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Numerical investigation of the effects of thermal expansion coefficient of pile and soil on the mechanical response of energy pile

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ABSTRACT: Considering the environmental pollution resulting from the consumption of fossil fuels, replacing clean energy with fossil fuels has become one of the most critical issues in the world. In order to exchange the heat between superstructures and the ground, the use of energy piles can be considered as an approach to take advantage of clean energy. In order to maintain the safety and serviceability of structures built on energy piles, it is necessary to properly study the effects of heat exchange between energy piles and the ground on the mechanical response of energy piles and the influence of various parameters on the interaction between piles and the soil. In this paper, a 3D finite difference model was initially created using FLAC software for the thermo - mechanical analysis of energy piles, and it was validated by comparing the results of the present model with those of field tests and numerical models performed by other researchers. Using the present numerical model, the effects of changing the thermal expansion coefficient of the energy pile and clayey soil on axial stress, shaft friction, and axial displacement along the energy pile under cyclic thermal loading have been investigated. The results indicate that changing the thermal expansion coefficient of pile materials causes significant changes in the behavior of energy piles under heating and cooling conditions; however, changing the thermal expansion coefficient of the soil has little effect on the mechanical behavior of the energy pile during heating thermal loading.

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1- Introduction

In recent decades, the use of ground source heat pump systems (GSHPS) for exchanging the heat between the superstructures and the ground in order to reduce the consumption of fossil fuels has been significantly expanded [1]. Energy piles are one of the GSHPS which has been widely used due to their advantages and good efficiency [2]. In order to maintain the safety and serviceability of structures built on energy piles, many researchers, using field tests [3-5], numerical models [6-8], and laboratory models [9-11], have studied the effects of thermal and coupled thermo-mechanical loading on the mechanical behavior of energy piles.

The main objective of this research is to investigate the effect of different amounts of thermal expansion coefficient of concrete energy piles and saturated clayey soil on the mechanical response of energy piles. Due to the fact that the effects of considered parameters on a single energy pile under cyclic thermal loading have not been studied so far, in the present work the effects of changing the thermal expansion coefficient of the energy pile and clayey soil in a cyclic thermal loading (including a period of heating, cooling, and thermal recovery) is investigated. Also, it is noticeable that in preceding studies, the effects of the considered parameters were only investigated on the axial stress and energy pile head displacement. Therefore, in this paper, in addition to the axial stress and displacement along the energy pile, the effects of changing the thermal expansion coefficient of the energy pile and clayey soil are also studied on the shaft friction of the energy pile.

2- Methodology

In this study, a numerical model was used to study the thermo-mechanical behavior of energy piles. The numerical model used in the analysis was built using FLAC3D software. The geometry, mechanical and thermal characteristics of the present numerical model were developed based on a documented prototype of a full-size energy pile installed in Lambeth College, London [5, 12, 13]. It should be noted that in the present model, the soil was considered saturated clay. For considering the soil-pile interaction, interface elements were used at the soil-energy pile interface. In this model, the ground and the energy pile can only exchange heat via the conduction mechanism. The mechanical constitutive models of the energy pile and soil were considered elastic and Mohr-Coulomb, respectively.

In order to verify the accuracy of the present model,

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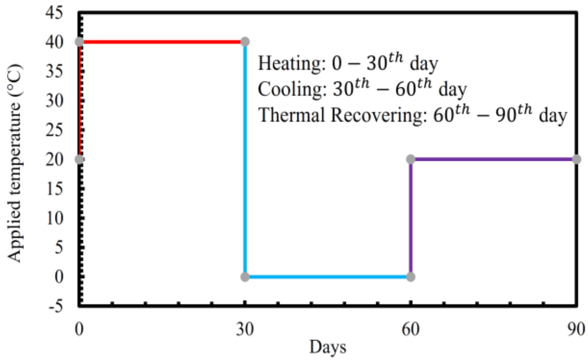

Fig. 1. Cyclic thermal loading applied to the energy pile

Table 1. Thermal expansion coefficients in the present study

Clayey soil thermal expansion coefficient (μK^{-1})	Energy pile thermal expansion coefficient (μK^{-1})
1, 5, 10	8.5, 12, 16

the thermal and mechanical responses of the present finite difference model were compared with the experimental data from the field test at Lambeth College [5, 12, 13] and also with those resulting from a finite element model created by Han et al. [14].

