New Technologies on TRT and Borehole Heat Exchange Systems

October 19, 2014

Hikari Fujii

Akita University, Japan

Contents of Presentation

1. Estimation of the vertical distribution of thermal conductivity through a TRT with optical fiber thermometers
2. Numerical simulation of Slinky-coil horizontal ground heat exchangers (GHEs)

U-tube with Optical Fiber Sensors

Installation of Horizontal GHE

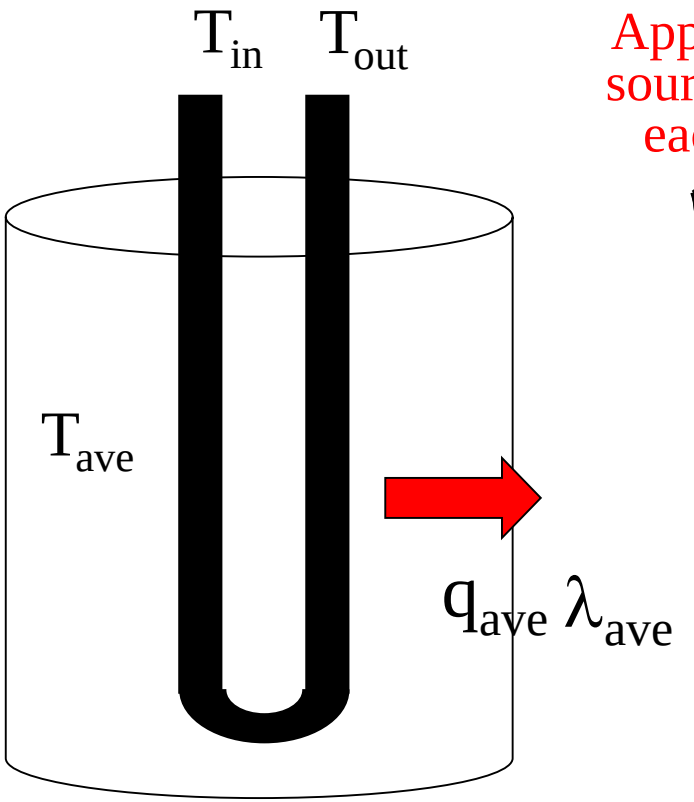
Procedures

1. Insert optical fiber sensors in U-tubes before circulation of heat medium.
2. Record initial temperature profile.
3. Circulate heat medium with appropriate heat load.
4. After heating period, record recovery temperature profiles for several days for interpretation.

Optical Fiber Thermometer
(Hitachi Cable Ltd. FTR-070)
-Resolution: 0.1K, Accuracy: 1.0K
-Min. Depth Interval: 1.0m
-Min. Time Interval: 60sec

Optical Fiber Sensors in U-tubes

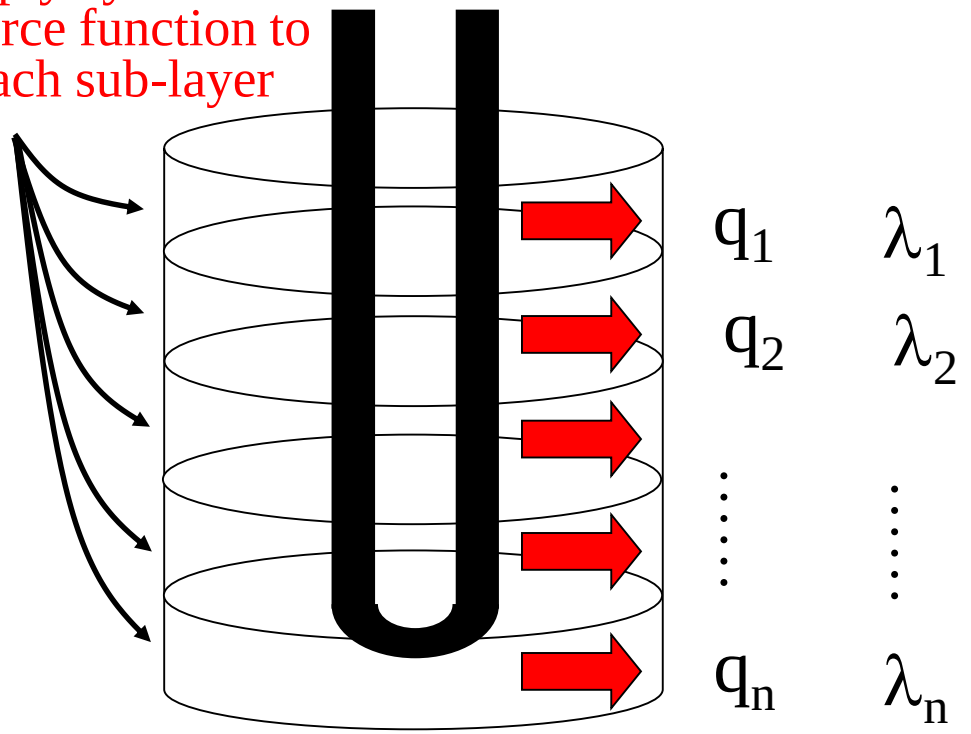
Multi-layer Model



Conventional Model

Only average λ can be obtained.

Apply cylindrical source function to each sub-layer



Multi-layer Model

λ can be estimated in each sub-layer.

Estimation of Thermal Conductivity

Estimate q and λ by minimizing objective function F using a nonlinear regression method.

