# Evaluation method of soil thermal property for shallow ground thermal energy utilization
# 浅層地中熱利用ための地盤熱特性評価方法の検討

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**Abstract:** This study aims at analyzing the shallow ground soil thermal property to contribute to the research on shallow thermal energy utilization and the design work, simulation work on the high-performance ground heat exchanger. In this paper, the calculation and simulation method were introduced firstly. Then the author conducted the simulation using STREAM V14.1 and analyzed the result of two types of arrangements of the ground probe. According to the simulation result, the field experiment was conducted in Sapporo. Finally, the measurement result of the shallow thermal property was compared with the simulation result and revealed the relationship between the surface temperature and thermal performance of shallow ground soil.

## 1. Introduction

In recent years, global warming has become a world environmental issue. The reason for global warming is increasing in CO2 emission. This problem strengthens people's interest in the application of the ground source heat pump systems. However, GSHP systems are not well popularized in Japan due to the expensive installation cost and the complex installation process, especially the initial drilling cost which is significantly higher than in other countries. Therefore, the small GSHP system by using the shallow ground energy is expected in Japan, which can reduce the expensive installation cost and facilitates construction works in tight spaces by using the small drilling and digging machine. However, as for the shallow energy utilization system, the ground surface temperature change and the different distribution of soil property will lead an influence on the thermal performance of the whole system. Therefore, before the installation work of the GSHP system, the soil thermal property test is needed as shown in Fig.1. In this research, we conducted the simulation and field experiment by using the vertical and horizontal probe to replace real heat exchanger, then evaluated the thermal performance of the soil thermal property for shallow ground, which is influenced by the surface temperature and different distribution of the soil thermal conductivity.

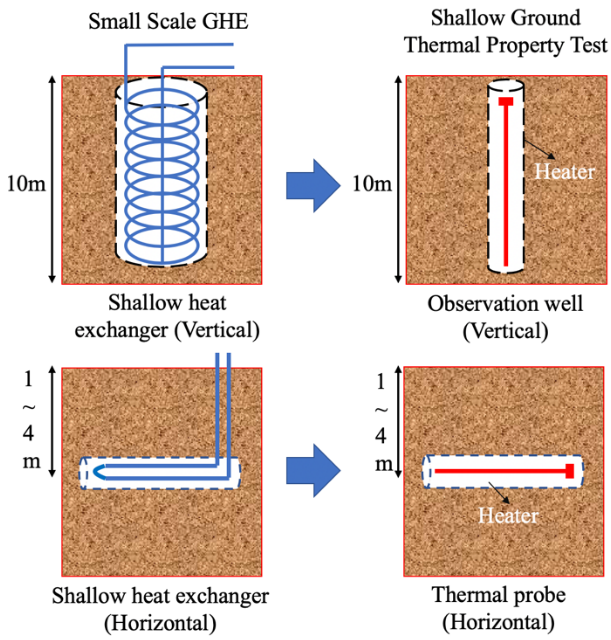



**Figure.1 The Schematic of Shallow Ground Thermal Property Test**

## 2. Simulation to Evaluate the Effect of the Ground Surface Temperature and Thermal Conductivity Distribution on Underground Thermal Property

### 2.1 Case of Vertical Observation Well

In order to evaluate the shallow soil property of the ground soil. The simulation model was created by using the CFD simulation software STREAM V14.1. For the case of vertical observation well. The created model is a 10-meter long vertical well with adiabatic surface as shown in Fig.2.

