Energy Pile Simulation – an Application of THM-Modeling

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Introduction: Energy piles, i.e. heat exchangers located within the foundation piles of buildings, are used for heating or cooling purposes. Although the absolute values of deformations and temperature gradients are small or moderate, the entire setting may be influenced by thermo-hydro-mechanical (THM) couplings. The fluctuating thermal regime can affect the deformation due to mechanical loading. Groundwater flow changes the temperature distribution around the piles and due to pore pressure can also have an effect on the mechanical state of the sub-surface material. We show, that such process interactions can be investigated by a coupled numerical approach.

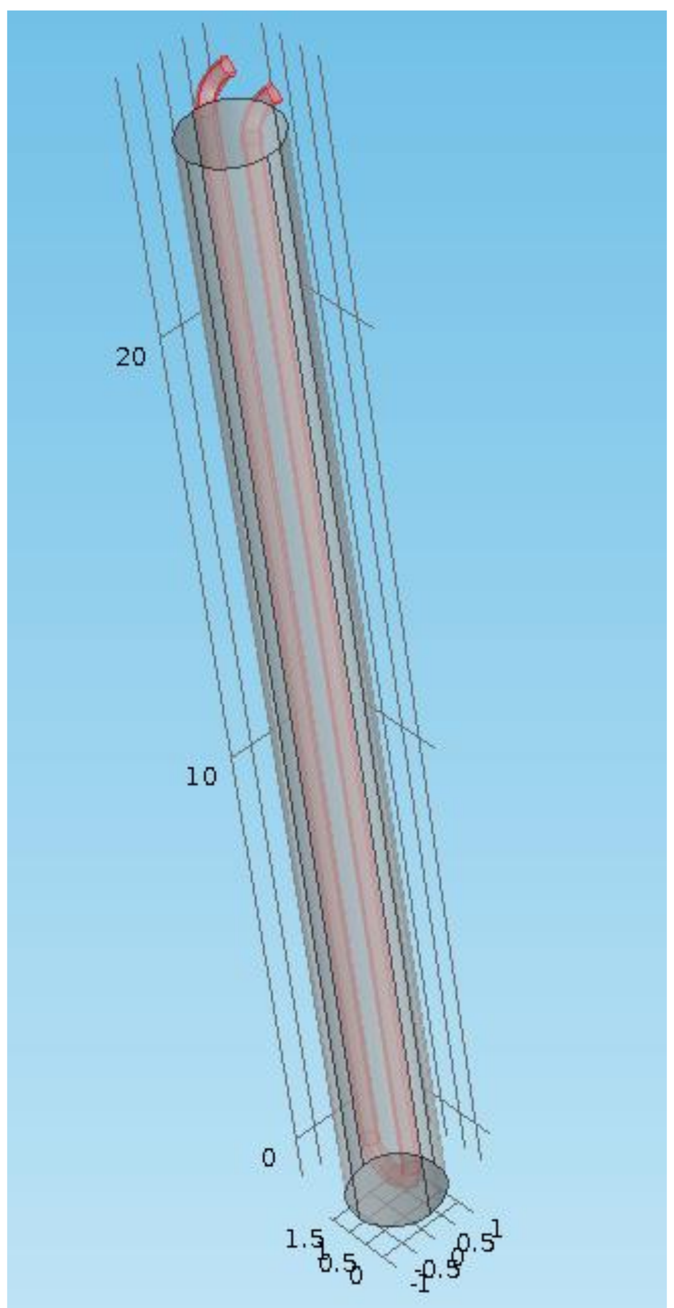

Figure 1. Sketch of an energy pile

Coupled modelling: In the model we treat the geomechanical, the thermal and the hydraulic regimes within the pile and the adjacent ground. In the ground we use the poroelastic stress-strain equation:

$$\boldsymbol{\sigma} - \boldsymbol{\sigma}_0 = \mathbf{C} : \left(\boldsymbol{\varepsilon} - \boldsymbol{\varepsilon}_0 - \beta/_3 \, (T - T_0)\,\mathbf{I} \right) - \alpha p \mathbf{I}$$

Fluid equation and Darcy's Law:

$$rS\frac{\partial p}{\partial t} + \nabla \cdot \left(r\mathbf{q} \right) = Q - r\alpha\frac{\partial e_V}{\partial t} \qquad \mathbf{q} = -\frac{k}{\mu}\nabla (p - \rho g z)$$

Heat equation:

$$\left(rC \right)\frac{\partial T}{\partial t} + \nabla \cdot \left((rC)_f T\mathbf{q} \right) = -\nabla \cdot k_T \nabla T$$

Variables and parameters: stress tensor $\boldsymbol{\sigma}$, strain tensor $\boldsymbol{\varepsilon}$, stiffness tensor **C**, temperature *T*, unity matrix **I**, thermal expansion coefficient β , Biot paramerter , hydraulic pressure *p*, Darcy velocity vector **q**, fluid density ρ, permeability *k*, fluid dynamic viscosity μ, acceleration due to gravity *g*, volumetric strain ε_V, storage parameter *S*, fluid source/sink-term *Q*, fluid specific heat capacity $(\rho C)_f$, specific heat capacity of the fluid-solid system (ρC) and its thermal conductivity k_T

