ENERGY PILES:
USING DEEP FOUNDATIONS AS HEAT EXCHANGERS

By C. Guney Olgun, Ph.D., James R. Martin, II, Ph.D., P.E., G. Allen Bowers, Jr.

There's a developing trend around the world to explore alternative energy sources. The main driving forces are growing global energy demand, depleting natural resources and the potential effects of greenhouse gas emissions from fossil fuel consumption. Geothermal energy is one of the promising renewable sources that can be utilized to offset such trends. To date, the use of geothermal energy has been limited mainly to certain hot spot areas where it is used either for district heating and/or electricity generation. However, the constant temperature and heat storage capacity of near-surface soils in any region represent a tremendous potential of stored energy that can be used for heating and cooling of structures.

How Do They Work?

Ground temperatures below a depth of about 20 ft remain stable compared to outside air temperatures, typically lying between 50-70° F in most U.S. regions. As an example, Figure 1 shows the ground temperature profile in Blacksburg, VA. Temperatures near the surface fluctuate with seasonal ambient temperatures. However, the temperatures at deeper levels remain stable at 60° F because the overlying ground acts as an insulator. This relatively constant temperature and the thermal storage capacity of the ground can be exploited for heating and cooling purposes.

Traditionally, geothermal boreholes have utilized this

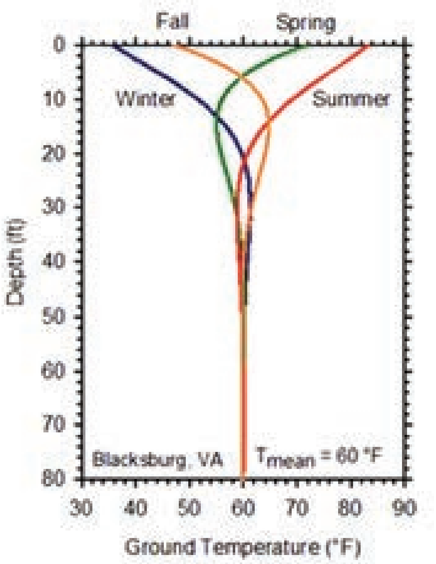

Figure 1. Seasonal ground temperature profile in Blacksburg, VA.

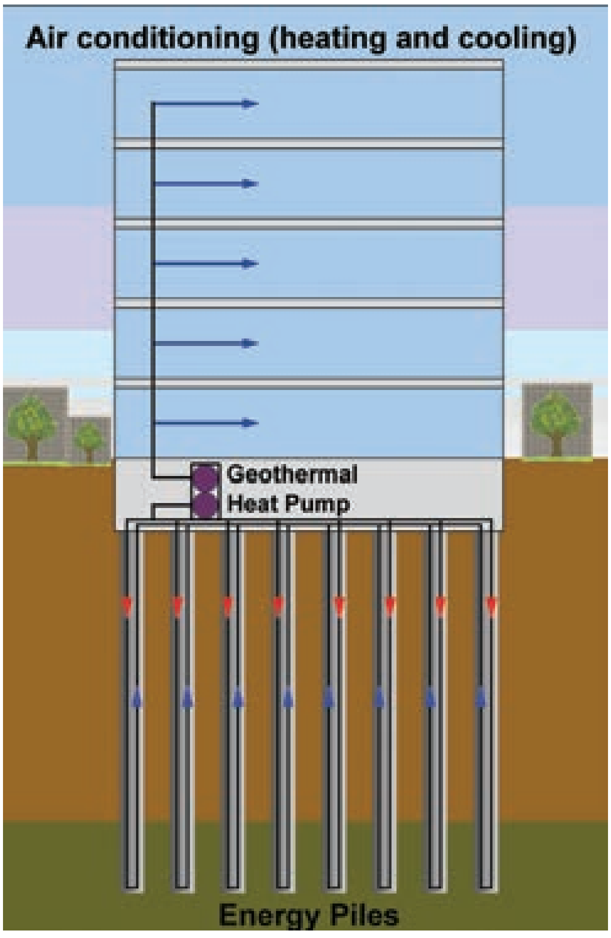

Figure 2. Energy pile system integrated to a building for heating and cooling.

concept for space heating and cooling. In this system, a circulation loop is placed in a small-diameter borehole typically extending to a depth of 200-300 ft. The hole is then backfilled with a mixture of sand, bentonite and/or cement. The loop is connected to a geothermal heat pump and the fluid inside the loop is circulated. The heat energy is fed into the ground for cooling in the summer and withdrawn from the ground for heating in the winter. Because geothermal heat pumps use the ground as a constant temperature source which serves as a more favorable baseline compared to the ambient air temperature, these systems work much more efficiently for space heating and cooling compared to air-sourced heat pumps.

