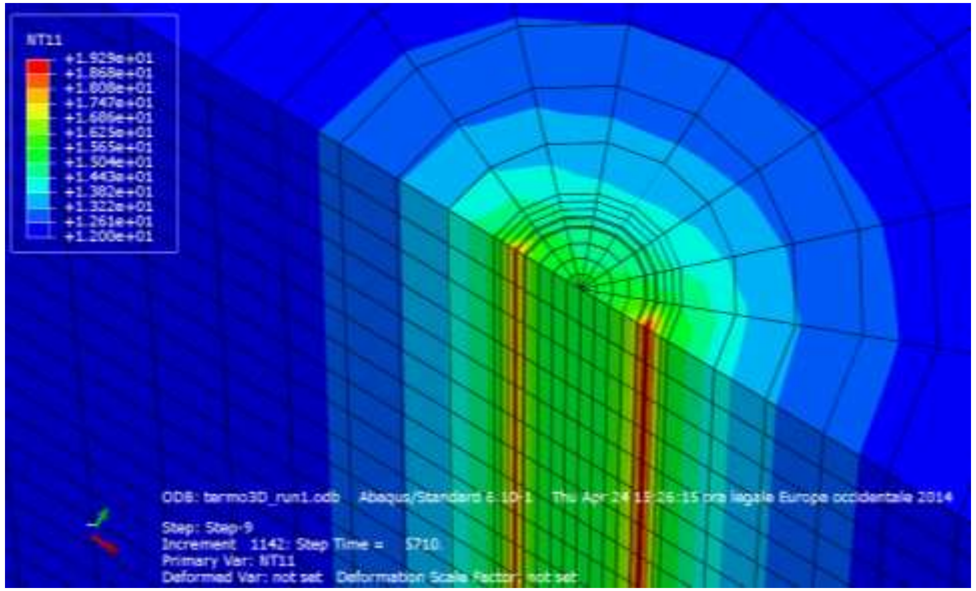
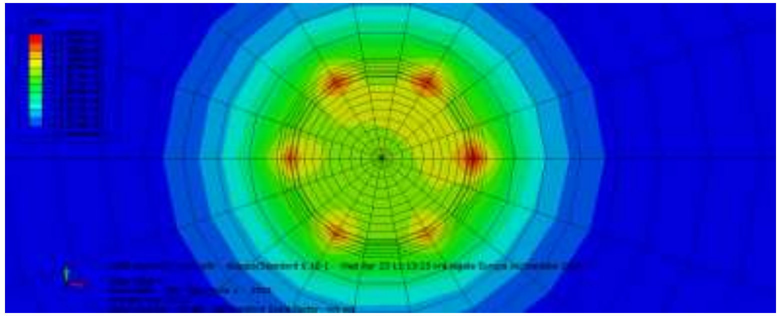
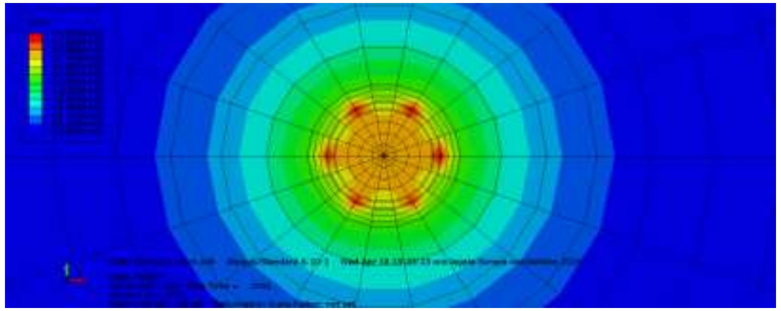
A new modelling approach for piled and other ground heat exchanger applications