Error in heat medium temperature

Error in vertical temperature profile

$$F = \alpha \sum^{nstep} (T_{o(obs)} - T_{o(cal)})^2 + (1-\alpha) \sum^{ntest} \left(\sum^{nlayer} (T_{ro(obs)} - T_{ro(cal)})^2 \right)$$

T_o: Water temperature at well outlet (K)

T_{ro}: Outer face temperature of GHE (K)

obs: observed, cal: calculated

nstep: Number of timestep

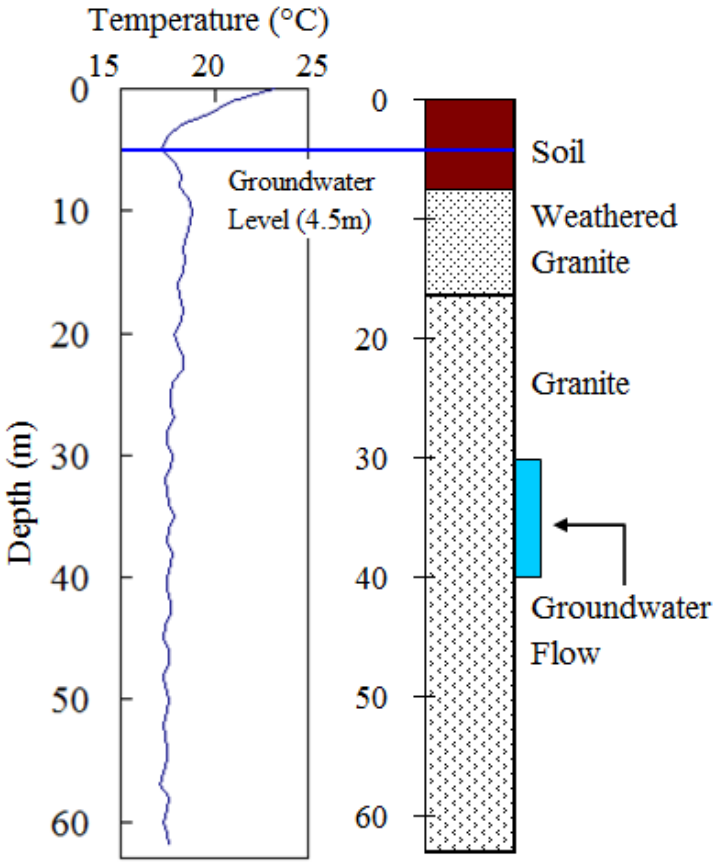
nlayer: Number of layer

ntest: Number of comparison between measured and calculated temperature profiles

α: Weighting factor

TRT using optical fiber thermometers

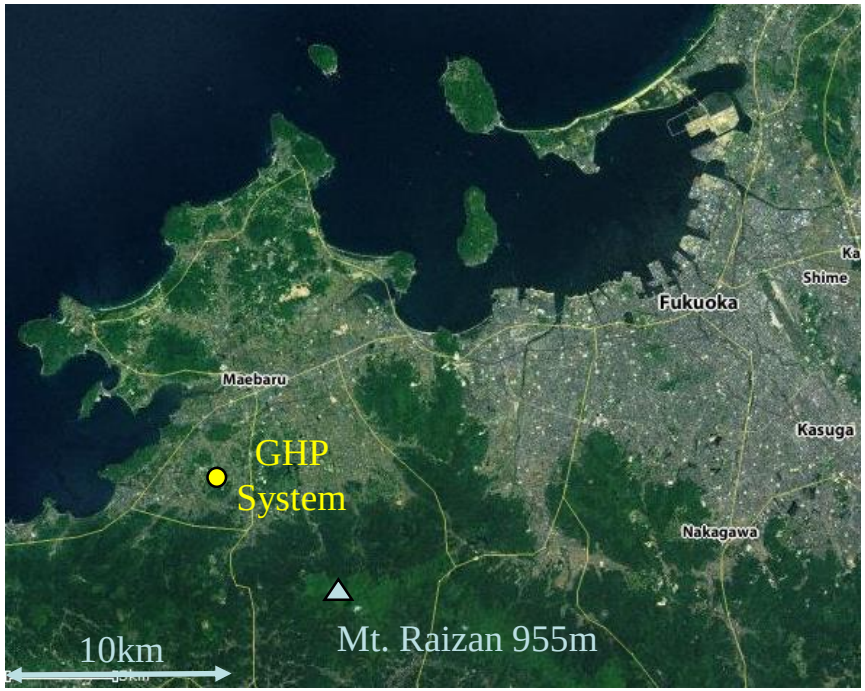
Geological and Well Information



Geological Column and Initial Temperature Profile

Information on Ground Heat Exchangers (GHE)

Type of GHE : HDPE Double U-tube (ID 25mm)
Grout : Silica Sand (20-65mesh/inch)
Heat Medium : Water



Location of GHP System

Information on TRT

- Test Duration : 3 days (Circulation)
  6 days (Recovery)
- Heat Load : 4 kW（64 W/m)
- Circulation Rate : 21 Liter/min