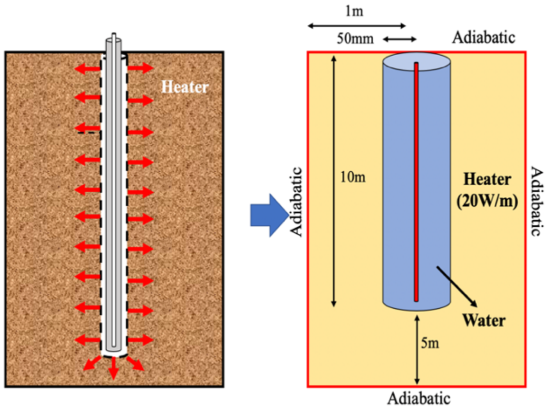
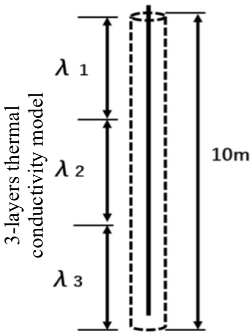



**Figure.2 The Vertical Observation Well (left) & Numerical Calculation Conditions (right)**

For an accurate result, we arranged the temperature sensor every meter, the vertical probe (Heat Flux=20W/m) was settled in the middle of observation well to heat the shallow ground soil. Also, the different calculation conditions are shown in Table.1 and Fig.3. In this simulation model, the underground soil was divided into 3-layers to apply the different thermal property changes thereby revealing the relationship between them.

**Table 1 Thermal Conductivity Distribution**




| | λ1 [W/(m·h)] | λ2 [W/(m·h)] | λ3 [W/(m·h)] |
|---|---|---|---|
| CASE 0-1 | 1.2 | 1.2 | 1.2 |
| CASE0-2 | 1.5 | 1.5 | 1.5 |
| CASE0-3 | 1.8 | 1.8 | 1.8 |
| CASE1 | 1.2 | 1.5 | - |
| CASE2 | 1.5 | 1.2 | - |
| CASE3 | 1.2 | 1.8 | - |
| CASE4 | 1.8 | 1.2 | - |
| CASE5 | 1.2 | 1.5 | 1.8 |
| CASE6 | 1.8 | 1.5 | 1.2 |
| CASE7 | 1.5 | 1.2 | 1.8 |
| CASE8 | 1.2 | 1.8 | 1.5 |
| CASE9 | 1.2 | 1.5 | 1.5 |
| CASE10 | 1.5 | 1.5 | 1.2 |

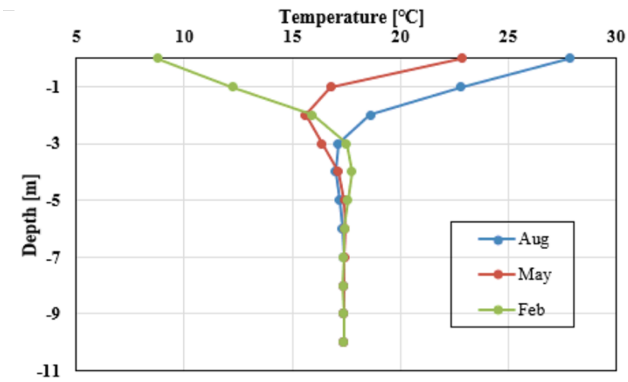



**Figure.3 Underground Temperature Distribution**

(1) Constant Thermal Conductivity with Different Underground Temperature Distribution

As shown in Fig.4, the different temperature distribution does not lead a very huge influence on the effective thermal conductivity. For the result of August, there is only a 3% difference compared with constant results. For the result of May, there is a 1% difference compared with constant results. For the result of February, there is a 4% difference compared with the constant results. This result reflected that the temperature distribution of each month will lead to a limited influence on the thermal conductivity for the cases of vertical observation well.

(2) Constant Underground Temperature Distribution with Thermal Conductivity Changes

