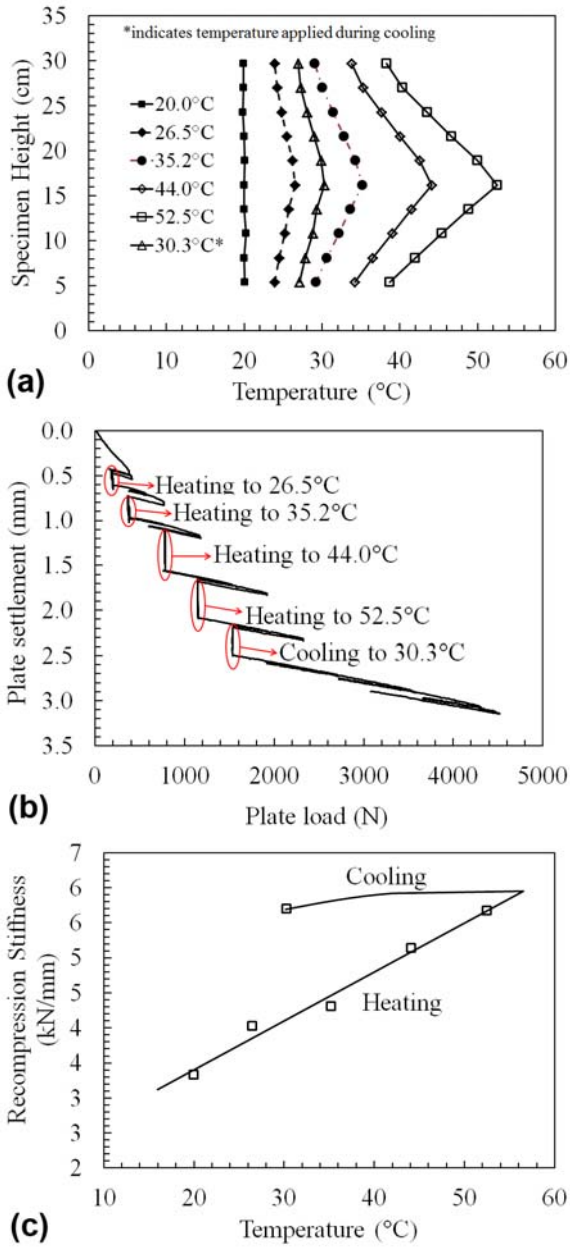


Figure 10: Physical modelling results (Coccia et al. 2013): (a) Temperature profiles; (b) Plate load test results after different stages; (c) Plate load stiffness values

5. CONCLUSIONS

The incorporation of heat exchangers into civil engineering infrastructure has the positive aspects of decreasing the installation cost of geothermal heat exchangers, permitting access to novel heat sources, and potentially improving the performance of civil infrastructure systems. Design issues and important performance metrics identified in previous studies are presented and discussed in the paper. The general conclusion of the combination of ground source heat pump systems and civil engineering systems is a feasible and sustainable solution to addressing implementation issues associated with near surface geothermal systems. Further, the heat exchange process can be harnessed to improve the primary functions of the civil engineering infrastructure.

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