Numerical simulation of the temperature and stress field in the rock heating experiment

P. Rálek[1],M. Hokr[1]

[1]Technical University of Liberec, Liberec, Czech Republic

petr.ralek@tul.cz , milan.hokr@tul.cz

COMSOL CONFERENCE EUROPE 2012

Introduction

The presented work is motivated by preparation and calibration of rock heating experiment in underground, for testing the rock properties for geothermal application, particularly cyclic energy storage [1, 2]. The experiment is placed at the Underground Educational Facility Josef in Central Bohemia [3] and adapts the concept of former experiments like [4, 5] to local conditions and particular application. The objective of the work was to predict the distribution and range of temperature and induced mechanical stresses in the area close to the heater. The results served for calibration of mechanical and temperature sensors, placed in several testing boreholes (Fig. 2).

Experiment

- water pipe heater installed in a horizontal borehole (diameter 86cm) placed at the tunnel heading (Fig. 1),
- heater is fixed to the rock face with the geopolymer and the rest of the borehole is filled by the isolation material; temperature is 90 °C
- surroundings of the borehole is covered by the small boreholes with sensors (temperature, deformation, pressure), Fig. 2.

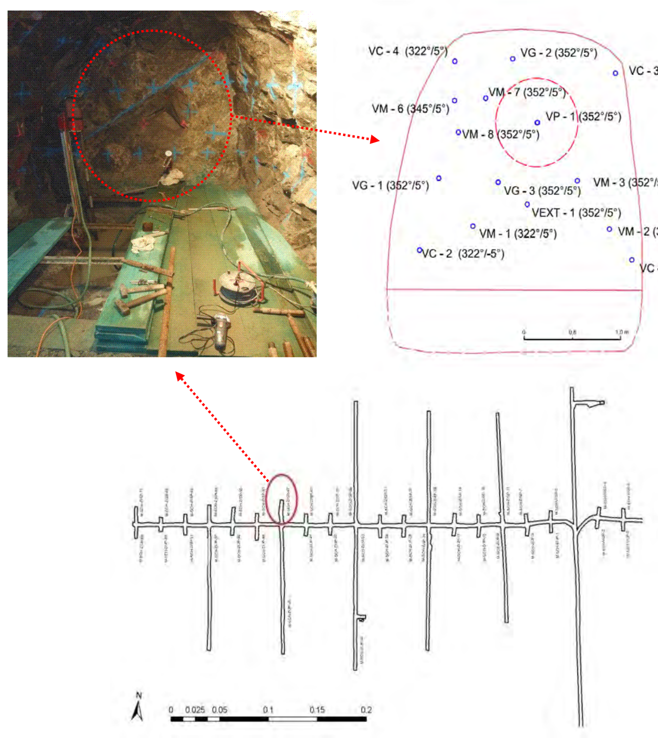


Figure 1: Location of the experiment and situation in the tunnel before the start of drilling.

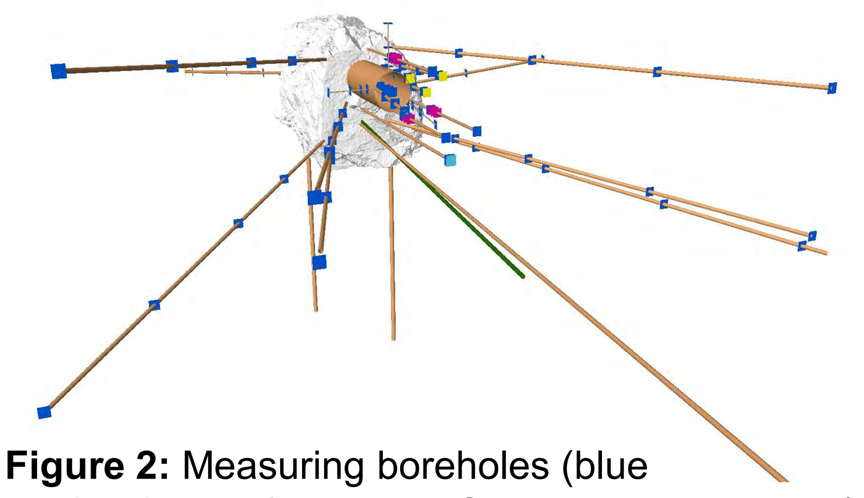


Figure 2: Measuring boreholes (blue marks shows placement of temperature sensors).

