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Thermal testing of soils

Recent developments at Imperial College

GSHPA Fifth Technical Seminar
26 November 2014, De Montfort University, Leicester
David M. G. Taborda

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Contents

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Background

- Research at the Geotechnics Section at Imperial College covers a wide range of topics (offshore geotechnics, tunnelling, excavations, embankments, advanced soil testing, computational geomechanics, etc.)

- Energy Geotechnics was established recently, including ground-source energy systems (2012) and nuclear waste disposal (2013)

- Interfaces with other areas of the Civil Engineering Department (subsurface hydrology, energy systems, materials, etc.) and College through the Energy Futures Lab

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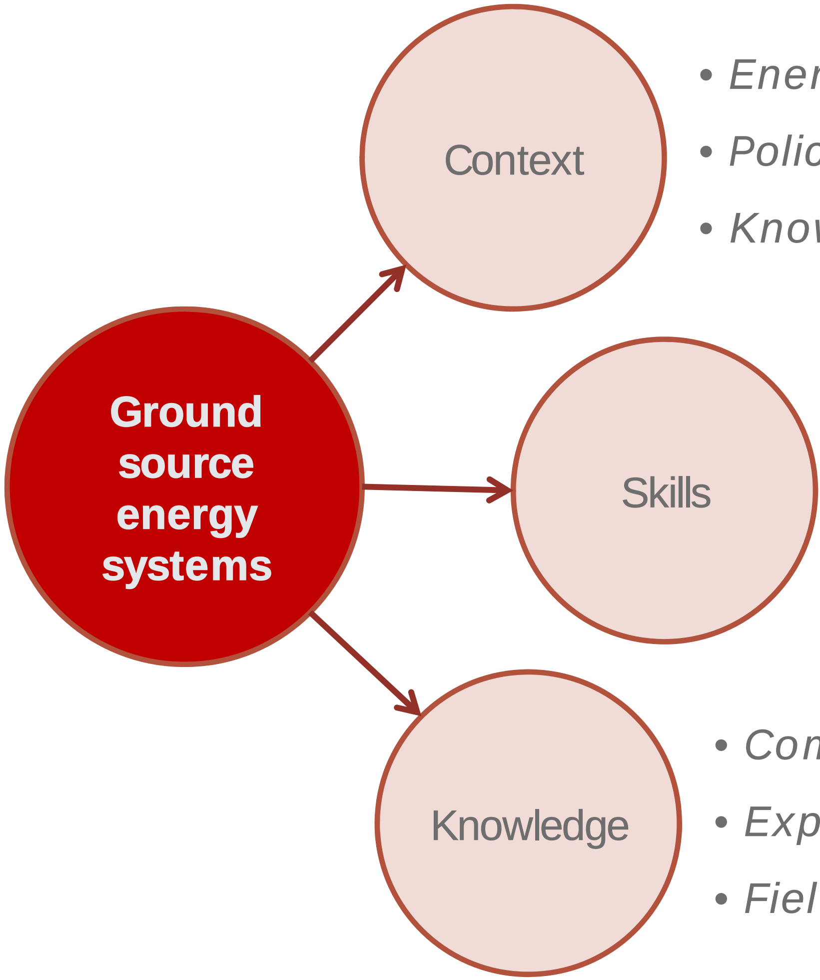
Research Approach

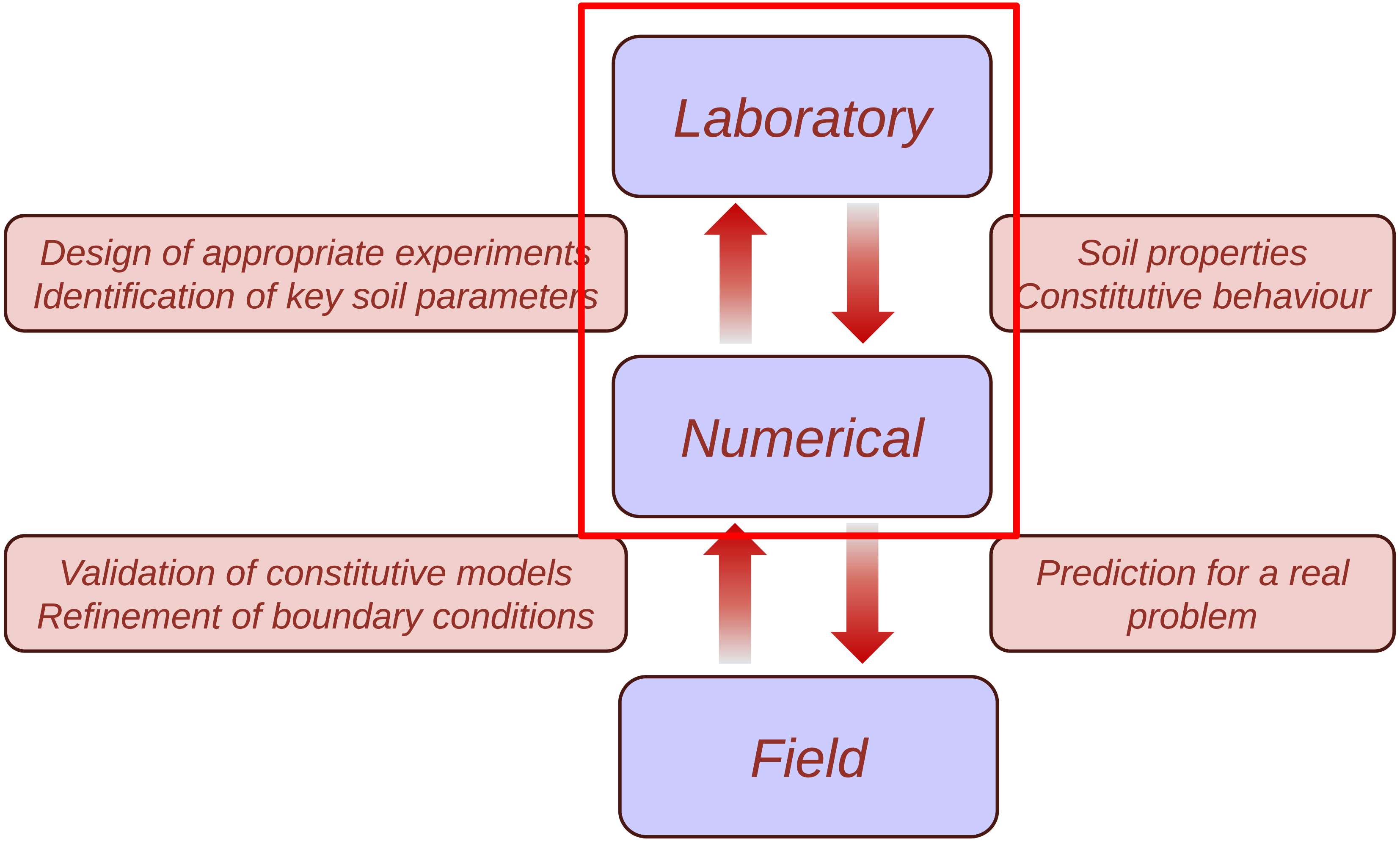


- *Energy systems*
- *Policy*
- *Knowledge transfer/technology deployment*

- *Curricula (UG Civ. Eng. / MSc Soil Mech.)*
- *MEng projects (1 completed)*
- *MSc dissertations (9 completed)*
- *PhD research (4 current)*

- *Computational Geomechanics*
- *Experimental techniques*
- *Field monitoring*

Research Approach



Computational Research

Upgrade of Finite Element Code ICFEP

- *Developed in-house over the last 30 years*
- *Finite Element code for the nonlinear analysis of Geotechnical structures under static or dynamic loads*
- *Hydro-mechanical coupling*
- *Capable of modelling saturated and unsaturated geomaterials*

↓

- *Implementation of heat flow algorithm and THM coupling*
- *Development of thermo-plastic mechanical models for geomaterials*