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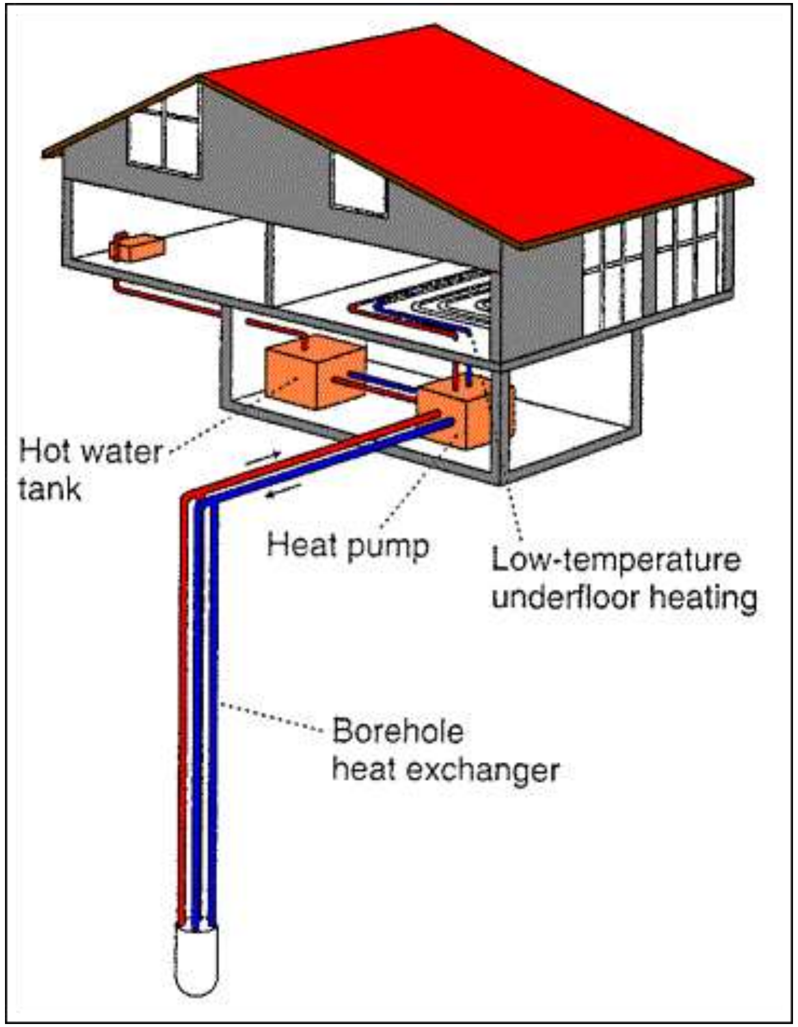
Ground heat exchangers

- **Borehole heat exchanger** (BHE): heat exchanger installed inside a borehole (∅=10-20 cm)

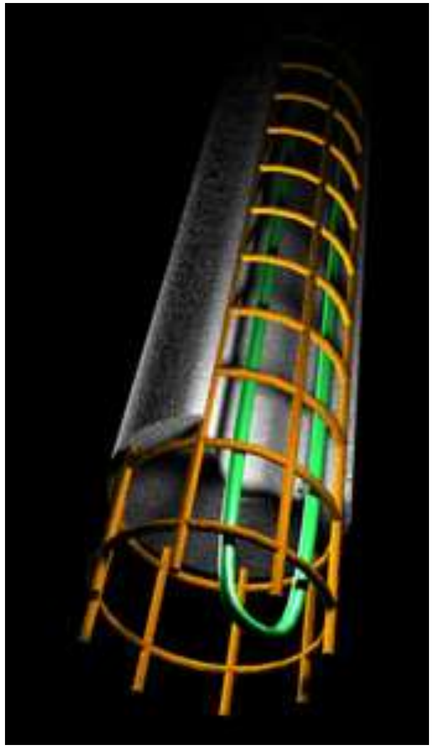
- routinely designed with commercial software
- with a simplified approach (linear infinite heat source, steady-state assumptions)



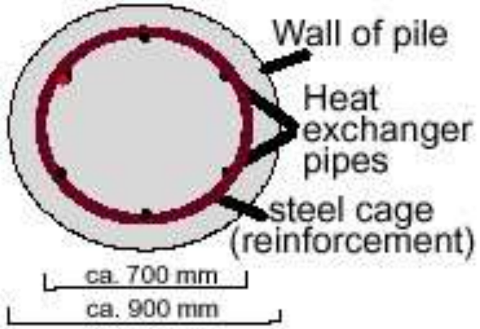
http://www.gtr.ethz.ch/

Ground heat exchangers

- **Energy pile** (EP): heat exchanger installed inside a piled foundation (∅ =0.3-2.0 m)
- routinely deisgned with 'mechanical criteria'. BHEs' Simplified thermal analysis is not adequate, since:
  - Different aspect ratio compared to BHEs
    -> the linear infinite source approximation doesn't apply
  - Much larger diameter
    -> important transient heat transfer effects