Over the past 20 years, this ground coupling concept has been expanded from geothermal borehole systems to the use of building foundation elements as heat exchangers. Energy piles in particular are one innovative technology that combines geothermal heat exchange and structural foundation support (Figure 2). In this hybrid system, geothermal loops are integrated into the deep foundation elements, such as piles, piers or drilled shafts, that are already in place to provide structural support (Figure 3).

A major cost associated with any deep geothermal borehole is the drilling required for installation. Because energy piles perform the dual function of exchanging heat and providing structural support, and are only installed at sites where pile foundations are already required, these systems provide the thermal performance of deep

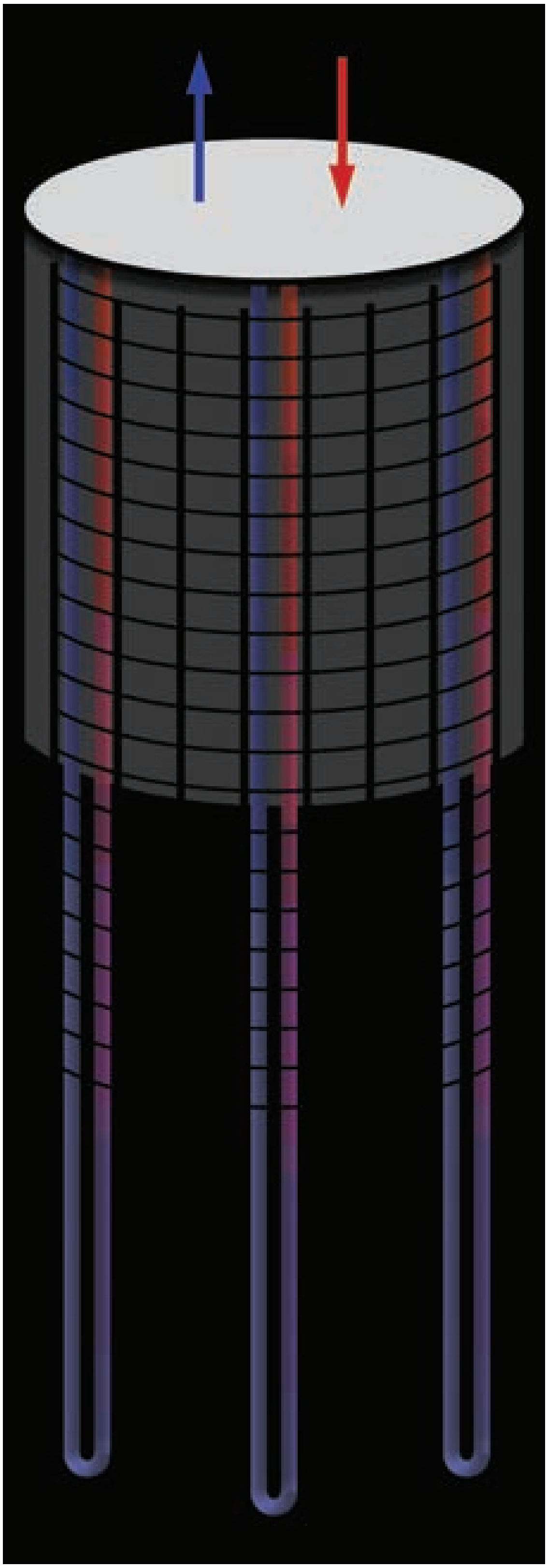

Figure 3. Components of an energy pile with multiple circulation loops as hot fluid is circulated in to extract colder temperatures from the ground.

geothermal systems without the additional drilling costs. Additional energy pile advantages include low maintenance, long lifetime, less variation in energy supply compared to solar and wind power, and environmental friendliness. Case studies show energy piles can significantly lower energy consumption for heating and cooling costs and reduce the building's carbon footprint. Energy cost savings for typical buildings outfitted with energy piles could be as much as 70 percent.

