Preliminary assessment of energy walls efficiency under different underground scenarios

Miriam Piemontese[1*], Marco Barla[1], Alice Di Donna[2], Fleur Loveridge[3]

[1] Politecnico di Torino, Department of Structural, Building and Geotechnical Engineering, Torino, Italy
[2] Laboratoire Sols, Solides, Structures – Risques, 3SR, Grenoble, France.
[3] Royal Academy of Engineering Research Fellow, University of Leeds, School of Civil Engineering, Leeds, UK
*mi.piemontese@hotmail.it

Introduction

Energy geostructures are structures in contact with the ground, such as foundations, diaphragm walls and tunnel linings, having the double role of providing structural stability and exchanging heat with the ground for heating and cooling of buildings and infrastructures, based on the principles of low enthalpy geothermal system. Among them, this work focuses on energy walls and aims to assess their energy efficiency through the use of FEM simulations, considering varying underground conditions.

Parametric analysis

For the parametric analysis the finite element software FEFLOW was chosen, in which the implemented thermo-hydraulic formulation was proven effective to simulate the behavior of a thermo active geostructure. The simulations were performed for a duration of 30 days both for winter and summer mode. After a critical analysis of previous case studies of energy walls (real or numerically simulated), the wall panel was considered to be 20 m high, 2.5 m long and 1 m wide, with an excavation depth of 10 m on one side (Di Donna et al., 2017). With a spacing of 50 cm, the arrangement of the pipes followed a double-U configuration, to a depth of 19.75 m and a lateral cover of concrete of 0.5 cm. They were positioned on the soil side of the wall only. The inlet temperature T_{in} in the pipe (external dimeter of 25 mm, thickness of 2.3 mm) was fixed to 28°C and 4°C for summer and winter respectively, with a velocity of 0.4 m/s. The outlet temperature T_{out} is the result of the simulation, through which it is possible to evaluate the heat Q extracted in winter and injected in summer as:

$$Q = mc_w(T_{in} - T_{out})$$

where m is the mass flow rate expressed in kg per second and c_w is the water heat capacity (in J/kgK).

Dealing with walls, the conditions of the air inside the excavation have an important impact on the heat exchange through the pipe. A distinction between tunnels and metro stations, i.e. high values of airflow velocity in the inside, and basements and underground car parks, i.e. near-zero value of airflow velocity, should be made. However, for the sake of simplicity, a constant temperature boundary condition (Dirichlet or 1st type BC) was adopted for the analyses described here. In absence of specific monitoring data, this assumption is more representative of applications where high airflow persists (Bourne-Webb et al., 2016). Figure 1 shows the 2D model with the initial and boundary conditions adopted. The boundaries have been proved to be far enough not to affect the results and a mesh sensitivity analysis has been performed. The external temperature was fixed to 30°C and 2.5°C for summer and winter respectively. In the excavation, the temperature can strongly vary according to the intended use. To take into account a general case, the temperature in the excavation should be lower in summer and higher in winter than the outside, since the environment is usually confined and not directly exposed to the external air. Therefore, a temperature of 20°C for summer and 10°C for winter were adopted.

This study focus on the influence of the site conditions on the energy efficiency of the wall, all the other aspects being fixed. The most affecting factors are the thermal and hydraulic properties of the soil and the presence of groundwater. The properties of the soil adopted were chosen according to the underground conditions of Torino, Italy, defined in Di Donna and Barla (2015). The properties of the other materials (concrete and water) are quite standard for energy geostructures applications and they can be found in the same mentioned paper. The influencing parameters varying throughout the simulations are:

- the ground temperature, in the range 8 – 18°C (typical of continental regions)
- the bulk thermal conductivity, in the range 0.9 – 3.9 W/mK
- the groundwater flow velocity in a range 0 – 2.0 m/d

To simulate different groundwater velocities different hydraulic heads were fixed to the lateral edges of the model, taking into account the hydraulic conductivity according to the Darcy's law. Only the case with a perpendicular direction of the water flow was considered.