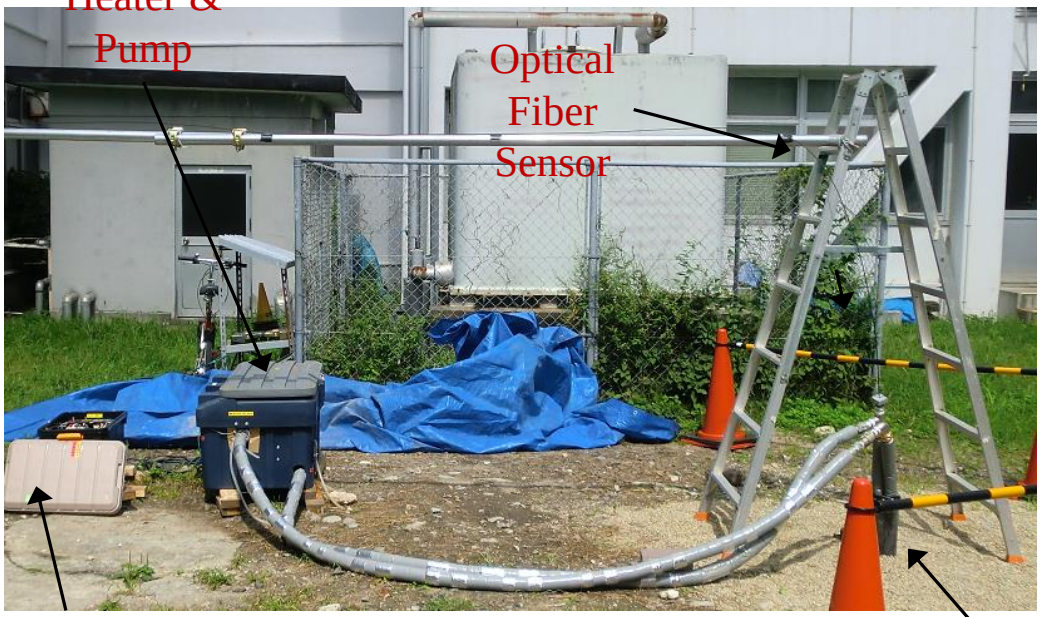
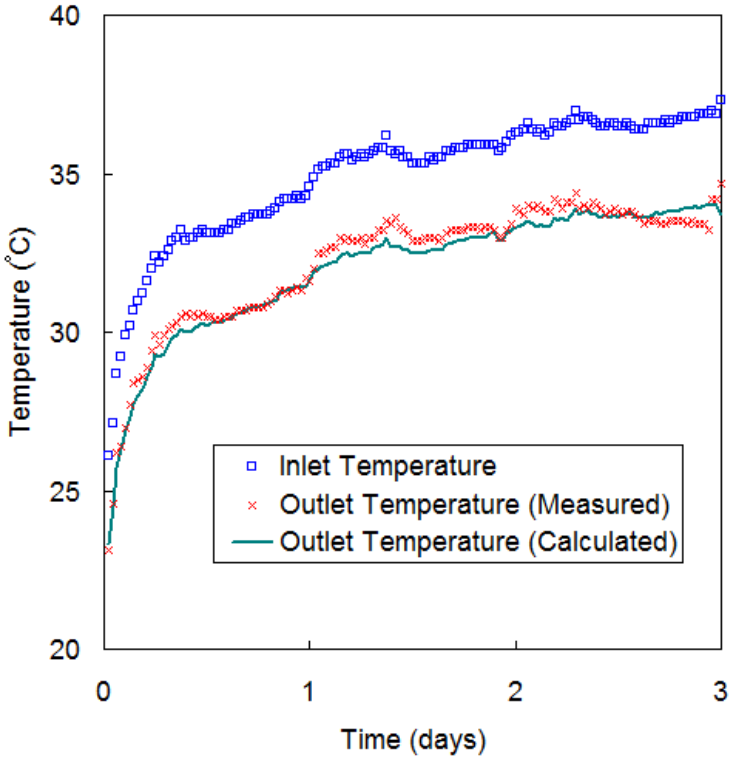


