Simulation of Freeze-Thaw-Cycles in BHE Grouts

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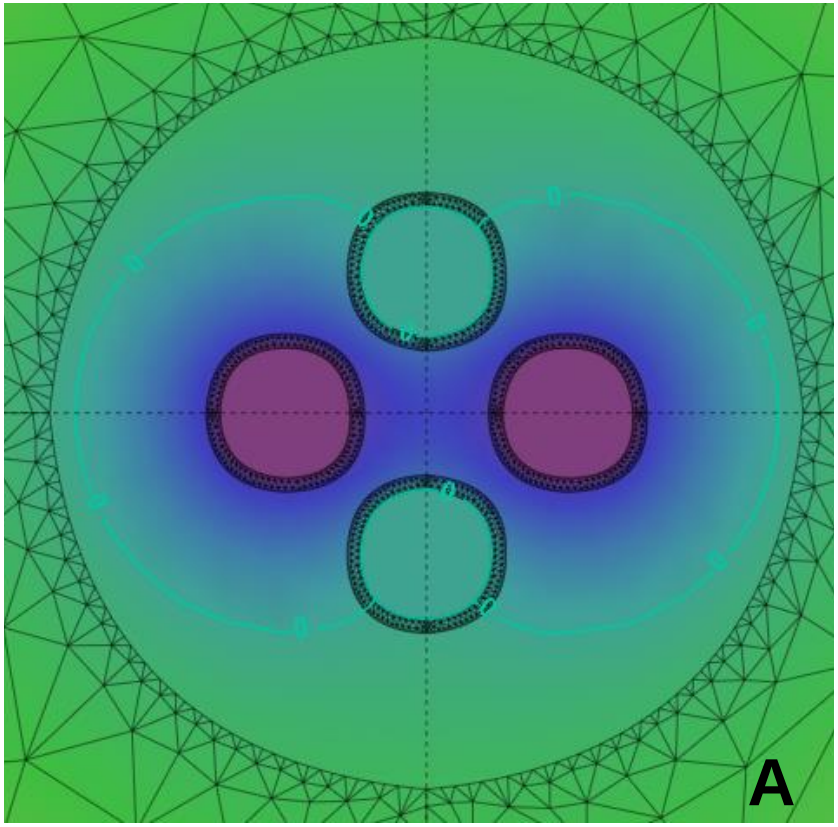
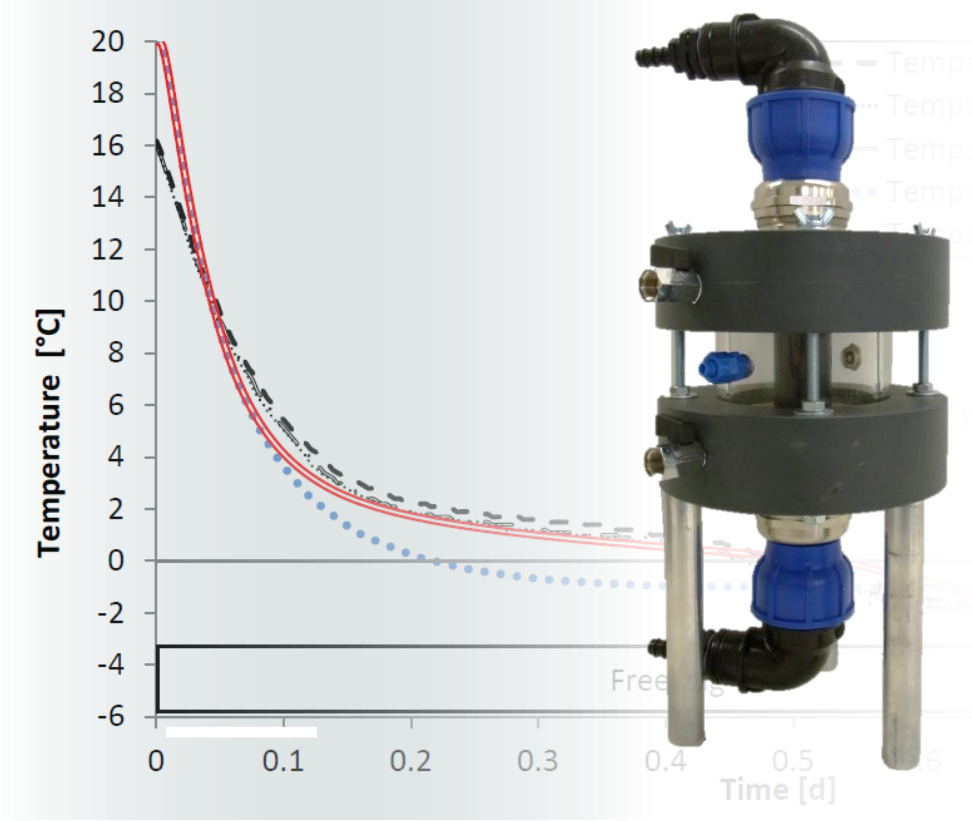
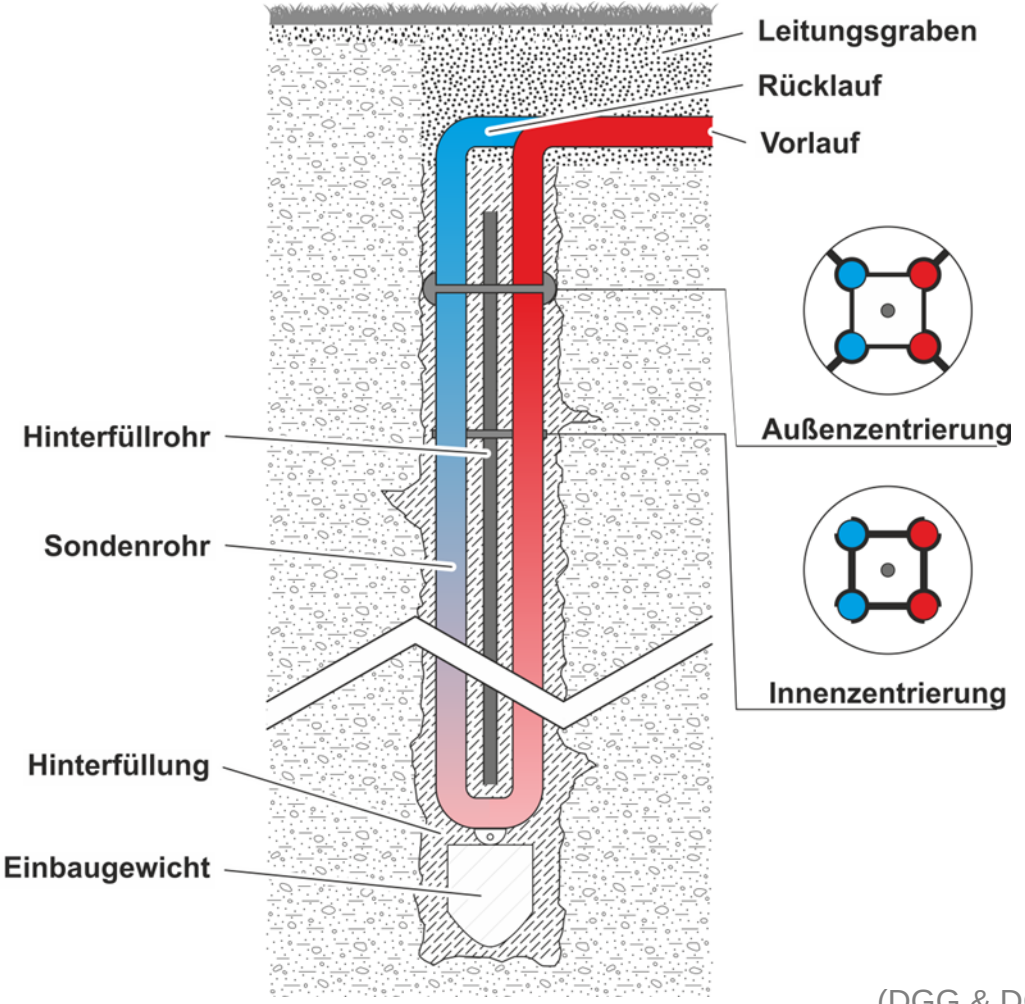




