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学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称　　博士（工学）　　氏名　Hobyung Chae

学 位 論 文 題 名

Study on new thermal response test analysis with partial groundwater flow and its application for ground source heat pump system design
(部分的に地下水流れが存在する地層に対する新しい熱応答試験の解析方法と地中熱ヒートポンプシステム設計への応用)

The main objective of the thesis is to propose a new thermal response test (TRT) analysis estimating partial groundwater flow and to develop its application for ground source heat pump (GSHP) system design. The proposed approaches for the TRT analysis provide more accurate performance predictions of the GSHP systems during a long-term operating system. The initial installation cost of the GSHP system could also reduce by suggesting appropriate borehole sizing based on the thermal properties in multi-layer of the ground. The application tool is developed to predict the energy consumption of the building, based on the GSHP system being able to calculate multi-borehole configuration under the conditions with the multi-layer with groundwater flows. This thesis consists of seven chapters, and the followings are brief descriptions of each Chapter.

Chapter 1 describes the causes of the environmental problems and their response on which many countries make an effort to solve. In terms of these global issues, the contribution of the GSHP system is reported to reduce GHG emissions and energy consumptions. In addition, the general background concerning the GSHP system, such as kinds of type, advantages, and disadvantages, research trends and developments, is introduced.

Chapter 2 provides heat transfer methodologies to predict the ground temperature variation and design the GSHP system. The historical review of thermal response test is also reported to understand the thermal property of the ground.

Chapter 3 suggests a practical TRT method to determine the groundwater velocity and the effective thermal conductivity simultaneously. An approximate formula of an equivalent single pipe is proposed to calculate the temperature change of the circulating fluid under the borehole conditions backfilled into the permeable material. The equivalent single pipe represents the temperature increases by the borehole thermal resistance and circulating fluid, and it is useful to estimate the design parameters in on-site TRT simply. The groundwater velocity and the effective thermal conductivity are determined by the iteration parameter estimation method. The method provides the best-fit parameters through the minimum root mean square error (RMSE) between the TRT data and calculated results. As a result, the groundwater velocity and the effective thermal conductivity in the test site were estimated to be 120 m/y and 4.7 W/(m K), respectively. The practical approach method could use standard TRT data for analysis without additional auxiliary equipment and complex simulation algorithms, designing the BHE in response to the annual building heat loads.

Chapter 4 proposes a novel TRT analytical method to estimate the groundwater velocity and the ef-

fective thermal conductivity in a multi-layer. The new idea called ‘relaxation time of temperature (RTT)’ is introduced to the TRT analysis. It is a moment when the temperature in the borehole recovers a certain level after stopping the heat injection. The RTT divides the ground into vertical zones with similar thermal properties. Finally, the temperature increments of the circulating fluid with the heat exchange rates in each zone are calculated by using the MLS theory according to the groundwater velocities. The calculated results are compared with the measured temperature data of each zone, and their best-fitting values estimate the groundwater velocities and the effective thermal conductivity in the test site. As a result, the groundwater velocity was 2750, 58 and 0 m/y, and the thermal conductivity was 2.4, 2.4 and 2.1 W/(m K) in each zone of the test site. These parameters were validated by comparing the circulating fluid temperature between the measurement data and calculated results during the long-term operating period. Its temperature error was 6.4

Chapter 5 verifies the effectiveness of the multi-layer TRT analysis method and proposes the method to reduce the initial cost of the GSHP system by determining the appropriate borehole size. The required borehole numbers are determined by the system performance in the 30th year after operating the GSHP system, based on the parameters estimated by the TRT analysis methods. The initial and operating costs are calculated to analyze the life cycle cost (LCC) of the GSHP system. The return of investment (ROI) period is analyzed by comparing it with an air source heat pump system. As a result, the GSHP system designed by considering the layer with high thermal dispersion could save 16.8

Chapter 6 introduces the application of a ground source heat pump system for nearly zero energy building. The application tool is developed to predict the energy consumption of the building, based on the GSHP system being able to calculate multi-borehole configuration under the conditions with the multi-layer with groundwater flows. As a result, the building loads designed for a zero energy building in a cold region were 76.5 GJ and 34.2 GJ for heating and cooling, respectively. Based on the conditions of the target building, it was considered that the BHEs were needed to10 BHEs to maintain high performance while reducing the initial investment cost. The depth of the layer where the groundwater flows affected the system performance. The increase of 20 m in the layer with the groundwater flow improved the system performance by 2.5

Chapter 7 summarizes the general conclusions of this thesis and introduces the development toward a zero-carbon society.

It is valuable in this thesis to figure out the groundwater velocity from the TRT results. Furthermore, it could propose the borehole size based on the partial groundwater flow in the multi-layer. The proposed TRT analysis methods provide the information in designing the GSHP system to reduce the initial cost and more accurate prediction of the system performance. Its application could utilize to realize the zero energy building based on the GSHP system design. It is believed that these research works above contribute to the low-carbon society.