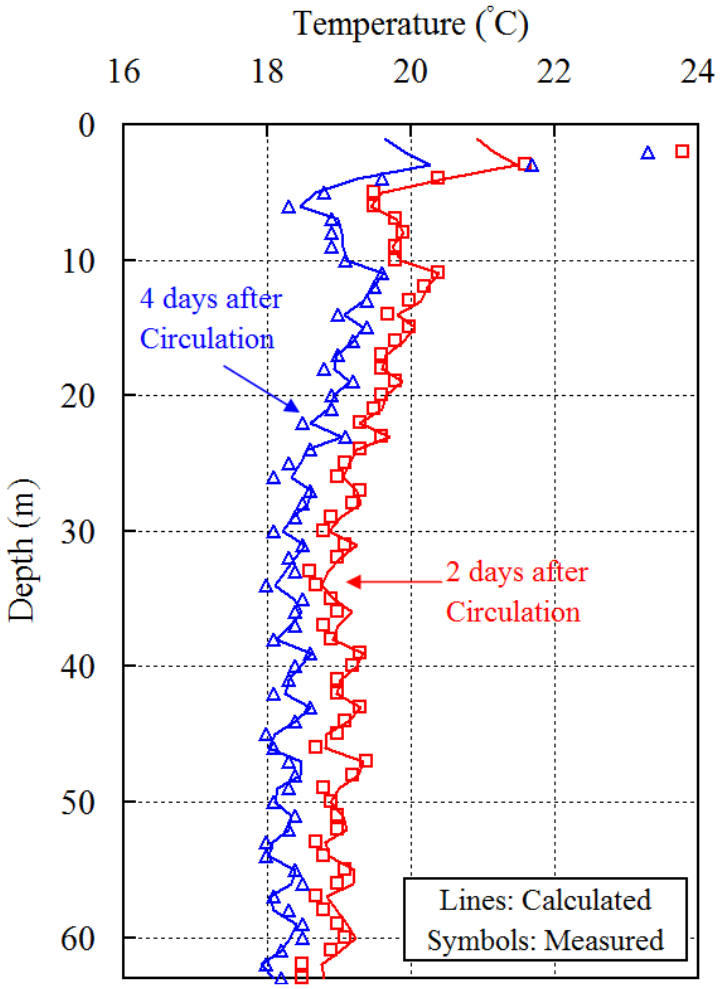
Photo of Equipment



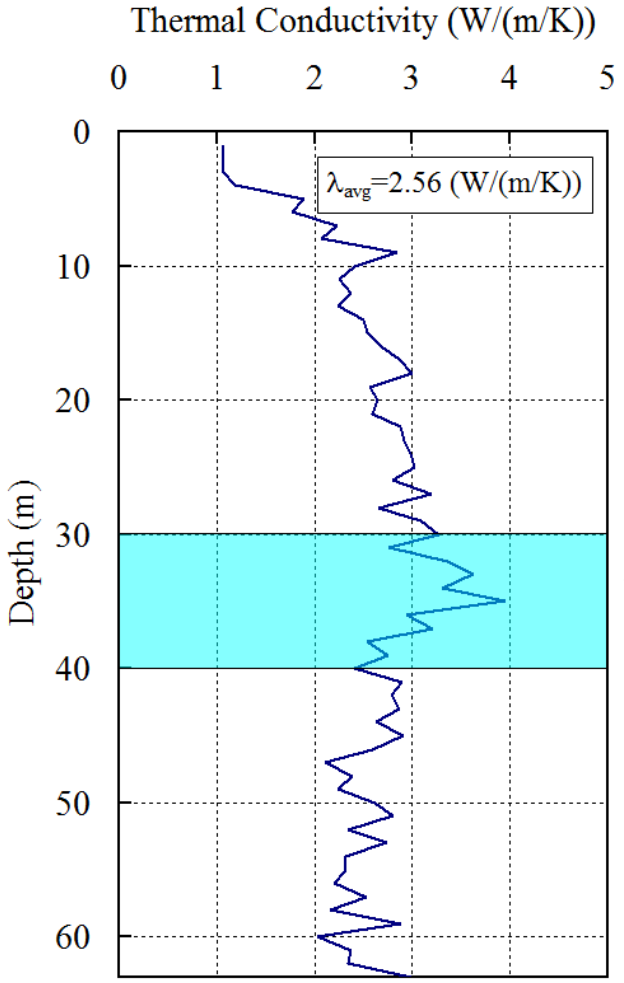
Matching Results of
Outlet Temperatures

TRT using optical fiber thermometers

Interpretation of TRT



Matching of Temperature Recovery



Interpreted Distribution of Thermal Conductivity

Background and contents

Background

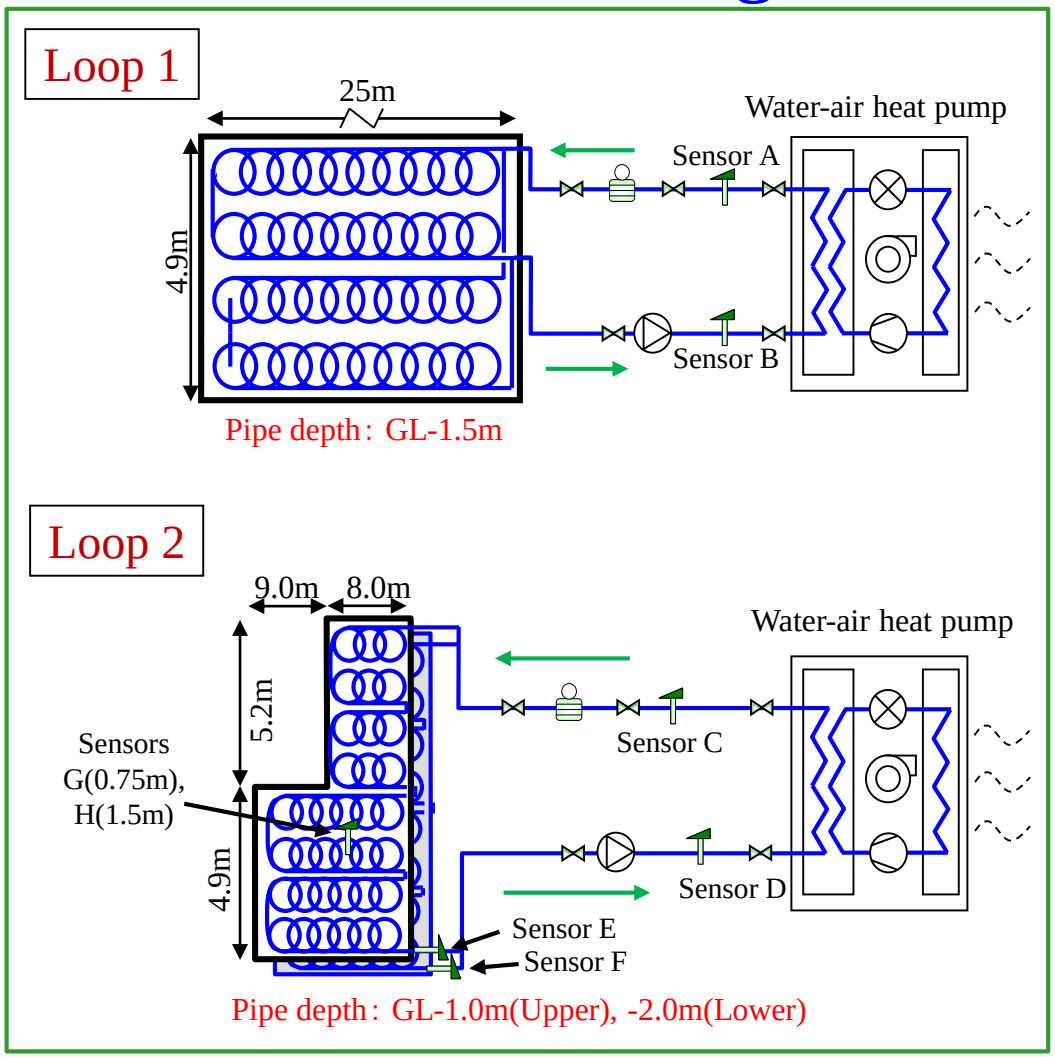
- Slinky-coil horizontal ground heat exchangers (HGHEs) save the initial cost of GSHP systems.
- The performances and optimum design of Slinky-coil HGHEs are not well studied.