BHE



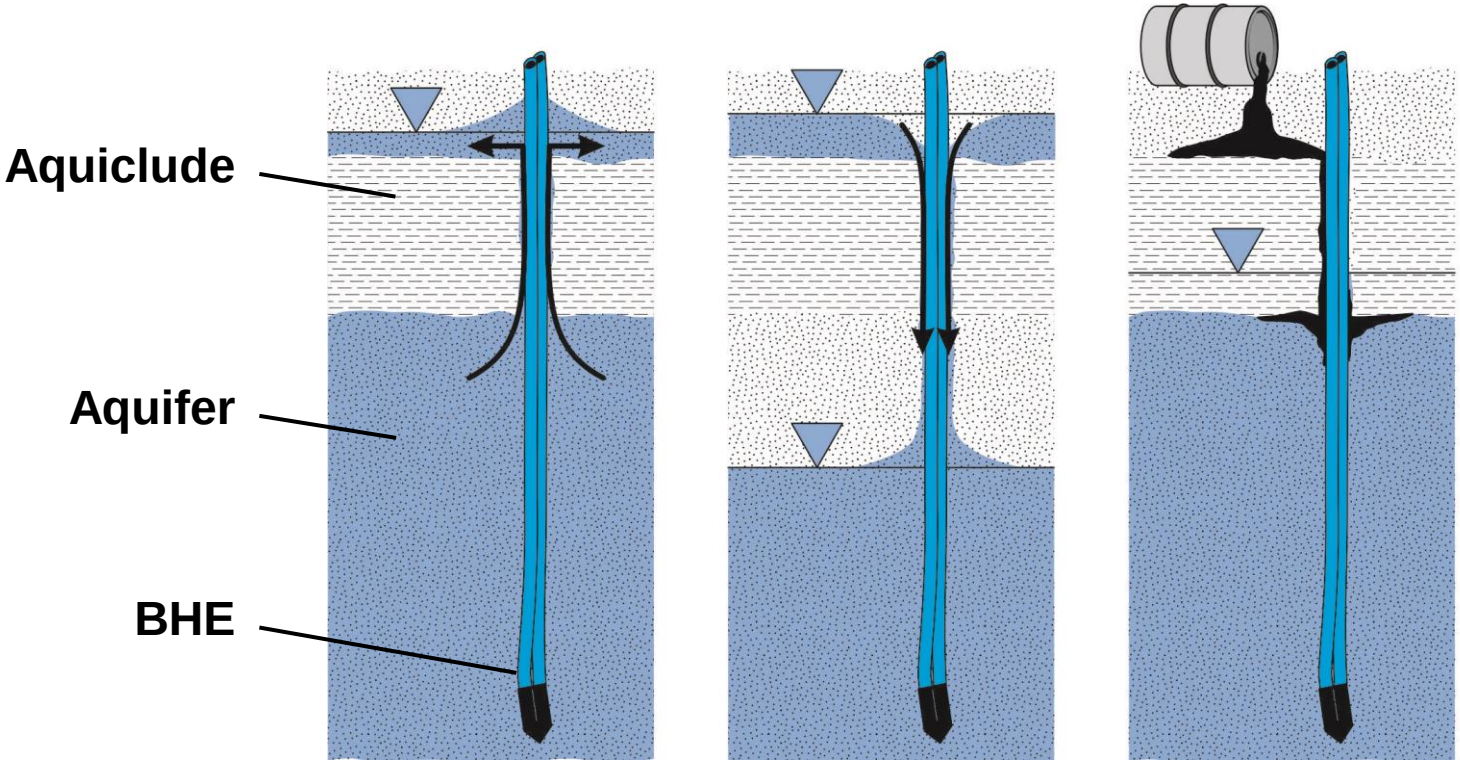
(DGG & DGGT 2014)

