Geotechnik im Bauwesen
Geotechnical Engineering
Univ.-Prof. Dr.-Ing. Martin Ziegler

RWTH
RHEINISCH-
WESTFÄLISCHE
TECHNISCHE
HOCHSCHULE
AACHEN

Short Report

File Reference: SF – 10.08.18.7-09.10 / II 2 – F20-09-1-041

Research Topic: „Utilization of Geothermal Energy with Thermo-Active Seal Panels for Groundwater Influenced Ground Structures“

Lemma: „Thermo-Active Seal-Panels“

Researching Institution:
Chair of Geotechnical Engineering
RWTH Aachen University
Mies-van-der-Rohe-Straße 1
52074 Aachen

Project Manager: Univ.-Prof. Dr.-Ing. Martin Ziegler

Persons in Charge: Dipl.-Ing. Sylvia Kürten

Supporting Institution:

NAUE GmbH & Co. KG
Gewerbestr. 2
32339 Espelkamp-Fiestel

The research report has been supported by the “Forschungsinitiative Zukunft Bau” of the Federal Office for Building and Regional Planning (BBR).

(File Reference: SF – 10.08.18.7-09.10 / II 2 – F20-09-1-041)

The author is responsible for the topic of the report.

1 Aim of the research project

The utilization of geothermal energy with borehole heat exchangers or geothermal heat collectors is a widespread opportunity to gain heat from the ground. Recently, the thermal activation of statically required building elements becomes more common. First of all, ground structures which have a huge contact area to the ground are suited for thermal activation. In this case, the heat exchanging pipes are attached to the required reinforcement. Thereby, additional drilling costs are omitted in contrast to conventional geothermal systems.

The aim of the research project was to extend the geothermal utilization of the ground with thermo-active ground structures. Therefore, thermo-active seal-panels are to be developed and tested. The development of the elements was carried out in cooperation with NAUE GmbH & Co. KG. Several practical and numerical investigations under different conditions were planned to prove the efficiency of the thermo-active seal-panels. Underground constructions which are influenced by (streaming) groundwater will be the main application area of the thermo-active seal panels. Due to the groundwater flow there is an additional energy potential in the ground, which should be considered while designing geothermal plants. Additionally, a systematic analysis of the influence of different parameters on the heat output and the heat-transmission resistance were planned. Therefore, a transfer of the result to other thermo-active structures would be possible.

2 Accomplishment of the research project

In the scope of the research project innovative thermo-active seal panels were developed and their efficiency was tested by several practical and numerical investigations. For evaluation the results were compared with documented performance data of thermo-active earth covered structures in practice.

For thermal activation the seal panels - manufactured from HDPE which are used for sealing of concrete structures against aggressive water - were provided with heat exchanging pipes. The heat transfer capacity and the heat-transmission resistance of the elements were determined with several laboratory tests in an especially developed test station. A scheme of the test station is shown in Figure 1 (left). The dimensions of the test station are 3 m x 3 m x 2 m. Two large-scale test sets - which had different wall constructions with a height of each wall of 1.7 m - were carried out for testing different system and operational parameters. Therefore, the pipe alignment, the pipe diameter, the pipe material, the flow rate in the heat exchanging circuit, and the groundwater velocity were varied.