Model geometry

The geometry of the model was made by simplification of the laser scanning of the tunnel (Fig. 3). We included only several measuring boreholes into the geometry. One part of the borehole consists of isolation and water pipe, second part consists of inner isolation, heater body and geopolymer layer (Fig. 4).

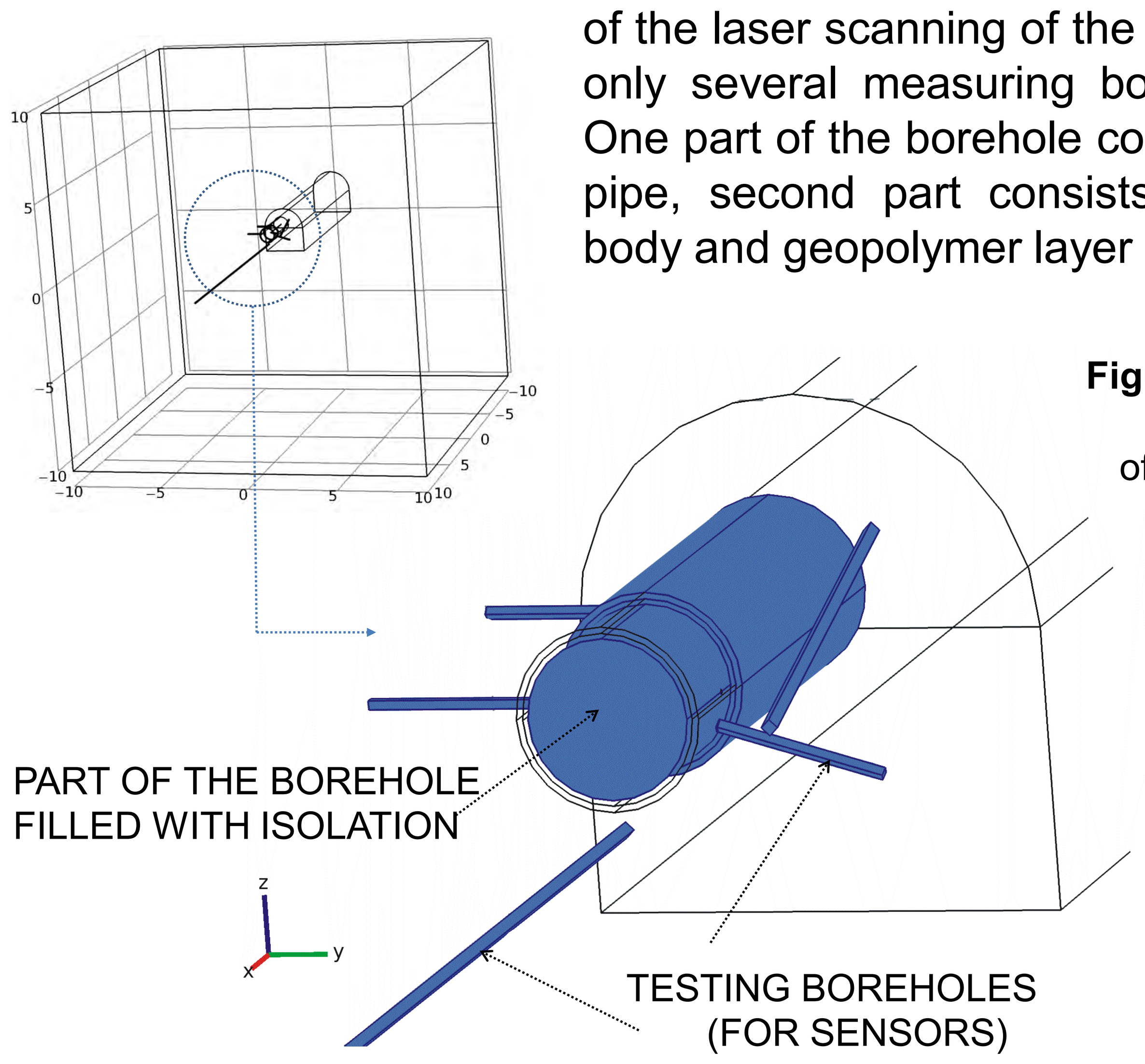


Figure 3: Geometry of the whole modeled domain and detail of the tunnel with the borehole.