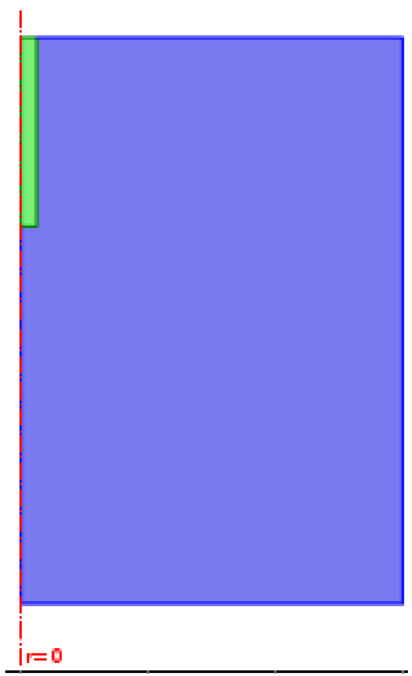

Figure 2. Sketch of model region; green: pile; blue: ground

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Results:

Max. displacement [m]	Pile =-Δ-pile	Ground	Δ-ground
Initial	0	2.5	0
Coupled interface	0.285	2.438	0.062
Water compressibility	0.285	2.438	0.062
Temperature-dependencies	0.283	2.421	0.079
Thermal stress	0.268	2.412	0.088

Table 1: Maximum deformation of pile and ground in dependence of various couplings considered

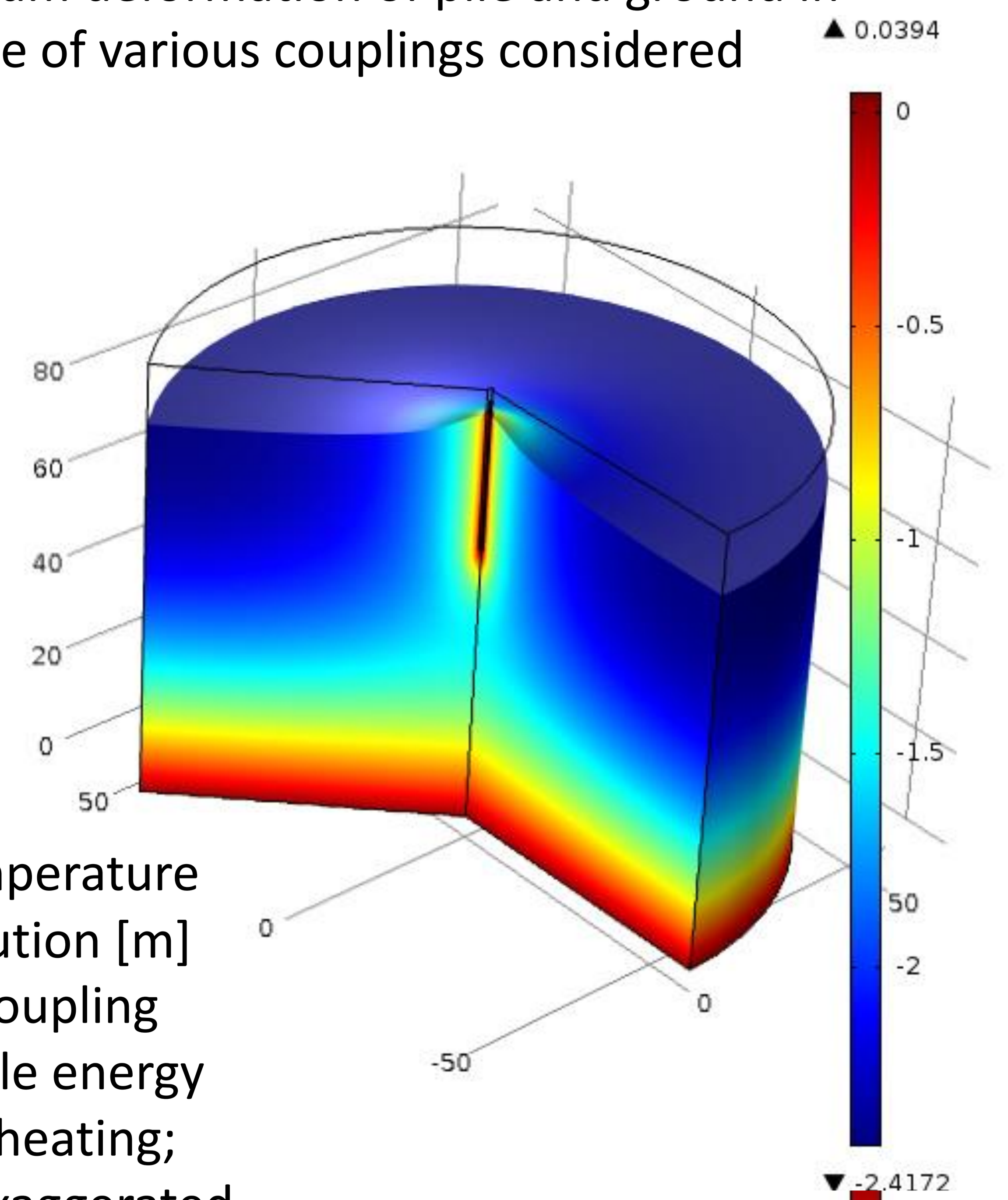

Figure 3: Temperature [° C] distribution [m] with heat coupling around a single energy pipe during heating; deformation exaggerated by factor 5

