Symposium on Energy Geotechnics
Accelerating the energy transition
3-5 October 2023, Delft, the Netherlands

Peer-reviewed Conference Contribution

The use of geothermal energy to prevent road pavement icing and damage in cold climate areas

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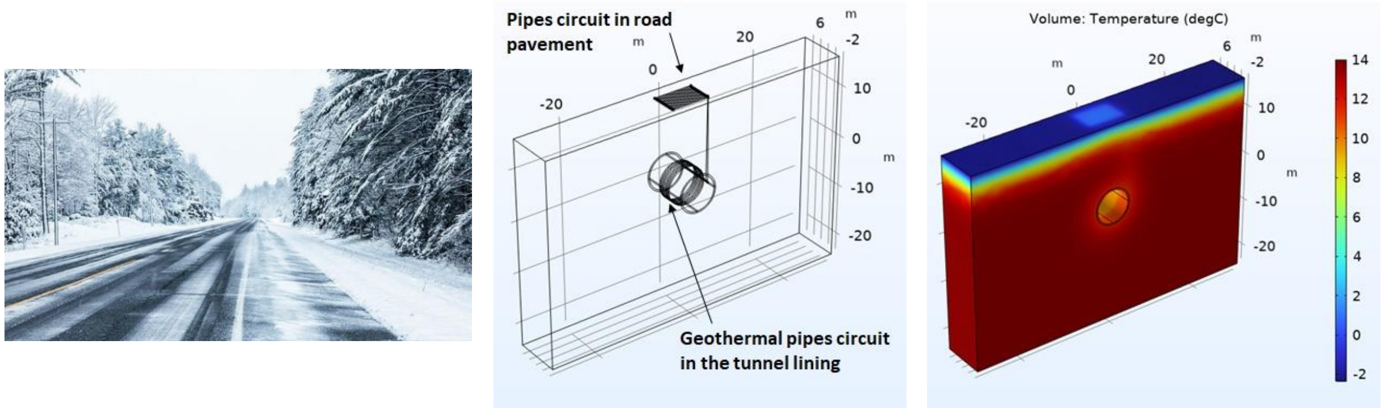
In cold climate or alpine regions, freezing temperatures and snow can result into road icing, with consequent threat of the circulation security (Figure 1(a)). When the road surface temperature goes below zero, not only the road surface ices, but also the soil below the pavement can undergo freezing. The phenomenon of soil freezing is complex due to the multi-phase and porous nature of the soil itself. Generally speaking, as ice expands in the soil pores, the soil volume increases (of about 9%, depending on the soil porosity and water saturation). This can induce frost heaving, with consequent damage of the road pavement. In this framework, the possibility to use geothermal energy systems embedded in tunnel linings for road pavement de-icing has rarely been investigated. In such systems, the concrete tunnel lining is equipped with a circuit of pipes, in which a heat carrier fluid circulates and exchanges heat with the ground. As the rock or soil around the tunnel is generally hotter than the external air temperature, heat is extracted from the rock or soil to the fluid, transported through the pipes circuit outside the tunnel, and used to de-ice the pavement road.

The objective of this study is to go a step forward in the investigation of this innovative application, for both road de-icing and prevention of frost heave. A portion of a geothermally activated tunnel and its connection to a road pipe circuit was simulated numerically (Figure 1 (b)). Appropriate climatic conditions were considered as boundary conditions at the surface level and inside the tunnel, according to available data. The efficiency of the technology was investigated under different climatic and exploitation scenarios. Figure 1 (c) shows as an example the thermal field obtained after the activation of the geothermal plant. The evolution of temperature on the road pavement surface and at the road pipes depth (30 cm from the road pavement surface) are presented on Figure 2 (a), together with the evolution of the external air and tunnel temperature, imposed as boundary conditions according to the monitored climatic conditions in the city of Oslo [1].