Contents of research

- Long-term heating and cooling tests
- Numerical simulation and case studies

Installation of Slinky-coils
(Aomori, Japan)

Long-term field tests

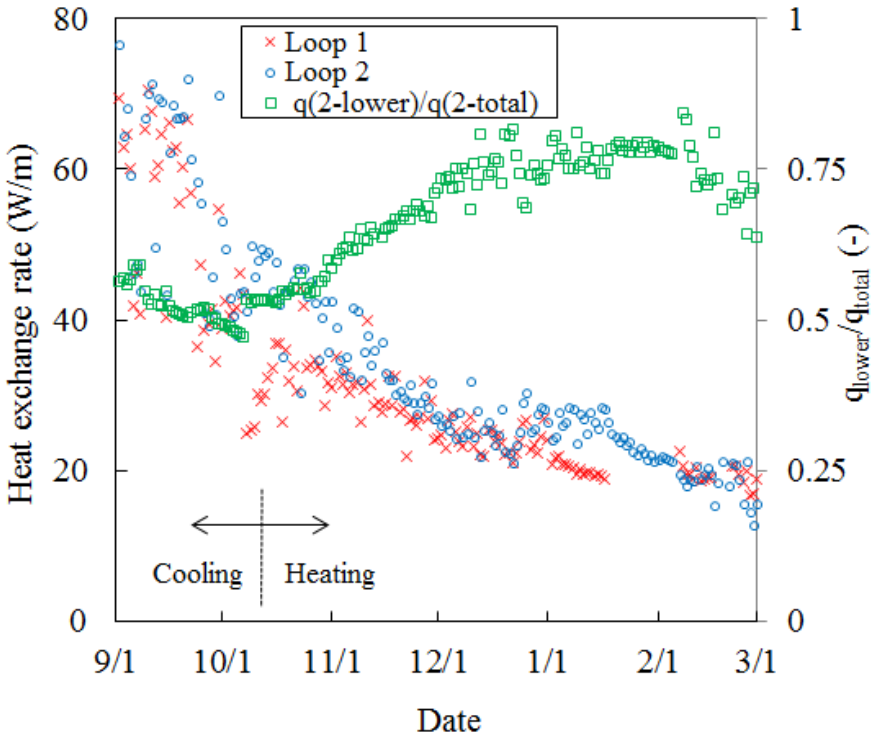


Schematic of field test facility

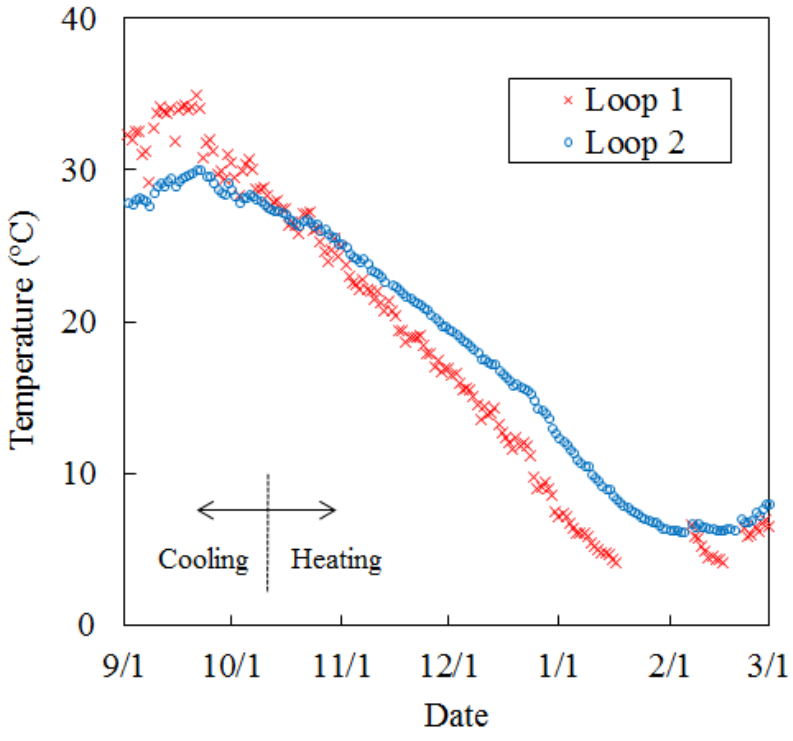
Test conditions

- Location: Itoshima, Japan
- Period: Sep. 2010 – Mar. 2011
- L of loop per layer: 100m
- λ of soil: 1.16 W/m/K
- Capacity of heat pump: 5 kW

