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Heat transfer performance of large energy pile group in a hybrid system subjected to imbalanced thermal load - A numerical investigation

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Introduction

When a energy pile system is coupled with other heating or/and cooling systems, determining the share of thermal demand that energy piles can meet is crucial in designing the size of each system. In the long term, imbalance in thermal load can affect the heat transfer performance of energy piles, and may also lead to annual accumulation of ground temperature over the years, ultimately causing system failure. Furthermore, the mechanical responses of energy piles are also affected by the temperature changes in the pile body and surrounding soil during operation. While Current researches have predominantly focused on mechanical response under temperature load, understanding the heat transfer performance of energy pile groups is equally necessary. Existing studies on heat transfer largely draw from ground source heat pump (GSHP) systems, despite differences in depth and diameter between energy piles and borehole heat exchangers (BHEs), particularly for closely spaced piles. To address this gap, we conducted a series of numerical experiments based on the Tsinghua Science Museum project to investigate the thermal behavior of energy pile group under annual, imbalanced load and the influence of pile spacing. Based on simulation results, we provide design recommendations on how to determine the proportion of heat load that can be carried by energy piles in hybrid systems.

Method

We utilized COMSOL software to conduct three-dimensional modeling of a single pile, and developed a two-dimensional model of a pile group using a self-programmed Matlab program. The accuracy of the model was evaluated by comparing it with the results obtained from energy pile field tests (thermal response tests and thermal performance tests) conducted in Shunyi, Beijing. Subsequently, we established two-dimensional and three-dimensional numerical models for the Tsinghua Science Museum project in Beijing. We performed a series of numerical experiments to investigate the behavior of energy piles under balanced and imbalanced temperature loads for one year. Furthermore, we simulated the thermal responses of energy pile groups with different pile spacings of 2m, 2.85m, and 4m.

Results

The cooling load surpasses the heating load causing an imbalanced load. The soil temperature rises noticeably by 2.6 °C compared to the initial state after an operation period of 1 year, indicating an undesirable phenomenon of soil heat accumulation. With continuous running over years, the system will fail due to the excessive soil temperature. Moreover, the heat exchange liquid temperature ranges from -4.35 ℃ to +39.65 ℃, which exceeds the acceptable range of 2 ℃ to 33 ℃. To address this concern, a hybrid system can be utilized where the energy pile system bears a balanced portion of the thermal load, and the auxiliary system bears the remaining load. Simulation under various thermal load proportions reveals a linear relationship between the maximum/minimum outlet temperature and the total heat exchange volume. An energy pile system undertaking 60% heating load and 40% cooling load can run stably for long periods. The soil temperature varies in a range of 8.5 ℃ to 17.9 ℃, while the pile body temperature has a variation range of 4.0 ℃ to 22.8 ℃ (Figure 1).

The study results for various pile spacings are presented in Table 1. Pile spacing plays a significant role in soil heat accumulation and heat exchange fluid temperature. Despite an invariable pattern in the inflow and outflow temperature curves for varied pile

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spacing, the flow temperature range is significantly influenced. The smaller the spacing, the more prominent is the thermal accumulation in the soil, leading to larger changes in soil temperature and the flow temperature. During design simulation, if the range of flow temperature exceeds the limits of the energy pile system, it may present a safety risk during system operation. In such cases, increasing the pile spacing can render the system more reliable and safe.

Conclusions

(1) Whether the system can operate normally can be judged by whether the simulation result of the heat exchange liquid temperature exceeds the limit value. There is a linear relationship between the flow temperature and the total heat exchange. Therefore, the proportion of the load that the energy pile system can bear in the hybrid system can be determined. For the Tsinghua project, the energy pile system can bear 60% of the heating load and 40% of the cooling load.

(2) The pile spacing affects the magnitude of variation in heat exchange fluid temperature by influencing the degree of heat accumulation in soil. If the range of flow temperature exceeds acceptable limits, it is advised to increase the pile spacing during the design phase to ensure the energy pile system can operate effectively.

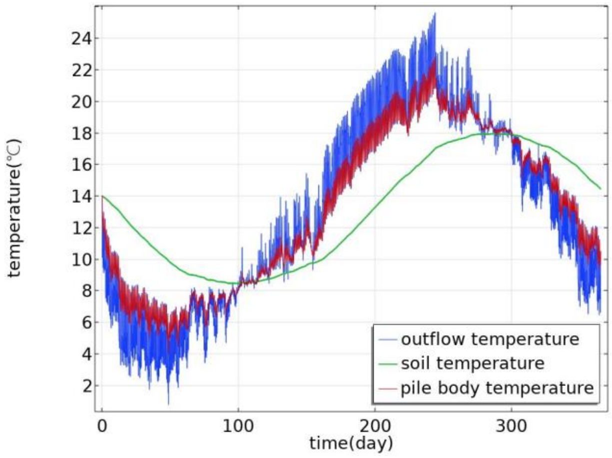

Figure 1: Outflow, soil, pile body temperature curves.

Pile spacing (m)	Soil temperature (℃)	Heat exchange liquid temperature (℃)
2	2.9~22.0	-4.0~29.2
2.85	8.5~17.9	-0.4~26.7
4	10.1~16.8	2.2~25.0

Table 1: Soil, heat exchange liquid temperatures with various pile spacings.

Contributor statement

Wanqi Tian: Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft. **Xiaohui Cheng**: Methodology, Writing - review & editing.

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