The use of energy piles has rapidly increased over the last decade, especially in Europe, where more than 500 applications are reported. Primary installations have been in Germany, Austria, Switzerland and the UK. Notable projects include the 56-story Frankfurt Main Tower in Germany, the Dock E Terminal Extension at Zurich International Airport in Switzerland and the One New Change building complex in London, England. Energy piles have seen very little use in North America, with only a handful of completed projects – the Marine Discovery Center in Ontario, Canada, the Lakefront Hotel in Geneva, NY and the Art Stable building in Seattle, WA.

Energy Pile Design

While some driven pile applications are reported, energy piles are typically installed with cast-in-place technology, such as drilled shafts, continuous flight auger piles or micropiles, among others. Other types of geotechnical structures in contact with the ground, such as shallow foundations, retaining walls, basement walls, tunnel linings and earth anchors, also offer significant potential for harnessing near-surface geothermal energy.

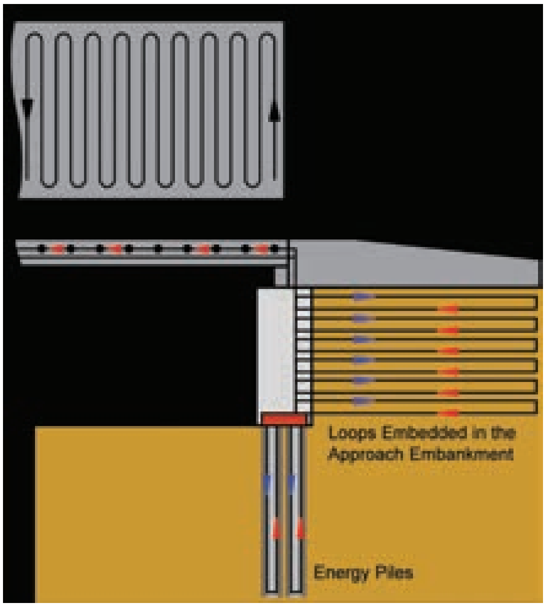

Figure 4. Energy pile system for storing heat energy in summer to be used for bridge de-icing in winter. Additional geothermal loops may increase heat storage capacity.

The use of energy piles extends beyond space heating and cooling. They can also be used to collect and store heat energy for de-icing bridge decks in the winter. The piles or drilled shafts used to support the bridge can in turn be used to store and withdraw heat energy. Heat can be collected from the asphalt pavement over the summer and it can be stored in the ground using the deep foundations (Figure 4). This stored energy can then be reclaimed to heat and de-ice the bridge deck in the winter. There is a potential to further integrate geothermal energy harvesting into the bridge substructure by placing geothermal loops into the approach embankment which would increase the thermal mass available for storing heat.

This simple application demonstrates how versatile energy piles can be and the possible significance of their contribution to the sustainable structures. Current practices for de-icing concrete bridges involve chemical salts, which can be harmful to the environment and lead to accelerated corrosion of the bridge deck and reinforcing steel. Energy piles could eliminate the need for de-icing salts on many bridges, extending their service life while providing a safe roadway for motorists.

Energy pile design needs to integrate geotechnical, structural and heat exchange considerations. Geotechnical characteristics of the foundation soils and the level of the structural loads are typically the deciding factors for the selection and dimensioning of the pile foundations. The geothermal heat exchange capacity of an energy pile is a key parameter to be considered in design. Thermal characteristics of the ground as well as the heating and cooling loads from the structure need to be considered for the number of piles that will be utilized as heat exchangers. Therefore, the thermal properties of the site need to be evaluated for an energy pile application in addition to the traditional geotechnical characterization for foundation design.