BHE Grouts

Heat Transport

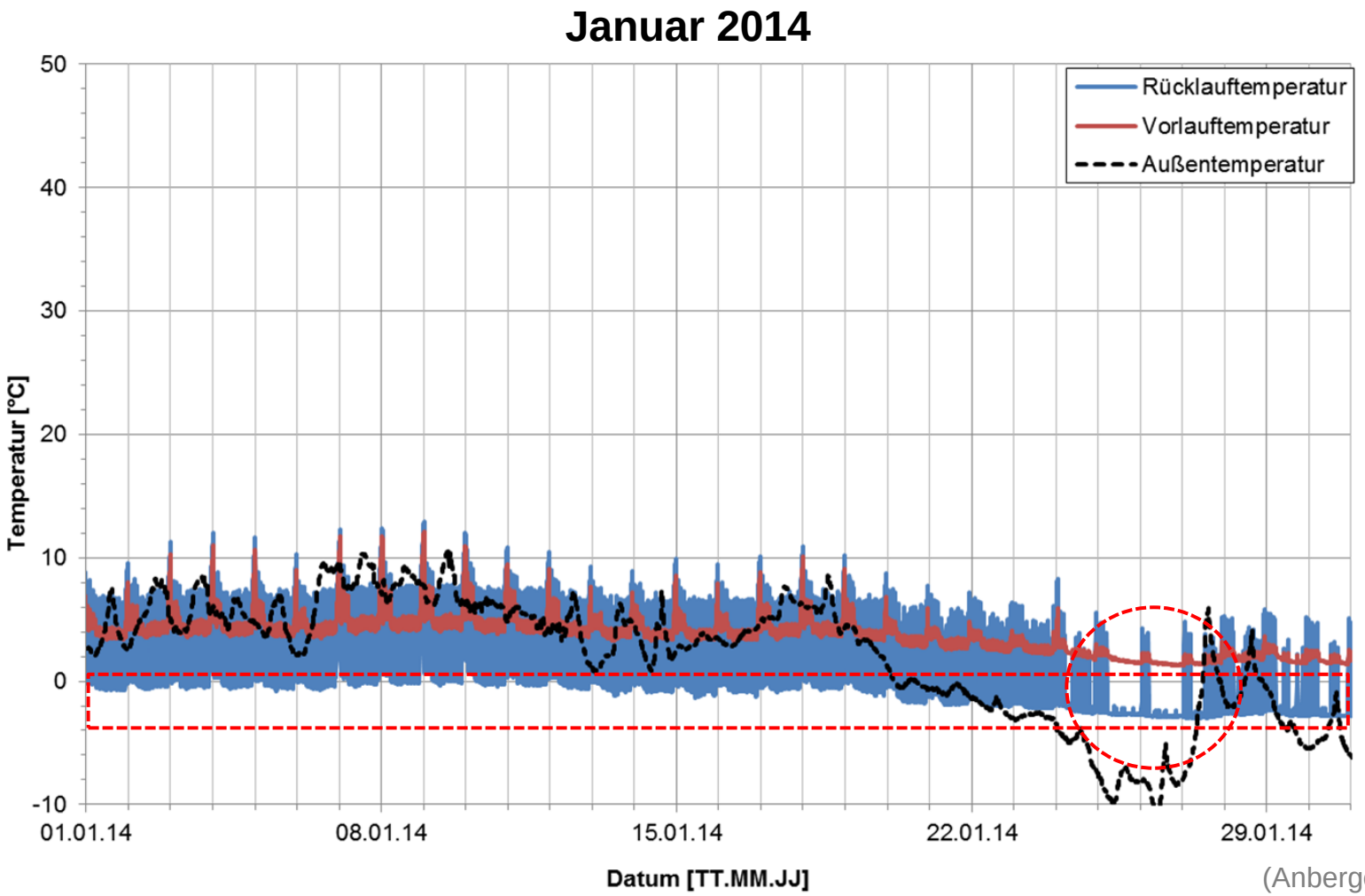
Sealing

(VDI 4640-2 2001).



(DGG & DGGT 2014)

Freeze-Thaw-Cycles



(Anbergen 2014)

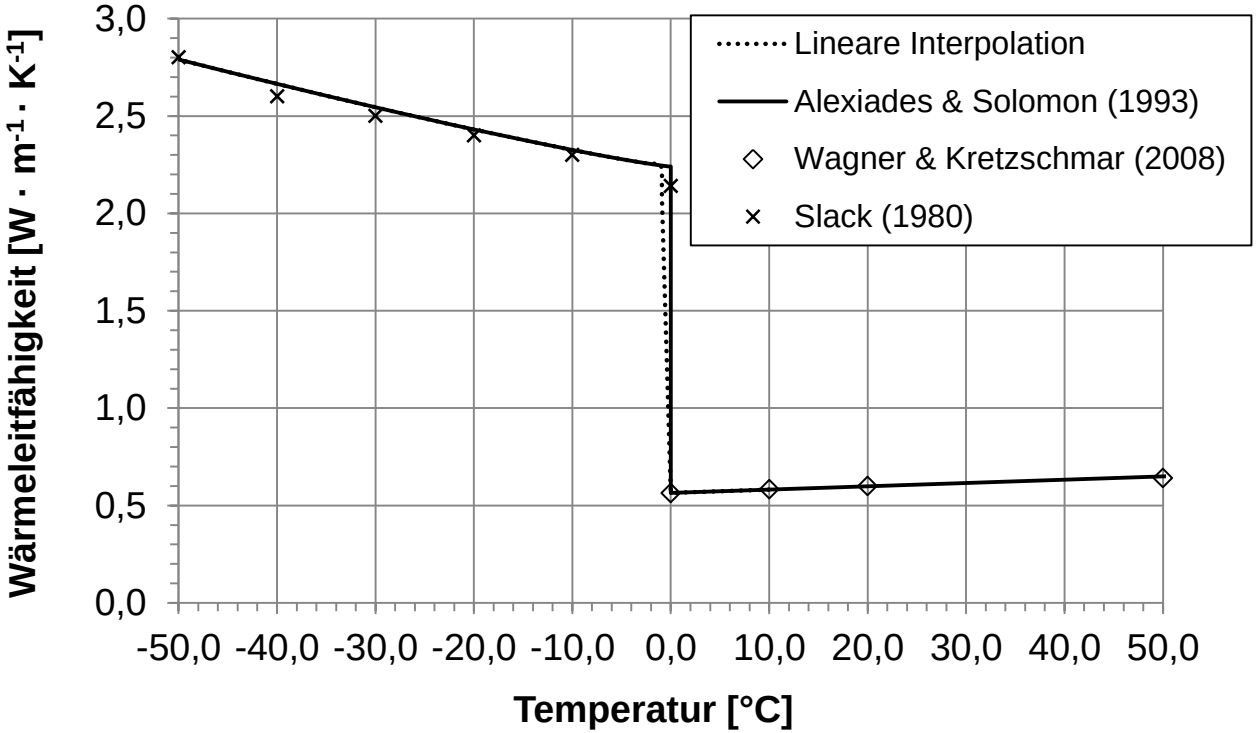
Heat Transport in FEFLOW

$$(\rho c)_{eff}\frac{\partial T}{\partial t} = \nabla \cdot \Big(\underbrace{\vec{\lambda}_{eff}\nabla T}_{\textbf{Konduktion}} - \underbrace{(\rho c)_{fluid}\vec{q}T}_{\textbf{Konvektion}}\Big)$$