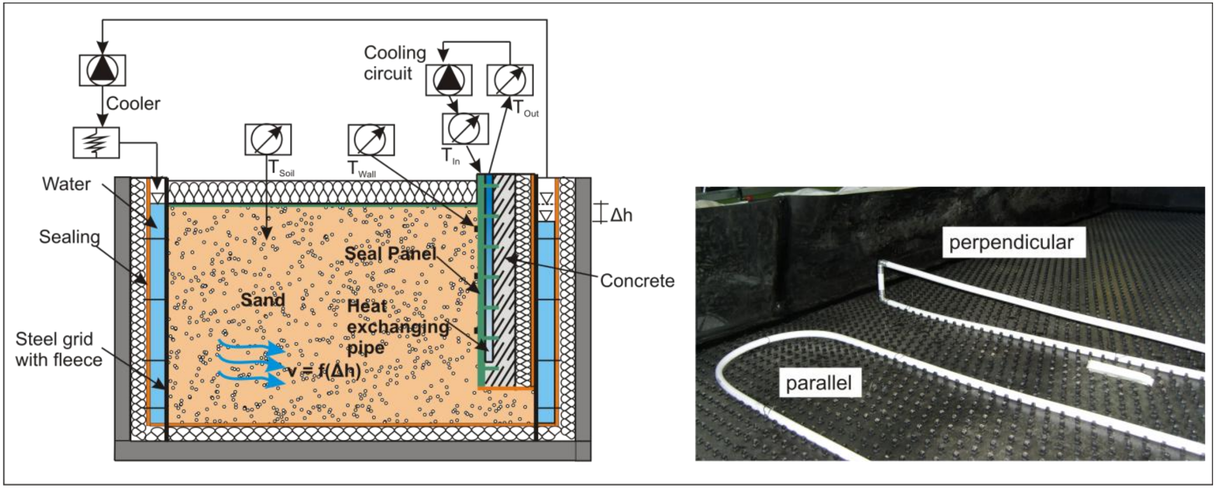

Figure 1: Schematic sketch of the construction of the test station (left) and different pipe alignments (right)

An overview of the different systems which were investigated together with its names is given in Table 1.

Table 1: System configurations of the laboratory tests

Name	Diameter d_a [mm]	Material	Type of the Pipe	Pipe Alignment
System 0.1	16	PE-RT	multilayer	perpendicular
System 0.2	16	PE-RT	multilayer	parallel
System 1.1	17	PE-XC	single-layer	perpendicular
System 1.2	17	PE-XC	single-layer	parallel
System 2.1	25	PE-RT	multilayer	perpendicular
System 2.2	25	PE-RT	multilayer	parallel

Each system was tested for groundwater velocities between 0 m/d and 1 m/d and flow rates in the heat exchanging circuit between 100 l/h and 550 l/h. For the tests which determine the heat transfer capacity a duration of about 6 hours was chosen to reach a state of a stable equilibrium. The duration of the heat-transmission resistance tests could be reduced to 3 hours to reach an equilibrium. The average temperature in the soil was set to about 11 °C at the beginning of the tests. The inflow temperature of the heat exchanging circuit was chosen to approximately 2.5 °C. The resulting temperatures in the return flow and the temperature in the soil were measured regularly.

Additionally, several numerical analyses with the finite difference program SHEMAT were carried out to determine the most important influencing parameters on the heat output of the thermo-active seal-panels. The numerical model was verified and calibrated with the results of the laboratory tests. Based on this base model a systematic sensitivity analysis was carried out. Therefore, influences of the soil (thermal properties, groundwater velocity and ground temperature), as well as influences of the system (pipe spacing, pipe alignment and pipe diameter) were investigated.

3 Summary of the results

A brief summary of the results is given below. A detailed description of all investigations and results can be found in the comprehensive final report.

3.1 Thermo-active structures – State of the art

Since the beginning of the 80th thermo-active concrete structures have been used for the geothermal utilization of the ground. In these systems the heat exchanging pipes are attached to the reinforcement. Construction examples of energy piles, energy diaphragm walls and energy ground slabs can be found in current practice. New developments focus on the geothermal activation of tunnel constructions. An overview of documented heat transfer capacities for the different thermo-active structures is given in Table 2.

Table 2: Heat Transfer capacity for different ground structures (according to Brandl, 2006; Markiewicz, 2004; von der Hude & Sauerwein, 2007; Franzius & Pralle, 2010)

Structure	**Heat Transfer Capacity**
Energy Pile	40 - 120 W/m
Energy Diaphragm Wall	19 – 100 W/m²
Energy Ground Slab	15 -30 W/m²
Energy Fleece	5 – 15 W/m²
Energy Anchor	8 -15 W/lfm
“Energietübbing”	10 – 20 W/m²

3.2 Heat Transfer Capacity and Heat-Transmission Resistance

The heat transfer capacity and the heat transmission resistance were determined to investigate the efficiency of the thermo-active seal panels. Therefore, laboratory tests under different conditions were carried out and the results were analyzed.

The achievable heat transfer capacity was determined in both of the large-scale test sets under different framework and boundary conditions. The resulting values are shown in Figure 2. The heat transfer capacity varied between 25 W/m² and 300 W/m² according to the operating conditions. Higher values could be achieved for high flow rates in the heat exchanging circuit (see also chapter 3.3). Comparing the results of the laboratory tests with the performance data that are documented in practice (see Table 2) it can be recognized that the efficiency of the thermo-active seal panels is quite satisfying.