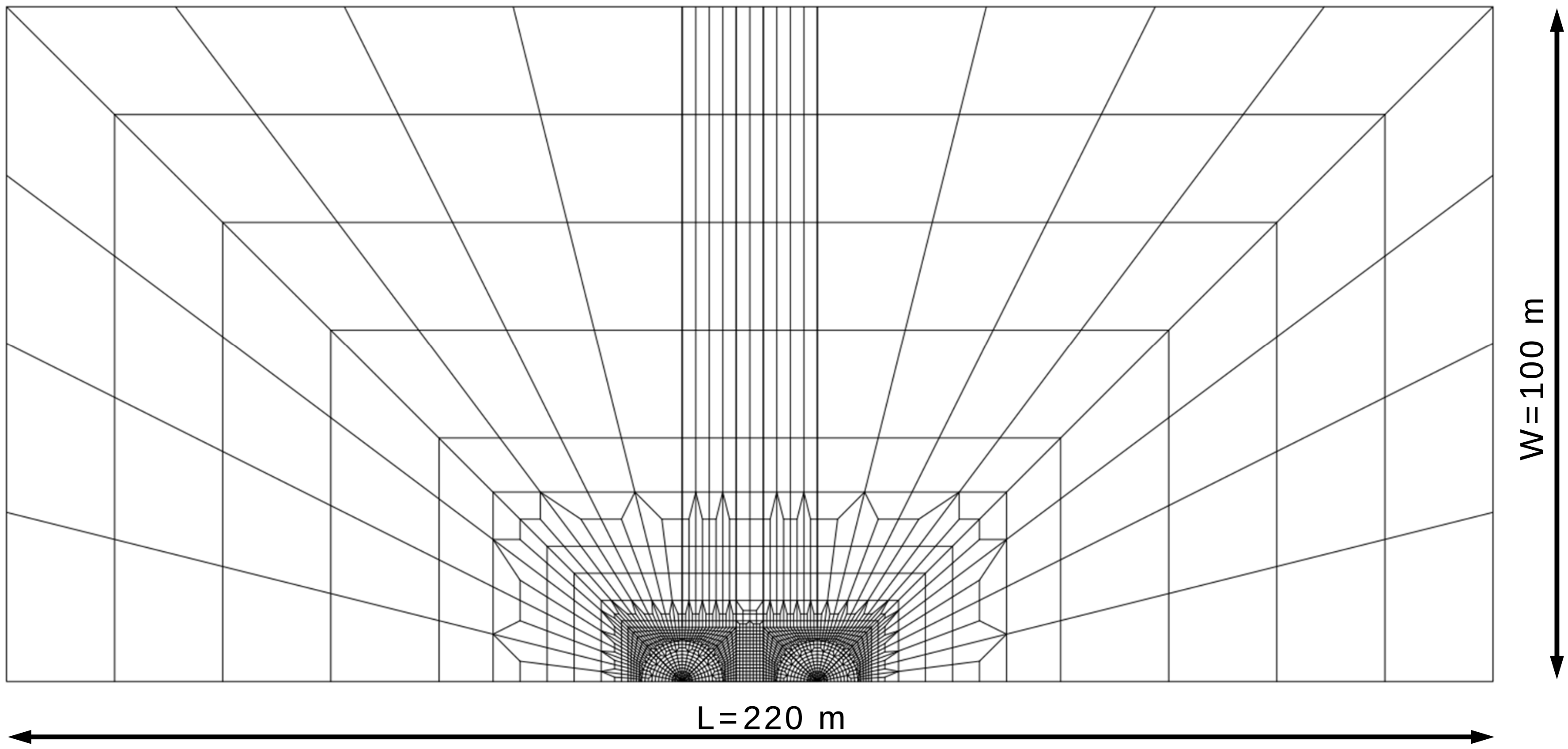
↓

- *Simulation of open loop systems and heat storage schemes*
- *Analysis and design of geotechnical structures under non-isothermal conditions*

Cui (2014); Gawecka (2016)

Simulation of open-loop systems

FE Mesh (1908 elements)



Gawecka (2014); Cui et al. (2015)

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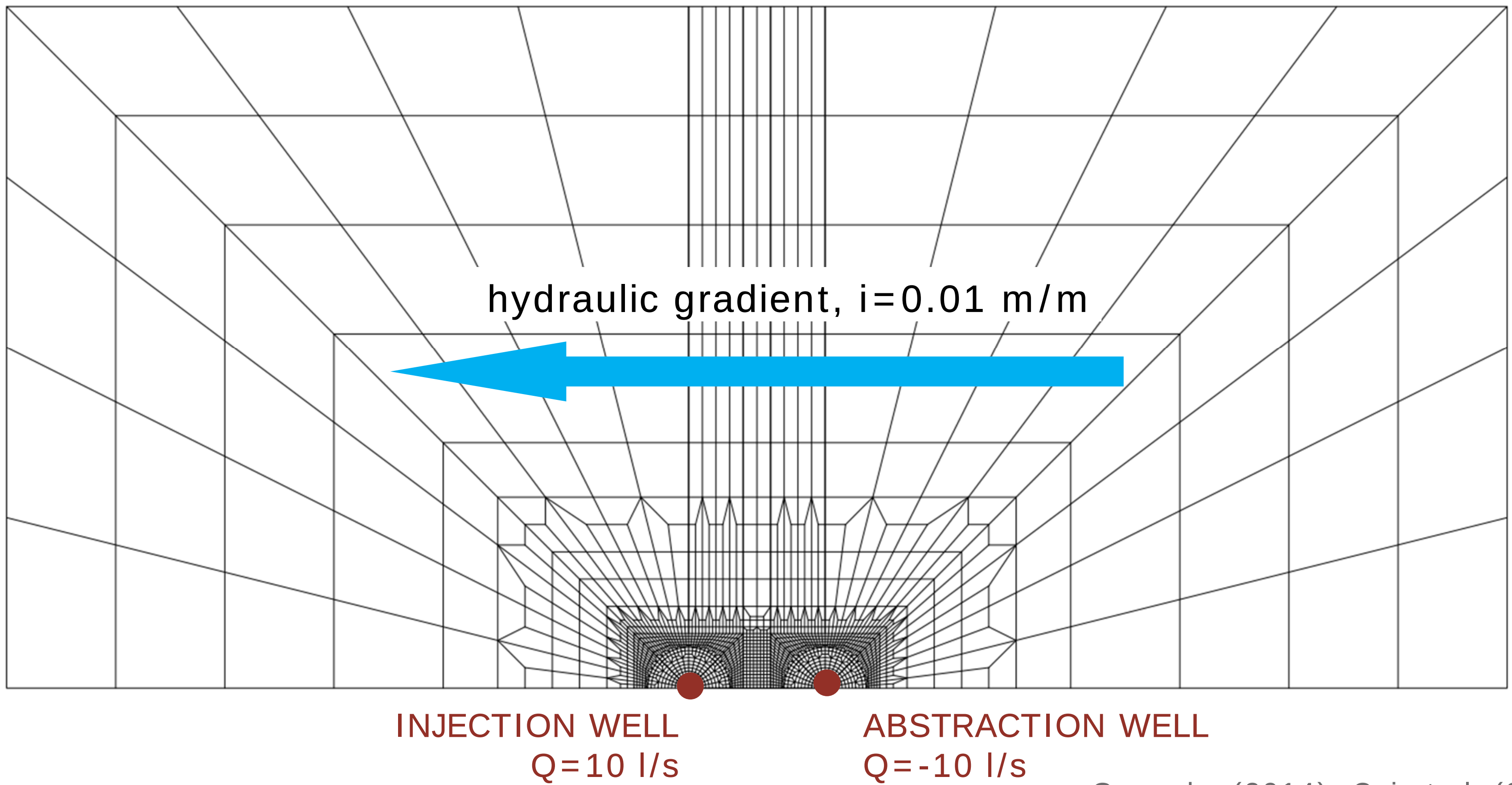
Simulation of open-loop systems

Hydraulic conditions (k = 0.05 m/day)



Gawecka (2014); Cui et al. (2015)

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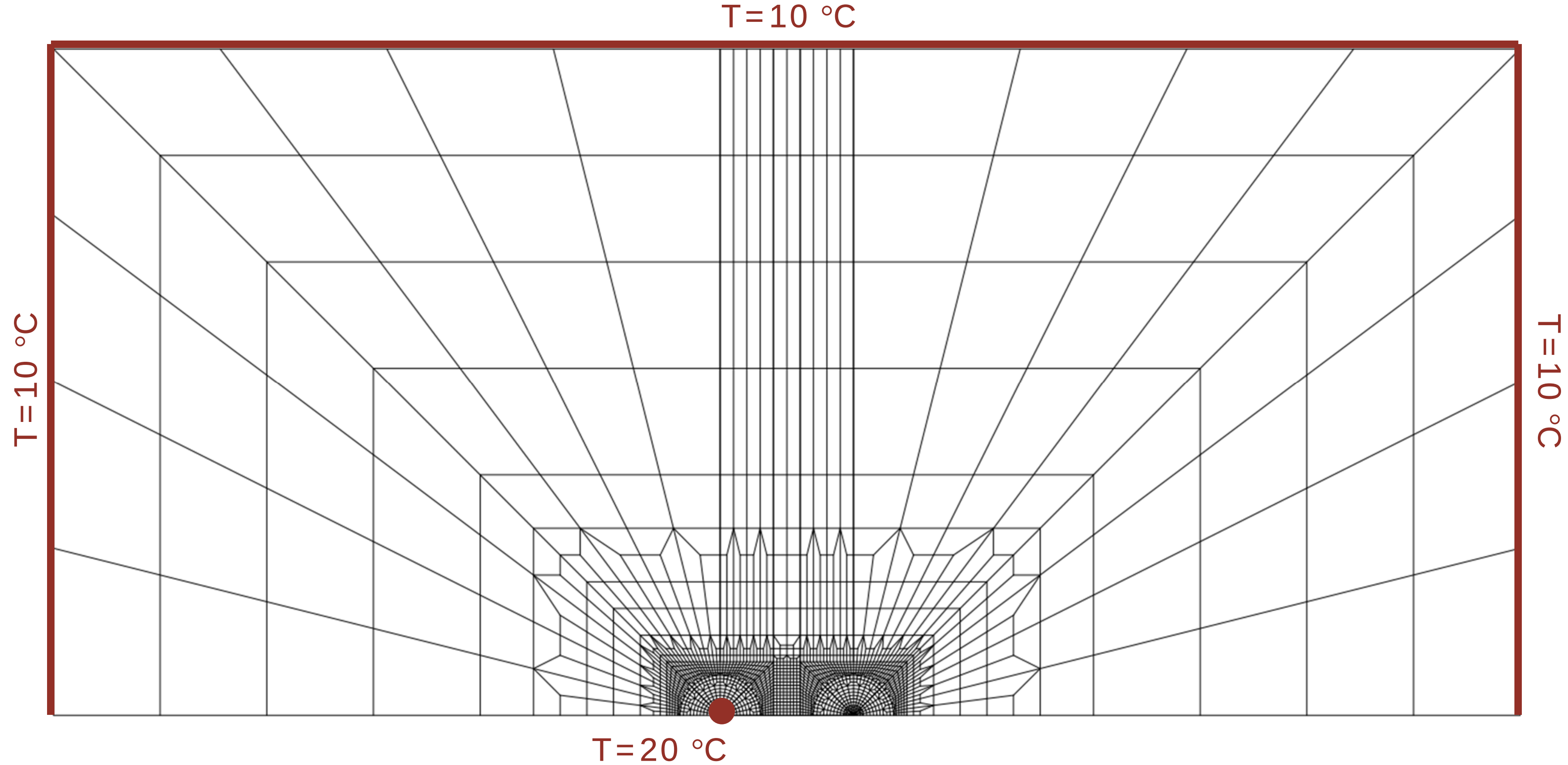
Simulation of open-loop systems