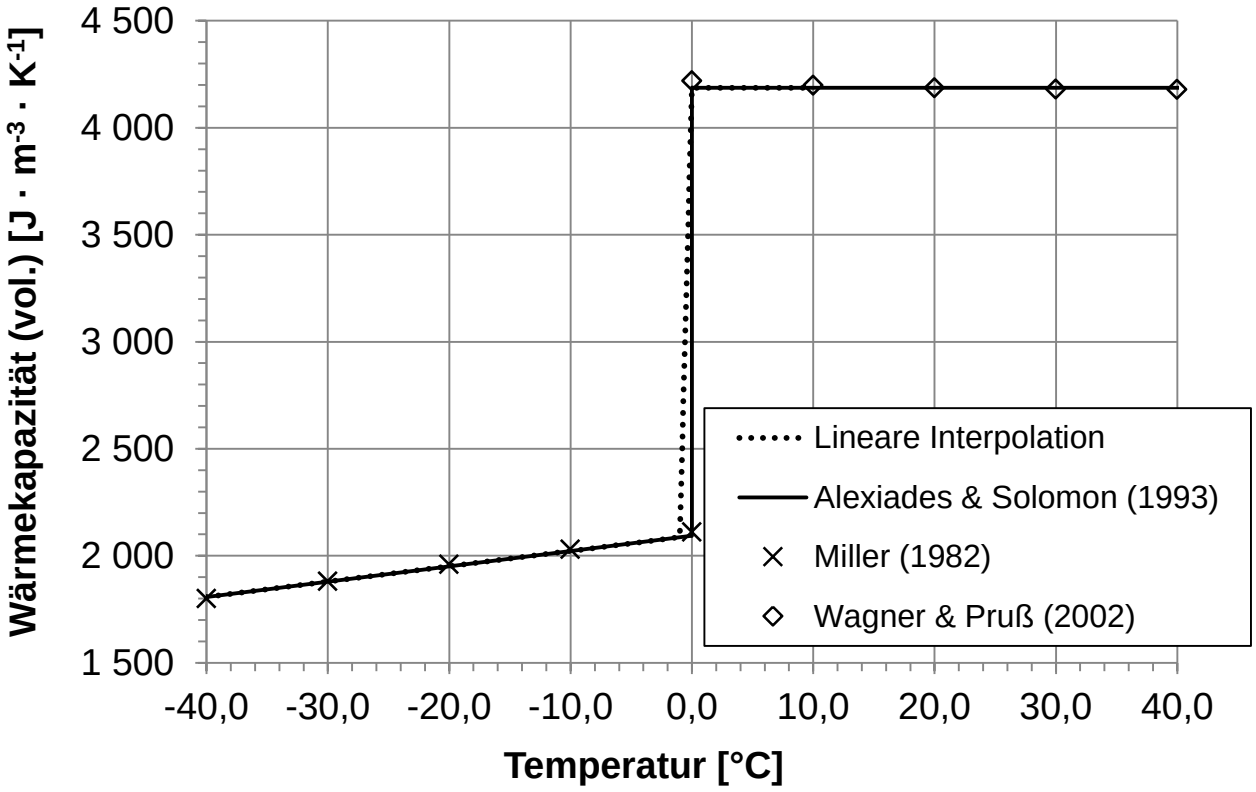
$$\vec{\lambda}_{eff} = \varepsilon \cdot \vec{\lambda}_{fluid} + (1-\varepsilon)\cdot \vec{\lambda}_{\text{solid}}$$

$$(\rho c)_{eff} = \varepsilon \cdot (\rho c)_{fluid} + (1-\varepsilon)\cdot (\rho c)_{\text{solid}}$$

