Relationship between apparent thermal conductivity obtained from simplified thermal response test and shallow subsurface geology in Fukushima Prefecture, Northeast Japan

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1. Introduction

Optimum ground-source heat pump (GSHP) systems can be realized by accurately estimating the ground thermal conductivity (apparent thermal conductivity) obtained from thermal response tests in situ. However, the conventional thermal response test has problems of the cost and simplicity of the tests. On the other hand, Jinguuji et al. (2002, 2010) devised a simplified thermal response test utilizing a borehole for a standard penetration test to be carried out at the time of building confirmation application. The simplified test enables higher-precision, more inexpensive, and simpler tests compared with the conventional test. Besides, the simplified thermal response test is useful as a survey method of groundwater environment (e.g. estimation of active aquifer and impermeable layer of groundwater flow), and it seems to contribute to storage of thermophysical properties of shallow subsurface (tens of meters) and groundwater data.

The AIST Japan and Fukushima GSHP Development Limited Liability Partnership have been conducting a survey in Fukushima Prefecture since 2018 for the purpose of demonstration evaluation and standardization of the effectiveness of the simplified thermal response test for installation of GSHP systems. In this presentation, the correspondence relationship between the apparent thermal conductivity values (λ values) obtained in 2018 from the simplified test carried out at 15 sites of Nakadori area (e.g. Fukushima City, Koriyama City) in Fukushima Prefecture and shallow subsurface geology.

2. Method: Simplified thermal response test

After drilling borehole (outside diameter: 66 mm, depth: 51 m) at each 15 site, boring rods (outside diameter: 40.5 mm) were installed in the borehole and filled with water, then a cable heater (50 m length) and a multi-point temperature sensor (every 1 m, 51 points) were bound and inserted in the rods. The heating quantity by the constant power output equipment was 20 W/m, the heating time was over 48 hours, and the temperature recovery time after the heating stop was over 60 hours. Temperature data during heating and recovering was acquired. The λ values was calculated from the temperature graph in the heating by the drawing method (Geo-Heat Promotion Association of Japan, 2014), and the λ were classified and arranged in the frequency distribution for each lithofacies interpreted from the slime sample in the drilling.

3. Result and Discusstion

The appearance range and peak of λ values ([W/m K]) of each lithofacies are as follows: 0.8˜3.3 and 1.6 (followed by 2.0, 2.1) for gravel layer; 0.8˜2.4 and 1.4 for sand layer; 0.8˜2.2 and 1.2 for mud layer; 0.8˜1.8 and 1.2 for tuff (including pyroclastic flow sediments); 1.8˜>4.0 and 3.1 for granite. Each value is generally consistent with literature values (Geo-Heat Promotion Association of Japan, 2014; “effective thermal conductivity”). The λ frequency distribution of each lithofacies shows the shape close to the normal distribution, although there is a tendency of slightly right convex overall, indicating that λ increase in layers affected by groundwater flow. The λ distribution of gravel layers (aquifers) tends to be convex to the right. Also, the increase of λ distribution in granite over 3.6 indicates that groundwater flows through the cracks of the granite.

When λ graph (depth direction) and geological column in each site are arranged, high and low peak are occasionally observed. High peaks (λ is often over 3) well occur in gravel layer and granite. On the other hand, the low peak was observed at the mud layer are sandwiched between gravel and/or sand layers. Except for granite, when λ values exceeds 3, the boundary conditions are very different, and the estimated value does not make any physical sense. This may be due to the stronger effect of the heat advection. In the meantime, it can be expected that the existence of the impermeable layer such as the mud layer is indicated by the peak of the low λ value.

Keywords: Simplified thermal response test, Conventional thermal response test, Apparent thermal conductivity, Geology, Groundwater, Fukushima Prefectur