*Advance Researches in Civil Engineering*
*ISSN: 2645-7229, Vol.2, No.3, pages: 15- 23*

# Geothermal Energy and Performance of Energy Pile Systems

*Fatemeh Sheshparia [1*], Masoud Amelsakhi [2]*

[1*] *M.Sc of Geotechnical Engineering, Dept. of Civil Engineering, Qom University of Technology, Iran.*
*(F_sheshpari@yahoo.com)*

[2] *Assistant Professor, Dept. of Civil Engineering, Faculty of Engineering, Qom University of Technology, Iran.*

*(Date of received: 02/06/2020, Date of accepted: 15/09/2020)*

**ABSTRACT**

*Geothermal energy is one of the most environmental-friendly and cost effective energy sources with potential to replace fossil fuels and help mitigate global warming. Recent technological progress, energy price variability, difficulty of oil and gas supply from foreign countries and the need to reduce fossil fuel deployment have made the exploitation of geothermal energy, especially for heating and cooling purposes, an attractive and viable energy alternative. The choice of the proper geothermal system (for heating or cooling) is essentially based on the need of cost containment and environmental constraints. Energy pile provides a mean to reduce energy consumption for space heating and cooling, while functioning as a support for superstructure. Despite of the environmental benefits of energy pile, some countries are still reluctant in implementing energy pile. This is because of knowledge gap on the influence of temperature cycles on energy pile ultimate and serviceability limit states. This paper reviews the geo exchanger and energy pile systems and highlights their applicability and efficiency as well as advantages and limits.*

**Keywords:**

*Geothermal energy; Energy pile; Heat exchanger; Fossil fuels*

## 1. Introduction

The World's energy consumption is rising due to population growth and the overall improvement of living standards, at the same time, fossil fuels are becoming less reliable due to negative environmental impacts, overuse of natural energy resources, rising prices and political instability in some of the major production countries. Geothermal energy contained in the subsurface of the Earth has been found to have a great potential as a directly usable and renewable energy. Shallow geothermal energy can be extracted from trench collectors and borehole heat exchangers, or through foundation elements, which when used for this purpose are also referred to as thermo-active foundations or energy foundations. Geotechnical engineers have played an increasing role in the conservation of energy. One particular topic that has received worldwide attention is energy piles. Energy piles are innovative technology that integrates heat pump and foundation piles. Through this integration, foundation piles can serve as heat-exchange element, and provides a mean to conserve energy in terms of providing thermal comforts for houses and buildings. By using foundation elements, which are already required for structural reasons, as ground heat exchangers, a considerable initial cost saving is achieved when compared to the construction of a separate system for the sole purpose of ground heat exchanging. Concrete is also a favourable material for exchanging heat with the ground due to its high thermal conductivity and thermal storage capacity. Heat is extracted or injected into the ground by the circulation of a fluid through polyethylene pipes installed inside these foundation elements. Geothermal reinforced concrete piles can have the additional HDPE tubing installed vertically in the pile, which is most common, or it can follow the reinforcement cage in a spiral approach to tubing layout. The additional pipes are referred to as the heat exchanger or absorber tubing and when installed vertically it forms a U-shape. The heat transfer or carrier fluid is made up of either water, water and glycol, or a saline solution [1]. Geothermal energy is defined as heat from the Earth. It is a clean and renewable resource. It is considered a renewable resource because the heat emanating from the interior of the Earth is essentially limitless. The heat continuously flowing from the Earth's interior, which travels primarily by conduction, is estimated to be equivalent to 42 million megawatts (MW) of power, and is expected to remain so for billions of years to come, ensuring an inexhaustible supply of energy [2]. Geothermal energy, the heat of the Earth, provides continuous, 24-hour a day, clean, sustainable energy production. Together, advances in technology, private investment, and government support are increasing geothermal energy production in the worldwide. Ground source heat pump (GSHP) systems produce renewable thermal energy that offer high levels of efficiency for space heating and cooling [3,4]. Ground heat exchangers are critical components in any GSHP system. Horizontal heat exchangers, vertical borehole heat exchangers and energy piles comprise the main different types of closed loop ground heat exchangers (Figure 1). Energy piles are concrete piles with built in geothermal pipes, i.e., they are thermos active ground structures that utilize reinforced concrete foundation piles as vertical closed-loop heat exchangers [5]. They vary in length from 7 to 50 m with a cross section of 0.3 to 1.5 m and can be either cast in place or precast driven. Ground source heat is a very attractive, economical, efficient and sustainable alternative to current heating practices. Unlike the air temperature, the temperature below the Earth's surface remains relatively constant throughout the year, somewhere between 10℃ to 15℃ below a depth of 6 m to 9 m.