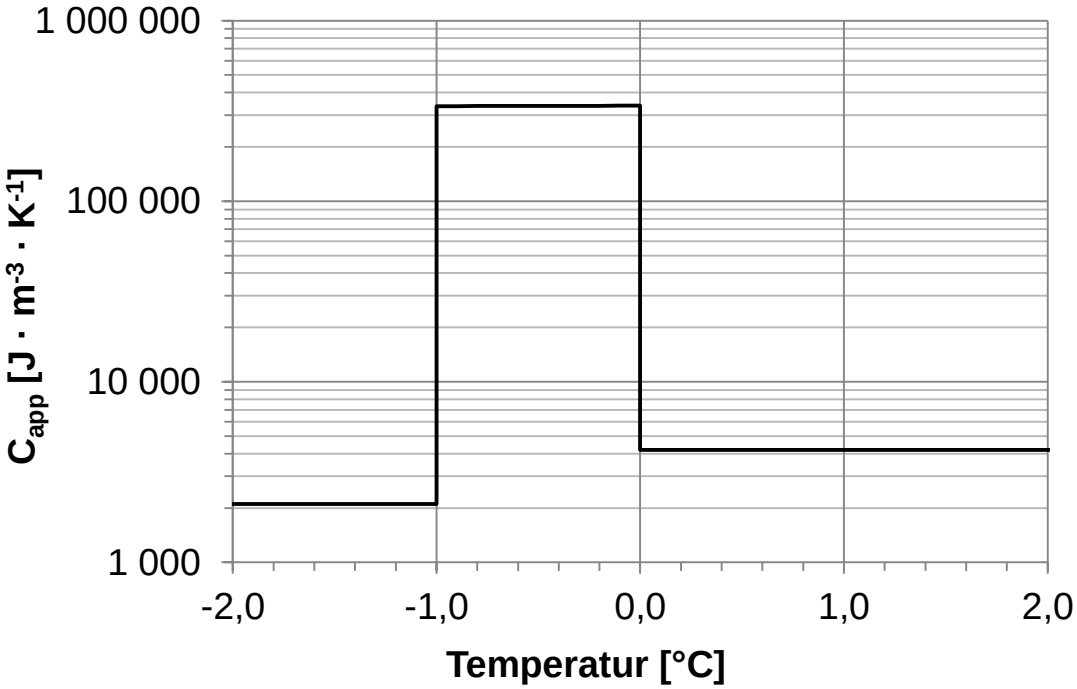
Thermal Conductivity



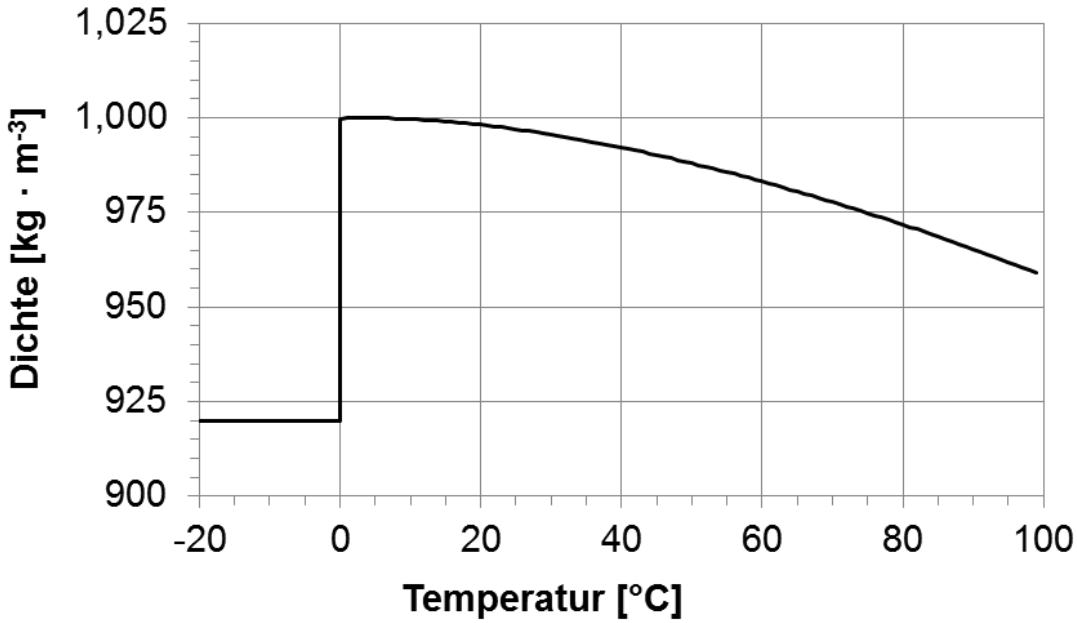
Heat Capacity



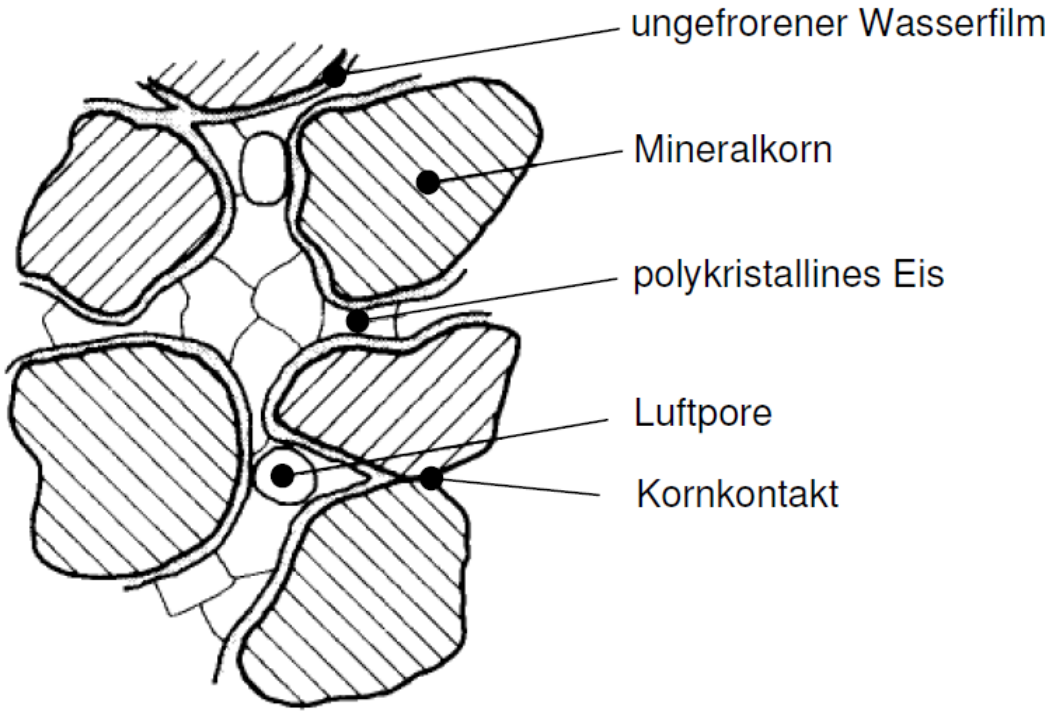
Latent Heat (Apparent Heat Capacity)



Density

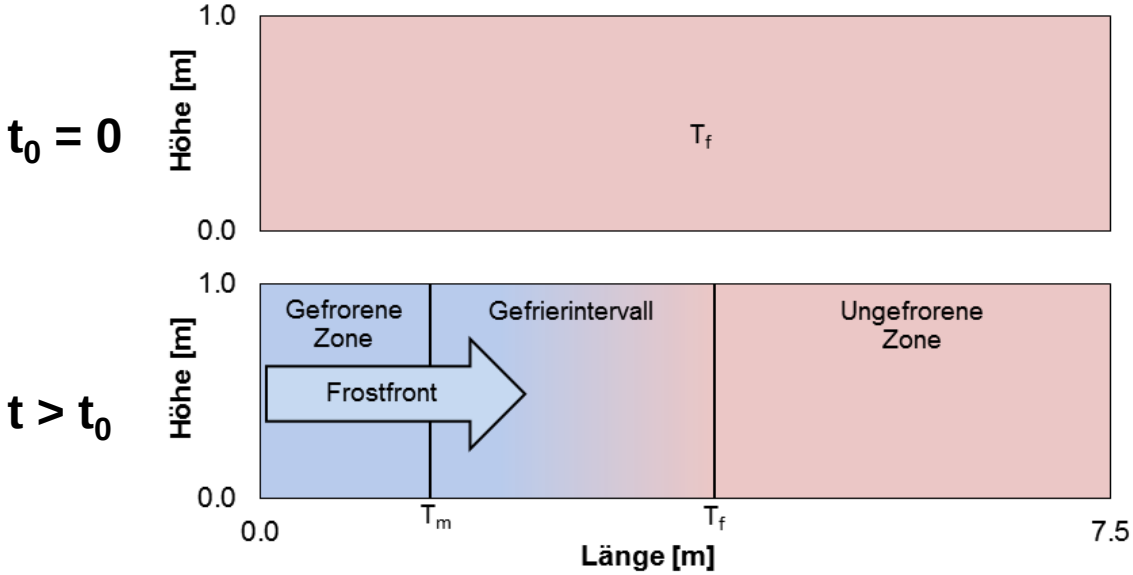

1,025
1,000
975
950
925
900
Dichte [kg · m-3]
-20
0
20
40
60
80
100
Temperatur [°C]