Test results



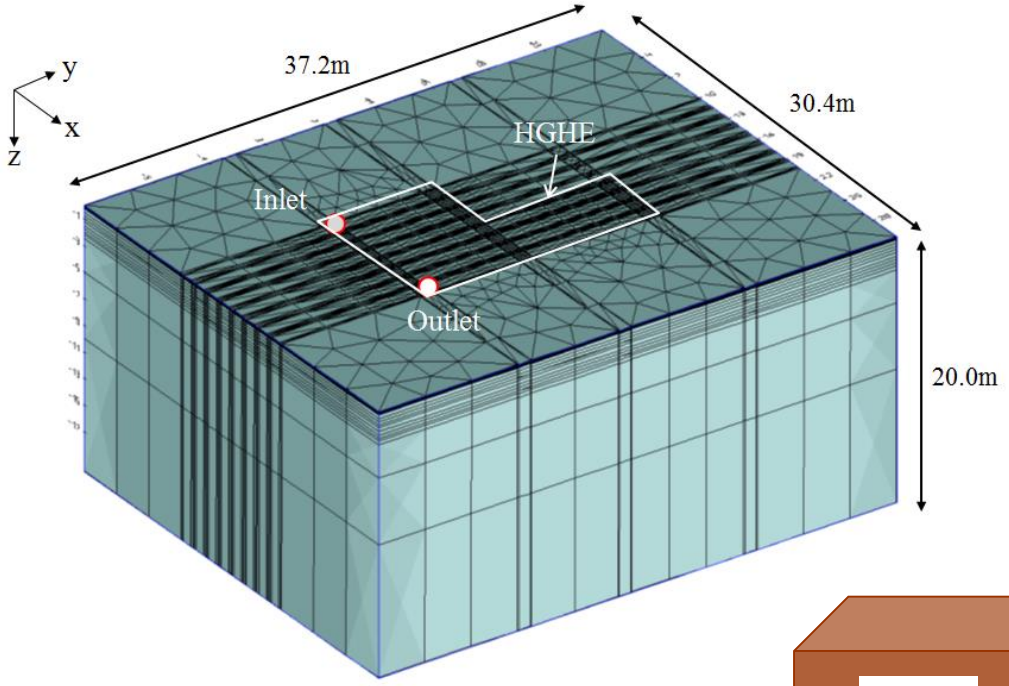
Heat exchange rates



Inlet temperature at heat pumps

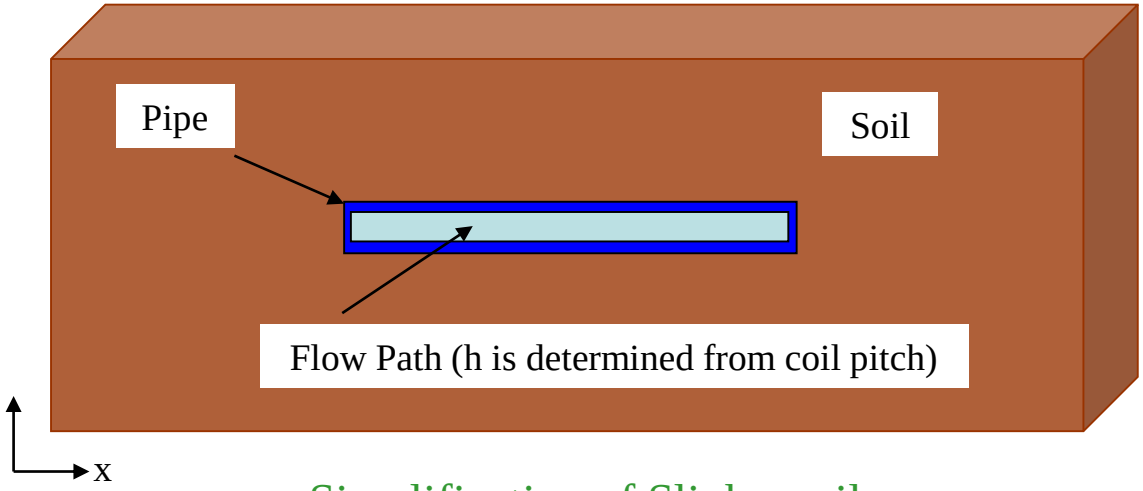
Loop 2 showed superior performance to Loop 1 because of the longer heat exchanger.

Modeling using FEFLOW



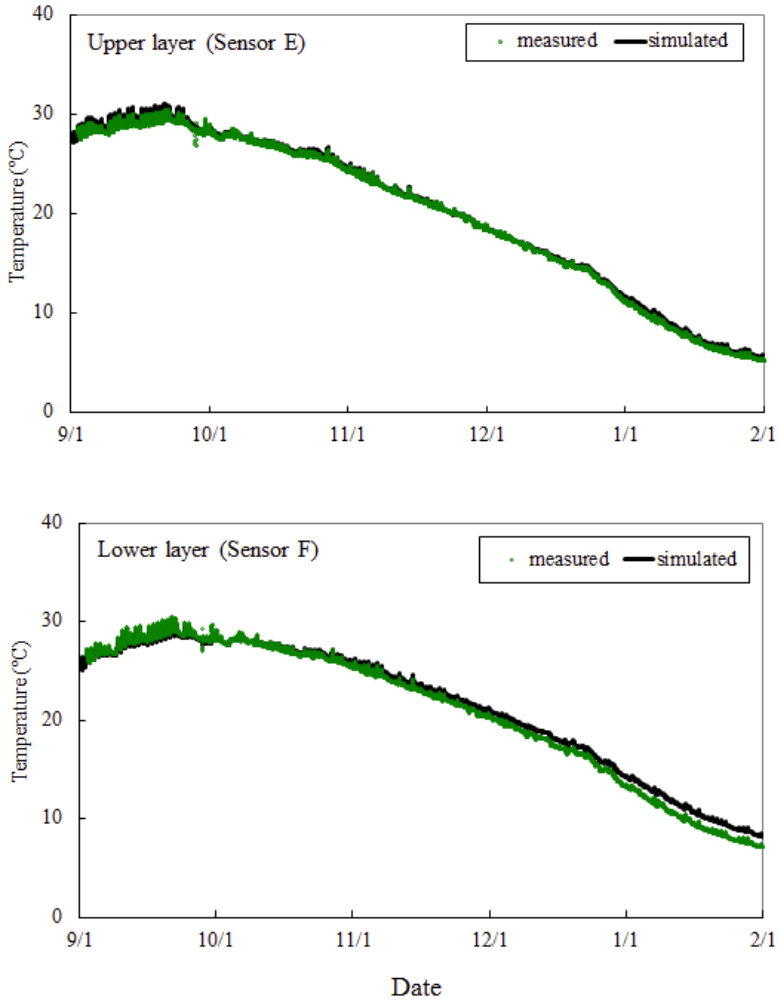
3D view of Loop 2 model

- Slinky-coils were simplified as a flat plate surrounded with a thin pipe.
- λ of the pipe was determined through history matching.
- Surface boundary conditions were calculated using sol-air temperatures (SAT).

