Abstract

Ground source heat pump (GSHP) systems, like thermal piles and walls, are considered to be an efficient solution for tapping geothermal energy. Despite the vast range of potential applications, current GSHP designs have very limited input from a geotechnical aspect. The main reason for this is that there are still many concerns about the thermal and geomechanical behaviour of a ground heat exchanger (GHE) and the ground. In order to ensure the safety and durability of GSHP systems and infrastructure, it is necessary to find a valid method to investigate relevant geothermal and geomechanical problems. In this thesis, an implicit and in-house finite element method (FEM) code is developed, which can simulate thermo-hydro-mechanical (THM) coupling processes in geothermal problems. Additionally, a new thermo-elasto-plastic constitutive model is proposed to simulate the thermo-mechanical behaviour of soil and the model is implemented in the code. The performance of the developed code is evaluated at three sites in London. The main aim is to investigate both short and long-term performance of (i) the combined open and closed loop GSHP system installed in One New Change retail centre, (ii) a thermal wall installed at a Crossrail station and (iii) a thermal pile loading testing at the Lambeth College.

A series of thermo-hydro coupled analysis is conducted to simulate the GSHP operations at the One New Change retail centre project. The well controlled operation of an open-loop system along with a closed looped system is an efficient option to improve the efficiency of a GSHP system. And the ground loop temperature is better controlled at the desired range when the open-loop wells are activated as a supplementary energy source in some extreme cases.

A series of thermo-hydro-mechanical 2D plane strain finite element (FE) analysis of the Dean Street thermal wall in London Clay is conducted. The GSHP operates by injecting cold coolant into absorber pipes during winter. Soil shrinkage and small changes in the earth pressures acting on the wall are observed. It is also found that the change in the bending moment of the wall due to the seasonal GSHP cycle is mainly caused by the thermal differential across the wall during the winter. And hence, the thermal expansion coefficient of concrete has large influence on the mechanical behaviour of thermal wall.

A series of thermo-hydro-mechanical 3D FE analysis of the Lambeth College thermal pile is conducted using the proposed thermo-elasto-plastic advanced Cam-Clay model. It is shown that the behaviour of the thermal pile is quite different between cooling phase and heating phase. During the cooling phase, the upper part of the pile shrinks and the soil-pile interaction is in the same direction as the mechanical loading conditions, causing further stiffness degradation and plastic behaviour. During the heating phase, the upper part of the pile expands and the soil-pile interaction is in the different direction as the mechanical loading conditions. So the effect of stress reversal makes the soil stiffness to increase.