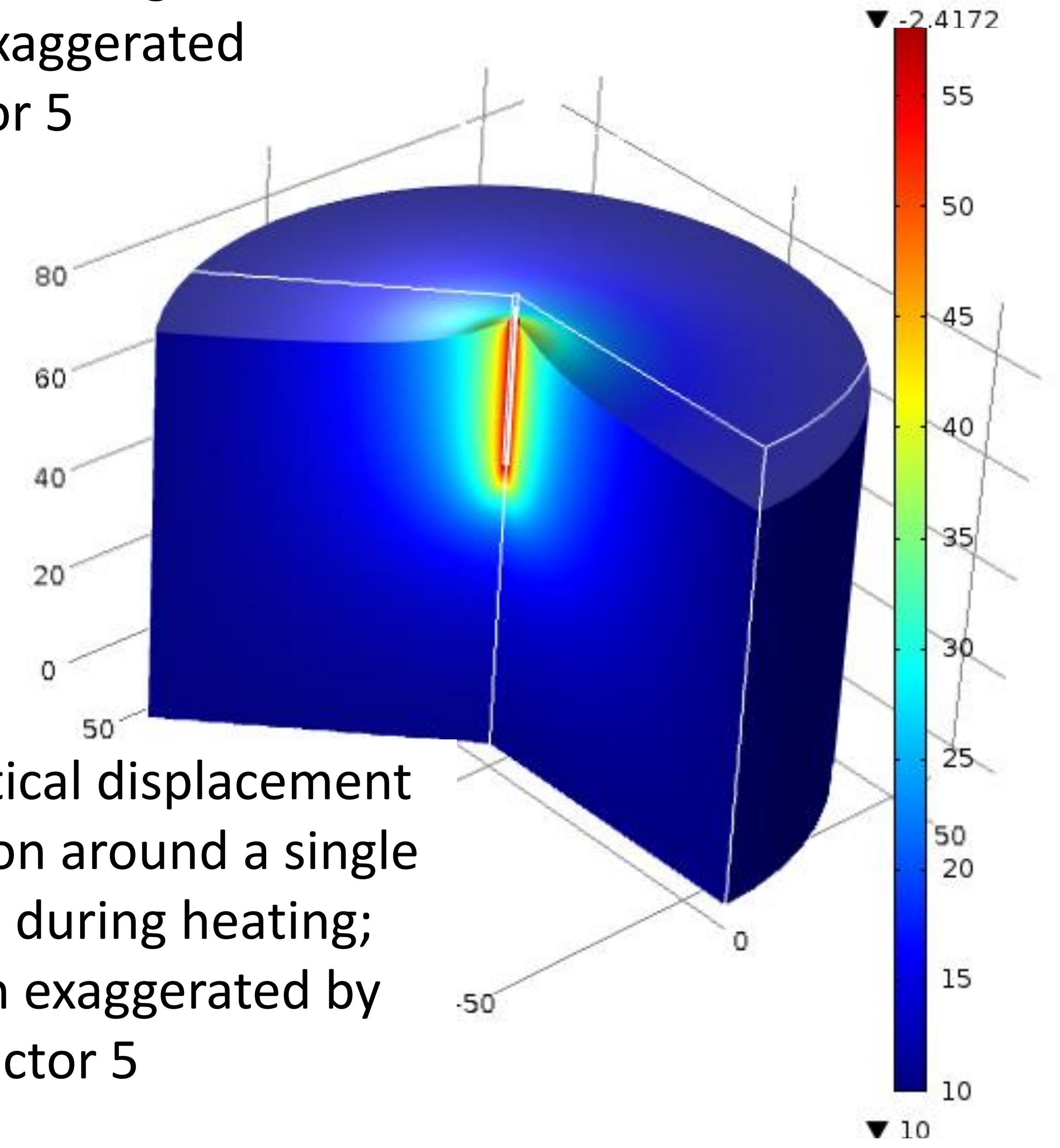

Figure 4: Vertical displacement [m] distribution around a single energy pipe during heating; deformation exaggerated by factor 5

Conclusions: The results show that

- fluid compressibility can be neglected
- temperature dependent properties of the fluid are responsible for minor changes only
- thermal expansion plays a major role, in particular for the pile

The presented model concept enables the simulation of coupled mechanical, hydraulic, thermal processes, which can be relevant for energy piles. The concept can be utilized for 1D, 2D and 3D models in cartesian or axi-symmetric coordinates, for steady-state as well as for transient problems. Convective processes resulting from groundwater or seepage flow can be considered, also.

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