Effect of temperature induced excess pore water pressure on the shaft bearing capacity of geothermal piles

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Abstract

It is established that soils with low permeability can experience substantial increases in the pore water pressures as a consequence of temperature rises (e.g. Vardoulakis, 2002; Muñoz et al., 2009; Pinyol and Alonso, 2010).

Geothermal piles are used to exchange heat from the ground for heating and cooling of superstructures (Brandl, 2006). In their cooling mode, the temperature of the circulated fluid is higher than the soil's temperature; hence, increasing the temperature of the latter up to 30 °C under normal operating conditions (e.g. Brandl, 2006; Bourne-Webb et al, 2009). In low permeability soils, these increases can potentially reduce the available effective stress and therefore, the available friction between pile and soil. If this reduction is in the same order than the mobilised shaft friction their effect on the shaft resistance can be significant.

In order to study the full thermo-hydro-mechanical interaction between pile and soil, Laloui et al (2006) presented the complete formulation of the problem and a solution compared to a field test. The excess pore water pressures are included implicitly within the formulation but since the permeabilities reported in their case study were in the order to 10^{-6} m/s, no significant excess pore water pressures were observed and therefore they remained constant. In turn, this had little effect on the available shaft friction. However, in the presence of lower permeability soils, these excess pore water pressures can reach values of 1MPa for temperature increments of 80 °C. For increments of 30 °C that are closer to geothermal piles, this excess pore water pressure was 0.2MPa (Muñoz, 2007), which in most practical cases of bearing piles would exceed the effective stress at the interface.

Based on this evidence, this paper presents a finite difference solution to the fully coupled formulation using both finite differences and a finite element code developed at UPC (CODE_BRIGHT (Olivella et al 1996) to study the development of excess pore water pressures in geothermal piles and its impact on the shaft friction at the pile-soil interface.

Figure 1 presents the results of the finite difference solution for a 1.0m diameter pile where a fluid is circulated at a temperature of 30°C (modelled as a line source). Figure 1a and 1b show that excess pore water pressures close to 40kPa developed in the pile-soil interface. The generated excess pore pressures are sustained for periods of 10 days at similar values before dissipation starts to occur as a consequence of Darcy's flow. This may explain, for instance, some of the differences between predicted and observed shaft frictions in field tests that were captured by Bourne-Webb et al (2009) in London Clay where a permeability of 10^{-10} m/s, as used here, or lower, is a plausible representation of the real values (Hight et al, 2007).

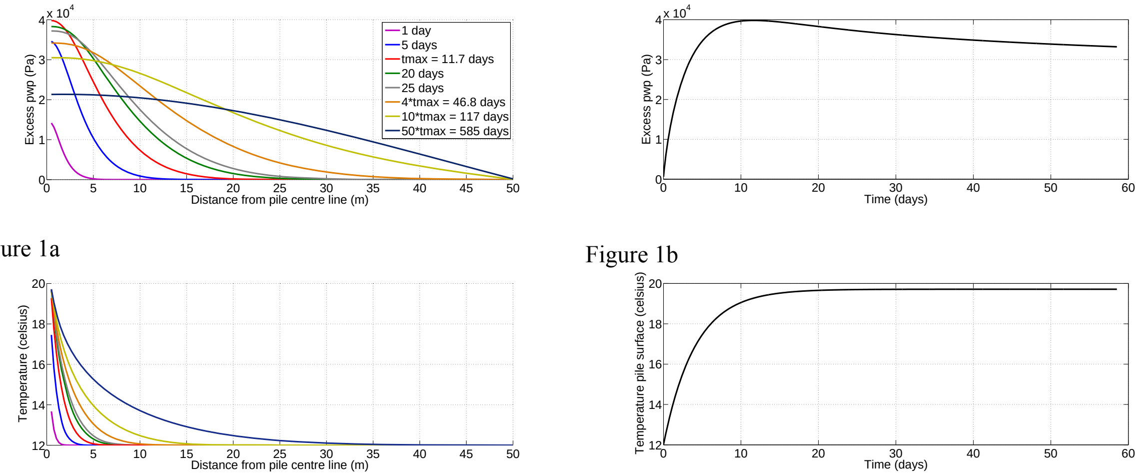

Figure 1a

Figure 1b

Figure 1c

Figure 1d

Figure 1. Results of finite difference solution for a permeability equal to 10^{-10} *m/s. (a) Excess pore water pressures distribution with distance from the pile-soil interface. (b) Excess pore water pressure at the pile-soil interface vs time. (c) Temperature distribution with distance from the pile-soil interface. (d) Temperature of the pile-soil interface vs time.*

In the previous results, a constant temperature of the fluid and the soil, equal to 12ºC, is imposed as boundary condition far away from the pile (50m from the centre line of the pile). This condition means that the heat flow will reach a steady state where the heat through the concrete pile equals the heat flow through the soil when the temperature distribution reaches essentially a constant distribution (see idealised linear final distributions in the soil in Figure 1c). The maximum temperature at the pile-concrete interface is reached only after 25 days approximately in the calculated case (see Figure 1d).

The results also show that permeability and thermal conductivities of the pile and soil are the dominating factors for the development of pore water pressures in geothermal piles. Hence, the paper presents a map of these parameters showing for which combinations the excess pore water pressures may reach values that would affect the typical shaft friction resistance of piles using the case presented by Bourne-Webb et al (2009) as field case study for validation purposes.

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