Prescribed temperatures → initial: 10°C; injection: 20°C



Gawecka (2014); Cui et al. (2015)

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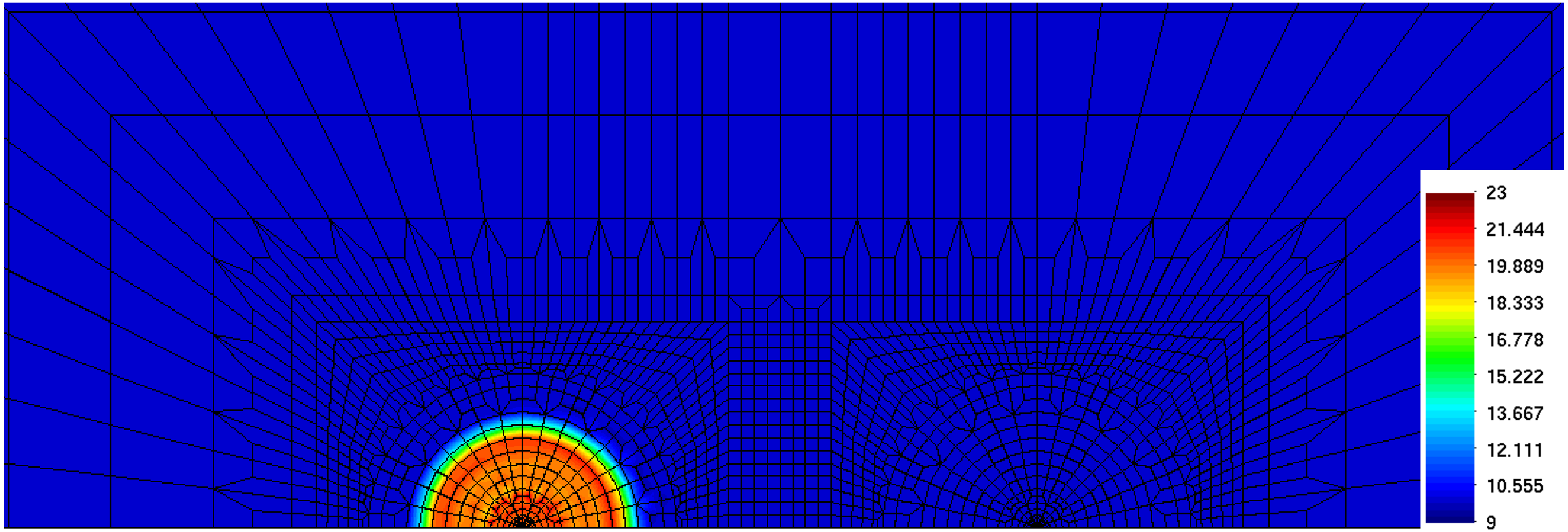
Simulation of open-loop systems

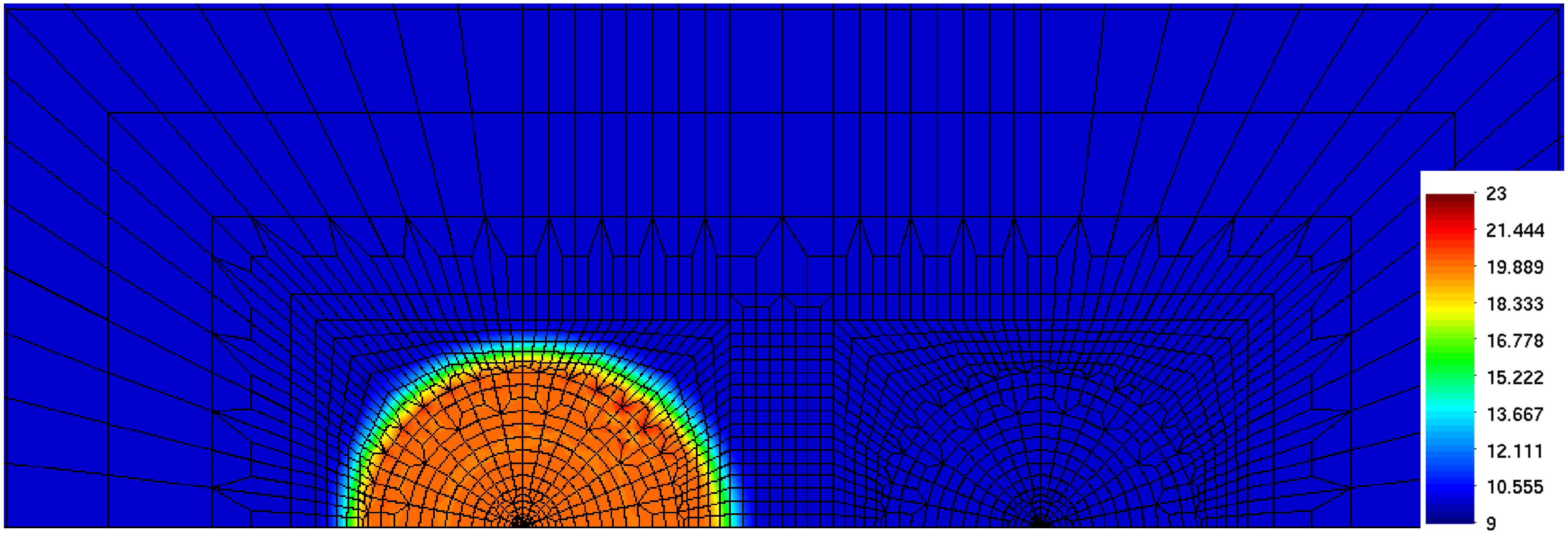
i=0.01 m/m *t=2 days*



Gawecka (2014); Cui et al. (2015)

Simulation of open-loop systems

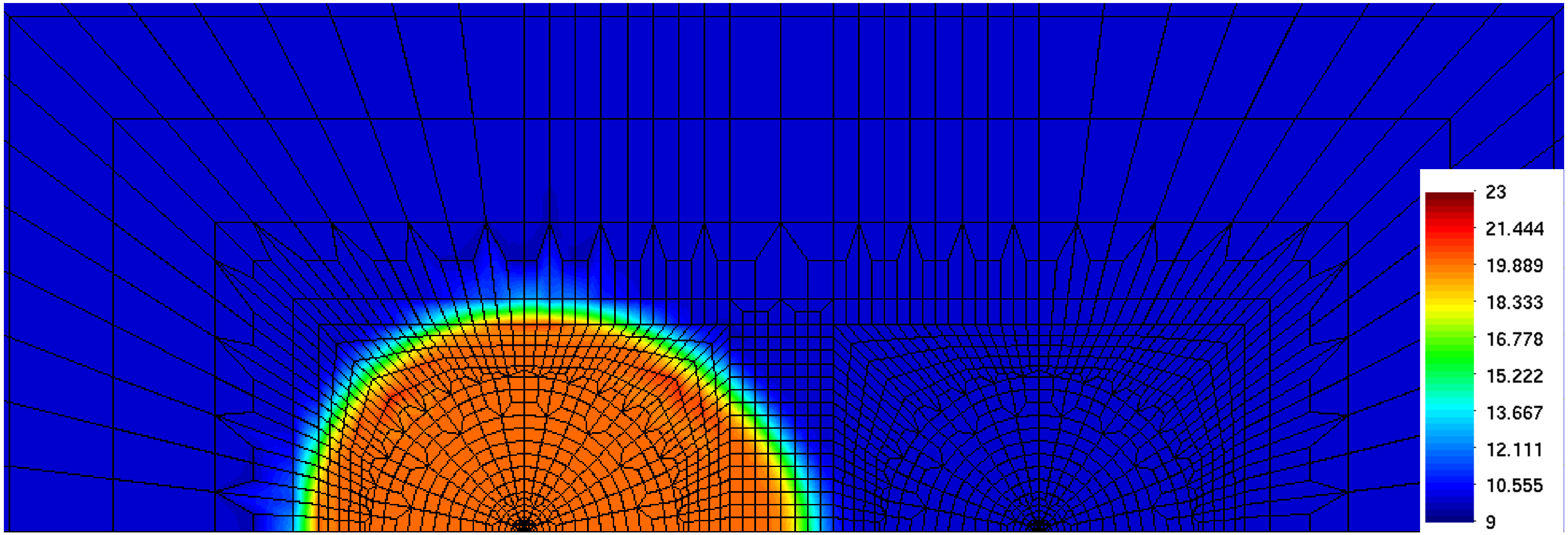
i=0.01 m/m *t=6 days*



Gawecka (2014); Cui et al. (2015)

