Thermo-hydro-mechanical simulation of an energy pile in soft clay with a rate-dependent anisotropic constitutive model

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With the on-going interest in sustainable development, energy piles received a lot attention in recent years because they can utilize geothermal energy for thermal control of buildings in an environmental friendly and economic way. Until now energy piles have been primarily employed in stiff subsoils where the primary function of the pile, such as mobilization of sufficient pile resistance and reduction of the settlements of the super structure, are typically not compromised. In soft sensitive clays, however, long-term stability during the lifetime for the soil adjacent to the pile needs to be ensured, considering both thermal loading and mechanical. Therefore, a thorough understanding on thermal processes and geomechanics of the energy pile system is needed to predict the pile-soil response to temperature change, e.g. the load transfer between the pile and soil, the generation and dissipation of excess pore pressures during heating and cooling, and potential thermal effects on the creep rate in the soil.

Recent studies on energy pile calculations were focused on the structural behaviour of piles, (Amatya et al., 2012), such as the load transfer process during heating (Knellwolf et al., 2011, Suryatriyastuti et al., 2014), and the extra strain within the pile caused by temperature increase (Akrouch et al., 2014). Nevertheless, the soft soil around the pile will also be influenced by thermal load introduced by temperature. The deformations of the soil in turn affect the stability of piles. In real-world energy pile system temperature cycles monthly, seasonally or yearly in a limited range (0-50°C) (Laloui, & Di Donna, 2011). During heating and cooling process, the structure of the soil skeleton can be destroyed by thermal consolidation effects. Meanwhile, viscous properties such as creep rate of soft sensitive clay could also be influenced. Depending on the number of loading cycles and permeability, the effect of thermal loading cycles on the accumulation of excess pore pressures should be considered as well, especially in soft contractive clays. This implies that modelling soft sensitive clay around an energy pile with a simplified elasto-plastic constitutive model is not sufficient to ensure a safe design.

Thermo-mechanical behaviour of clay has been investigated both theoretically and numerically. Advanced models were proposed to predict stress-strain behavior of saturated clay under thermal load (among others (Gera et al., 1996; François et al., 2009; Hueckel et al., 2009; Hong et al., 2013). The focus is on coupling the convection-diffusion equation and the storage equation with an advanced constitutive model for soft soils, rather than explicitly model the thermal effects in a thermo-plastic constitutive model. At this stage the thermal convection is set equal the groundwater flow velocity and the effects of thermal loads on the generation of additional pore water pressures by water expansion (Campanella, & Mitchell, 1968). The Creep-SCLAY1S model (Sivasithamparam et al, in press) will be used to model the soft sensitive clay. Example results of a pipe-pile-soil system in a simplified analysis using elasticity for the soil are shown in Fig.1. The temperature development in time is shown in Fig. 2. The more advanced modelling will present the excess pore pressures, effective stress, creep rate and volumetric plastic strain in soft clay which are observed in simulation.

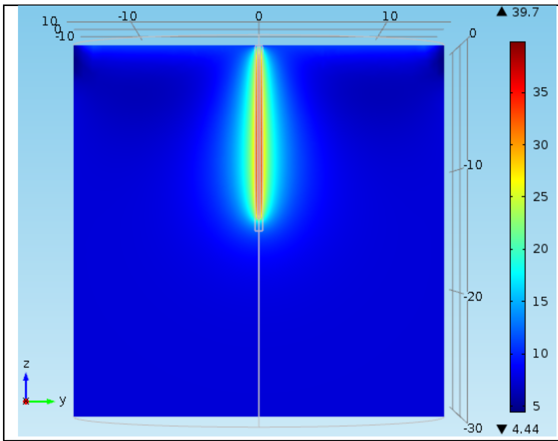

Figure 1. Temperature distribution in the pile-soil system after 150 days of heating

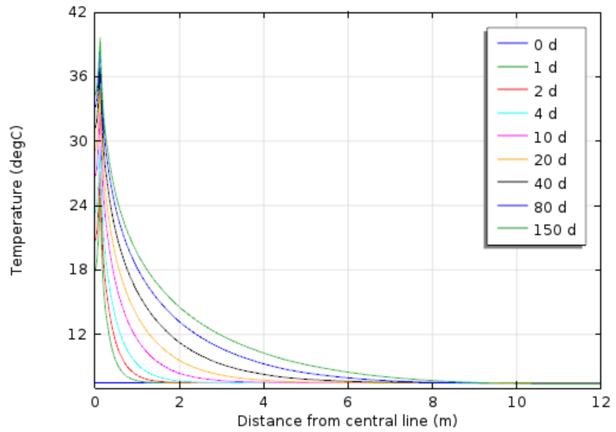

Figure 2. Temperature in the depth of 10m in radical direction.

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