A Prediction of Energy Piles' Long-Term Operation Using a Coupled Thermo-Hydro-Geomechanical Model

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Abstract

An energy pile harvests geothermal energy to heat and cool a building by integrating ground heat exchanger (GHX) pipes into the building's deep foundation, and extracts heat from the ground in the winter to heat buildings and injects heat into the ground during the summer. In areas with moderate climates, the heating and cooling loads are relatively balanced; thus the long-term performance of the energy pile is sustainable. On the other hand, energy piles in warmer climates require more cooling such as in the southern US, or in large high-rise buildings, where internal heat generation requires a greater cooling capacity, excess heat will accumulate in the ground after each year of operation. After years of operating energy piles in imbalanced heat injection/extraction cycles, accumulated heat can increase the ground temperature, leading to potential decrease of energy piles' efficiencies, complex soil properties and volume change, as well as ground surface displacement. Unfortunately, long-term experimental data or analytical solutions are not available for a complete understanding of these problems and their effects.

This study aims to develop a 3D fully-coupled thermo-hydro-geomechanical model in the COMSOL Multiphysics® software by integrating the Subsurface Flow, Heat Transfer, and Geomechanics modules to predict the system performance of GHX in a long term operation in terms of COP and exergy efficiency. The coupling of three modules will strongly rely on the inter-connected material properties of water and soil, such as thermal conductivity, specific heat capacity, thermal expansion coefficient and other related moduli, for example due to the strong effects from thermal conductivity of soil to GHX performance, the thermal conductivity of soil will be inputted as a function of water content, degree of saturation and temperature. The proposed numerical model will be used to analyze complex thermal-hydro-geomechanical responses of soil and a complete energy pile under heat accumulation from long-term operation of a cooling-dominated energy pile accounting for the effects of ground water movement. Furthermore, the stress, contact pressure and displacement of the energy pile caused by mechanical and thermal loading will also be studied. To verify the proposed 3D fully-coupled numerical model, the ATLAS III Boom Clay heating/cooling test model will be chosen and recreated. The model can be verified by comparing the results obtained from the experiments and this proposed integrated model. Then the model will be used to predict the long-term operation of a GHX in a 30-stort office building, assuming to be located in Austin, TX.

It is important to mention that in this study the convective heat transfer of water vapor has been neglected, therefore only liquid water convection will be considered. A future

work will be to integrate the multiphase transition from liquid to vapor with the proposed model, in order to further reveal the complete thermo-hydro-geomechanical effects to the performance of the prolonged heat injection of GHX.