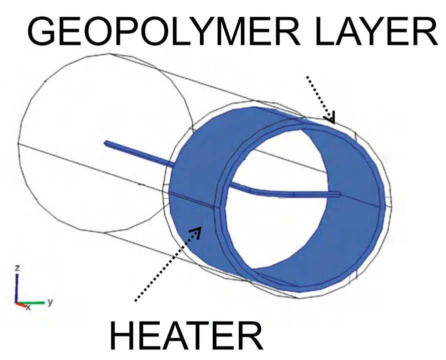


Figure 4: Detail of the borehole with heater body.

Physical description

- unsteady heat conduction in solid with thermoelasticity

$$\rho C_p \frac{\partial T}{\partial t} + T\frac{\partial}{\partial t}S_{elast} = \nabla\cdot(k\nabla T) + Q_h$$

- convective cooling at the boundaries of the tunnel

$$\mathbf{n}\cdot(k\nabla T) = h_x(T_1 - T) \quad on\ \partial\Omega_x$$

- stable temperature on the outer boundary

$$T = T_0 \quad on\ \partial\Omega_D$$

Numerical solution – Heat Transfer Module & Solid Mechanics

- heat transfer in solids in different parts: granite masiff, isolated part of the borehole, water pipe heater, testing boreholes,
- convective cooling at the head tunnel and remaining sides of the tunnel,
- consequent linear elastic material model for computing the induced mechanical stresses and deformations

Visualization

- slices in 3D
- line graphs along testing boreholes (Fig. 5)

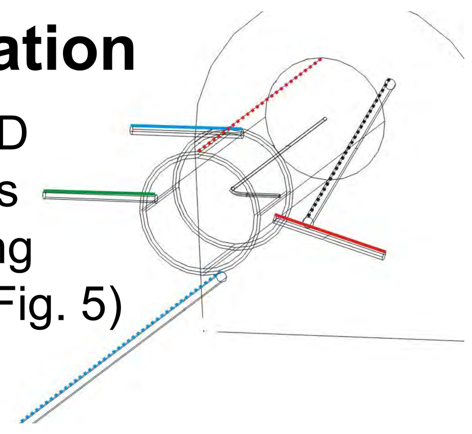


Figure 5: Lines for visualization. Colors respond to the graphs.

Figure 6: Distribution of the temperature field [K].

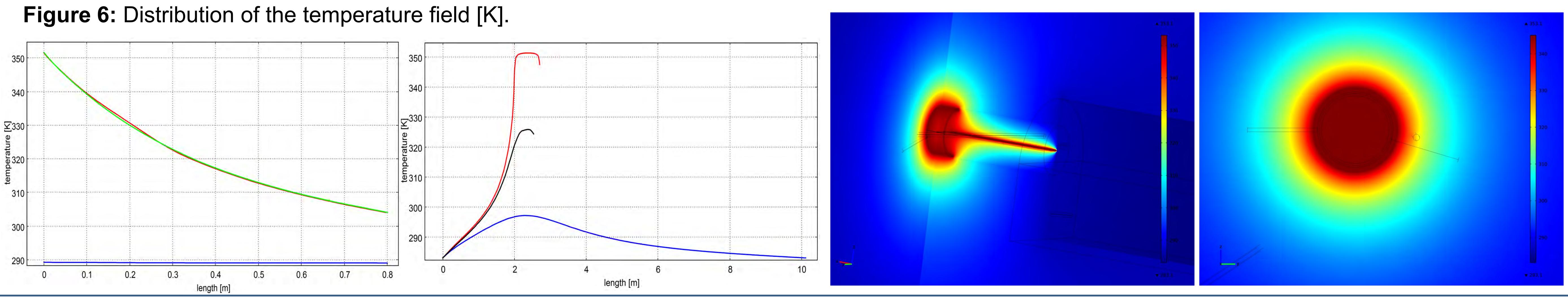


Figure 7: Distribution of the pressure field [Pa].

