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The potential of energy micropiles as energy geostructures

Le potentiel des micropieux énergétiques comme geostructures énergétiques

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ABSTRACT: The energy crisis presently faced in the world and particularly in Europe, is raising alarm for the transition from fossil fuels to sustainable and renewable energy resources. It is in this light that low enthalpy geothermal energy is increasingly getting attention, in the heating and cooling sectors. With diversified technologies of geothermal extraction, it is important to choose the right technology for every situation considering both the economic and technical aspects. In the context of structural rehabilitation of buildings, micropiles stand as the optimum choice for retrofitting and underpinning of existing foundations. This technology could also be advantageously extended in the sector of energy rehabilitation, as the thermal performance of micropiles suitably equipped to allow heat exchange between the ground and the building has proven promising for use in heating, ventilation, and air conditioning systems. Although very similar to energy piles, the behavior of energy micropiles is expected to be different mainly due to the difference in sizes and spacing. As such, a comprehensive understanding of the thermo-mechanical behavior of energy micropiles is important in view of their application. To date, however, little research has been conducted on the subject. The paper introduces energy micropiles, discusses their thermal performance and thermo-mechanical behaviour, and describes a real case of energy micropiles application.

RÉSUMÉ: La crise énergétique à laquelle le monde est actuellement confronté, et particulièrement l'Europe, sonne l'alarme quant à la transition des combustibles fossiles vers des ressources énergétiques durables et renouvelables. C'est dans cette optique que l'énergie géothermique à basse enthalpie retient de plus en plus l'attention, dans les secteurs du chauffage et du refroidissement. Avec des technologies diversifiées d'extraction géothermique, il est important de choisir la technologie adaptée à chaque situation, en tenant compte à la fois des aspects économiques et techniques. Dans le contexte de la réhabilitation structurelle des bâtiments, les micropieux constituent le choix optimal pour la rénovation et la reprise en sous-œuvre des fondations existantes. Cette technologie pourrait également être avantageusement étendue au secteur de la réhabilitation énergétique, car les performances thermiques des micropieux convenablement équipés pour permettre l'échange thermique entre le sol et le bâtiment se sont révélées prometteuses pour une utilisation dans les systèmes de chauffage, de ventilation et de climatisation. Bien que très similaire aux pieux énergétiques, le comportement des micropieux énergétiques devrait être différent principalement en raison de la différence de dimension et d'espacement. Alors, une compréhension complète du comportement thermomécanique des micropieux énergétiques est importante en vue de leur application. Mais à ce jour, peu de recherches ont été menées sur le sujet. Cet article présente les micropieux énergétiques, discute de leur performance thermique et de leur comportement thermomécanique, et décrit une étude de cas réel d'utilisation des micropieux énergétiques.

Keywords: Energy micropiles; rehabilitation of buildings; thermal performance.

1 INTRODUCTION

In response to the 2022 energy crisis in Europe, the European Commission announced the joint action plan REPowerEU, aiming to reduce Russian gas consumption in the EU by 2/3 by the end of 2022 and phase it out by 2027. One of its focuses is "clean energy transition" with the goal of increasing the EU's 2030 renewable energy target from 40% to 45%. This crisis has boosted interest of geothermal energy across Europe.

Wells were the only methods used to harness geothermal energy until energy geostructures were introduced in the 1980s. Energy geostructures interact with the soil combining the conventional structural role with the energy one. They include foundations (piles, slabs), retaining walls (diaphragm walls, sheet walls), tunnels. Energy foundations with a specific heat flux typical between 20W/m and 80W/m (Brandl, 2006), are widely used today (Loveridge et al., 2020). Successful implementation of these foundations has been recorded (Sani et al., 2019). Diaphragm walls, typically used as retention systems, offer a long-term exchanged power per square meter of about 15-20W/m2 (Bourne-Webb et al., 2016; Di Donna et al., 2017). Tunnels provide a larger volume of ground and surface for heat exchange. The heat exchanged can be directly utilized by adjacent buildings and integrated into district heating and cooling systems (Barla and Di Donna, 2018). The specific heat exchange power obtained from energy tunnels can range from 10 – 20 W/m2 in the absence of groundwater flow and 50-60 W/m2 in the case of relevant groundwater flow (Barla and Insana, 2023).

Heat transfer between the ground and the structure occurs through plastic pipes within the geostructure, where a heat exchanger fluid, like water, water + glycol, or a saline solution, circulates. Energy geostructures are cost effective and eco-friendly, and require no new infrastructure compared to energy wells, with a comparable thermal performance. Among them, micropiles, commonly used for structural retrofitting and rehabilitation of buildings, could be an appropriate solution for heating and cooling existing buildings with minimal available space.

This paper introduces the concept of micropiles, followed by the energy micropiles. The thermal performance and the thermo-mechanical behaviour of energy micropiles are discussed. Finally, a real case study involving the utilization of energy micropiles is presented.