Simulation of open-loop systems

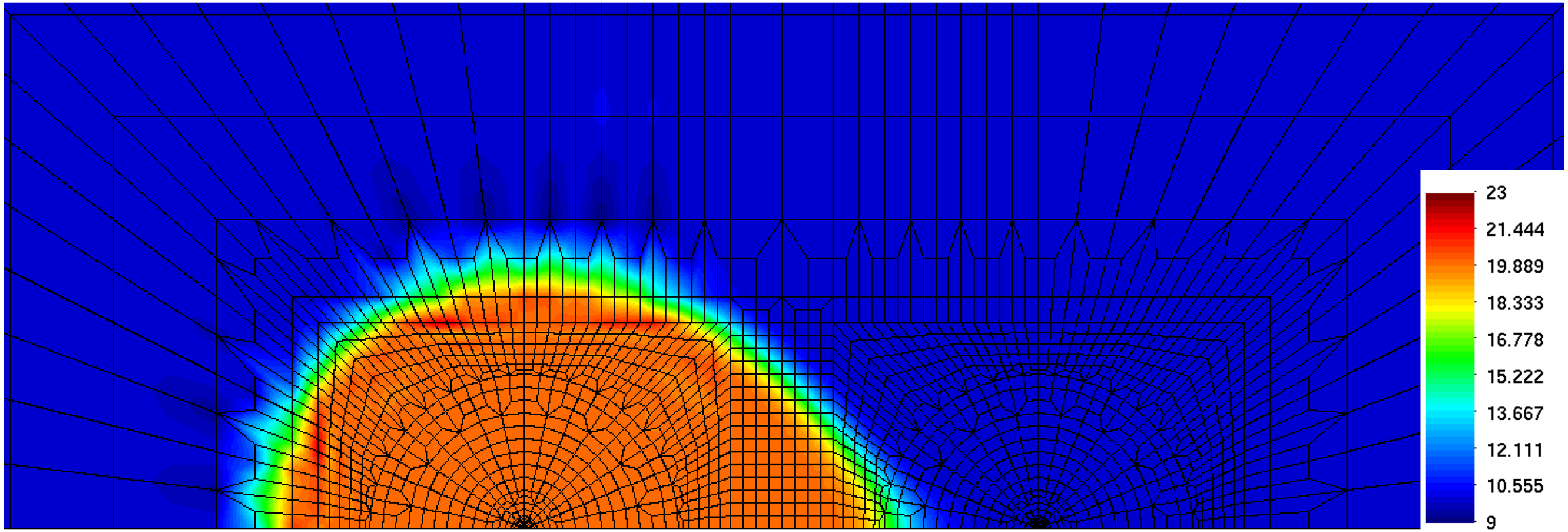
i=0.01 m/m *t=10 days*



Gawecka (2014); Cui et al. (2015)

Simulation of open-loop systems

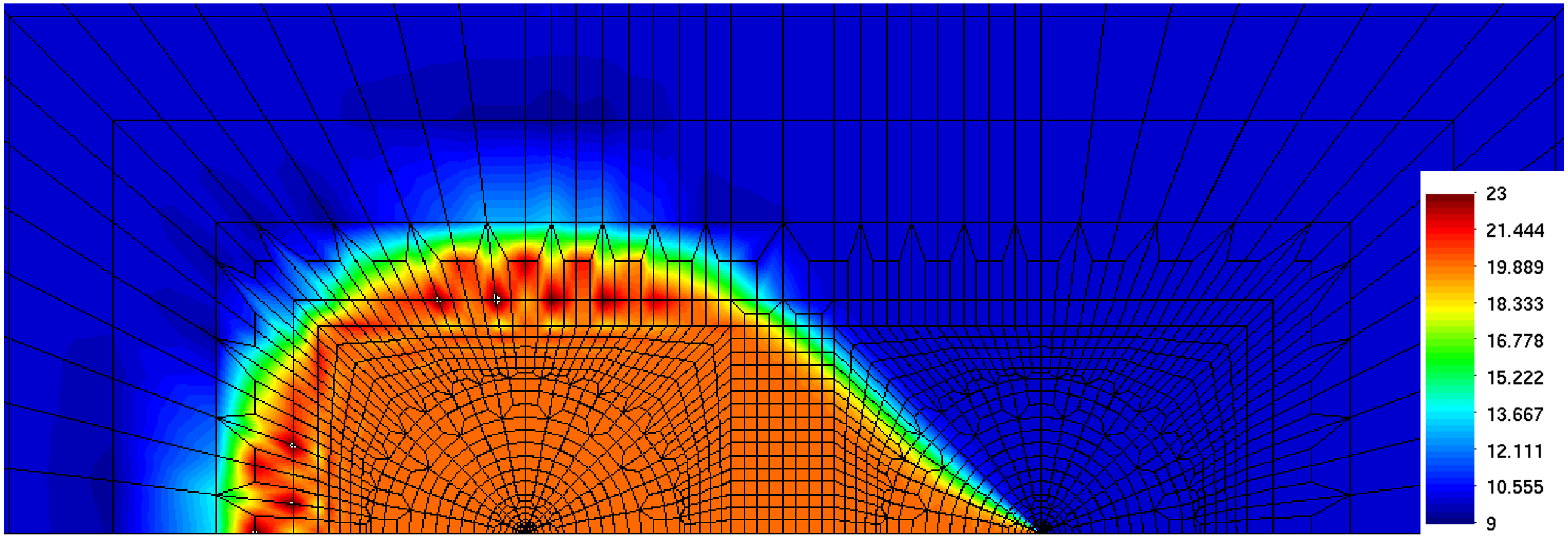
i=0.01 m/m *t=14.5 days*



Gawecka (2014); Cui et al. (2015)

Simulation of open-loop systems

i=0.01 t=21 days



Gawecka (2014); Cui et al. (2015)

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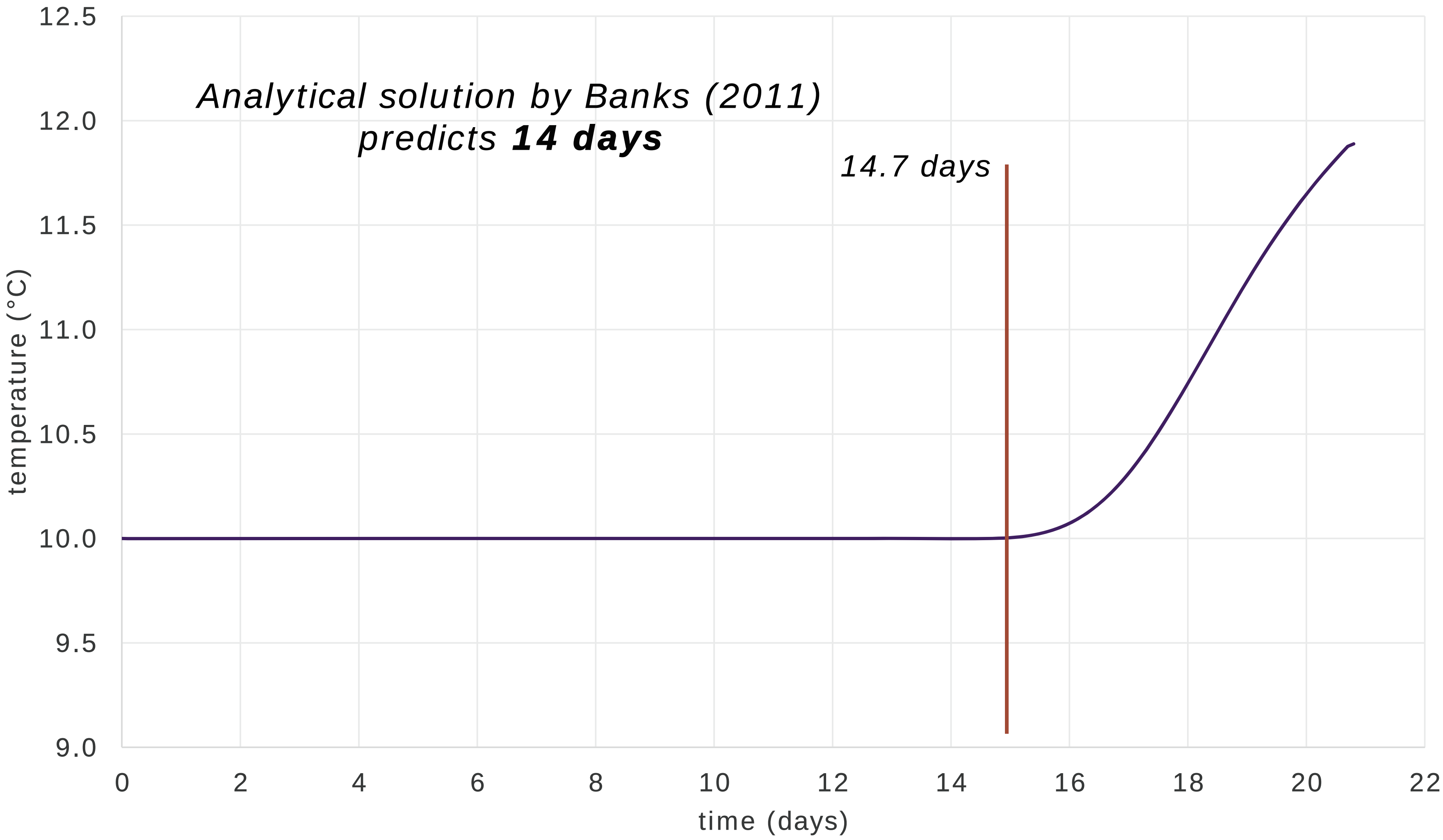
Simulation of open-loop systems



Gawecka (2014); Cui et al. (2015)

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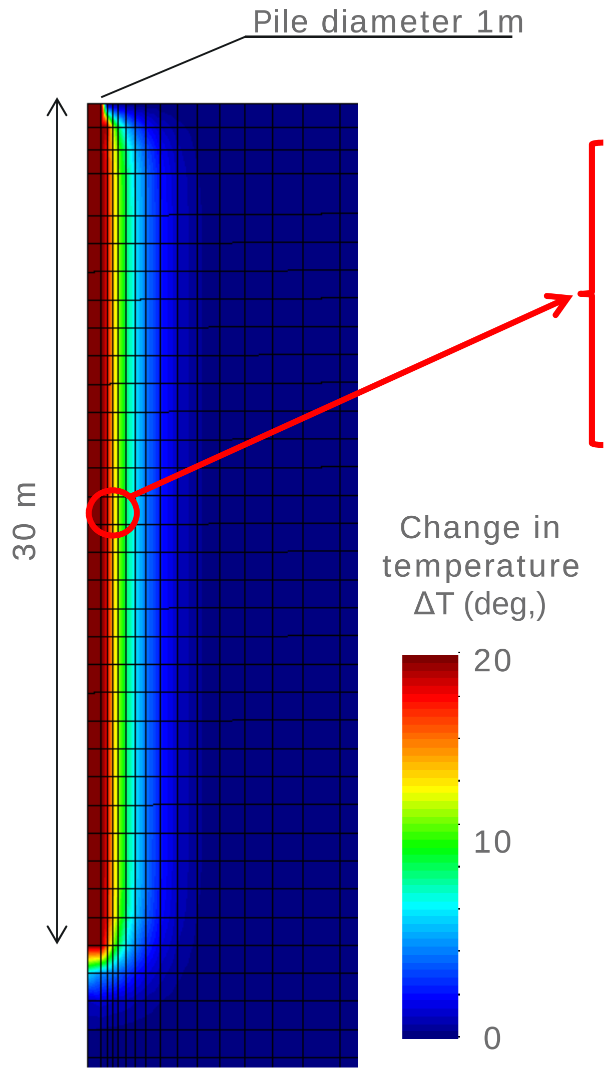
Simulation of thermo-active piles