*Advance Researches in Civil Engineering*
*ISSN: 2645-7229, Vol.2, No.3, pages: 15- 23*

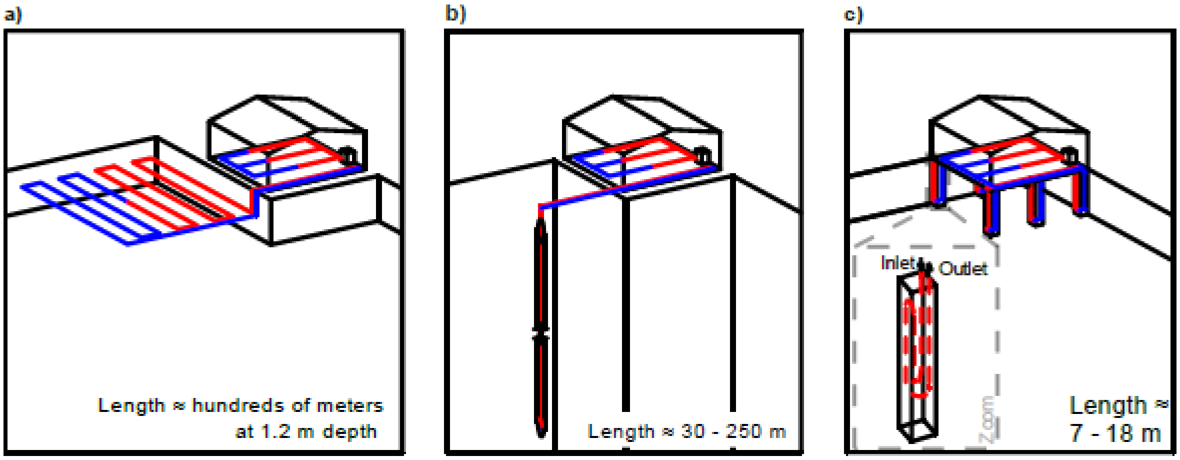


**Figure 1.** Description of main closed loop GSHP systems: a) horizontal heat exchangers; b) vertical borehole heat exchangers; c) pile heat exchangers.

## 2. Shallow Geothermal Energy and Its Use

There are two main types of ground source heat exchangers, open and closed systems. They are, however, all based on the same principle: the use of a circulating fluid, generally water, to extract or inject heat into the ground. In open systems, water is directly extracted/injected into aquifers. Two wells are generally required, one to extract the ground water and another to re-inject it into the same aquifer. In closed systems, a fluid, generally a water/ glycol mix, circulates inside plastic tubes, called absorber pipes, which can be placed directly into boreholes or cast inside foundation elements such as piles. As the fluid circulates inside these pipes, it will exchange heat with the ground, to provide heating during the winter and cooling during the summer. The depth of heat penetration and the response time depend on the thermal properties of the ground. The thermal properties of soils are affected by several parameters, among others: mineralogy, particle shape, contact between soil particles, and volumetric ratio of the constituents, porosity, grain size distribution and degree of saturation [6].

## 3. Heat Transfer Mechanisms

The transfer of thermal energy is defined as heat and is measured in Joules (J). Heat flow can occur due to phase changes or by three distinct mechanisms: conduction, convection and radiation.

### *3.1. Conduction*

If there is a temperature gradient within a body, heat will flow from the higher temperature region to the lower temperature region due to molecular motion and interaction, as adjacent atoms vibrate against each other or as electrons move from one atom to another. This phenomenon is known as thermal conduction which only occurs within a body or between two bodies that are in contact.

### *3.2. Convection*

Convection is the process of heat transfer through the movement of a fluid or a gas. In general, it can be seen as the heat transferred between a surface and a moving fluid at a different temperature. For instance, convective heat transfer can take place in permeable soils as a result of seepage flow. If the soil particles and the water are at different temperatures, convective heat transfer will take place.

