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Thermally induced long-term behavior of energy piles under vertical-horizontal combined mechanical loads

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At present, energy piles have been gradually applied to support the foundation of bridge abutments, high-rise buildings, earth retaining structures, seafront structures, or buildings located on the sloping ground [1, 2, 3]. During the long-term service, energy piles are subjected to vertical-horizontal combined mechanical loads while under thermal cycles. Nevertheless, most of the research presented in the literature focused on the effects of thermal cycles on the axial mechanical responses of energy piles [4, 5, 6]. Studies evaluating the effects of thermal cycles on the long-term behavior of energy piles under vertical-horizontal combined mechanical loads are scarce.

To this end, this study presents an experimental method based on a small-scale pile model installed in saturated kaolin clay to study the long-term thermomechanical performance of energy piles under thermal cycles and inclined mechanical loads. As shown in Figure 1, the experimental setup consists of a cylindrical steel soil tank, a temperature control system, and a data acquisition system. The soil tank has a diameter of 548 mm and a height of 980 mm. A two-layer geotextile filter and an insulation PVC material covered the internal and external surfaces, respectively. The model pile is made of an aluminum tube with a length of 600 mm, an outer diameter of 20 mm, and an inner diameter of 18 mm. The outer surface of the pile was coated with sand to maximize the roughness.

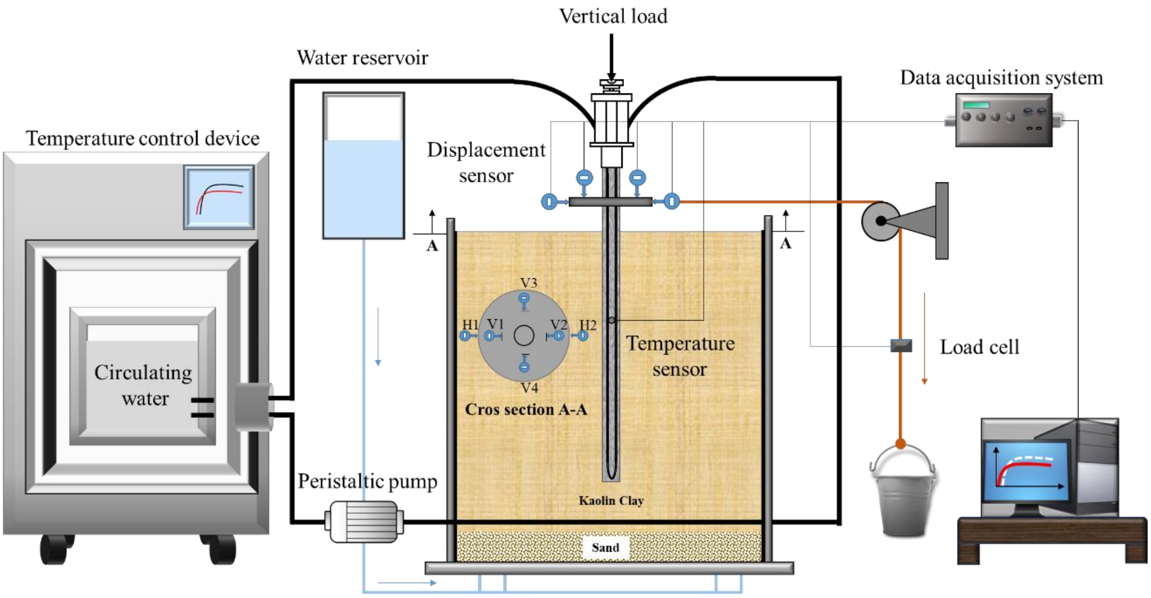

Figure 1: Schematic view of the experimental setup.

During the tests, the model pile was placed at the center of the soil tank. The distance between the pile tip and the bottom of the soil tank was 340 mm, which equals 17 D (i.e., the outer diameter of the pile), and the distance between the outer surface of the pile

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and the inner wall of the soil tank was 264 mm, corresponding 13.2 D. The above values are all greater than 10 D and the influence of boundary effect on the test results can be considered to be insignificant [7]. Besides, the particle-size scaling effect can be negligible because the ratio of the pile diameter to the mean particle size of the kaolin clay is larger than the threshold value of 40 suggested by Fioravante [8].

The testing protocole can be divided into four steps. (i) First, a sand layer of 40 mm was placed on the bottom of the soil tank to ensure that water could flow from the bottom to the top more quickly. Then the kaolin clay with an optimum water content of 29% was compacted by 50 mm thick layers until the soil tank was full of kaolin clay with a maximum dry density of 1450 kg/m^3. (ii) Second, a water reservoir was used to inject de-aired water from the bottom of the soil tank for two months. (iii) Third, the vertical mechanical load of 100 N, corresponding to 20% of the pile resistance, was applied to the pile head for two days, and the settlement of the pile head was observed to be stable. Then, three levels of horizontal loading of 35, 71, and 109 N were selected to apply to the pile head and maintained for one month at each level to consolidate the soil before the coming of thermal cycles. (iv) At each horizontal load level, fifteen thermal cycles with an amplitude of ±4.5 ℃ were applied to the pile by the temperature-controlled bath and a peristaltic pump. Each thermal cycle was completed within 24 hours, which consisted of a heating duration of 3 hours, a cooling duration of 3 hours, and a recovery duration of 18 hours for active heating to return to the initial temperature.

The results show that irreversible settlement and horizontal displacement of the pile head are induced by the thermal cycles. The effect of thermal cycles on the mechanical response of the model energy pile is more pronounced in the horizontal direction compared to the axial direction. The most significant increment of irreversible pile head settlement and horizontal displacement is caused by the first heating-cooling cycle; then, as the number of thermal cycles increases, the subsequent increments decrease and tend to stabilize. Furthermore, the finite element method was employed to simulate the model test and compare experimental and numerical results to discuss the mechanisms at the origin of the irreversible displacement to gain further insight into the experimental data. The results highlight the critical role of inclined mechanical loads in the pile-soil interaction subjected to long-term thermomechanical loading.

Data Availability Statement

All data, models, and code generated or used during the study appear in the published article.

Acknowledgments

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