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Numerical modelling of energy piles under combined loading

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The growing use of fossil fuels and other non-renewable energy sources has made climate change a critical global issue. In order to counter this threat, several countries are engaged in an ecological transition, and are looking for technologies using renewable energy sources. In this context, energy geostructures, such as thermo-active (or energy) piles, have been developed, consisting in fixing heat exchanger pipes to the reinforcement cages of foundation piles to extract/inject the heat from/into the ground with the purpose of meeting the building heating and cooling demands. Their specificity is their dual function: structural support and energy exchanger.

In the case of energy piles, two aspects can be critical and should be considered in their design. The first is the nature of the cyclic thermal loading, which can affect the mechanical response of the energy pile. In fact, during temperature variation along the pile, stresses change and pile head movements are induced (Figure 1), due to the thermal dilatancy/contraction of the pile and the behaviour of the soil-pile interface [1, 2, 3, 4, 5, 6]. Consequently, cyclic thermal loading can induce a deterioration of the shear stresses at the soil-pile interface and hence a deterioration of the pile's bearing capacity [7]. The second aspect concerns the adaptation of design under combined lateral and axial loads. Indeed, the co-existence of a lateral loading can affect the axial response of the pile and vice-versa [8]. These configurations are the most favourable for installing heat exchanger pipes since, mechanically, they require reinforcement cages all along the pile height. Studies on energy piles have mainly investigated their behaviour under axial loading. Energy piles under lateral loading have hardly been considered [9].

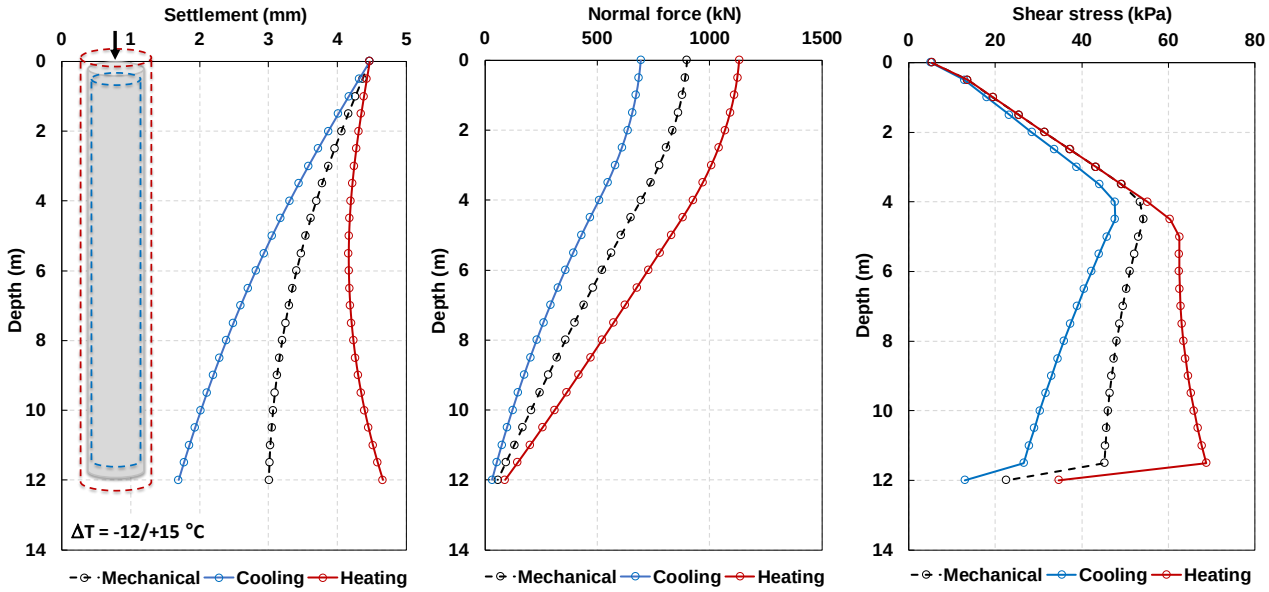

Figure 1: Comparison between mechanical results and results of first thermal cycle in the case of fixed head pile

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The aim of this paper is to present a practical calculation tool for modelling energy piles that takes into account the combined loading on the pile response. An original 1D finite element approach is developed for engineering practice, taking into account the rheology of the problem. The pile is discretised in beam finite elements with three degrees of freedom at each node (vertical displacement, horizontal displacement and rotation). The soil is modelled by surface shear and normal springs. This tool is based on the solution of the equilibrium equation of the global system by an iterative plastic correction procedure. This correction is based on the yield criterion defined in the code.

The main strength of this approach lies in its capability to consider a 3D failure envelope for an energy pile, capturing its behaviour under combined axial, lateral and cyclic thermal loading. It can clearly represent the critical effects of these loads by adopting an appropriate behaviour law for the soil-pile interface. In addition to being practical and easy to use, this tool has the advantage of reducing calculation time compared to more complex 3D numerical methods, especially in the case of cyclic thermal loading.

Contributor statement

Mirna Doghman Conceptualization, Investigation, Methodology, Software, Visualization, Writing-Original Draft
Hussein Mroueh: Conceptualiztion, Methodology, Funding acquisition, Supervision, Validation, Writing-Review & Editing

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