### *3.3. Radiation*

All bodies emit energy constantly through electromagnetic radiation. The intensity of this energy flux depends on the body's temperature and the nature of its surface. For instance, if we sit in front of a fire most of the heat we feel is transferred to us by radiation. Even though all of the three heat transfer mechanisms previously mentioned can take place in a soil medium, thermal conduction is generally the dominant process, while convection and radiation usually have negligible or small effects. Table 1, indicates typical thermal conductivity values of common soil constituents.

**Table 1. Usual thermal conductivity values of substances common in soils [7]**

| Substance | Thermal conductivity (W/m.K) |
|---|---|
| Quartz | 8.79 |
| Clay Mineral | 2.93 |
| Organic Matter | 0.25 |
| Water | 0.57 |
| Ice | 2.18 |
| Air | 0.025 |

## 4. Thermal Expansion in Soils and Concrete

The coefficient of thermal expansion (CTE) describes the tendency of a material to change in volume when subjected to a temperature change and it is defined as the fractional increase in length per unit rise in temperature. Most materials increase in volume when heated due to the increased thermal vibration of their atoms which results in an increase in the average separation distance of adjacent atoms, however, this is not the case for soils, which can also present a contractive behavior when heated. Thermal strains in soils due to thermal loading are the result of thermal expansion/contraction of the soil particles and pore water, which due to their different thermal expansion coefficients results in the build-up of excess pore pressures, and the rearrangement of the solid skeleton of the soil. Many past studies report a great influence of the over consolidation ratio (OCR) on the thermal volume changes of clays. When heated, normal and lightly over consolidated clays present a plastic contractive behavior while high OC clays an elastically expansive behavior which increases with OCR and is followed by plastic contraction [8, 9].

*Advance Researches in Civil Engineering*
*ISSN: 2645-7229, Vol.2, No.3, pages: 15- 23*

## 5. The Effect of Heating and Cooling

When a body is subjected to a temperature change, it will attempt to expand if heated or contract if cooled. If the body is free to expand/contract it will change in volume without any development of additional stresses. However, if the body is partially or fully restrained thermally induced stresses will develop, whose magnitude will be proportional to the amount of restraint the body is subjected to.

### *5.1. Free Body Response (No Restraint)*

When heated or cooled, a free body will expand or contract proportionally to its coefficient of linear thermal expansion, α ($m/m/K$), and to the applied change in temperature, $\Delta T$, as expressed by Equation 1, where $\varepsilon_{T-Free}$ represents the free thermal strain.

