Symposium on Energy Geotechnics
Accelerating the energy transition
3-5 October 2023, Delft, the Netherlands

Peer-reviewed Conference Contribution

Effect of pile spacing on the thermal performance of thermo-active pile groups

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Thermo-active piles differ from conventional piles in a way that they have pipes embedded within them, which allow a carrier fluid to circulate through and exchange heat with the ground, in order to provide low carbon heating and cooling. Sustainability targets, such as the Merton Rule, which requires a proportion of the energy demand of the building to be generated on site using renewable sources [1, 2], have facilitated the growing popularity of designing piles to be thermo-active in the United Kingdom [3, 4, 5]. In order to fulfil these sustainability targets and to determine accurately the energy savings by designing piles to be thermo-active, the thermal performance of thermo-active piles has to be determined.

Thermo-active piles are often deployed as a group, with values of spacing considerably smaller than those adopted in fields of borehole heat exchangers. As a result, thermal interference occurs between them, penalising their thermal performance [6], compared to the case of a single standalone thermo-active pile, as the piles are heated or cooled by adjacent piles within the pile group. Considering thermo-active piles with identical geometry, pipe arrangement and heating/cooling conditions, it is not difficult to establish that the upper bound of thermal performance corresponds to piles operating as single standalone thermo-active piles, without the effects of thermal interference. When thermo-active piles operate as a group, the spacing between the piles and the pile group size govern the effects of thermal interference, hence the penalty in thermal performance compared to the upper bound case. In order to quantify the penalty in thermal performance when thermo-active piles operate as a group, this paper considers infinitely-large thermo-active pile groups, where piles are separated by 3, 4, 5 and 6 times the pile diameter, respectively. This approach establishes lower bounds of thermal performance, which are dependent on the pile spacing for the thermo-active pile considered. The realistic thermal performance of the thermo-active piles within a finite-sized pile group with a given pile spacing would therefore lie between the lower and upper bounds as explained above.

The thermo-active piles considered in this research are 900 mm in diameter, 20 m in length with double U-loop pipe arrangement. They are heated up with a constant inlet temperature of 20°C above the initial ground temperature, which is assumed to be 20°C, for a duration of one year. A flow rate of $1 \times 10^{-4}\ m^3 \cdot s^{-1}$ per U-loop is adopted and water is used as the carrier fluid, which has a volumetric heat capacity of $4.18 \times 10^6\ J \cdot m^{-3} \cdot K^{-1}$. The thermal conductivities of the thermo-active pile and soil are $2.3\ W \cdot m^{-1} \cdot K^{-1}$ and $1.8\ W \cdot m^{-1} \cdot K^{-1}$, respectively, and the volumetric heat capacities of the thermo-active pile and soil are $1.9 \times 10^6\ J \cdot m^{-3} \cdot K^{-1}$ and $1.8 \times 10^6\ J \cdot m^{-3} \cdot K^{-1}$, respectively.

Three-dimensional thermal numerical analyses are conducted using COMSOL Multiphysics® [7]. To establish the upper bound of thermal performance, a single thermo-active pile is placed at the centre of a domain which is 80 m by 80 m and is 40 m deep, where all the domain boundaries are prescribed with a no change in temperature thermal boundary condition. To establish the lower bounds of thermal performance, which are solely dependent on the pile spacing as infinitely-large thermo-active pile groups are considered, the thermo-active pile is placed at the centre of a domain where the length of the sides is given by the pile spacing (therefore, pile spacings of 3, 4, 5 and 6 times the pile diameter correspond to domain sizes in plan of $2.7\ m \times 2.7\ m$, $3.6\ m \times 3.6\ m$, $4.5\ m \times 4.5\ m$ and $5.4\ m \times 5.4\ m$, respectively). Due to symmetry, the four sides of the domain are modelled as adiabatic to

DOI: https://doi.org/10.59490/seg23.2023.505

account for the presence of the adjacent piles. The domain is 40 m deep and the top and bottom boundaries are prescribed with a no change in temperature thermal boundary condition.