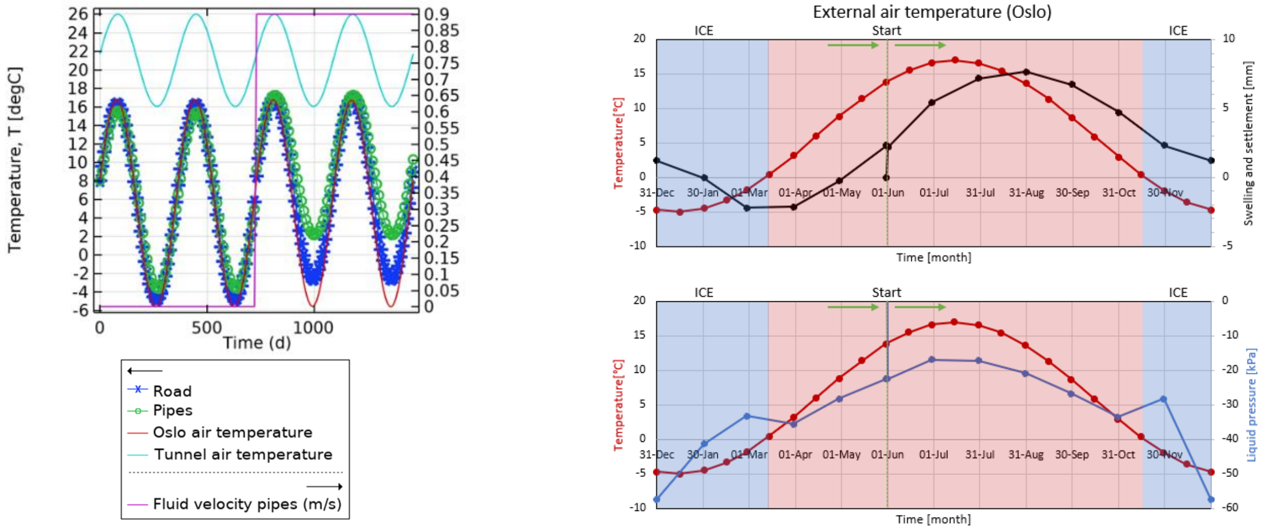


(a) (b) (c)

Figure 1: (a) Road icing and damage due to freezing, (b) geometry of the model, and (c) thermal field after the activation of the geothermal system.

DOI: https://doi.org/10.59490/seg23.2023.500

The geothermal system was activated after two years of simulation, by changing the fluid pipes velocity from 0 (non active system) to 0.9 m/s (purple curve on the right axis on Figure 2 (a)). The results show that the road temperature increases thanks to the activation of the system (i.e. when the fluid pipes velocity is imposed to 0.9 m/s).



(a) (b)

Figure 2: Results in terms of: (a) temperature evolution before and after the activation of the geothermal system, (b) road heave and liquid pressure evolutions before the activation of the geothermal system.

Furthermore, a recently developed thermo-hydro-mechanical constitutive model for frozen soils [2] was used to quantify the soil heave due to freezing, with and without the activation of the geothermal system. For this purpose, a similar numerical model has been developped where a column of saturated soil below the road and the tunnel were modelled. The phreatic water table is at the ground surface level and gravity as well as the geostatic stress conditions are considered. The soil is a clay with a low hydraulic conductivity of $K_w=4.1\times10^{-10}$ m/s and a thermal conductivity of $\Gamma=2.35$ W/m/K. The other soil properties are: soil stiffness E=100 MPa, Poisson's ratio $\nu=0.3$, porosity n=0.25, solid grain thermal volumetric expansion coefficient $\alpha_s=3.4\times10^{-4}$ K^{-1}. The same soil surface climatic conditions used in the first part were applied. The temperature evolution obtained in the road from the previously mentioned analyses (Figure 2 (a)) was imposed to reproduce the effect of the geothermal activation on the road behaviour. Furthermore, the soil surface is free of stress to study the soil swelling and settlement. The bottom limit of the soil column is hydraulically drained and allows heat flux (at constant liquid pressure and temperature). The lateral far field boundaries are thermally adiabatic, hydraulically impervious, and with oedometric conditions. The results were firstly compared with the case without geothermal activation to quantify the effects in terms of road heave and settlement (Figure 2 (b)). Swelling and settlement are due to thermal expansion and compression of the soil under positive temperature (T>0°C) and to frost heave and thaw settlement under negative temperature (T<0°C). The liquid pressure at the road surface is also depicted (Figure 2 (b)). These results and comparisions allowed understanding the performance of the technology in reducing road mechanical damage induced by freezing.

Contributor statement

Di Donna and Pardoen : concept, numerical modelling, analyses of the results, and writing.

Acknowledgments

This work was funded by the LabEx Tec21. The Laboratory 3SR is part of the LabEx Tec 21 (Investissement d'avenir – grant agreement n. ANR-11-LABX-0030).

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