$$\varepsilon_{T-Free} = \alpha\Delta T \tag{1}$$

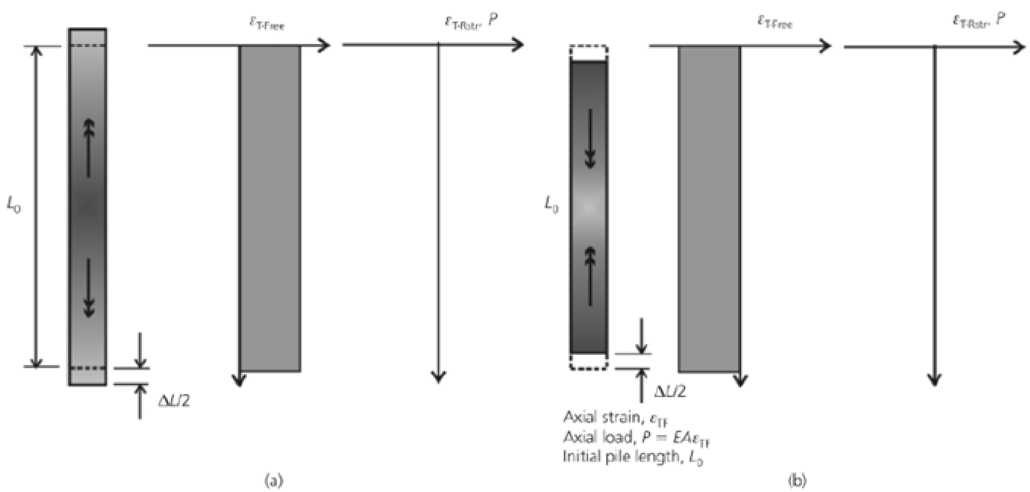


**Figure 2.** Thermal response of a non-restrained pile (free body): a) heating; b) cooling [10]

### *5.2. Perfectly Restrained Body*

In contrast to the previous case, if the pile is perfectly restrained and its ends are not able to move, any applied thermal load will lead to additional axial load, uniform compressive stress if the pile is heated and uniform tensile stress if the pile is cooled. Considering the pile as a perfectly elastic and homogeneous material, the additional axial load, P, due to a temperature change will be proportional to the cross-sectional area, A, Young´s Modulus, E, and the equivalent strain due to the restraint, $\varepsilon_{T-Rstr}$, which for the case of a perfectly restrained body is equal to $\varepsilon_{T-Free}$.

$$P = EA\varepsilon_{T-Rstr} \tag{2}$$

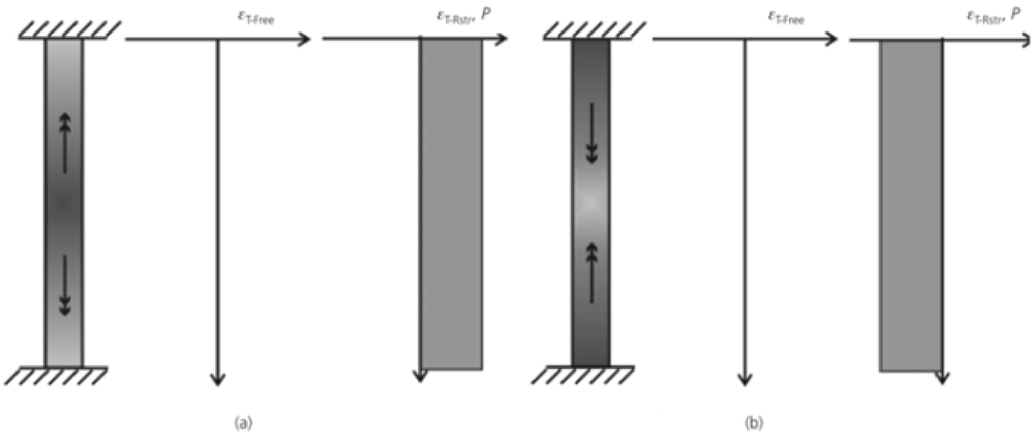


**Figure 3.** Thermal response of a perfectly restrained pile: a) heating; b) cooling [10]

## 6. Mechanical Aspects of Pile Heat Exchangers

Energy piles will be subject to a change in temperature relative to the initial condition over time, generating thermal stresses and head displacements. The pile will not expand or contract freely since it is confined, at different levels of restrain, by the structure on top and the surrounding soil (Figure 4). Thus, the measured strain changes due to temperature change will be less than the free axial thermal strain and the restrained strain induces a thermal stress [11].

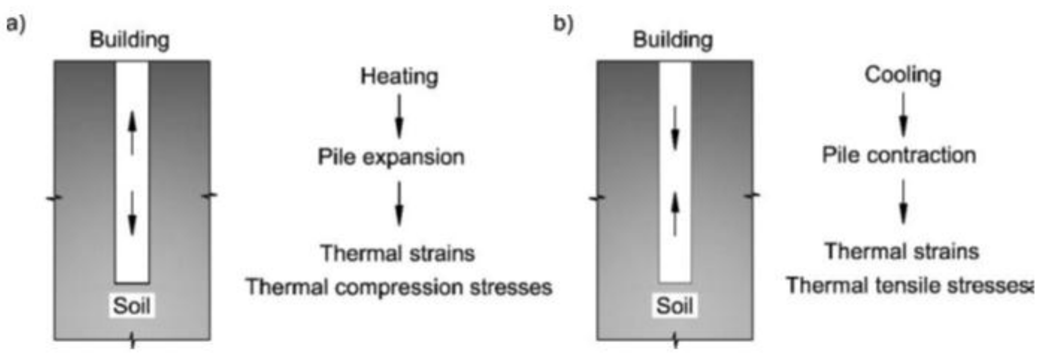


**Figure 4.** Response mechanism of a pile heat exchanger to thermal loading; a) for heating and b) for cooling.

## 7. Thermal Aspects of Pile Heat Exchangers

The temperature disturbance in the pile-soil system depends as well on the thermal properties of the concrete and the surrounding soil, the geometry of the pile and the foundation pile arrangement. Hence, an assessment of the induced temperature changes with respect to the initial undisturbed temperature needs to be carried out to estimate the induced thermal stresses and strains expected in an energy pile foundation.