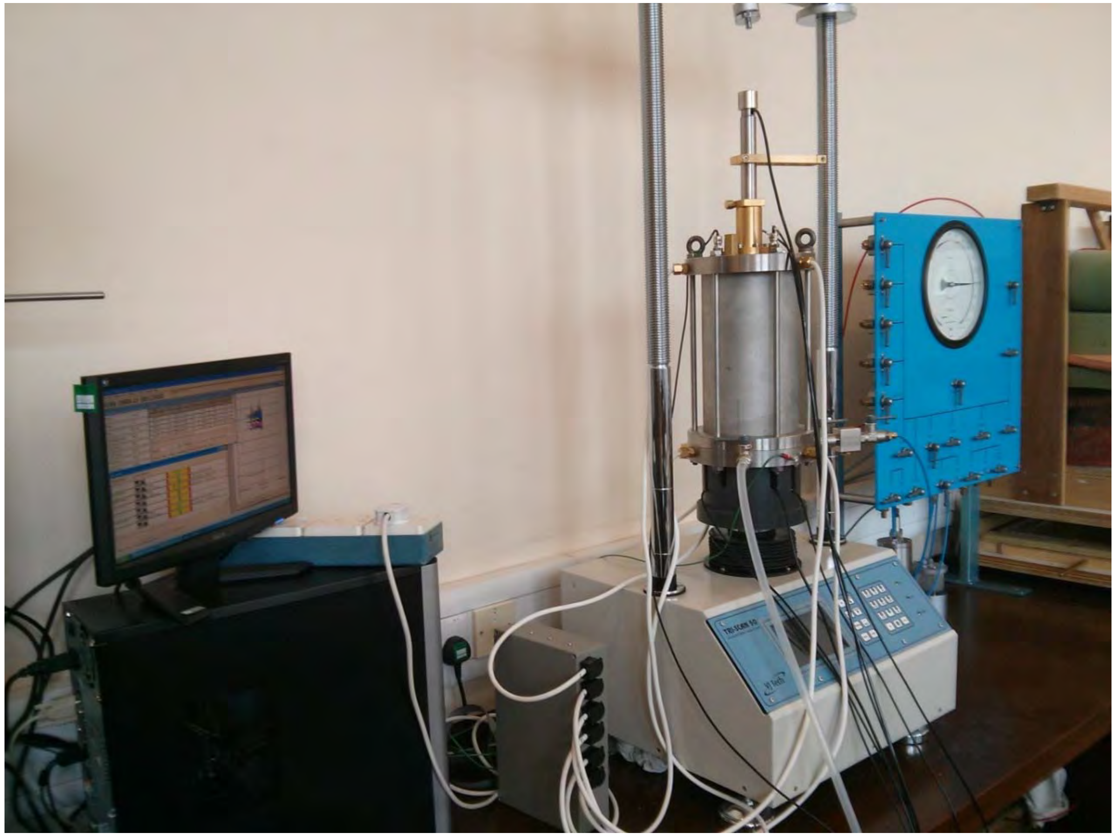


- *Changes in pore water pressure?*
- *Effect on strength?*
- *Effect on stiffness?*
- *Time to reach hydraulic and thermal equilibrium?*

- *Expand the current testing facilities to include temperature control*
- *Acquire and develop experimental techniques for temperature-controlled tests*

Experimental Research

Temperature-controlled triaxial apparatus Mk1



Main characteristics

- *sample diameter – 38 mm or 50 mm*
- *strain-controlled loading*
- *confining pressure up to 800 kPa*
- *heating elements at both extremities of sample*
- *maximum working temperature of 85 deg C*

Calonge Martinez (2013)

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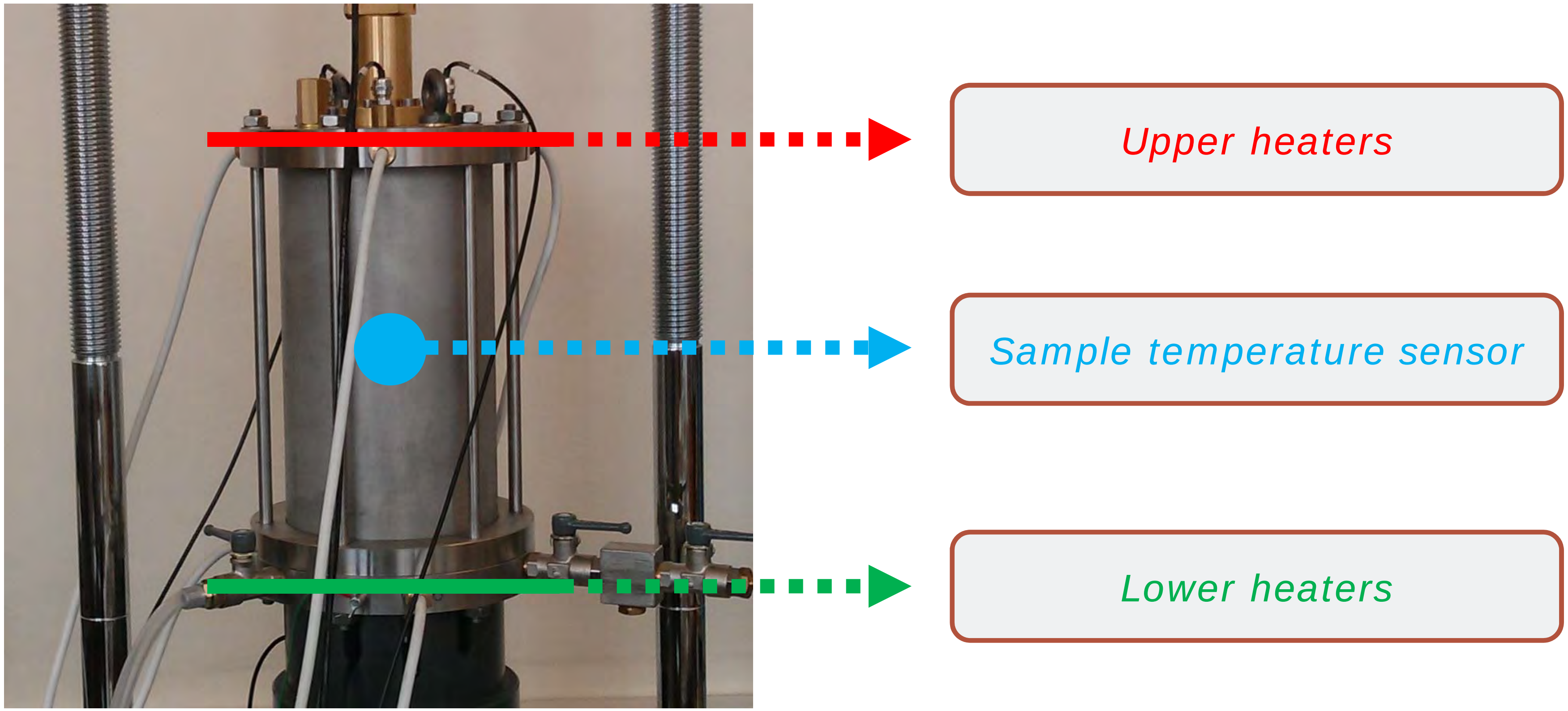
Experimental Research