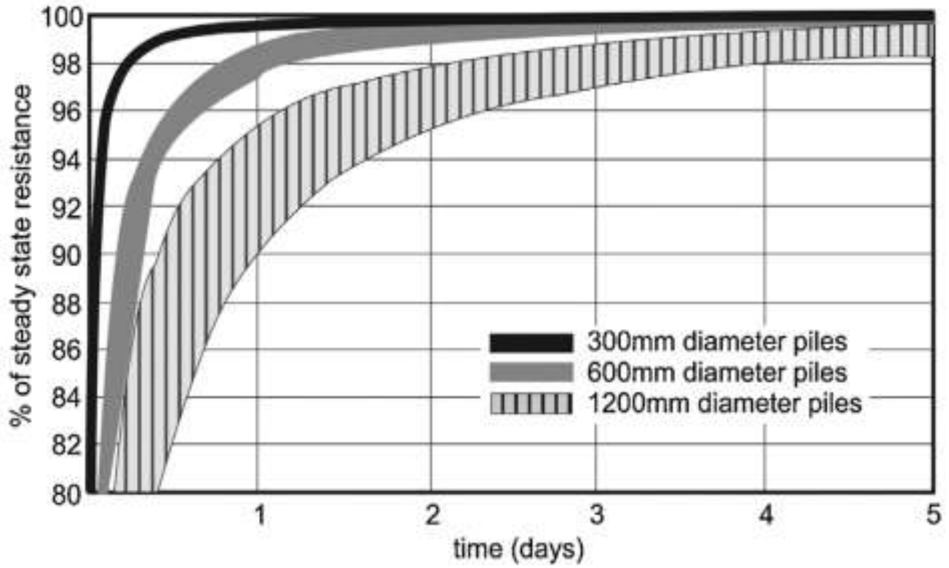
http://www.geothermie.de/

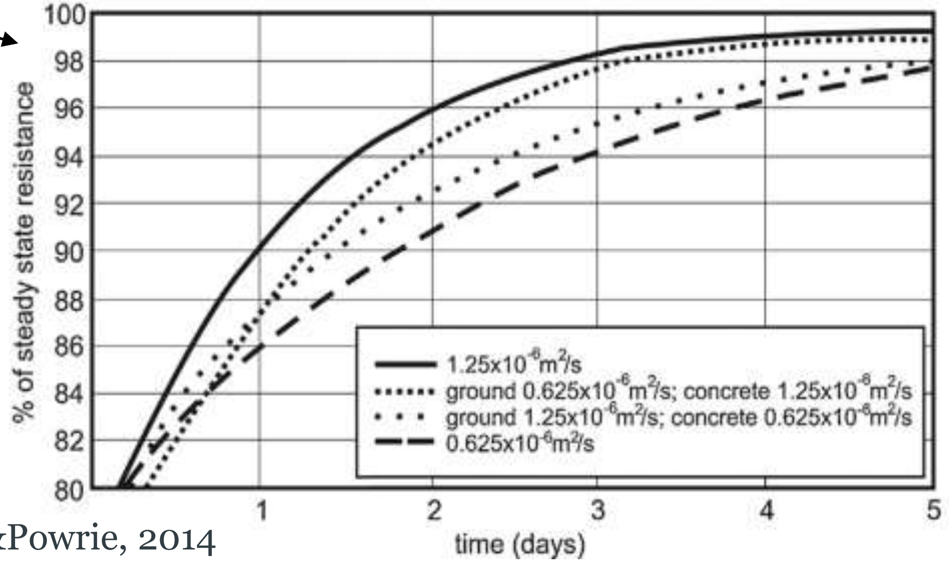


http://www.geothermie.de/

Actual thermal behaviour of EPs

- The time needed to reach steady state depends on
  - ∅ pile, no. & position of pipes, thermal conductivity
  - Type of heat pulse
- Surface temperature changes both along a vertical and horizontal section: 3D effects