3- Results and Discussion

In this section, using the verified numerical 3D model, the effects of varying the thermal expansion coefficient of concrete energy pile and clayey soil on the axial stress, displacement, and shaft friction along the energy pile were studied. The energy pile was only subjected to cyclic thermal load, as shown in Figure 1. Different amounts of thermal expansion coefficients considered for the energy pile and clayey soil are mentioned in Table 1.

The results indicate that increasing the energy pile thermal expansion coefficient leads to an increase in axial strain as well as restricted axial strain along the energy pile under heating and cooling periods. As a result, axial stress also increases along the energy pile. In addition, the results show that increasing the energy pile thermal expansion coefficient causes axial displacement of the energy pile and soil-pile relative movement to increase during both heating and cooling conditions; thus, energy pile shaft friction increases as well. Figure 2 shows that by increasing the energy pile thermal expansion coefficient, the difference between the amount of displacement of the energy pile at the end of thermal recovery

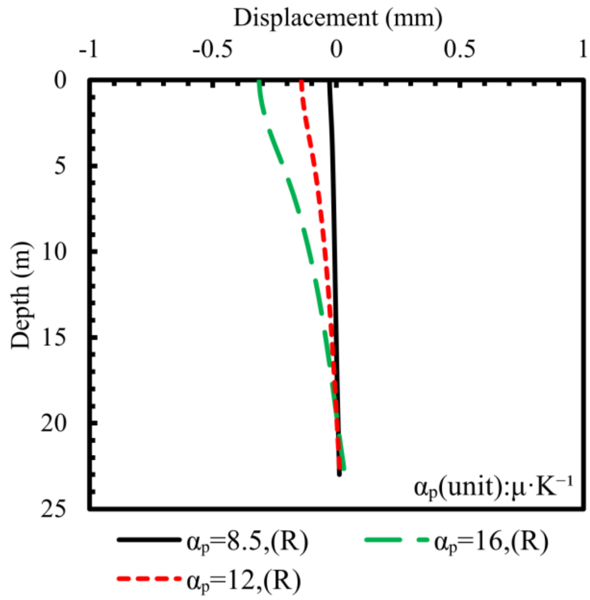

Fig. 2. Energy pile displacement at the end of thermal recovery

and the initial stages (displacement=0) also increases. This matter affects axial stress and the energy pile shaft friction at the end of thermal recovery as well.

Concerning the effects of increasing the soil thermal expansion coefficient on the mechanical responses of the energy pile, the results indicate the energy pile shaft friction is reduced when the energy pile is subjected to heating. Decreasing energy pile shaft friction as a result of increasing the clay thermal expansion coefficient at the heating stage leads to a decrease in axial stress along the energy pile. Also, the results show that by increasing the clay thermal expansion coefficient, at the end of the heating period, energy pile head displacement also increases. In contrast, the energy pile toe displacement decreases. It should be noted that based on the results of this paper, the effect of varying the thermal expansion coefficient of the clayey soil on the mechanical responses of the energy pile is negligible.

4- Conclusions

In this study, the effects of changing the thermal expansion coefficient of energy pile and saturated clay on the mechanical response of a single energy pile, including axial stress, axial displacement, and energy pile shaft friction under cyclic thermal loading, were investigated. For this purpose, a 3D finite difference thermo-mechanical model was used.

Based on the results, it was observed that increasing the thermal expansion coefficient of the pile causes an increase in axial stress, axial displacement, and pile shaft friction under heating and cooling conditions.

The results show that increasing the soil thermal expansion coefficient leads to a reduction in axial stress and pile shaft friction and an increase in pile head displacement under the heating condition.

The results indicate that changing the thermal expansion coefficient of the pile materials causes significant changes in the behavior of energy piles under heating and cooling conditions. However, changing the thermal expansion coefficient of the clayey soil has little effect on the mechanical behavior of the energy pile only during thermal heating loading.

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