Postprint: Dynamic Thermal Response Analysis Method for U-Tube Energy Piles in Layered Ground under Transient Heat Source Conditions

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Abstract

Energy piles, integrating bearing capacity and heat exchange functions, hold significant value in ground source heat pump applications. However, under layered foundation conditions, the heat transfer mechanism of pile-soil heat exchange is considerably complex, and existing analytical methods predominantly rely on constant heat source models. Such simplified assumptions fail to effectively capture the influence of dynamic thermal power variations on the thermal response of energy piles. Consequently, enhancing the accuracy of this dynamic response has emerged as a pivotal challenge in current research. To address this issue, a dynamic response calculation model for U-tube energy pile-soil heat exchange under non-constant heat source conditions in layered foundations is proposed based on finite layer heat conduction theory and step heat flux theory. This model adopts the inlet temperature of the U-tube as input, and by employing a piecewise superposition method for temperature influence effects, equivalently treats the pile-soil heat exchange process as a time-varying heat source, thereby establishing a non-constant heat flux model. According to the principle of energy conservation, the temperature distribution along the heat transfer fluid within the U-tube and the variable heat source intensity distribution are solved for different time steps. Furthermore, using the variable heat source intensity along the U-tube as input and combining it with the finite layer heat conduction calculation method for layered foundations, the time-varying characteristics of the foundation temperature field are determined, thereby effectively simulating the response process of energy pile-soil heat exchange under dynamic thermal power variations. The research results demonstrate that the proposed model not only circumvents the high computational time consumption associated with complex numerical calculations but also achieves high computational efficiency, and can accurately characterize the temperature response variations of energy piles under non-constant heat flux conditions. This model provides a reliable

theoretical basis and an efficient computational tool for engineering design, system optimization, and operational analysis.

Full Text

Dynamic Response Analysis of Heat Conduction in U-shaped Pipe Energy Piles Embedded in Layered Foundations under Unsteady Heat Source Conditions

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Abstract

Energy piles, which integrate load-bearing capacity with heat exchange functionality, represent a critical technology in ground-source heat pump systems. However, the heat transfer mechanism between piles and soil in layered foundations is inherently complex, and most existing analytical methods rely on simplified constant heat source models that fail to capture the effects of dynamic thermal power variations on energy pile thermal response. This limitation has emerged as a key challenge in improving the accuracy of dynamic response predictions. To address this issue, we propose a dynamic response calculation model for heat exchange between U-shaped pipe energy piles and soil in layered foundations under unsteady heat source conditions, based on finite layer heat conduction theory and step heat flux theory. The model employs the inlet temperature of the U-shaped pipe as input and utilizes a piecewise superposition method for temperature influence effects to equivalently represent the pile-soil heat exchange process as a time-varying heat source, thereby establishing an unsteady heat flow model. According to the principle of energy conservation, we solve for the axial temperature distribution of the heat exchange medium within the U-shaped pipe and the distribution of variable heat source intensity at different time steps. Subsequently, using the variable heat source intensity along the U-shaped pipe as input and incorporating the finite layer heat conduction calculation method for layered foundations, we determine the time-varying characteristics of the foundation temperature field, effectively simulating the dynamic response process of energy pile-soil heat exchange under variable thermal power. The results demonstrate that the proposed model not only avoids the computational inefficiency associated with complex numerical simulations but also achieves high computational efficiency while accurately characterizing the temperature response variations of energy piles under unsteady heat flow conditions. This model provides a reliable theoretical foundation and an efficient computational tool for engineering design, system optimization, and operational analysis.

Keywords: Energy piles; Unsteady heat source; Layered foundation; U-shaped buried pipe; Dynamic thermal response

Note: Figure translations are in progress. See original paper for figures.