Hydraulic Conductiviity of Grouts



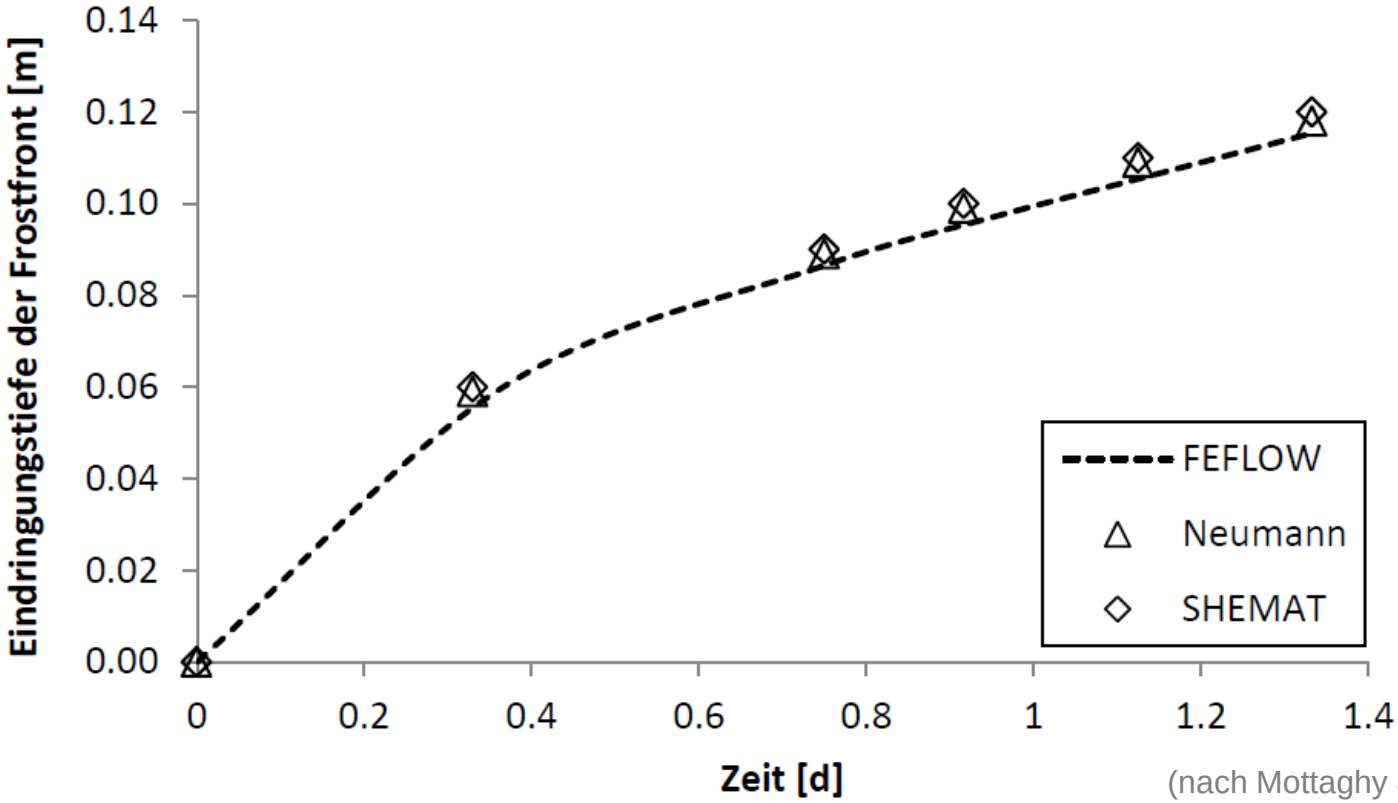
(Orth 1986)

Stafan Problem



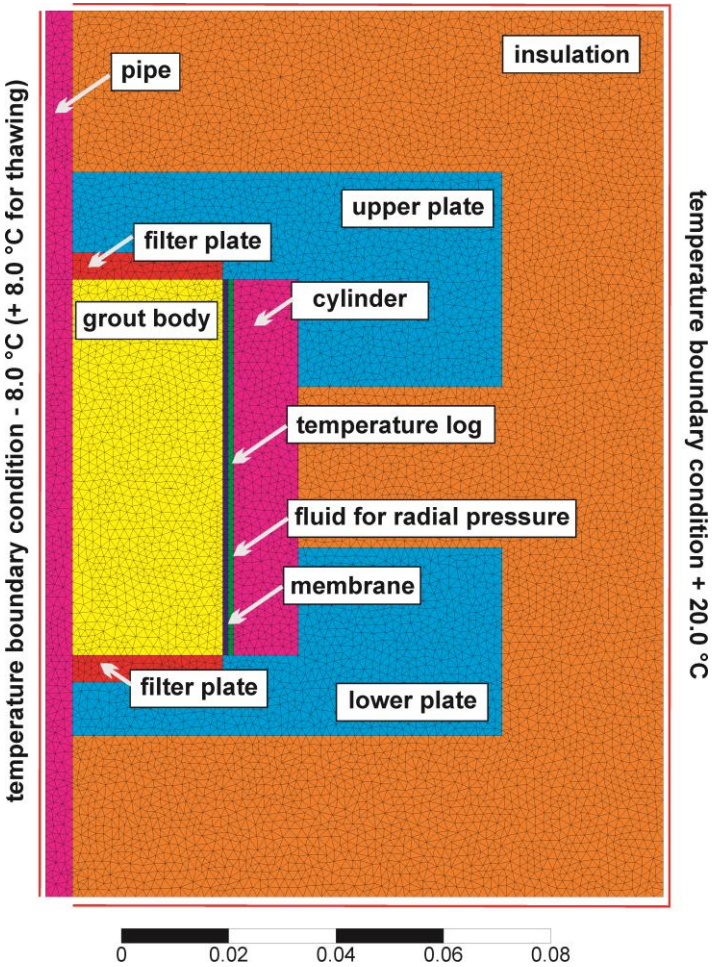
(nach McKenzie et al. 2007)