2 ENERGY MICROPILES

Micropiles are smaller – diameter (usually less than 30 cm), drilled and grouted non-displacement piles that are usually reinforced. Micropile installation involves drilling a hole, placing reinforcement, and grouting the hole. In addition to this conventional type, steel micropiles and self-drilling micropiles are available today. These smaller piles may be feasible under the following constraints (Sabatini et al., 2005):

- Limited access or location in remote areas.
- Need for a support system in close proximity to existing structures.
- Difficult ground and drilling conditions (such as karstic areas, uncontrolled fills, boulders, etc).
- Requirements for minimizing noise and vibration.

Micropiles can be used for both in-situ reinforcement and structural support. Extending their application to provide heating and cooling to buildings could be very useful in many cases.

2.1 Thermal performance of energy micropiles

Ronchi et al., (2018) carried out numerical simulations for a conventional grouted micropile in summer conditions. Results of the numerical study show that a thermal power of about 30W/m was obtained after a 6-month period. In wet sediments, up to 111W/m of thermal power was obtained from the self-drilling grouted TITAN 73/53 energy micropile (Ischebeck, 2015). These values are comparable to those of energy piles, signifying the promise of energy micropiles as a technology for heating, ventilation, and air-conditioning systems.

Pipe length, concrete thermal conductivity and pipe diameter are the most important parameters in maximising the thermal efficiency of energy micropiles (Cecinato and Salciarini, 2022). However, the small section of micropiles poses a challenge when considering the pipe arrangements commonly employed in larger piles such as the W, spiral, partly W and the double-U shape. In literature, two primary pipe configurations stand out for energy micropiles, the single-U and the coaxial. Due to the greater possibility of interference in small sizes micropiles with U-pipes, it is predicted that the coaxial pipe configuration should be the most suitable for energy micropiles. Moreover, with the large volume of water in the annular space of the coaxial pipe arrangement, the micropile can serve as a storage tank, as water has a high specific heat capacity. However, the intrusion of grout in the annular space could reduce the thermal potential of the micropiles in the long term and should therefore be investigated.

In addition, increasing the number of micropiles in a group will increase the overall heat exchange rate of the system, although it reduces the average heat exchange rate of individual micropiles (Kong et al., 2021). The spatial arrangement of energy micropiles within a group exhibits minimal or negligible influence on the average heat exchange rate of each micropile (Kong et al., 2021). However, closely spaced thermally activated micropiles should be avoided as thermal interference can result in a significant loss of function (Lupattelli et al., 2023) with time. When the fluid inlet velocity and/or the inlet temperature of the heat exchange fluid are increased, the pile temperature also increases (Kong et al., 2021). Consequently, meticulous design considerations are imperative to ensure the structural integrity of the energy micropile system remains uncompromised.

2.2 Review of the thermo-mechanical behavior of energy micropiles

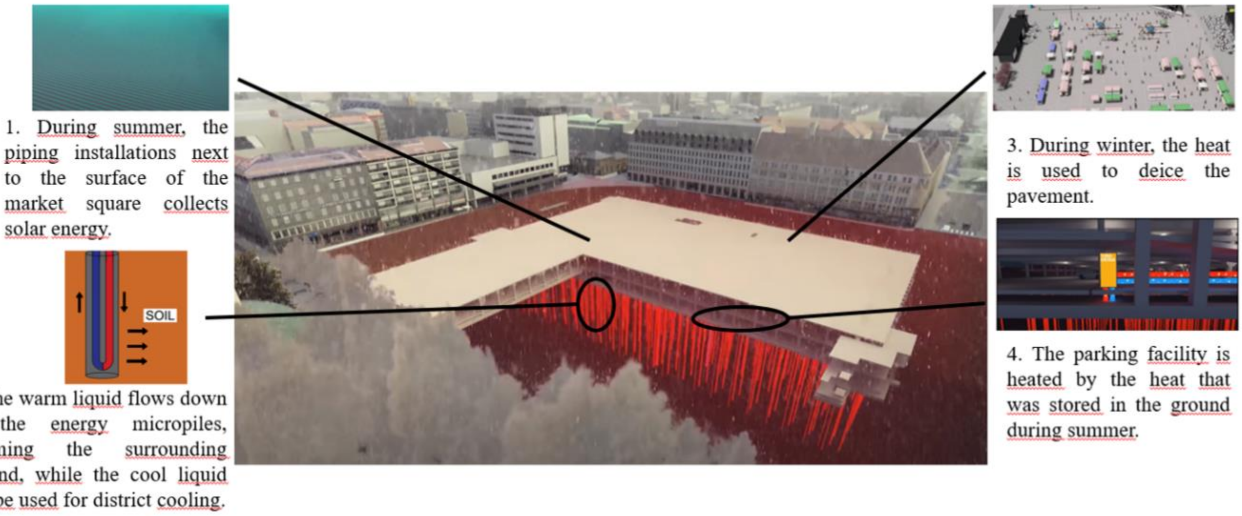
Although the energy micropile system and the energy pile system are quite similar, their behavior cannot be assumed to be similar both mechanically and thermally, as the former has negligible end bearing capacity and smaller dimensions (Ronchi et al., 2018). Unlike energy piles, very little research has been done on energy micropiles. It is important to note that due to poor cleanout at the toe of micropiles, the side shear resistance largely controls the restraint for thermal expansion and contraction of energy micropiles (Casagrande et al., 2022).