Loveridge&Powrie, 2014

FEM numerical model

Use of software ABAQUS

- To integrate 3D transient conduction through the concrete & the ground

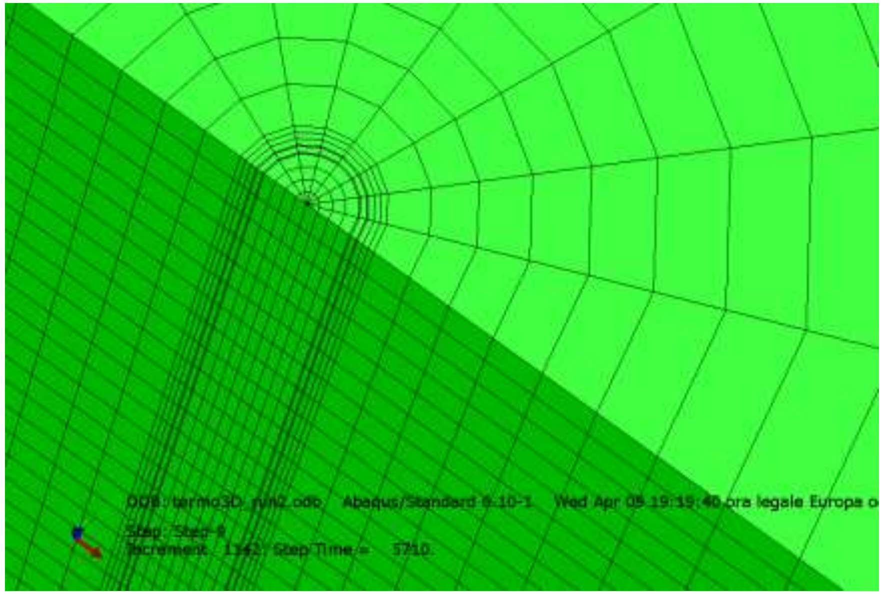
$$\rho_s c_{ps} \dot{T} = \nabla \left(\lambda_s \nabla T \right)$$

+ Bespoke user subroutines

- To model the convective heat transfer at the fluid/solid interface and the temperature changes in the fluid along the pipe

$$\dot{m} c_{pf} \nabla T = h \Delta T$$

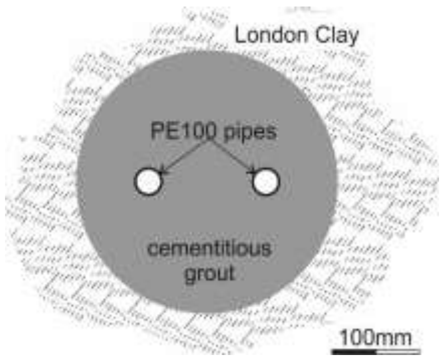
- 3D FE mesh manually created to minimise computational time
- Simmetry can be exploited for single U-pipe EPs

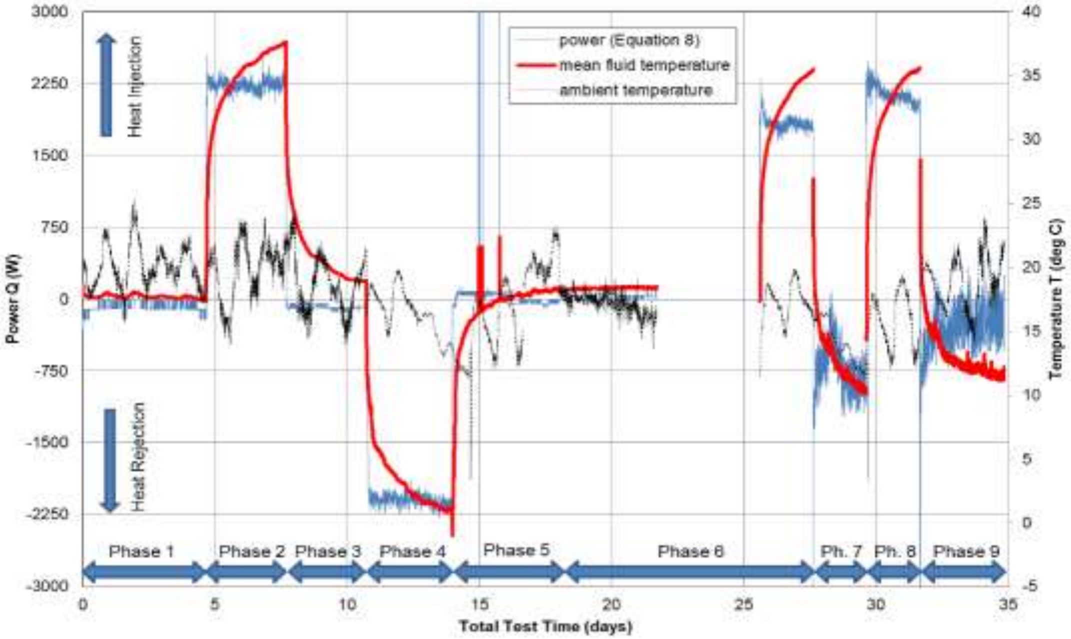


Numerical model validation
against field data

- The outcome of a thermal response test (TRT) on a single test pile installed in London clay was reproduced
  - ∅=30 cm, L= 27m, single U-pipe, equipped with sensors measuring both concrete and exchanger fluid temperature