In most cases, field thermal conductivity tests are necessary to verify design assumptions similar to the approach used for running a conventional pile load test to prove capacity. Current procedures for thermal conductivity tests were developed for small-diameter geothermal boreholes. In this test, heat energy is injected into the ground by circulating hot fluid through the borehole loops. The rate of temperature increase is then measured to calculate thermal conductivity. Although this test can also be used for energy piles, its results currently do not have a direct correlation because energy piles have much larger diameters (typically 1-4 ft) than boreholes. The current guidelines for thermal conductivity field tests limit the diameter of the test element to six inches.

Ongoing research projects to develop testing methods specific to energy piles include performing thermal conductivity tests at field installations. The field test setup consists of insulated inlet and outlet pipes connected to the energy pile (Figure 5). Heated fluid is injected and circulated through the energy pile at a constant flow rate using the pump inside the test truck. Heating is controlled within the truck using resistance heating coils.

Figure 5. Field thermal conductivity test in progress.

Challenges

Energy piles bring new challenges to geotechnical pile design. During a heat exchange operation, the pile will expand and contract relative to the soil as heat is injected and extracted, respectively. These relative movements have the potential to alter the shear transfer mechanism at the pile-soil interface. The cyclic and repeated nature of these reversals also has the potential to fatigue the soil near the pile surface over long periods of operation. Furthermore, the range of temperature increases near the pile surface, though limited by practical operational guidelines, can have a significant effect on pore pressures and soil strength.

These are new questions being raised about energy piles. Researchers, along with a series of industry participants, are performing full-scale field tests, laboratory tests and advanced numerical modeling to address such questions and develop refined design guidelines for energy piles. Currently, there are seven full-scale field tests installed and planned – five in the U.S., one in Turkey and one in Egypt. These tests will provide a better understanding of energy pile behavior in different soil and climatic conditions.

The relatively constant temperature and the thermal storage capacity of the ground can be exploited for heating and cooling purposes.

One of the obstacles slowing broader application of energy piles is related to the overall project timeline and the involvement of the geotechnical engineer in the design process. Typically, the architect develops the building concept and works with the mechanical engineers with the HVAC design of the structure. By the time the geotechnical engineer is involved in the foundation design, the major decisions about the heating and cooling system for the structure are already made. After this point, it is very difficult to have major changes accepted that would allow implementation of the energy piles.

In a recent project in Manhattan, energy piles were adopted later on in the design process. This was only possible because the owner asked for a geothermal borehole system for heating and cooling. At the time, it was evident that pile foundations would be needed for structural support. The consultant for the geothermal system design recommended energy piles, which made it an economical alternative for the owner. This outcome is not typical, as HVAC considerations are usually well established and not easily changeable by the time the foundation system is considered.

Moving Forward

The use of deep foundations as heat exchangers opens a new frontier for geotechnical engineering. Energy piles in particular represent an important new step toward the sustainable design of green structures that use net-zero energy for heating and cooling. They significantly reduce energy costs throughout the life of the structure and reduce carbon footprints. This technology also brings new challenges that need to be addressed, such as site characterization and integrated building design that involves working closer with other professionals early in the planning and design process. Education and awareness of all parties involved in the design process can lead to a more integrated design and planning approach that will enable energy piles to become a more accepted cost-effective solution.

AUTHORS

C. Guney Olgun, Ph.D., is a research assistant professor of Civil and Environmental Engineering at Virginia Tech. His research interests include geotechnical earthquake engineering, dynamic soil-structure-foundation interaction, seismic performance of improved ground and thermo-active foundation systems. He can be reached at colgun@vt.edu

James R. Martin, II, Ph.D., P.E., is a professor of Civil and Environmental Engineering, and director of the Disaster Risk Management Institute at Virginia Tech. His research interests include geotechnical earthquake and foundation engineering, site response, liquefaction, probabilistic seismic hazard assessment and soil and site improvement. He can be reached at jrm@vt.edu

G. Allen Bowers, Jr. is a graduate student in the Department of Civil and Environmental Engineering at Virginia Tech. He is researching the application of bridge deck de-icing using energy piles. He can be reached at: bowers07@vt.edu

This article is based upon work supported by the National Science Foundation under grants CMMI-0928807 and CMMI-1100752. Any opinions, conclusions or recommendations expressed herein are those of the authors and do not necessarily reflect the views of the National Science Foundation.