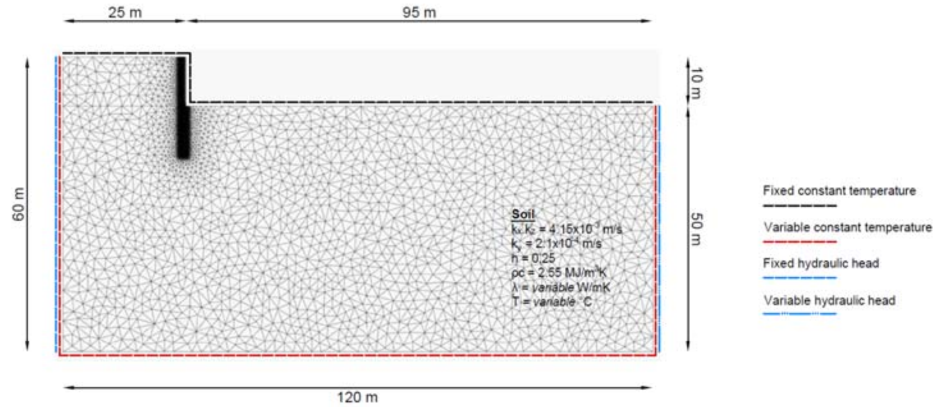

Fig. 1. Geometry and boundary conditions of the model

Conclusions

From the outcomes of the numerical analyses, in figure 2 it is possible to appreciate the linear variation with the ground parameters of the injected/extracted heat both for summer and winter.

In summer, the difference between the inlet and the outlet temperature decreases with the increase in soil temperature, as a result of which the efficiency decreases. The opposite trend is shown in winter mode. The maximum efficiency is in summer, as the difference of temperature reaches the highest values in the operational mode with respect to the winter case. Concerning the other ground parameters, in both cases the exchanged heat power increases when groundwater velocity and thermal conductivity increase. However, it comes out that the influence of groundwater flow reduces as the thermal conductivity enhances. Therefore, when the conductive factor (thermal conductivity) becomes more significant, the influence of the convective component (groundwater flow) becomes less important.

With the obtained results, the charts can give a reasonable quantification of the heat that can potentially be exchanged (in W/m^2 of wall panel) with the ground, for both winter and summer according to the specific site conditions.

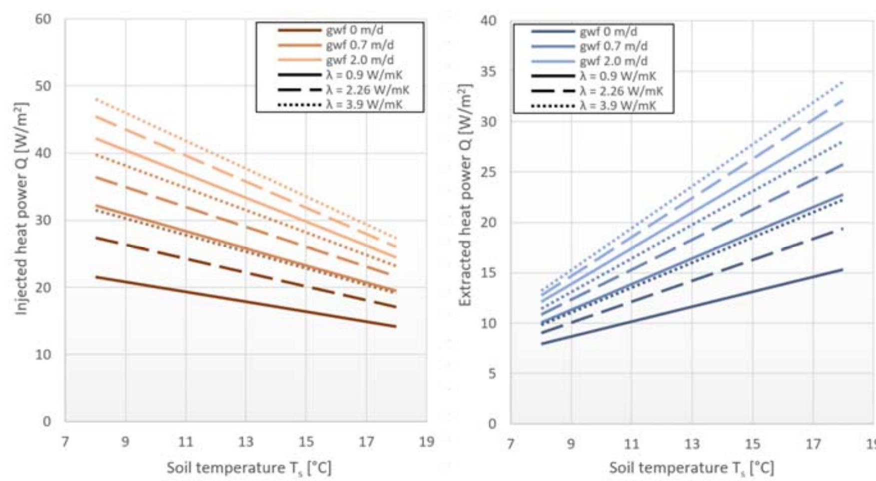

Fig. 2. Effect of temperature on the energy performance (different colors = groundwater flow velocities (gwf), different hatching = bulk thermal conductivities (λ)): on the left summer mode, on the right winter mode)

References

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