The evolutions with time of thermal performance (in terms of power per unit pile length) are presented in Figure 1(a), while Figure 1(b) plots the thermal performance of an infinitely-large pile group as a percentage of that of the single pile. Note that the power of the thermo-active piles is evaluated based on the temperature differentials between the pipe inlets and outlets. Clearly, the power per unit pile length (see Figure 1(a)) reduces with time due to the reduction in the thermal gradient between the hot pipe and the surrounding concrete, eventually reaching a relatively constant value after a year of operation. It can also be seen that, when the pile spacing reduces, effects of thermal interference (i.e. where the limited volume of soil between piles is heated up by several piles) increase significantly, resulting in considerably lower powers. Referring to Figure 1(b), it can be observed that when piles are separated by 3 times the pile diameter, the lower bound of power is only 18% of a single pile (i.e. the upper bound) after around 120 days of operation, whereas when the piles are separated by 6 times the pile diameter, the lower bound of power still retains 40% of the upper bound after a year of operation.

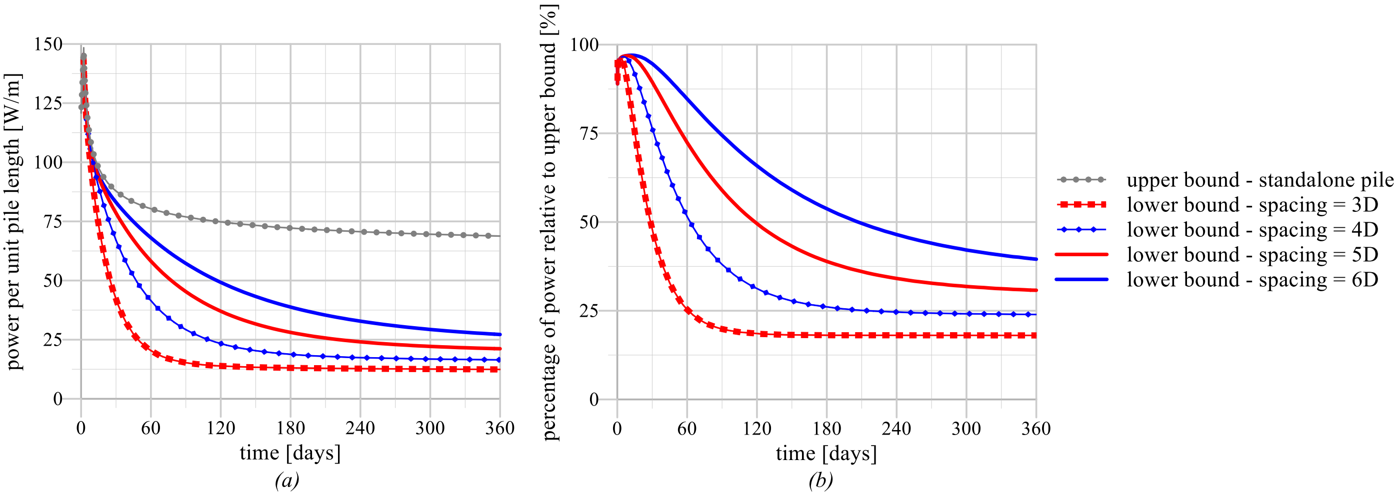

Figure 1: (a) Evolutions of thermal performance with time and (b) percentage of power the lower bounds are relative to the upper bound.

Contributor statement

Ryan Liu: Conceptualisation, Data Curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualisation, Writing – original draft, Writing – review & editing; David Taborda: Conceptualisation, Formal analysis, Funding acquisition, Methodology, Project administration, Supervision, Resources, Validation, Writing – review & editing.

Acknowledgments

This research is part of the SaFEGround (Sustainable, Flexible and Efficient Ground-source heating and cooling systems) project, which is funded by the Engineering and Physical Sciences Research Council (EPSRC) (grant number: EP/V042149/1).

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