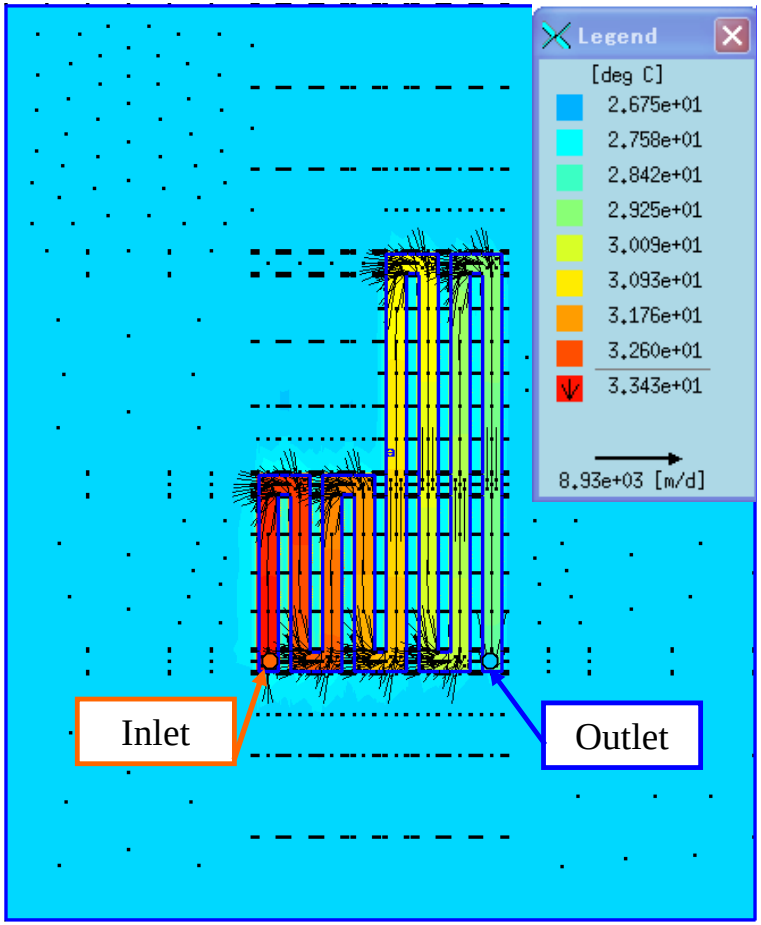


Simplification of Slinky-coils

Results of history matching (Loop 2)



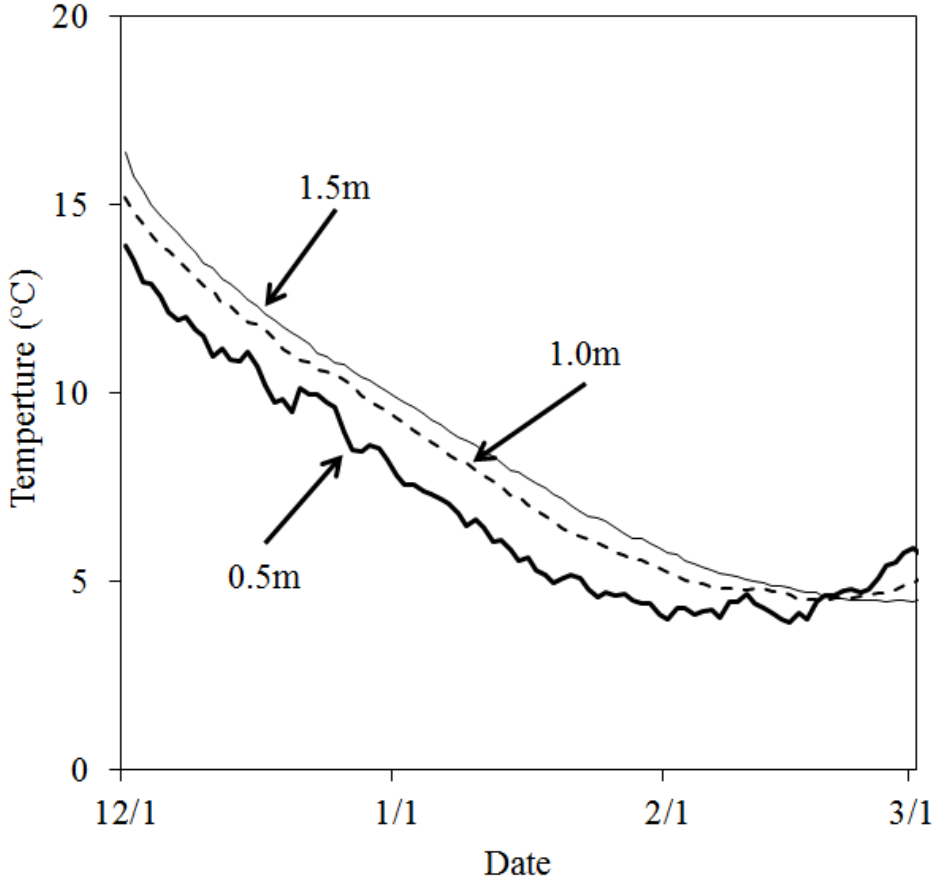
Heat medium temperatures



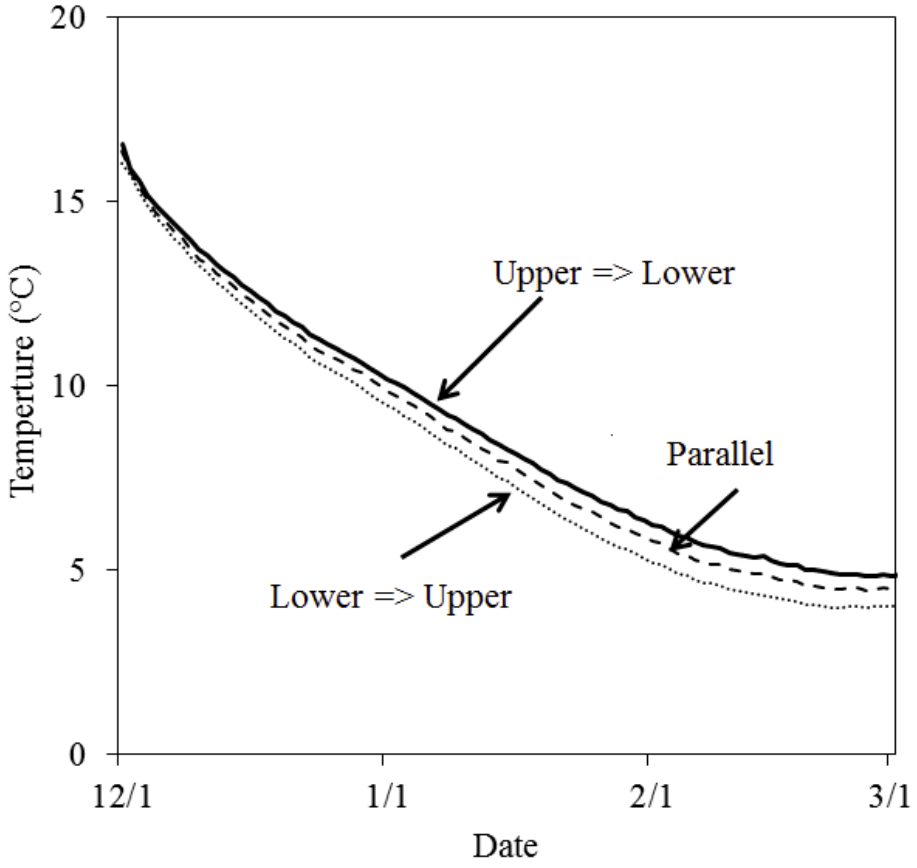
Temperature distribution at -1.0m
(Cooling operation)