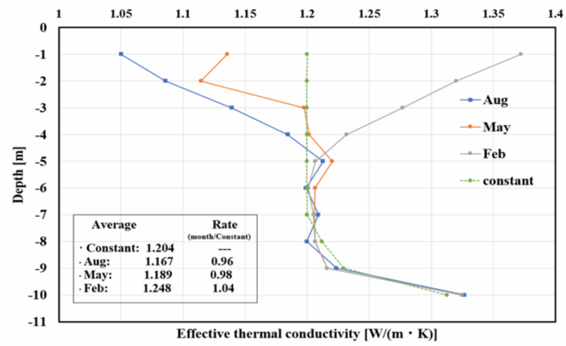



**Figure.4 Effective Thermal Conductivity at Each Depth (Vertical Observation Well)**

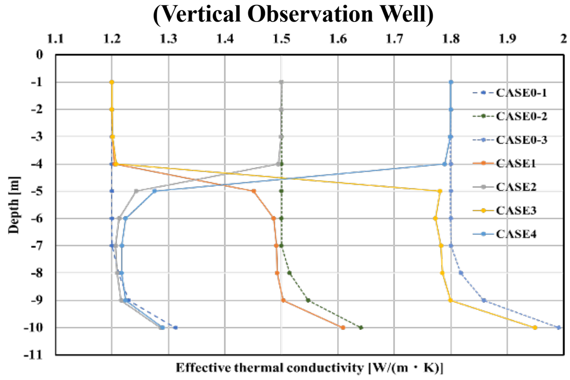



**Figure.5 Effective Thermal Conductivity at Each Depth (Vertical Observation Well CASE 1~4)**

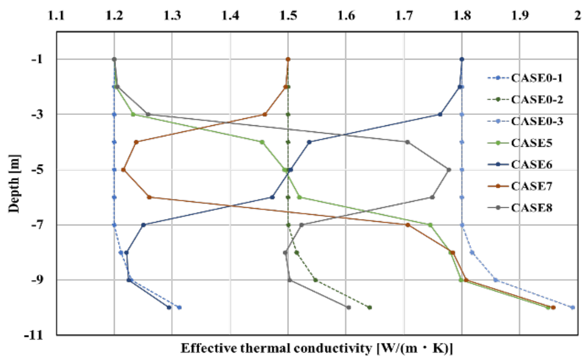



**Figure.6 Effective Thermal Conductivity at Each Depth (Vertical Observation Well CASE 5~8)**

**Table.2 Comparation of Thermal Conductivity**

| | Average constant λ [W/(m·h)] | Average calculated λ [W/(m·h)] |
|---|---|---|
| CASE0-1 | 1.2 | 1.2 |
| CASE0-2 | 1.5 | 1.51 |
| CASE0-3 | 1.8 | 1.81 |
| CASE1 | 1.35 | 1.36 |
| CASE2 | 1.35 | 1.34 |
| CASE3 | 1.5 | 1.53 |
| CASE4 | 1.5 | 1.48 |
| CASE5 | 1.5 | 1.49 |
| CASE6 | 1.5 | 1.51 |
| CASE7 | 1.5 | 1.5 |
| CASE8 | 1.5 | 1.49 |
| CASE9 | 1.4 | 1.4 |
| CASE10 | 1.4 | 1.31 |

Through Fig.5, Fig.6 and Table.2 we could find there is a very limited influence of the thermal conductivity changes by depth from the simulation results.

### 2.2 Case of Horizontal Thermal Probe

For the case of horizontal thermal probe. The created model is a 1-meter long horizontal thermal probe which was buried in underground 1~4 meters as shown in Fig.7.

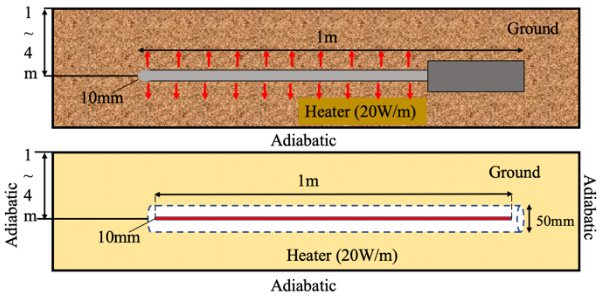



**Figure.7 The Horizontal Thermal Probe(left) & Numerical Calculation Conditions (right)**

As for horizontal situation, the limited influence led by thermal conductivity changes is foreseeable. Therefore, we only analyzed the temperature distribution condition.