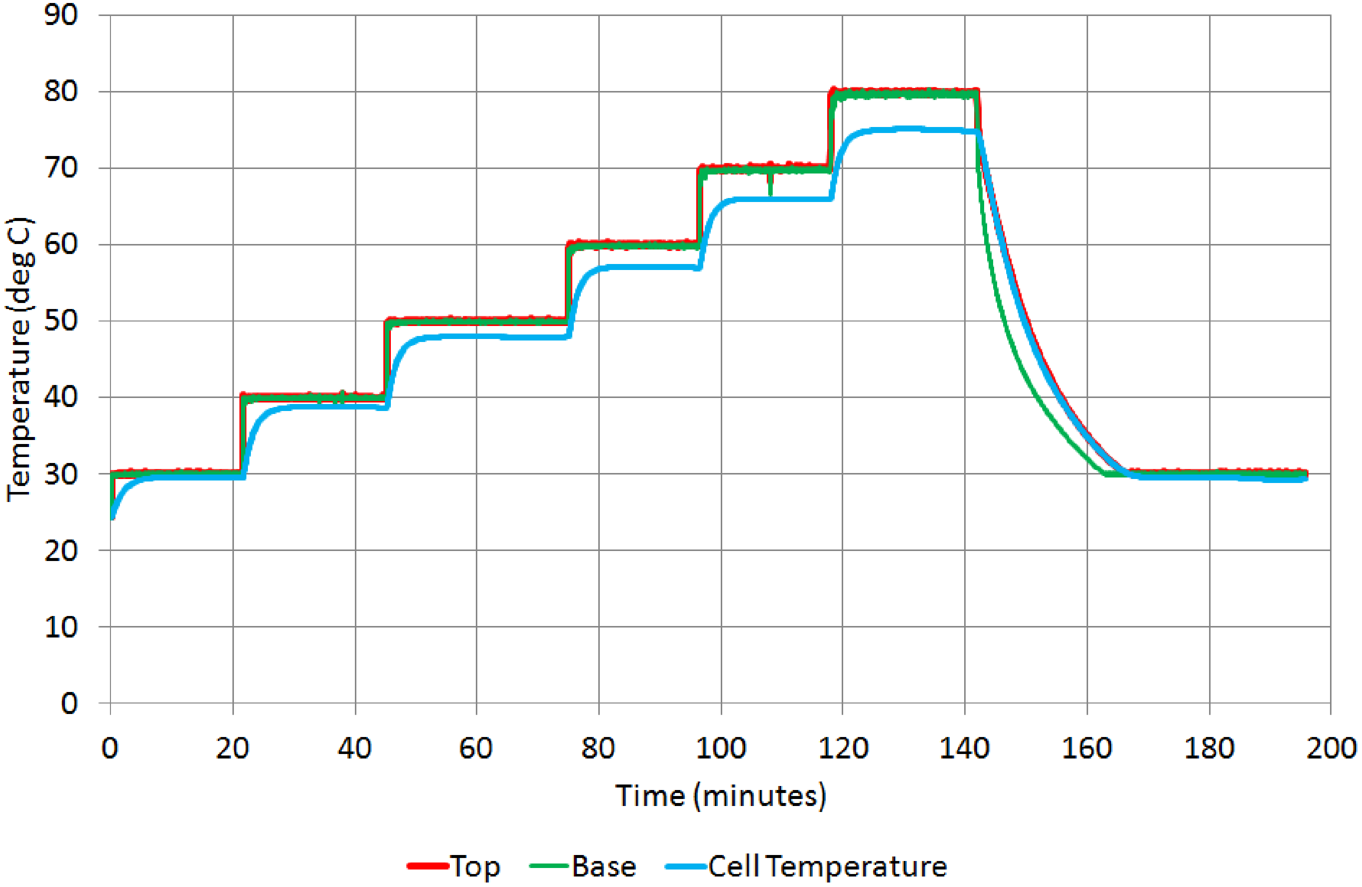
Temperature-controlled triaxial apparatus Mk1



Calonge Martinez (2013)

Experimental Research

Temperature-controlled triaxial apparatus Mk1



Calonge Martinez (2013)

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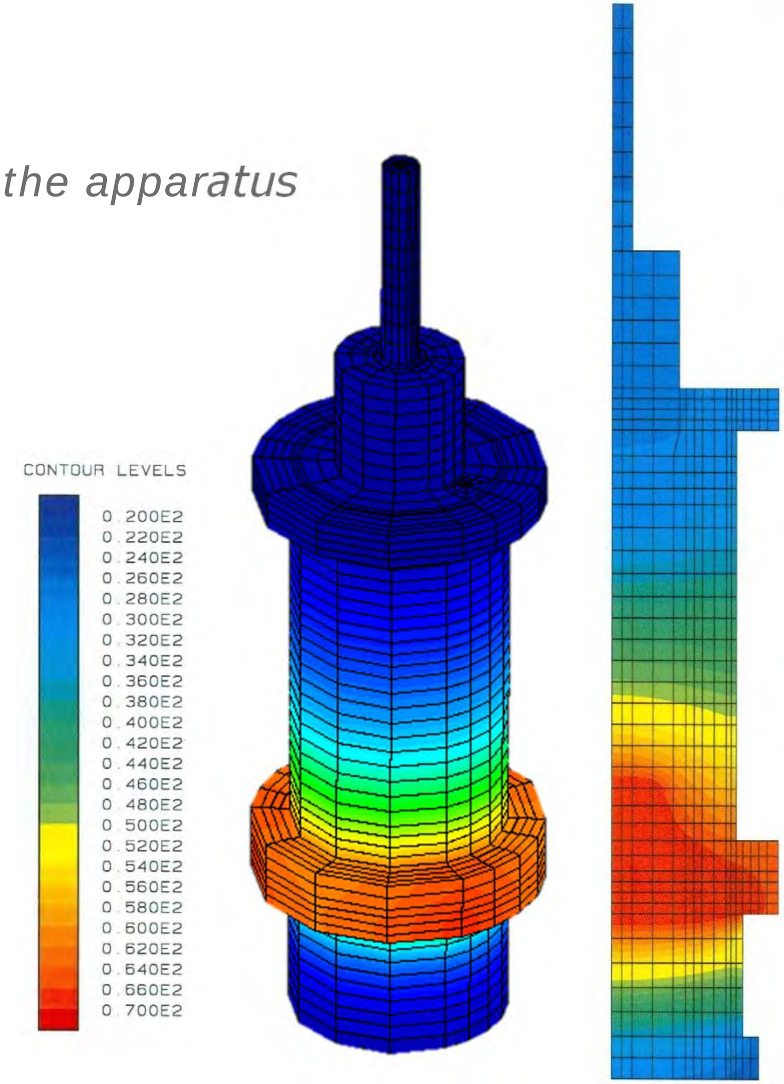
Experimental Research

Finite-element analysis:

- *Understand the thermal performance of the apparatus*
- *2D axisymmetric and 3D analyses*
- *Simulation of convective heat transfer*

$$q = h \cdot (T - T_{\infty})$$

- *Cell filled with air or water*
- *Different tests:*
    - o *Lower heaters only*
    - o *Upper heaters only*
    - o *Both sets of heaters*



Gawecka (2014); Calonge Martinez et al. (2015)

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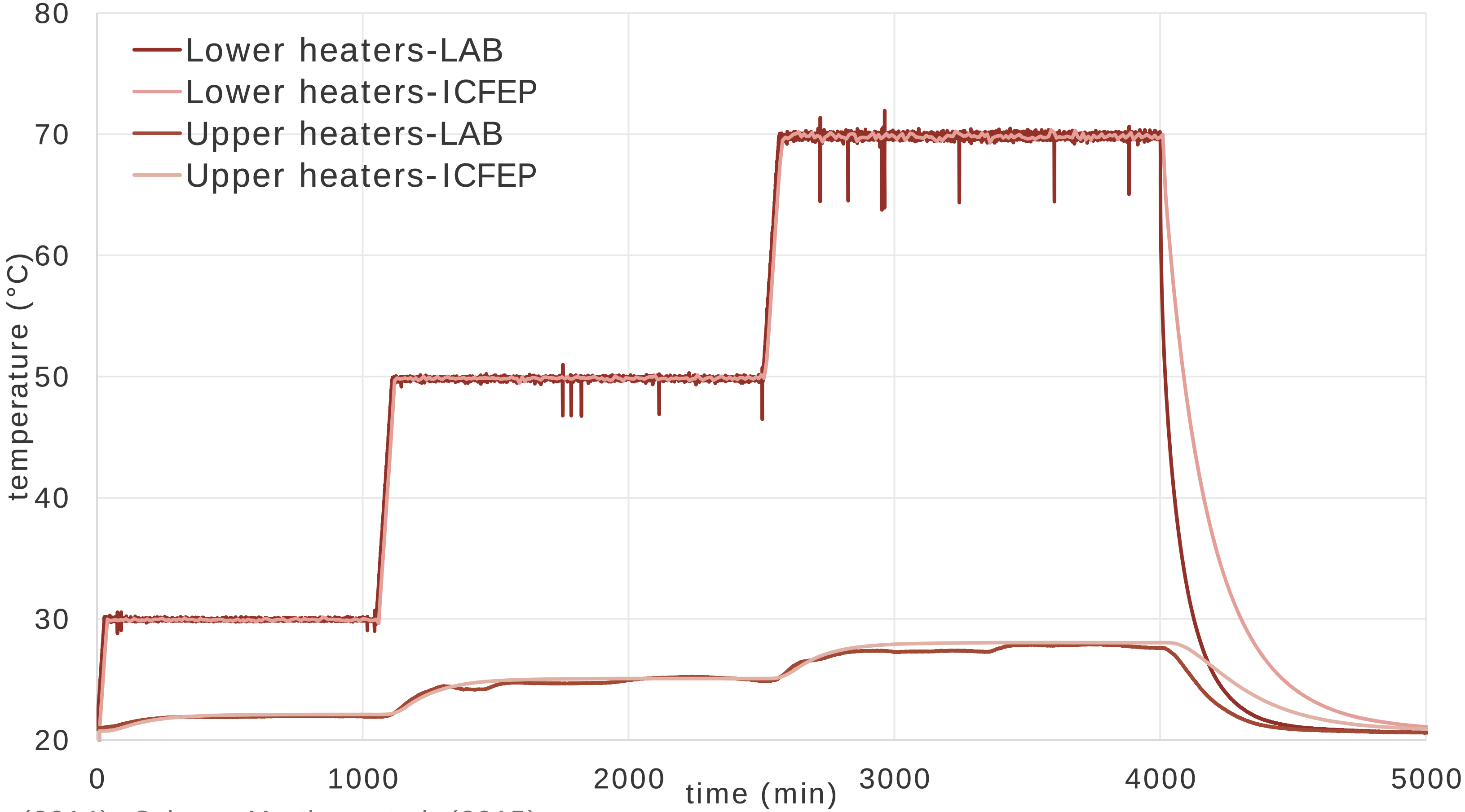
Experimental Research

Simulation of a test with lower heaters only



Gawecka (2014); Calonge Martinez et al. (2015)

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Experimental Research

Laboratory testing and finite-element analysis:

- *Demonstrate the uniformity of temperature within the sample*
- *Three temperature sensors within the samples*
- *Different tests:*
    - *No cell*
    - *Cell filled with air*
    - *Cell filled with water*
    - *Cell filled with water + insulation*
- *Good agreement with FE analyses*
- *Differences between sensors in the sample limited to 0.2 deg C*