Benchmark



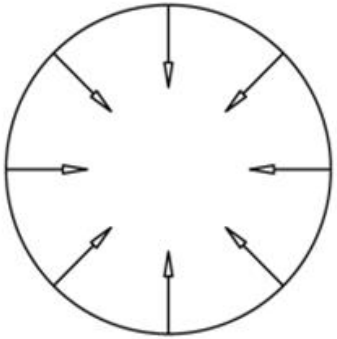
(nach Mottaghy & Rath 2006)

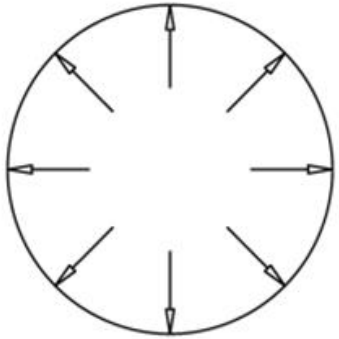
Experimental Validation

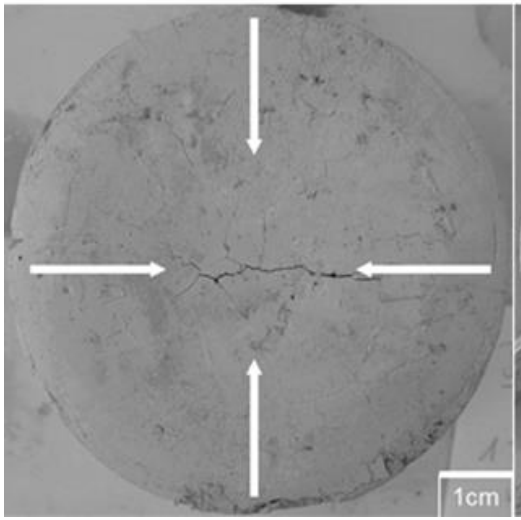


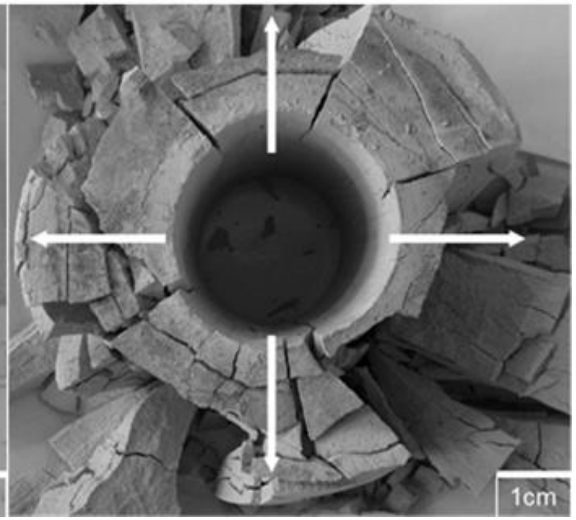
(Anbergen et al. 2014, Canadian Geotechnical Journal, in review)