The numerical model well reproduced the field test results.

Sensitivity Studies (Heating)



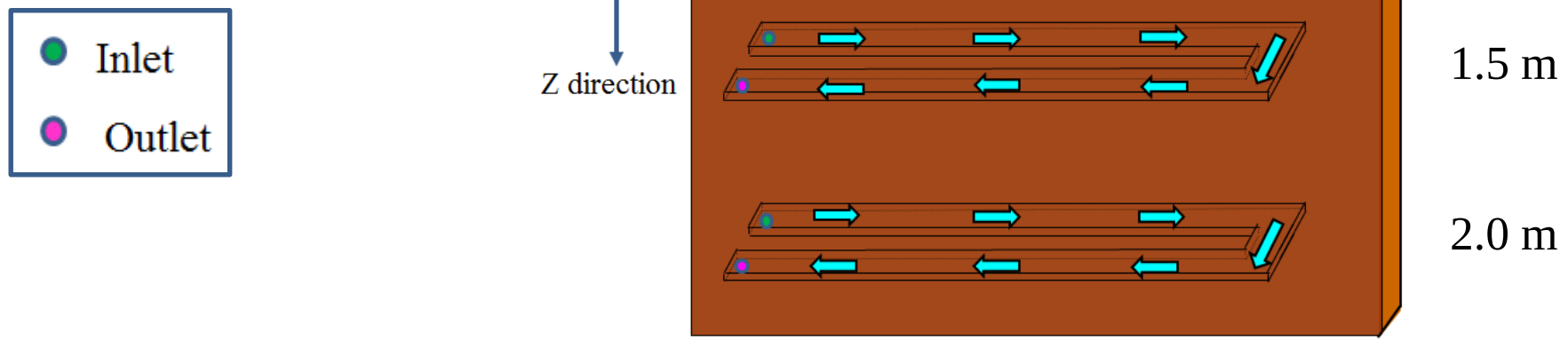
Heat medium temperature vs.
depth of upper layer



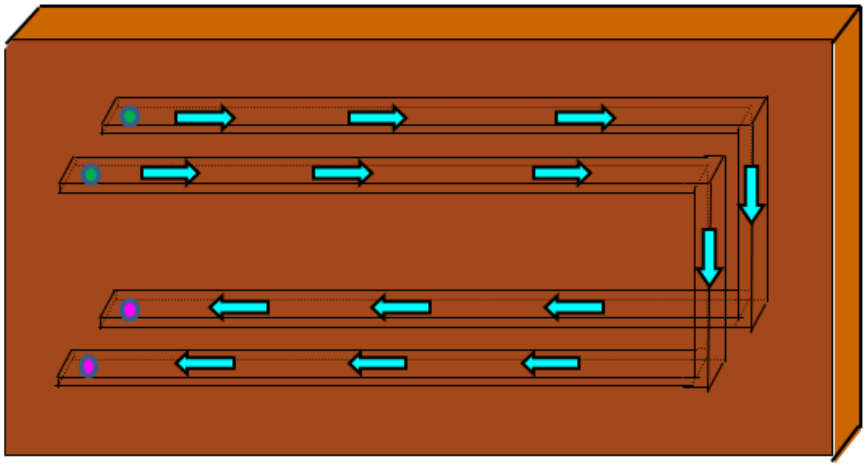
Heat medium temperature vs.
circulation directions

Circulation directions

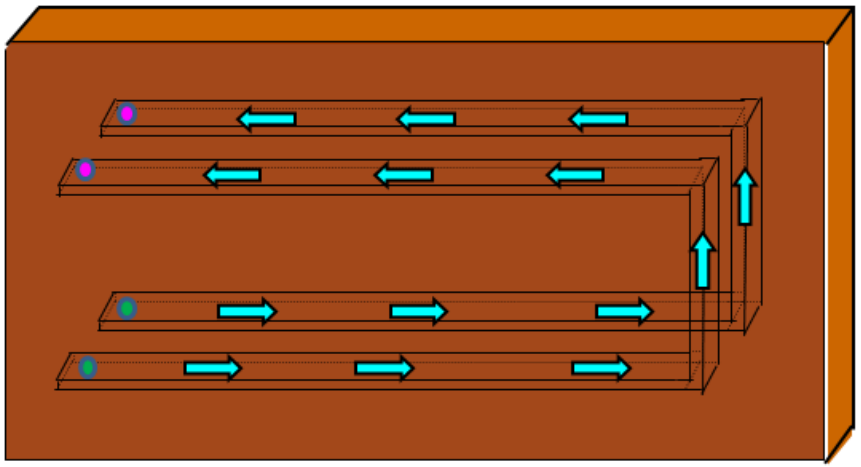
Parallel



Upper to lower



Lower to upper



Summary

- The application of optical fiber thermometers on TRTs is effective to determine the optimum well length in heterogeneous formations.

- Numerical models of Slinky-coil HGHEs were developed using FEFLOW and was validated with field test results. Sensitivity calculations were carried out to optimize the design parameters of HGHES.

Thank you for your kind attention.