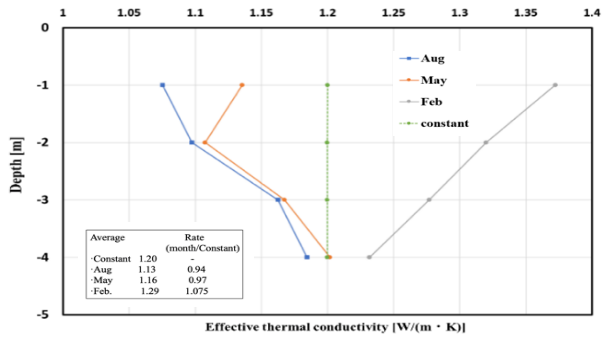



**Figure.8 Effective Thermal Conductivity at Each Depth (Horizontal Thermal Probe)**

From the result shown in Fig.8, the different temperature distribution will affect the effective thermal conductivity of horizontal thermal probe. For the result of August, there is a 6% difference compared with constant results. For the result of May, there is a 3% difference compared with constant results. For the result of February, there is a 7.5% difference compared with the constant results. Compare to the vertical observation well this result reflects the temperature distribution of different months will lead a visible influence on horizontal to arrange situation especially in the cold season. Therefore, it is necessary to conduct the field experiment for horizontal thermal probe.

## 3. Field Experiment

In this research, we also conducted the field experiment. Fig.9 shows the schematic of the experiment site.

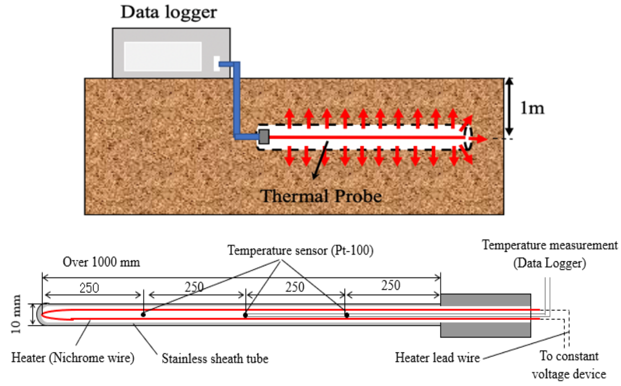



**Figure.9 Schematic of Experiment Site (upper) and Horizontal Thermal Probe (lower)**

In the field experiment, we have arranged 2 thermal probes (Heat Flux=6W/m) at the depth of 1 m in the ground parallelly. The thermal probe A was set to release the heat continuously. The thermal probe B was used for estimating the soil thermal property as shown in Fig.9. The data logger was also set to record the data of soil temperature changes when the probe is working.

### 3.1 Result of Field Experiment

Fig.10 shows the experiment result and the ambient air temperature changes during the thermal property test.

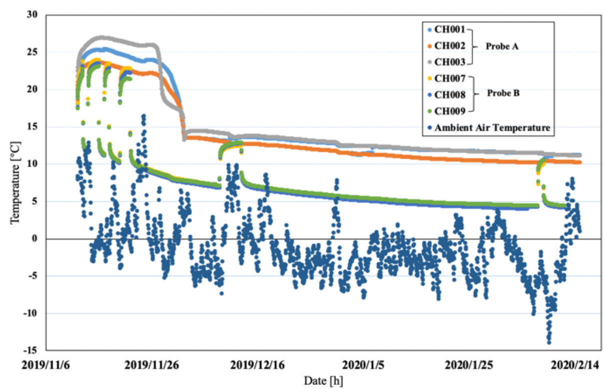



**Figure.10 Experiment Result**

According to this result, we can find the soil temperature is gradually decreased with the ambient air temperature even in the case of Probe A. At the same time, the effective thermal property test was estimated by using Probe B in December and February, the results are shown in Fig.11~12.