## 8. Experimental Observations of the Effect of Heating and Cooling a Pile

In this section, the results of tests performed on energy piles are described. These tests were conducted with the aim of improving our knowledge regarding the impact of the thermal load on the geotechnical performance of pile foundations.

### *8.1. Switzerland*

System design and construction of the New Terminal E at Zürich Airport has been presented in Laloui & Di Donna [12]. New terminal was built on 440 foundation piles, of which 300 were equipped with five U-pipes fixed on the reinforcement. Piles were approximately 30 m in length with a diameter ranging from 0.9-1.5 m fully passing through soft lake deposits and standing on a moraine layer. Terminal has been in use since 2004. It has proven to be economically more profitable than a conventional pile system.

### *8.2. United Kingdom*

In the work of Suckling & Smith [13], an example of the first energy pile installation in the UK built in 2001 has been presented. A six storey structure included a basement up to 7 m below the existing ground level. Soil consisted of 4 different layers with a groundwater table at about 5 m below the surface. Length and diameter of the piles ranged from 9-15 m and 600-750 mm, respectively.

### *8.3. United Kingdom*

Some of the research projects performed in Austria have been presented in the work of Brandl [1]. A rehabilitation centre comprising of seven floors, two of them beneath the ground surface, was constructed on a system of 175 piles, of which 143 were fitted with heat exchangers. Diameter of the piles was 1.2 m while the pile length varied between 9-18 m depending on the static requirements and ground properties. Ground consisted mostly of silty sand and clayey to sandy silt with groundwater at 4-5 m below the surface.

## 9. Geothermal Energy Supplies over the World

Geothermal energy supplies more than 10,000 MW to 24 countries worldwide and now produces enough electricity to meet the needs of 60 million people [14]. The Philippines, which generates 23% of its electricity from geothermal energy, is the world's second biggest producer behind the U.S [15]. Geothermal energy has helped developing countries such as Indonesia, the Philippines, Guatemala, Costa Rica, and Mexico. The benefits of geothermal projects can preserve the cleanliness of developing countries seeking energy and economic independence, and it can provide a local source of electricity in remote locations, thus raising the quality of life.

## 10. Comparing Geothermal Plants to Fossil Fuels

Unlike fossil fuel power plants, no smoke is emitted from geothermal power plants, because no burning takes place; only steam is emitted from geothermal facilities. Emissions of nitrous oxide, hydrogen sulfide, sulfur dioxide, particulate matter, and carbon dioxide are extremely low, especially when compared to fossil fuel emissions.

**Table 2. Emissions from geothermal facilities compared with coal facilities**

| Emission | Nitrogen oxide (NOx) | Sulfur Dioxide (SO2) | Particulate Matter (PM) | Carbon Dioxide (CO2) |
|---|---|---|---|---|
| Sample Impacts | lung irritation, coughing, smog formation, water quality deterioration | wheezing, chest tightness, respiratory illness, ecosystem damage | asthma, bronchitis, cancer, atmospheric deposition, visibility impairment | global warming produced by carbon dioxide increases sea level, flood risk, glacial melting |
| Geothermal emissions (lb/MWh) | 0 | 0-0.35 | 0 | 0-88.8 |
| Coal emissions (lb/MWh) | 4.31 | 10.39 | 2.23 | 2191 |
| Emissions Offset by Geothermal Use (per yr) | 32 thousand tons | 78 thousand tons | 17 thousand tons | 16 thousand tons |

While most geothermal plants do not emit sulfur dioxide directly, when a small amount of hydrogen sulfide is released as a gas into the atmosphere, it eventually changes into sulfur dioxide and sulfuric acid. Therefore, any sulfur dioxide emissions associated with geothermal energy derive from hydrogen sulfide emissions.