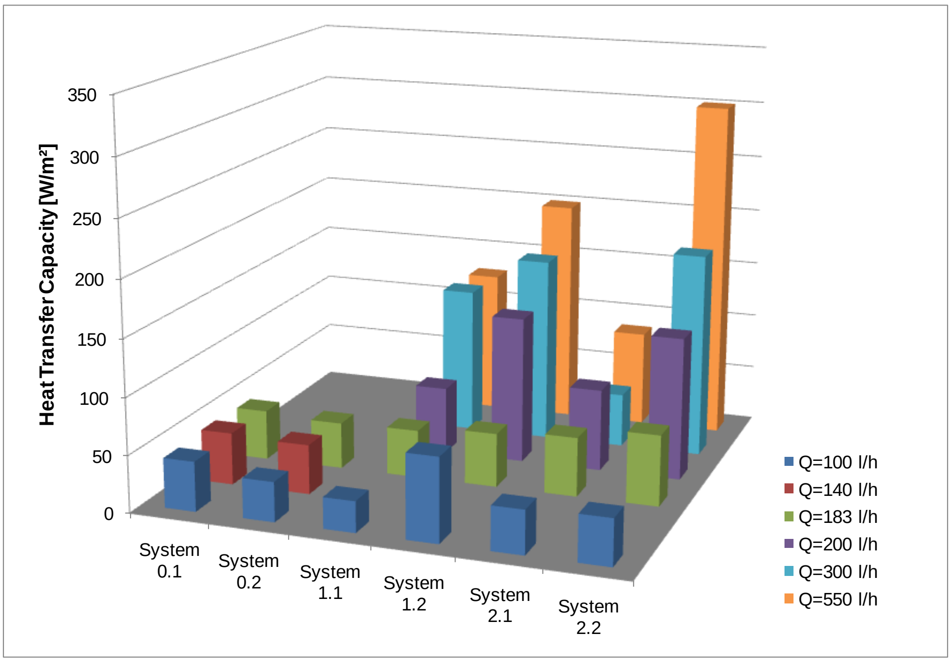

Figure 2: Heat transfer capacity for different system configurations (laboratory tests)

Additionally, the heat-transmission resistance was determined in the scope of the second large-scale test set. Therefore, supplemental temperature sensors were fastened to the outside of the seal panel. The heat transmission between the soil and the heat exchanging system is a plane and asymmetrical problem in this case. Furthermore, the inflow and return flow are spatially separated from one another. Due to that, the physically correct description of the heat transmission problem is very complex. Therefore, an approximative method for calculating the heat-transmission resistance was applied. An overview of the results is given in Figure 3.

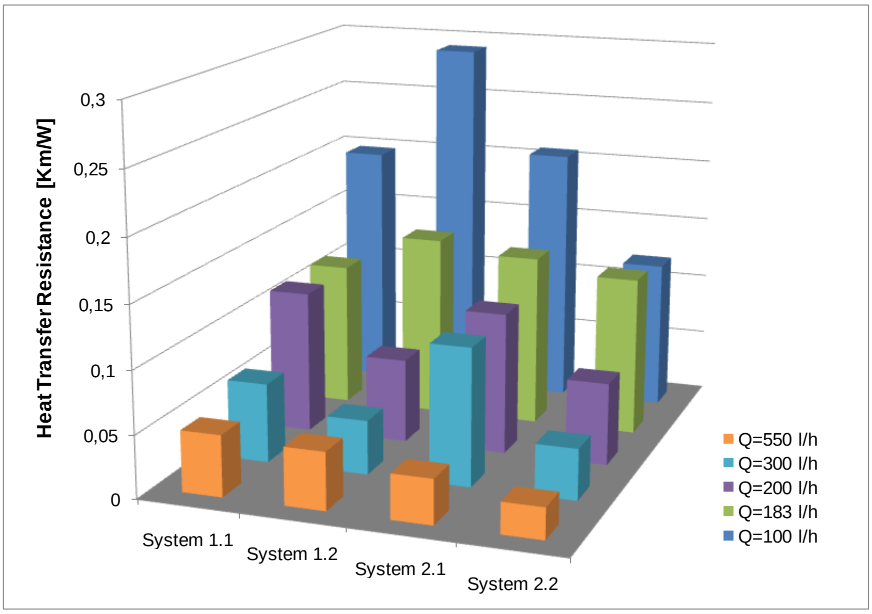

Figure 3: Heat-Transfer Resistance for different system configurations (laboratory tests)

The results of the heat-transmission resistance varied between 0.03 Km/W and 0.3 Km/W. Again, the lowest values correspond to high flow rates in the heat exchanging system. The value of the heat-transmission resistance of conventional geothermal probes is about 0.1 Km/W. Therefore the obtained results confirm the good efficiency of the thermo-active seal panels.