Gawecka (2014); Calonge Martinez et al. (2015)

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New Experimental Equipment

Temperature-controlled triaxial apparatus Mk2

Main characteristics

- *sample diameter – 50 mm or 100 mm*
- *strain-controlled loading*
- *confining pressure up to 5 MPa*
- *working temperatures from 5 deg C to 85 deg C*

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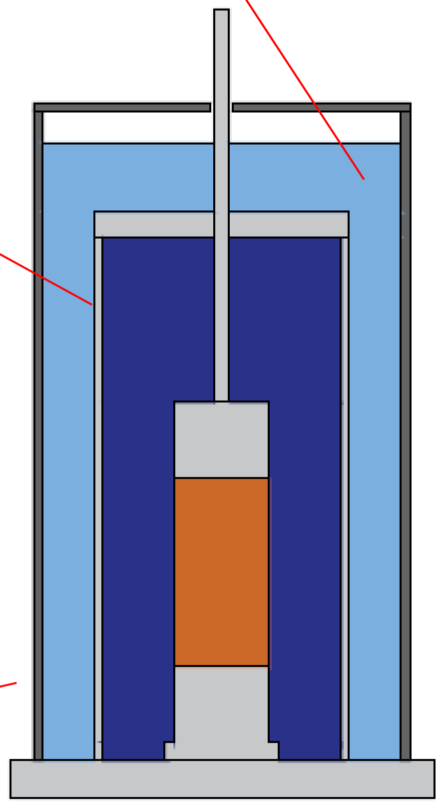
New Experimental Equipment

Temperature-controlled triaxial apparatus Mk2



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New Experimental Equipment

Thermal & Hydraulic conductivity cell

Main characteristics

- *sample diameter – 50 mm or 100 mm*
- *determine thermal conductivity under stresses up to 800 kPa*
  - *divided-bar configuration (two materials)*
  - *thermal flux sensor*
- *determine hydraulic conductivity under temperatures between 5 deg C and 85 deg C and stresses up to 5 MPa*

Three possible configurations for the apparatus

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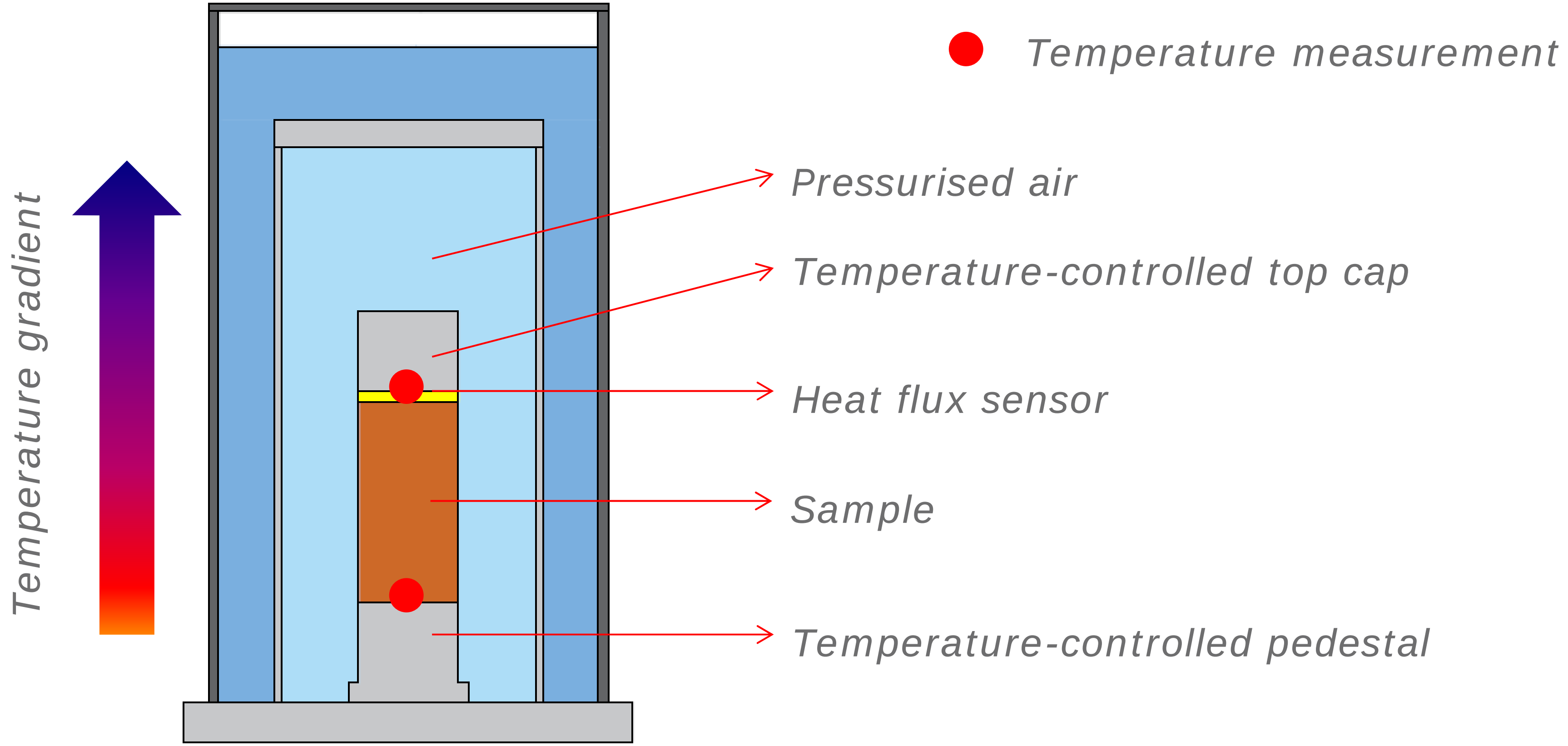
New Experimental Equipment

Thermal & Hydraulic conductivity cell

Configuration I – Thermal conductivity with heat flux sensor



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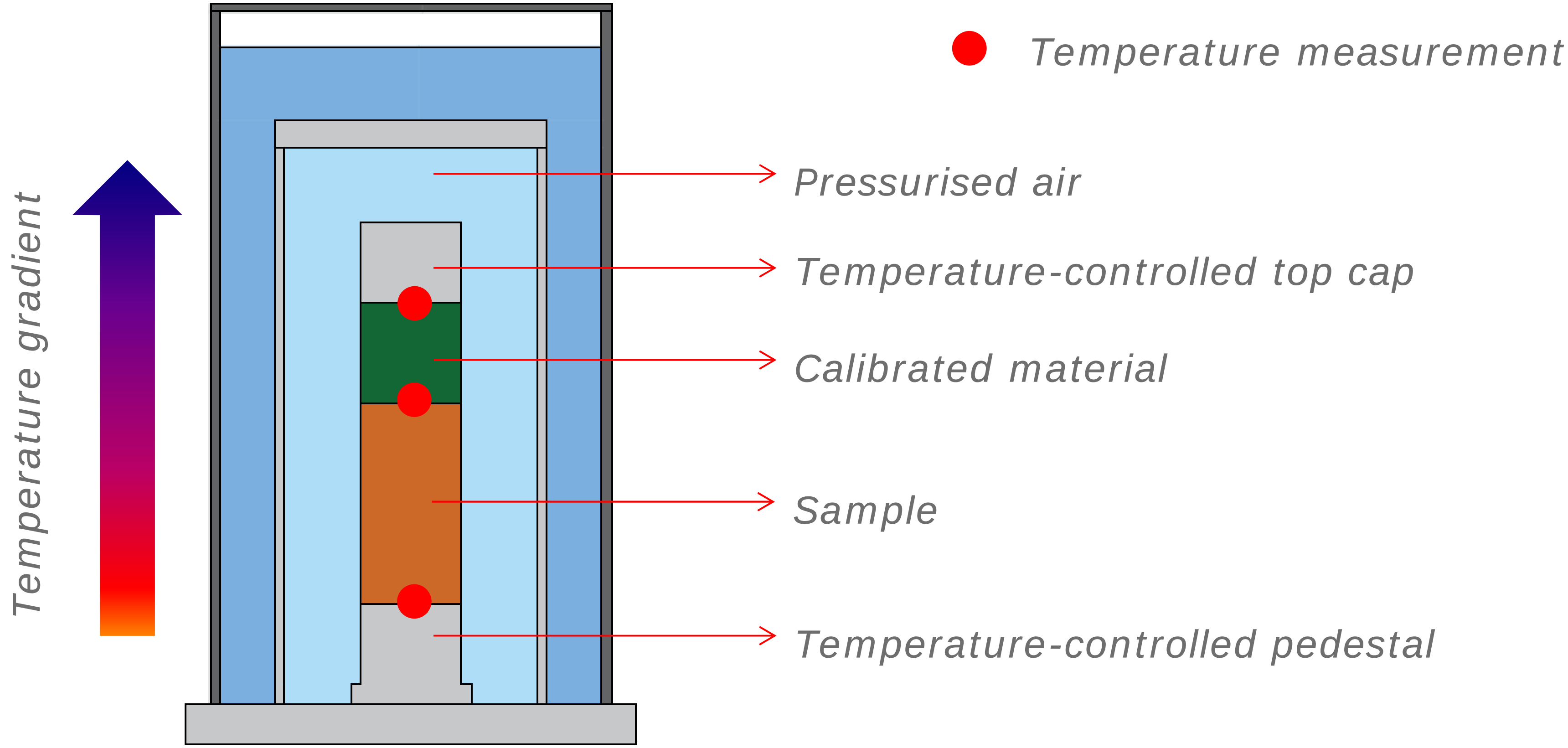
New Experimental Equipment