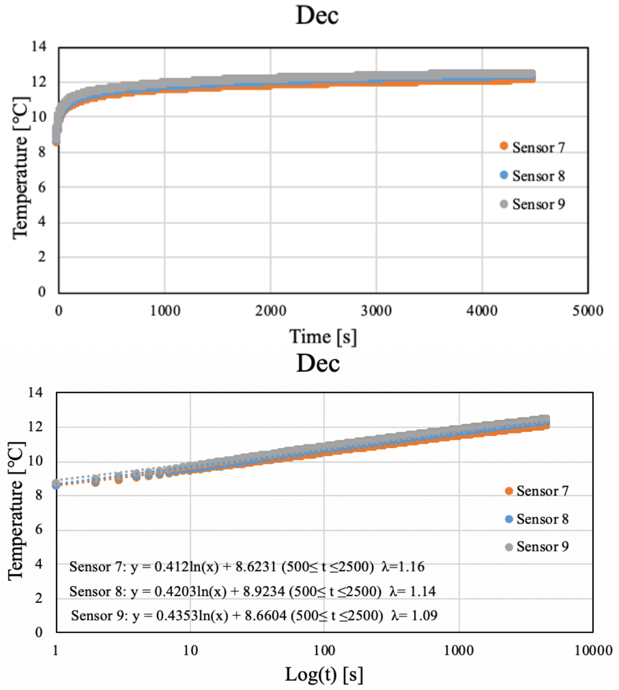



**Figure.11 December Thermal Test**

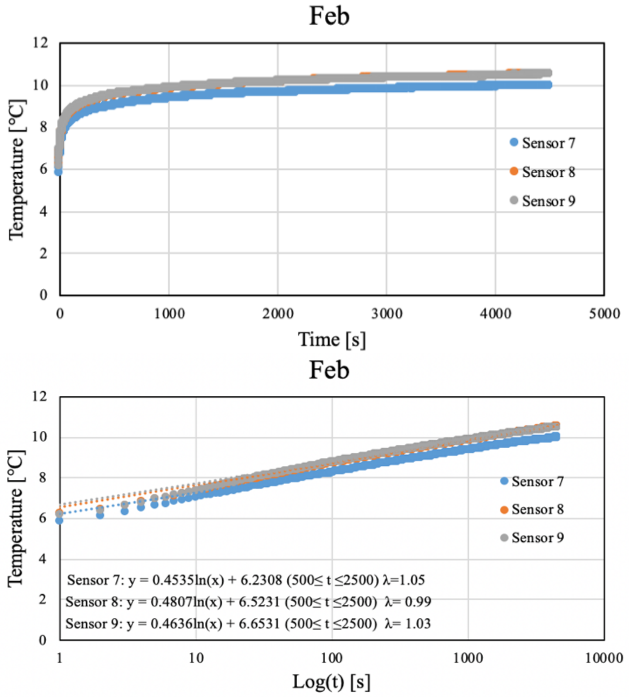



**Figure.12 February Thermal Test**

For heating progress in December, the calculated effective soil thermal conductivity of sensors 7, 8, 9 is 1.16, 1.14, 1.09 respectively. For heating progress in February, the calculated effective soil thermal conductivity of sensors 7, 8, 9 is 1.05, 0.99, 1.03, respectively. Compare with the simulation, the result in December reflects a good match with the simulation result. But when it comes to the result in February, it might because the moisture content in February was less than December, then leads to a small thermal conductivity in February compared with the result in December. As for the simulation result, it's also might because the simulation does not consider the changes in the moisture content percentage of the soil, etc. Although it does not produce an expected fitting result between experiment and simulation this time, it still reflected the real conditions of the shallow ground thermal property.

## 4. Conclusion

(1) In this research, we have analyzed the thermal property of the ground soil in different heating situation. The result shows, for vertical observation well, as for the changes in temperature, there is a little effect on soil thermophysical properties, it is due to the small temperature changes in the deep soil layer. But as for the horizontal thermal probe situation, due to the shallow buried depth, the temperature change of soil in different months will lead to a significant effect on the thermophysical properties.

(2) Compare the result of December and February in a field experiment, the thermal conductivity of each sensor in December is bigger than in February. Also compare with the simulation result, the difference is might because of the different moisture content percentage in the soil.

(3) Through the comparison result, the discussion of horizontal thermal property in other months is necessary.

## Acknowledge

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