3.3 Influencing parameters on the heat output

To achieve an optimal design of thermo-active seal panels the most decisive parameters on the heat output must be known. Therefore, a systematic sensitivity analysis was carried out in the scope of the research project. Here, the results of the laboratory tests as well as the numerical analysis were considered for interpretation.

The influence of the groundwater flow on the heat output could not be identified due to experimental-related effects. Because of the streaming conditions in the test station the increase of the input velocity did not cause an increase of the streaming velocity close to the wall in the same scale. The accomplished numerical analyses confirm this fact. For this reason the influence of groundwater flow will not be taken into account in the interpretation of the results below. Hence, it could be shown that a groundwater flow has a positive impact on the heat output only when the thermo-active ground structure will be charged directly by the groundwater flow. For determining the exact influence of groundwater flow on the heat transfer capacity of thermo-active seal panels additional research work is necessary.

The influencing parameter on the heat output can divided into parameters of the soil and system parameters which will be regarded separately below. To analyze the influence of the soil its thermal properties (heat conductivity and heat capacity) and the undisturbed ground temperature were varied. The achieved heat transfer capacities depending on the different parameters are shown in Figure 4. The results given in this figure were obtained for a pipe alignment parallel to the wall.

An increasing ground temperature implies an increasing energy potential in the ground. Due to that the laboratory tests as well as the numerical analysis show that the undisturbed ground temperature is the most decisive parameter on the heat output of thermo-active seal-panels (see Figure 4 above). Regarding the thermal properties of the soil it can be shown that heat conduction is the dominating heating transportation mechanism in this case (see Figure 4 c). Because of the minor groundwater velocity close to the wall the heat capacity is only of subordinate importance (see Figure 4 d). However, the influence of the heat capacity will increase with increasing groundwater flow and in order to that with increasing heat convection.

The parameters of the soil cannot be modified in practice. However, for a correct plant design they have to be determined as detailed as possible. The sensitivity analysis has shown that first of all the undisturbed ground temperature should be determined as accurately as possible.