For micropiles installed in granular soils and subjected to cyclic thermal loading, (Lupattelli et al., 2023) observed the development of irreversible settlement during the initial cooling cycles. However, these settlement values were deemed negligible and could be disregarded during the design process. When installed in stratified soil, the behavior of energy micropiles becomes a little more complex and needs more attention. (Casagrande et al., 2022) carried out TRT tests to understand the impact of different soil layers on the thermomechanical response of EMPs. An interesting finding was the development of plastic strains which occurred only in the organic clay layer after a certain amount of heating, while all the other layers (silty sand and sand soil) kept the thermo-elastic behavior. Furthermore, it was observed that the mobilized coefficient of thermal expansion decreased following each successive heating cycle. This reduction was associated with an increase in side shear resistance, thereby increasing restraint along the pile's length induced by heating. Additionally, variations in the coefficient of thermal expansion were noted across different soil layers, with the lowest value recorded in the organic clay soil layer.

Just like energy piles, thermal axial stresses are induced by thermal loading in energy micropiles. These stresses increase both with the inlet fluid temperature (Kong et al., 2021) and the number of loading cycles (Casagrande et al., 2022). Significant compression stresses were observed for long, slender micropiles (Lupattelli et al., 2023). Therefore, thermal stresses should also be considered during the structural design process. These observations highlight the complexity of the thermo-mechanical behavior of energy micropiles. The observations discussed in this section pertain to micropiles with a U-pipe configuration. However, to the best of the authors' knowledge, no study on the thermo-mechanical behavior of coaxial energy micropiles has been conducted. Thus, further research is essential for an appropriate design of these small piles.

3 REAL CASE OF ENERGY MICROPILES APPLICATION

Europe’s first zero energy parking, Toriparkki, is situated underneath the Turku market square in Finland (Figure 1). The 30.000 m^2 parking produces 100% of the heat energy used by combining solar energy, district heating, geothermal energy and underground thermal storage. The geothermal system comprises of 561 steel energy small diameter piles amongst the 2000 piles installed. The micropiles lengths range from 15 to 45 m, with diameters of 14 cm and 17 cm (Lautkankare et al., 2020). Inside the 40 mm U-tube polyethylene pipes, water circulates. The ground being constituted of clay is appropriate for thermal energy storage.



1. During summer, the piping installations next to the surface of the market square collects solar energy.

2. The warm liquid flows down to the energy micropiles, warming the surrounding ground, while the cool liquid can be used for district cooling.

3. During winter, the heat is used to deice the pavement.

4. The parking facility is heated by the heat that was stored in the ground during summer.

Figure 1. Illustration of the Toriparkki parking facility during winter. Adapted from (NollaE, 2019).

In summer, the surface of the market square is heated by the sun and the warm liquid flows underground through the piping system to the energy piles, warming the surrounding ground to a maximum depth of 50 m. The storage capacity and the heating power of the heat storage system are about 11.2 GWh and 6.6 M respectively. As autumn arrives, the thermal energy storage reaches its peak warmth, and the heated ground starts to release heat to the liquid in the energy piles. This warmed liquid then flows back up to the surface piping. Throughout winter, the heat stored underground is utilized to deice the pavement and heat the parking facility. As time progresses, the stored heat gradually diminishes, allowing the cool liquid in the system to be utilized for district cooling during spring. This heating system reduces CO2 emissions annually by about 950 tons compared to a heat pump facility.

4 CONCLUSIONS

Energy geostructures such as energy piles, slabs, walls, and tunnels, are efficient in providing renewable and clean energy for heating and cooling of buildings. However, their widespread adoption faces a common challenge in densely populated cities, where space constraints make it difficult, if not impossible, to implement individual geothermal systems. Micropiles, mostly used in structural retrofitting and rehabilitation, hold promise for providing sustainable energy for heating, ventilation, and air conditioning of existing buildings. Recent research has shown that the thermal performance of energy micropiles is comparable to that of energy piles. However, the small section of micropiles poses some challenges both in the thermal efficiency and thermo-mechanical behaviour. Nevertheless, it is predicted that the coaxial pipe configuration could be the most suitable pipe configuration for energy micropiles. In conclusion, more research should be carried out on energy micropiles for an appropriate thermal and thermo-hydro-mechanical design.

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