Thermal & Hydraulic conductivity cell

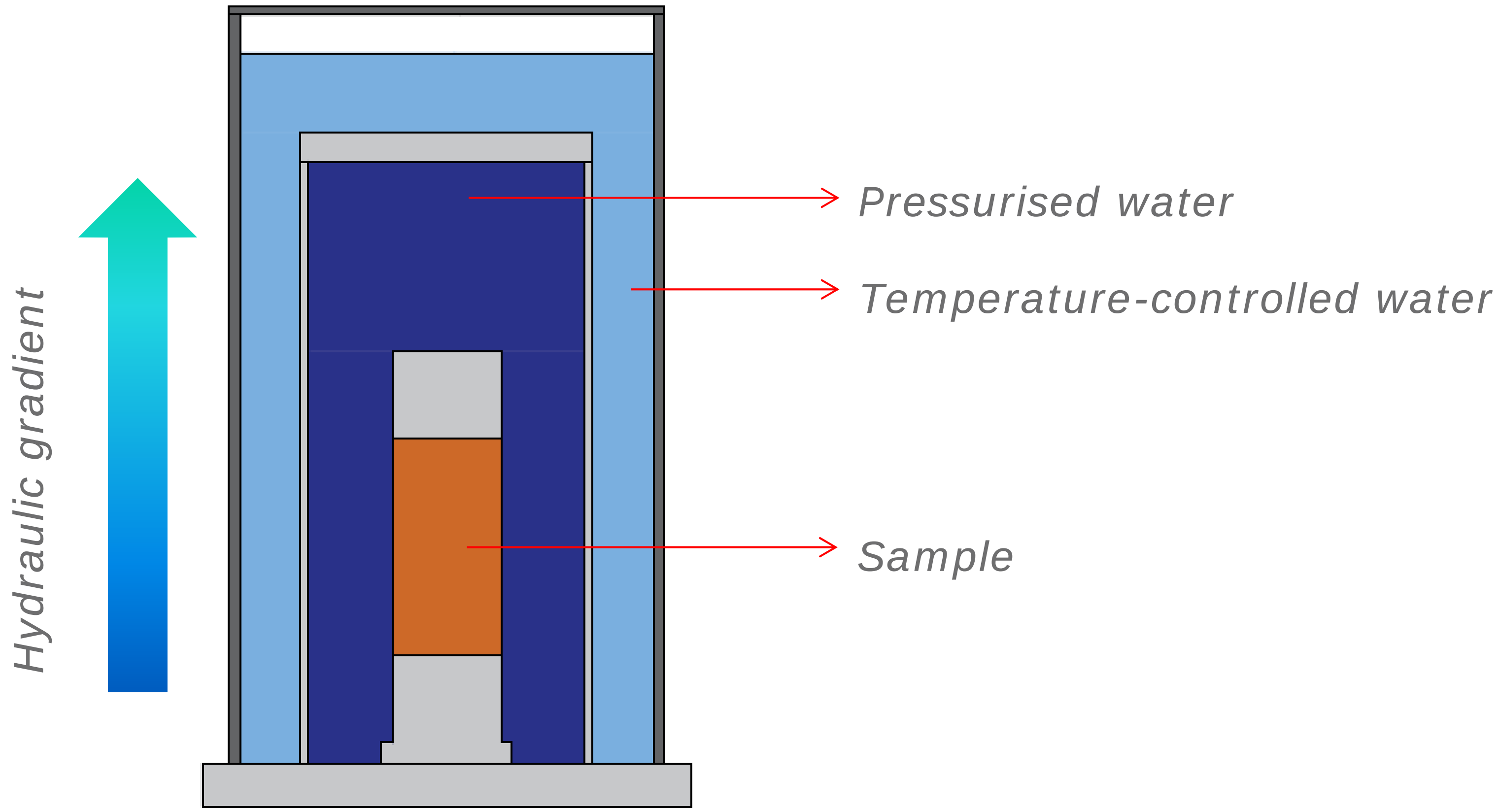
Configuration II – Thermal conductivity with additional material



New Experimental Equipment

Thermal & Hydraulic conductivity cell

Configuration III – Hydraulic conductivity

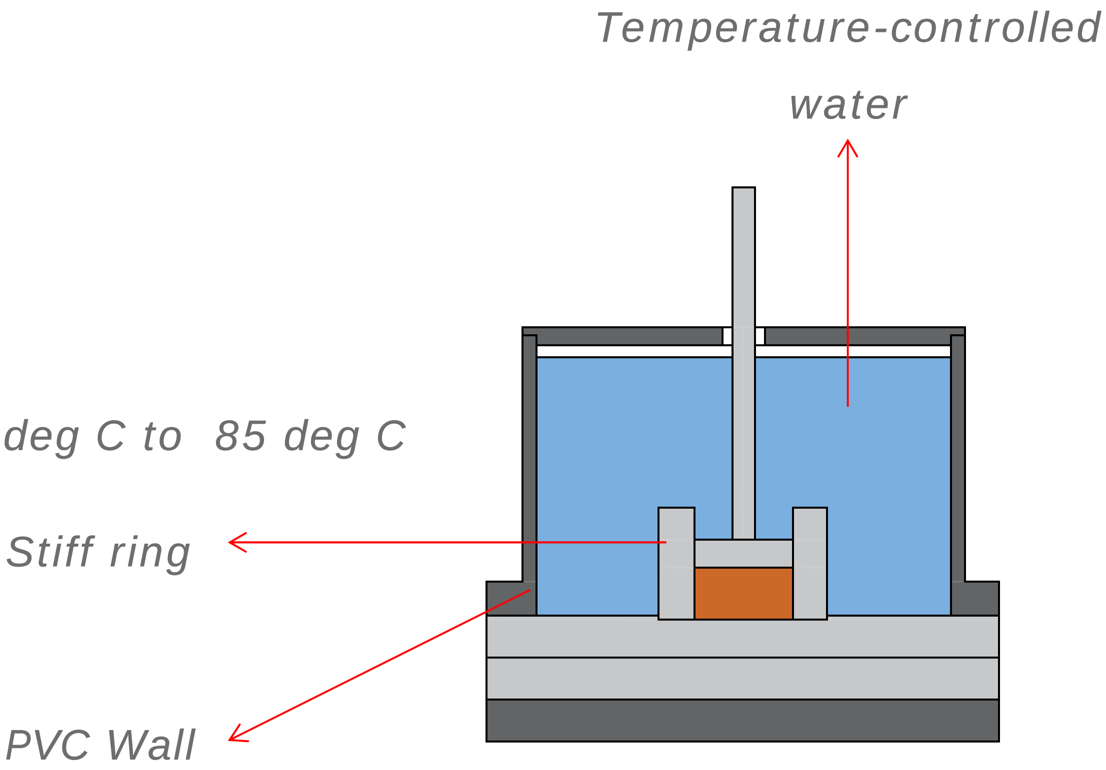


New Experimental Equipment

Temperature-controlled oedometer

Main characteristics

- *sample diameter – 70 mm*
- *strain-controlled loading*
- *working temperatures from 5 deg C to 85 deg C*



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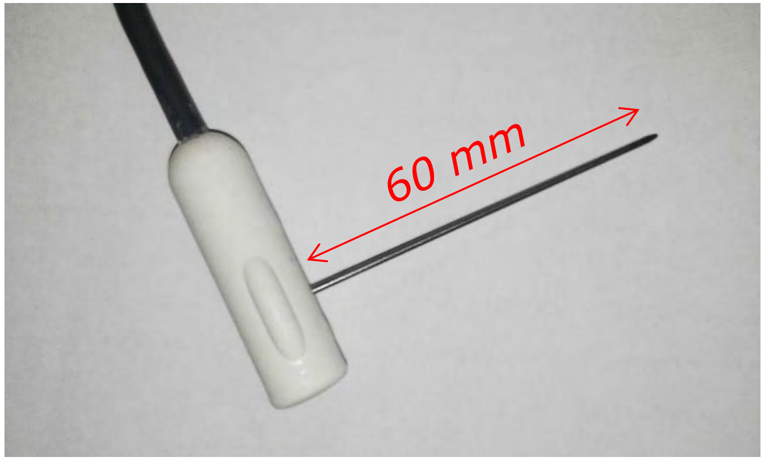
New Experimental Equipment

Direct measurements of thermal conductivity & heat capacity

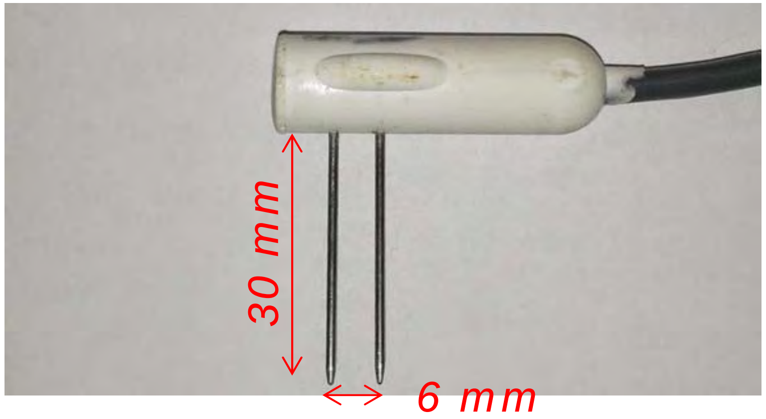


Thermal conductivity sensor

(manufactured by East 30 Sensors)

Thermal conductivity & heat capacity sensor

(manufactured by East 30 Sensors)



Summary & Conclusions

- Integrated approach to research on ground source energy systems with experimental characterisation, computational modelling and field work
- Numerical code ICFEP upgraded to deal with Thermo-Hydro-Mechanical problems (e.g. open-loops, thermo-active piles)
- Experimental facilities include two temperature-controlled triaxial apparatuses, one conductivity cell and one oedometer
- Design of experimental equipment based on FE simulations

Thermal testing of soils

Recent developments at Imperial College

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