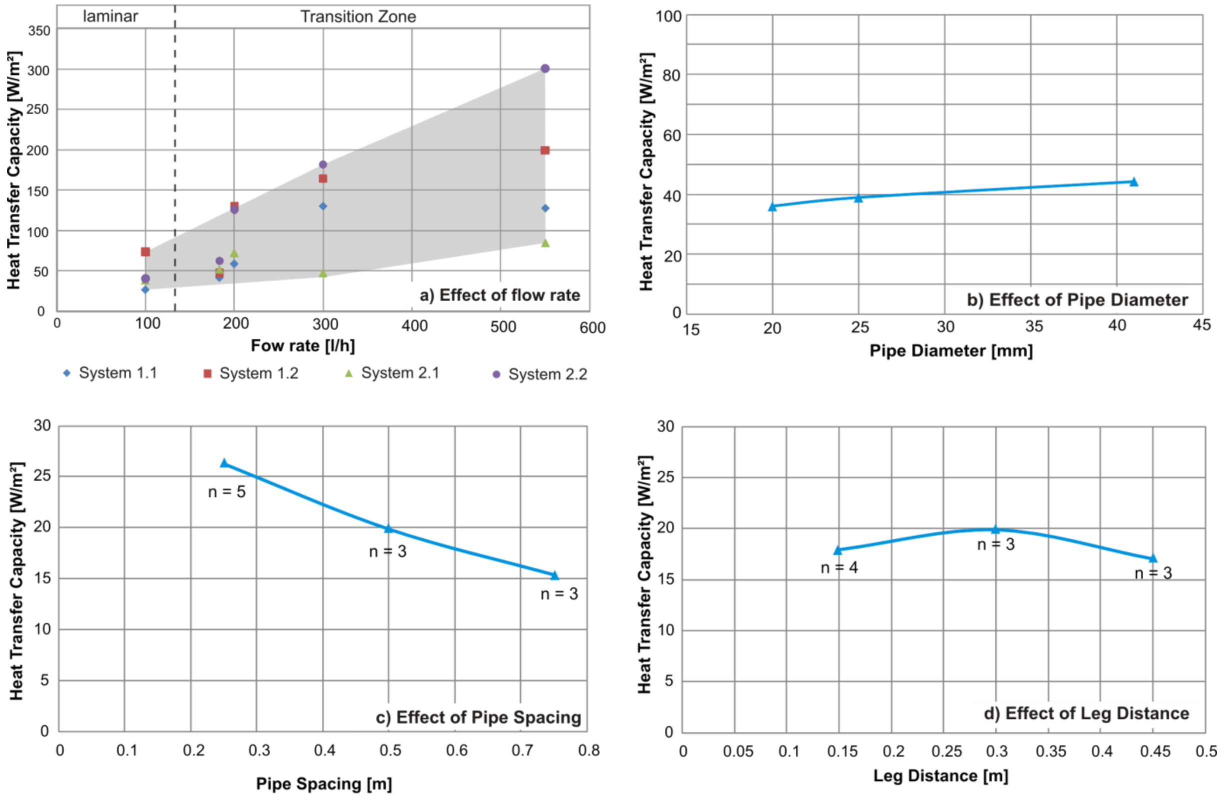

Figure 4: Heat transfer capacity depending on the parameters of the soil

By choosing the correct system parameters the efficiency of thermo-active seal panels can be optimized. Furthermore, an optimal designed heat exchanging system will increase the achievable heat output significantly. Therefore, the influence of the heat exchanging pipes (pipe alignment, pipe material and pipe diameter) as well as the influence of the flow rate in the heat exchanging circuit was varied in the sensitivity analysis as well.

The flow rate in the system and the heat transfer surface between soil and heat exchanger could be identified as the most important factors of the achievable heat output. The base material of heat exchanging pipes is normally a Polyethylen (PE), so that the heat conductivity of the pipe materials which were tested was very similar. Therefore the influence of the material can be neglected. The laboratory tests and the numerical analyses both shown that a pipe alignment parallel to the wall leads to a higher heat transfer capacity compared to a pipe alignment perpendicular to the wall. Therefore, Figure 5 shows the determined dependencies between the heat transfer capacity and the system parameters which were achieved for a pipe alignment parallel to the wall. Furthermore, this pipe alignment offers constructive advantages because the existing anchors of the seal panel fix the heat exchanging pipes. That is why a pipe alignment parallel to the wall is recommended for thermo-active seal panels.