Experimental Validation

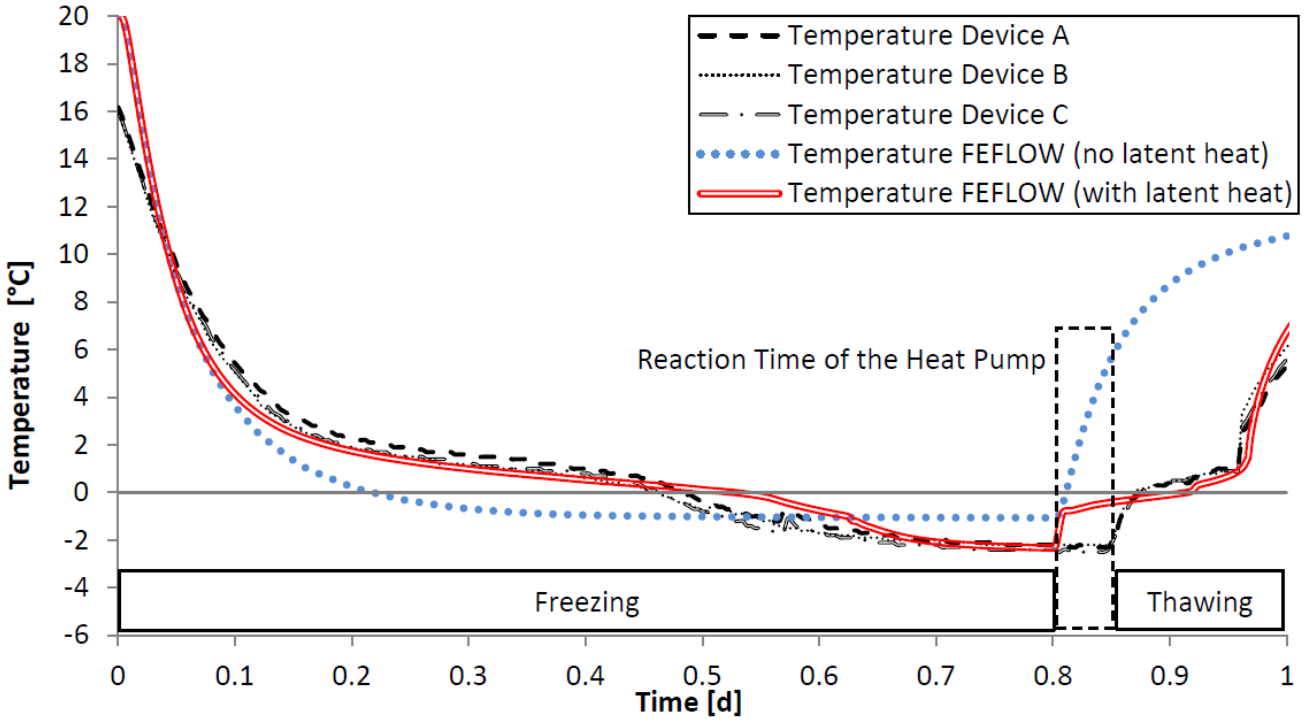








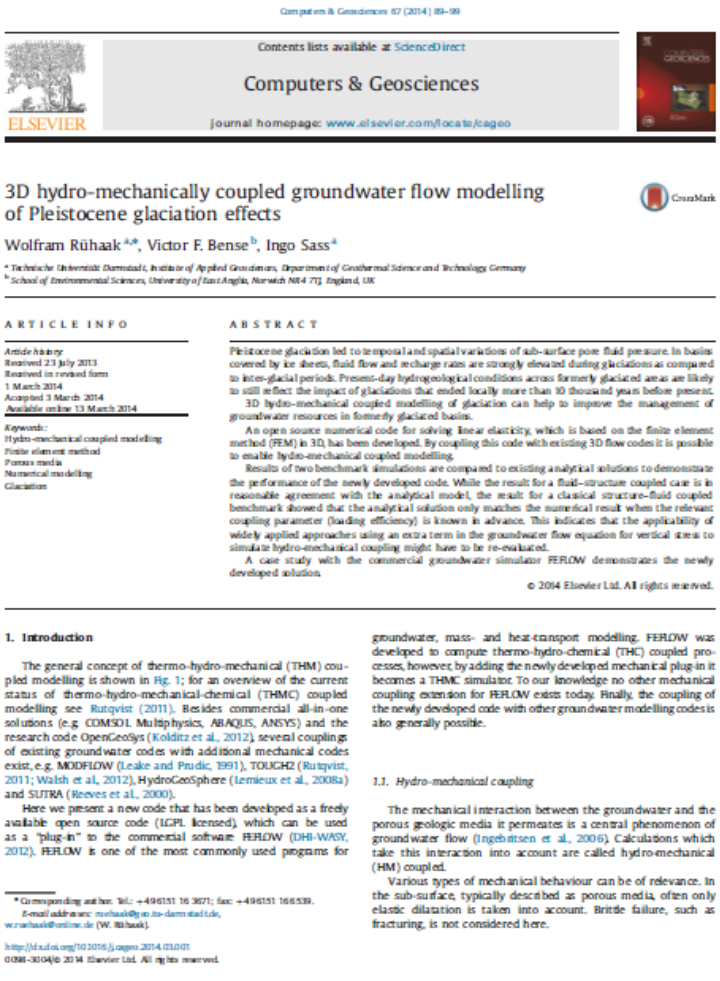
Experimental Validation



(Anbergen et al. 2014, Canadian Geotechnical Journal, in review)

Thermographic measurements confirm the results.

mcf/ffp



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3D hydro-mechanically coupled groundwater flow modelling of Pleistocene glaciation effects

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ABSTRACT

Pleistocene glaciation led to temporal and spatial variations of sub-surface pore fluid pressure. In basins covered by ice sheets, fluid flow and recharge rates are strongly elevated during glaciations as compared to inter-glacial periods. Present-day hydrogeological conditions across formerly glaciated areas are likely to still reflect the impact of glaciations that ended locally more than 10 thousand years before present.

3D hydro-mechanical coupled modelling of glaciation can help to improve the management of groundwater resources in formerly glaciated basins.

An open source numerical code for solving linear elasticity, which is based on the finite element method (FEM) in 3D, has been developed. By coupling this code with existing 3D flow codes it is possible to enable hydro-mechanical coupled modelling.

Results of two benchmark simulations are compared to existing analytical solutions to demonstrate the performance of the newly developed code. While the result for a fluid–structure coupled case is in reasonable agreement with the analytical model, the result for a classical structure–fluid coupled benchmark showed that the analytical solution only matches the numerical result when the relevant coupling parameter (loading efficiency) is known in advance. This indicates that the applicability of widely applied approaches using an extra term in the groundwater flow equation for vertical stress to simulate hydro-mechanical coupling might have to be re-evaluated.

A case study with the commercial groundwater simulator FEFLOW demonstrates the newly developed solution.

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1. Introduction

The general concept of thermo-hydro-mechanical (THM) coupled modelling is shown in Fig. 1; for an overview of the current status of thermo-hydro-mechanical-chemical (THMC) coupled modelling see Rutqvist (2011). Besides commercial all-in-one solutions (e.g. COMSOL Multiphysics, ABAQUS, ANSYS) and the research code OpenGeoSys (Kolditz et al., 2012), several couplings of existing groundwater codes with additional mechanical codes exist, e.g. MODFLOW (Leake and Prudic, 1991), TOUGH2 (Rutqvist, 2011; Walsh et al., 2012), HydroGeoSphere (Lemieux et al., 2008a) and SUTRA (Reeves et al., 2000).

Here we present a new code that has been developed as a freely available open source code (LGPL licensed), which can be used as a "plug-in" to the commercial software FEFLOW (DHI-WASY, 2012). FEFLOW is one of the most commonly used programs for groundwater, mass- and heat-transport modelling. FEFLOW was developed to compute thermo-hydro-chemical (THC) coupled processes, however, by adding the newly developed mechanical plug-in it becomes a THMC simulator. To our knowledge no other mechanical coupling extension for FEFLOW exists today. Finally, the coupling of the newly developed code with other groundwater modelling codes is also generally possible.

1.1. Hydro-mechanical coupling

The mechanical interaction between the groundwater and the porous geologic media it permeates is a central phenomenon of groundwater flow (Ingebritsen et al., 2006). Calculations which take this interaction into account are called hydro-mechanical (HM) coupled.

Various types of mechanical behaviour can be of relevance. In the sub-surface, typically described as porous media, often only elastic dilatation is taken into account. Brittle failure, such as fracturing, is not considered here.

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- Finite Element Code
- Diffusion Equation / Linear Elasticity
- 3D using tetrahedrons
- C++; PARDISO and GPU solver
- integrated into FEFLOW as plug-in
  → THMC coupling
- http://sourceforge.net/projects/ffp/ (LGPL)

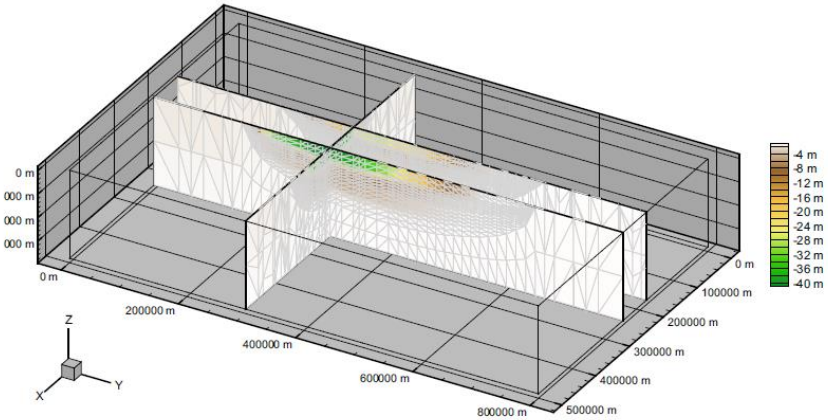

Fig. 11. Vertical displacement after ten thousand years (view is 20 times exaggerated).

Thanks

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