## 11. Conclusions

The literature review shows a vast amount of information and studies regarding thermo-mechanical aspects of pile heat exchangers. The analyzed research concludes that the thermal loads and displacements resulted from the geothermal use of the energy piles are not likely to lead to geotechnical or structural failure. However, energy piles are structural elements and they need to be treated as such. Therefore, the energy pile design needs to incorporate geotechnical, structural and heat transfer considerations. The induced thermal stresses and strains depend on the temperature change caused by the ground thermal load, which results from the building heating and/or cooling needs. The temperature disturbance and its magnitude in the pile-soil system will also depend on the thermal properties of the concrete and the surrounding soil. Hence, a prior assessment of the induced temperature changes with respect to the initial undisturbed temperature needs to be carried out in order to estimate the induced thermal stresses and strains. The relative values of the coefficient of thermal expansion for the soil and the concrete play a key role in dictating the direction and the magnitudes of the developed stresses in a pile subjected to thermal loading. If the soil is more thermally expansive than concrete, the ground surface temperature has a very important influence over the thermally induced stresses developed in the pile. This effect was however considerably less significant if the concrete is more expansive than soil. In the past few decades, energy piles have proved to be innovative and environmentally friendly structural elements that function as heat exchangers providing energy to the overlaying structure. Although this technology has been recently applied in various countries, there are still important knowledge gaps on the consequences of the application of such technology because of the potential risks that might arise due to unforeseen induced cyclic thermal stresses making construction companies reluctant to apply energy piles in daily practice.

## 12. References

[1]- Brandl, H., 2006, **Energy foundations and other thermo-active ground structures**, Geotechnique, 56(2), 81-122.

[2]- Energy and Geosciences Institute, University of Utah. Prepared by the U.S. Geothermal Industry for the Renewable Energy Task Force, 1997, Briefing on Geothermal Energy. Washington, D.C.

[3]- Rees, S. J., 2016, **1 - An introduction to ground-source heat pump technology, in: Advance Ground-Source Heat Pump System**, Woodhead Publishing, pp.1–25. doi:http://dx.doi.org/10.1016/B978-0-08-100311-4.00001-7.

[4]- Lund, J. W. and Boyd, T. L., 2016, **Direct utilization of geothermal energy 2015 worldwide review**, Geothermics. 60, 66–93.

[5]- Brandl, H., 2006, **Energy foundations and other thermo-active ground structures**, Geotechnique, 56, 81–122.

[6]- Knellwolf, C., Peron, H., and Laloui, L., 2011, **Geotechnical analysis of heat exchanger piles**, Journal of Geotechnical and Geoenvironmental Engineering, 137, 890–902.

[7]- Rees, S. W., Adjali, M. H., Zhou, Z., Davies, M. & Thomas, H. R., 2000, **Ground heat transfer effects on thermal performance of earth contact structures**, Renewable and Sustainable Energy Reviews, 4, 213-265.

[8]- Cekerevac, C. and Laloui, L., 2004, **Experimental study of thermal effects on the mechanical behaviour of a clay**, International Journal for Numerical and Analytical Methods in Geomechanics, 28(3), 209–228.

[9]- Baldi, G., Hueckel, T., and Pelegrini, R., 1998, **Thermal volume changes of the mineral-water system in low-porosity clay soils,** Canadian Geotechnical Journal, 25, 807–825.

[10]- Bourne-Webb, P., Amatya, B. & Soga, K., 2013, **A framework for understanding energy pile behaviour**, Proceedings of the Institution of Civil Engineers Geotechnical Engineering.

[11]- Murphy, K. D., McCartney, J. S., 2014, **Thermal Borehole Shear Device**, Geotechnical Testing Journal, 37. 20140009. doi:10.1520/GTJ20140009.

[12]- Laloui, L. and Di Donna, A., 2013, **Energy Geostructures**, Innovation in Underground Engineering. ISTE Ltd, London.

[13]- Suckling, T. P. and Smith, P. E. H., 2002, **Environmentally friendly geothermal piles at Keble College**, Oxford, UK. In: International Conference on piling and deep foundations, 445-452.

[14]- Dorn, J., 2008, **World Geothermal Energy Production Nearing Eruption (Aug. 2008)**, Earth Policy Institute, Retrieved December 20, 2008.

[15]- Dorn, J., 2008, **World Geothermal Energy Production Nearing Eruption (Aug. 2008)**, Earth Policy Institute. Retrieved December 20, 2008.