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

Peer-reviewed Conference Contribution

Numerical modelling of Energy Quay Walls to assess their thermal behaviour

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The use of the subsurface as a heating and cooling source through shallow geothermal installations has increased in the last decades [10]. So-called Energy Geostructures (EGs) represent a more innovative technology, serving the dual purpose of providing structural support to the ground/building and exchanging heat with the ground [2]. EGs can serve the purposes of several energy applications: they can be coupled with ground source heat pumps to provide space heating and cooling as well as domestic hot water.

Energy sheet pile walls (ESPs) are a novel type of EG consisting of sheet pile walls equipped with steel pipe heat exchangers. When they are used to support the banks of canals or in port docks, they allow extraction of thermal energy from both soil and water [12]. The latter are called Energy quay walls (EQW) and are currently experimented at selected sites along canals in the Netherlands [7]. The energy efficiency of EQWs is expected to be influenced by the undisturbed ground temperature profile, ground thermal conductivity and thermal capacity, and operational and construction parameters [8] [9]. However, due to the lack of standard methods for the design of EQWs, further studies are needed to fully understand both their thermal and thermo-mechanical behaviour [1]. Based on the data collected from an EQW test field installed in Delft (NL) (Figure 1(a)), a Finite Element (FE) numerical model was developed for the accurate 3D analysis of the heat exchange phenomena taking place in the EQW.

The EQW test site is characterized by two different heat exchanger types: the first one reaches 3 m depth and is aimed at exchanging heat mostly with the canal water. The second one has a depth of 15 m and exchanges heat with both water and soil. A monitoring system was installed composed by a total of 56 thermistors, 20 thermowells and 5 flowmeters to measure respectively the soil and canal water temperature, the heat exchanger fluid temperature and the flow velocity of both heat exchanger fluid and canal water. Different thermal activation combinations of deep and shallow loops were tested to assess the EQW thermal behaviour and the induced temperature changes into the soil [5].

To analyse in detail the EQW thermal performance, the FE numerical model was built with the COMSOL Multiphysics software. The considered heat exchange processes are convection within the heat-carrier fluid and between the canal and the soil, and conduction in the soil and other solid domains. Radiation phenomena were considered negligible in the model. The FE model was set up using the built-in "heat transfer in pipes" module allowing quicker computations by representing heat exchanger pipes in a simplified 1D fashion. The domain dimension was chosen in order to keep the lateral and bottom surfaces far enough from the EQW, to avoid boundary effects. For the boundary conditions, a fixed temperature of 12°C [3] was assigned to the bottom domain boundary while the detected air temperature time history was assigned to the top of the domain. Thermal insulation was assigned to the lateral boundary surfaces. The water canal was directly simulated as part of the domain. The heat convective flow of water was taken into account by using inflow and outflow boundary conditions and by assigning to the canal the detected water velocity. A thermal initialization calculation was performed to start the calculation with accurate initial conditions in terms of temperature distribution within the domain [6]. The thermal conductivity, specific heat capacity and density of the different soil layers were determined through empirical correlations based on cone penetration tests results carried out near the EQW [11], corroborated by literature datasets based on the geological characterization of the soil [4]. Heat exchange between the EQW and the surrounding soil was simulated by activating the heat transfer flow within the pipes, assigning the measured inlet temperature and fluid velocity.

DOI: https://doi.org/10.59490/seg23.2023.518

An example comparison between the measured gained thermal power and the simulated results for the first 200 days of thermal activation of the EQW is shown in Figure 1(b). Except for the first 20 days of thermal activation, characterised by unreliable measurements because both the heat pump and the monitoring system were being tested to check the integrity of the system, it can be observed that the numerical simulation effectively reproduces the gained thermal power, as well as the induced temperature changes into the soil (not shown for the sake of brevity).

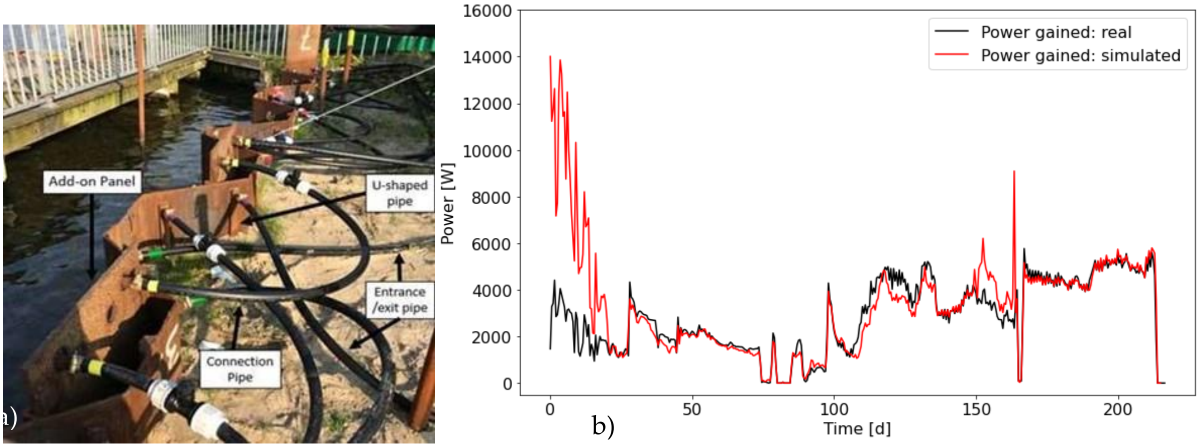

Figure 1: a) Energy sheet pile wall test site b) Comparison between measured and simulated thermal power profile during EQW geothermal operation.

After model validation against the data collected from the test field research activities continue. Further numerical parametric analyses are performed to identify the best combination of design and site parameters to maximize the energy efficiency. Additionally thermo-mechanical analyses are used to assess the magnitude of thermally induced displacements and stresses.

Contributor statement: Gerola M.: Conceptualization, Formal analysis, Visualization, Writing – original draft, Writing – review & editing; Cecinato F.; Conceptualization, Formal analysis, Writing – review & editing; Haasnoot J.: Conceptualization, Project administration, Resources, Writing – review & editing; Vardon P.J.: Conceptualization, Writing – review & editing.

Acknowledgments: Research funding under the "PON tematica Green – DM 1061/2021" scheme of the Italian Ministry of University and Research, co-funded by CRUX Engineering BV (Delft, NL), is gratefully acknowledged.

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