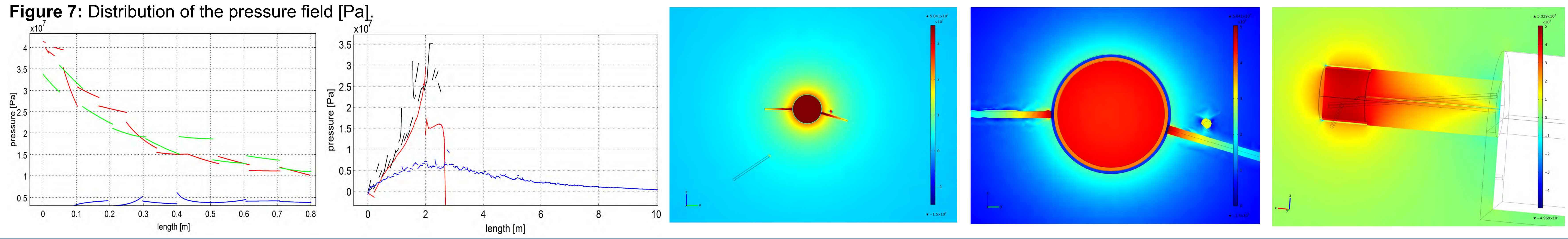
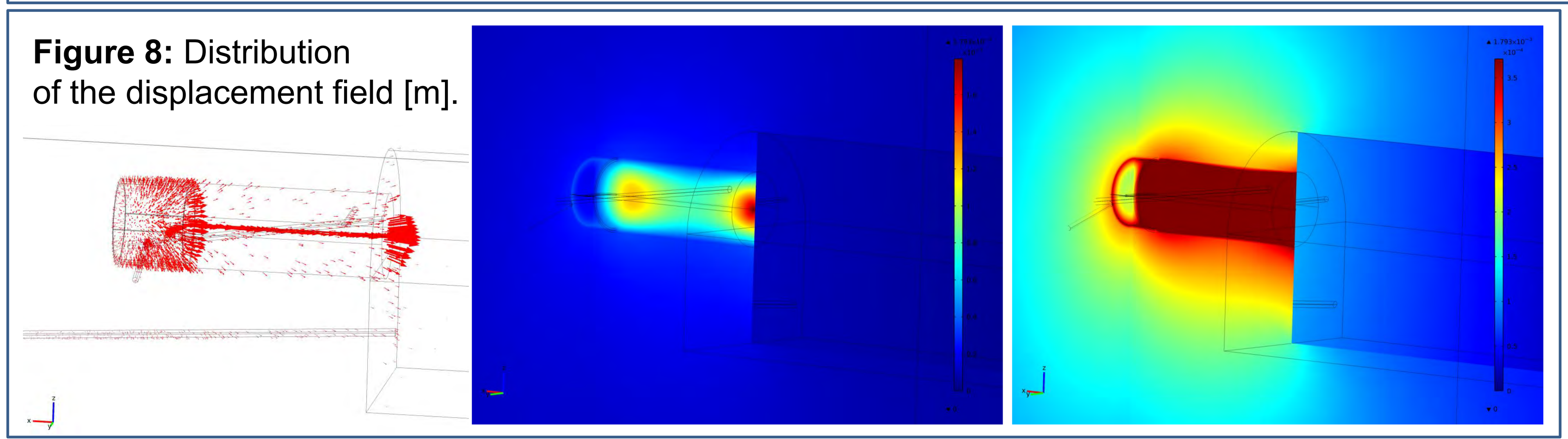


Figure 8: Distribution of the displacement field [m].



Conclusion

The results describe well the range of temperature and pressure in the area close to the borehole, where the sensors will be installed (Fig. 6-7).
Temperature, in 1m surroundings, decreases from 90°C to about 30°C. The heat-induced stress has complicated shape very near the heater body and testing boreholes, but it depends mainly on the properties of the rock. Pressure, in 1m surroundings, decreases from 50 MPa to about 7MPa (we chose to display the pressure instead of stress field due to its simplicity).
The general shape of the temperature and stress field outside the borehole is influenced primarily by properties of the rock.

References: 1. H. Hokmark, B. Falth, Thermal dimensioning of the deep repository. Influence of canister spacing, canister power, rock thermal properties and nearfield design on the maximum canister surface temperature, *SKB report*, **TR-03-09** (2003)

2. H.F Zhang, X.S. Ge, H. Ye, Modeling of a space heating and cooling system with seasonal energy storage, *Energy*, **32**, p. 51–58 (2007)

3. The JOSEF Underground Laboratory, Czech Technical University, http://www.uef-josef.eu (2011)

4. E. Detournay, T. Senjuntichai, I. Berchenko, An in situ thermo–hydraulic experiment in a saturated granite II: analysis and parameter estimation, *Int. J. Rock Mech. Min. Sci.*, **41**, p. 1395–1411 (2004)

Acknowlegment: This work was realized under the state subsidy of the Czech Republic within the research project FR-TI3/325 supported by Ministry of Industry and Trade.