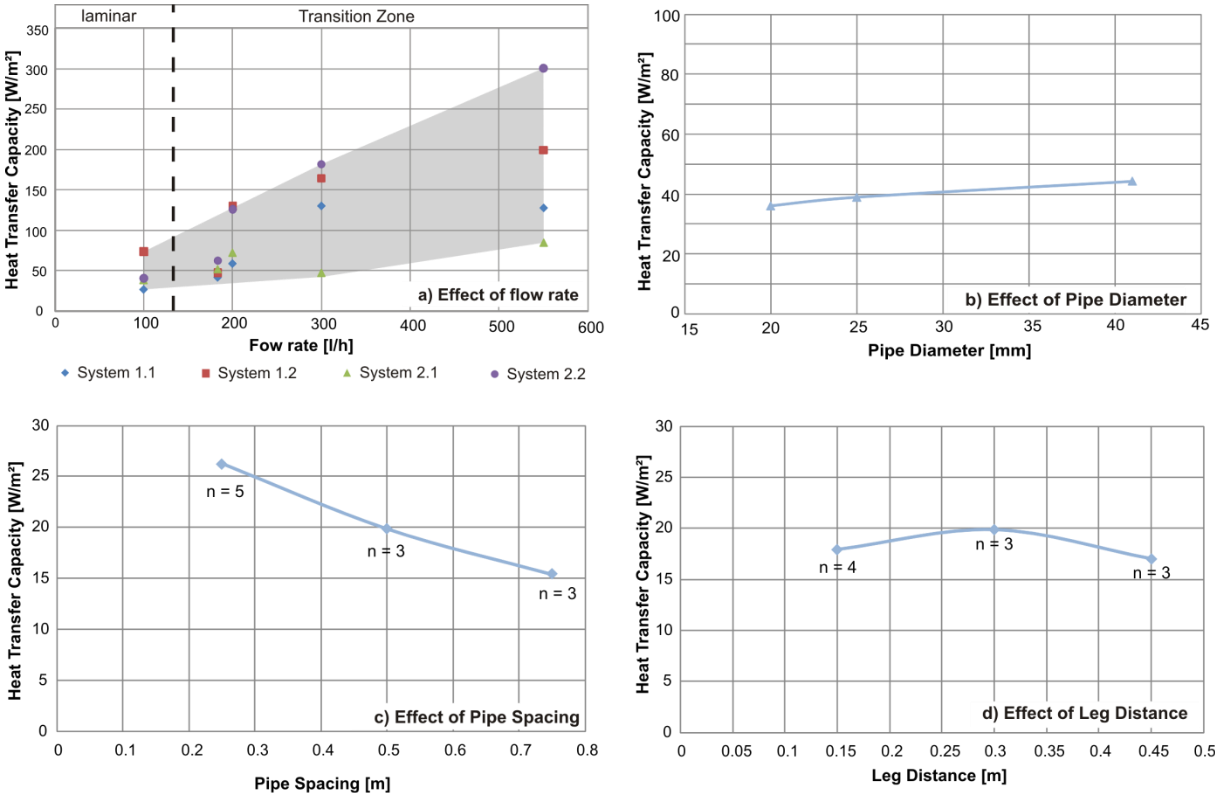

Figure 5: Heat transfer capacity depending on the system parameters

With an increasing flow rate in the system the heat transfer capacity increases significantly (see Figure 5 a). If the flow condition in the pipe is not laminar anymore, this effect is increasing due to a better heat transfer between the pipe and the heat exchanging fluid. Therefore, thermo-active seal panels should be operated with a flow rate which causes a nearly turbulent flow condition.

The heat transfer surface between soil and heat exchanging system is in addition to the pipe alignment also influenced by the pipe diameter and the pipe spacing. An increasing pipe diameter leads to an increasing heat output (see Figure 5 b). Certainly, the maximum diameter is defined by the existing spacing of the anchors of the seal panel. Furthermore, the required flow rate in the system to reach a nearly turbulent flow - and thus the required pump capacity - increases with an increasing pipe diameter. For the design of thermo-active seal panels the optimal pipe diameter has to be chosen depending on the properties of the seal panel and the hydraulic parameters. Furthermore, energetic as well as commercial aspects have to be taken into account.

Regarding all pipe systems in the wall it can be said that heat output of the thermo-active seal panels increases with decreasing pipe spacing (see Figure 5 c). A minor spacing leads to an interference of the single pipes so that the heat output of each pipe decreases. Nevertheless, due to the increasing number of pipe systems which can be integrated in the wall the total heat output increases. Therefore, the energy loss connected to the interference of the pipes can be neglected. Furthermore, the distance between inflow and return flow influences the heat transfer capacity (see

Figure 5 d). The distance should be big enough to avoid a thermal short cut. A larger spacing does not lead to a higher benefit because of the decreasing number of possible pipe systems in the wall. In summary, when designing the heat exchanging pipe system of thermo-active seal panels there should be the maximum number of pipe systems integrated in the wall element. This implies that the pipe distance should be as small as possible and the distance between inflow and return should only be as big as necessary.

4 Conclusion

In the scope of this research project different practical und numerical investigations were carried out, which have shown that the utilization of geothermal energy with thermo-active seal-panels is possible. The obtained heat transfer capacities and heat-transmissions resistances are promising. The undisturbed ground temperature, the flow rate in the heat exchanging circuit as well as the heat transfer surface between ground and heat exchanging pipe can be considered to be the determining influencing parameters on the heat output. Due to experimental-related reasons the influence of a groundwater flow on the heat output could not be quantified in this project so that further research on this subject is necessary. The work performed in this project regarded the primary circuit only. Further research is necessary to include the heating circuit in the investigation. Furthermore, a detailed description of the heat transfer of a plane thermo-active structures should be carried out.

References:

Brandl, H. (2006): Energy foundations and other thermo-active ground structures. Géotechnique, Vol. 56(2), pp. 81-122

Franzius, J.N.; Pralle, N. (2010): Geothermie im Tunnelbau – Technische, wirtschaftliche und vertragliche Aspekte. Brokerage Event „Nutzung von Geothermie im Bereich unterirdischer städtischer Infrastrukturen“, Bergisch Gladbach

Markiewicz, R. (2004): Numerische und experimentelle Untersuchungen zur Nutzung geothermischer Energie mittels erdberührter Bauteile und Neuentwicklungen für den Tunnelbau. Dissertation TU Wien

Von der Hude, N.; Sauerwein, M. (2007): Energiepfähle in der praktischen Anwendung. Mitteilungen des Institutes und der Versuchsanstalt für Geotechnik der Technischen Universität Darmstadt, Heft Nr. 76, 95-109