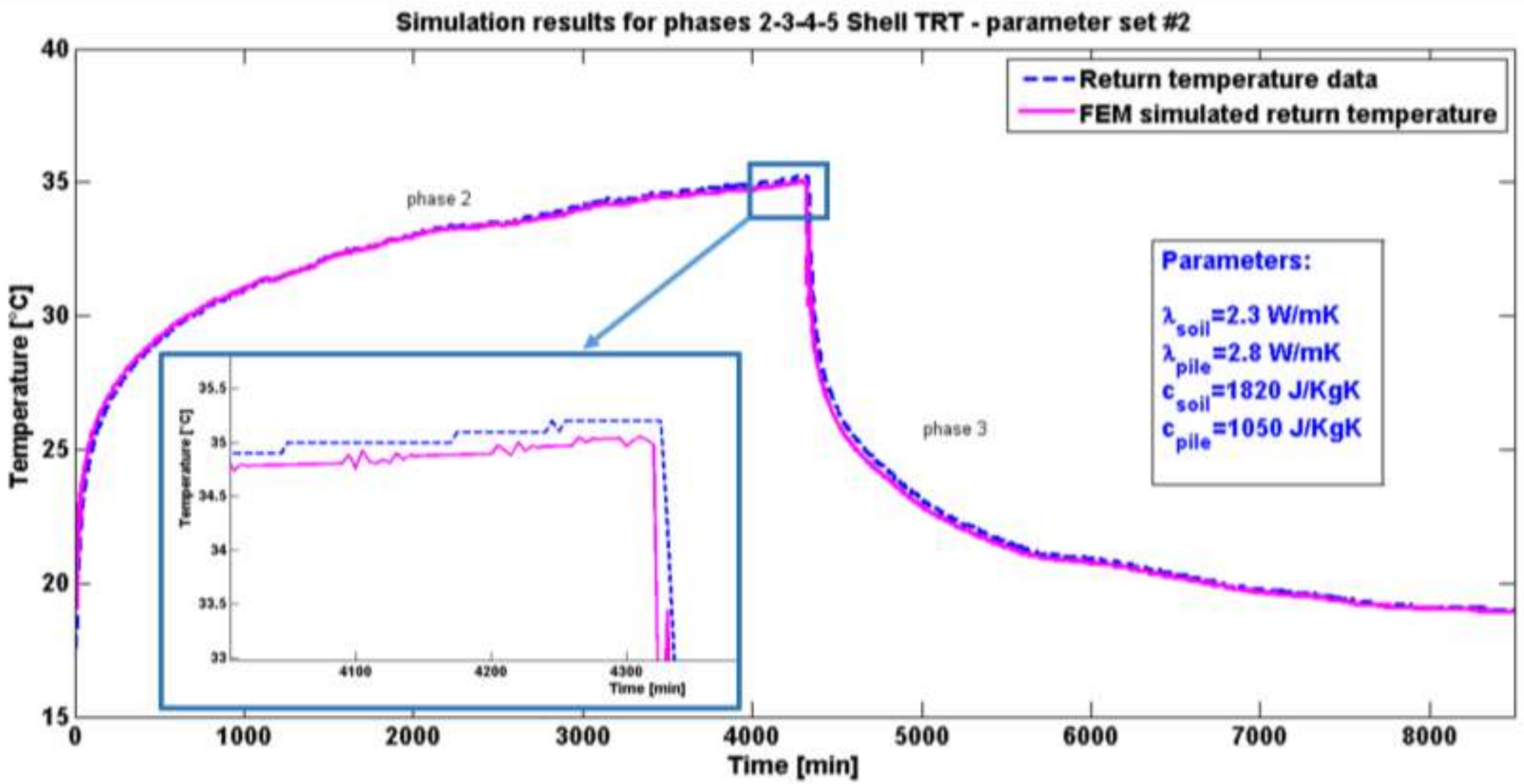
– Input data:
* Inlet fluid temperature
* Geometry & thermal properties of materials





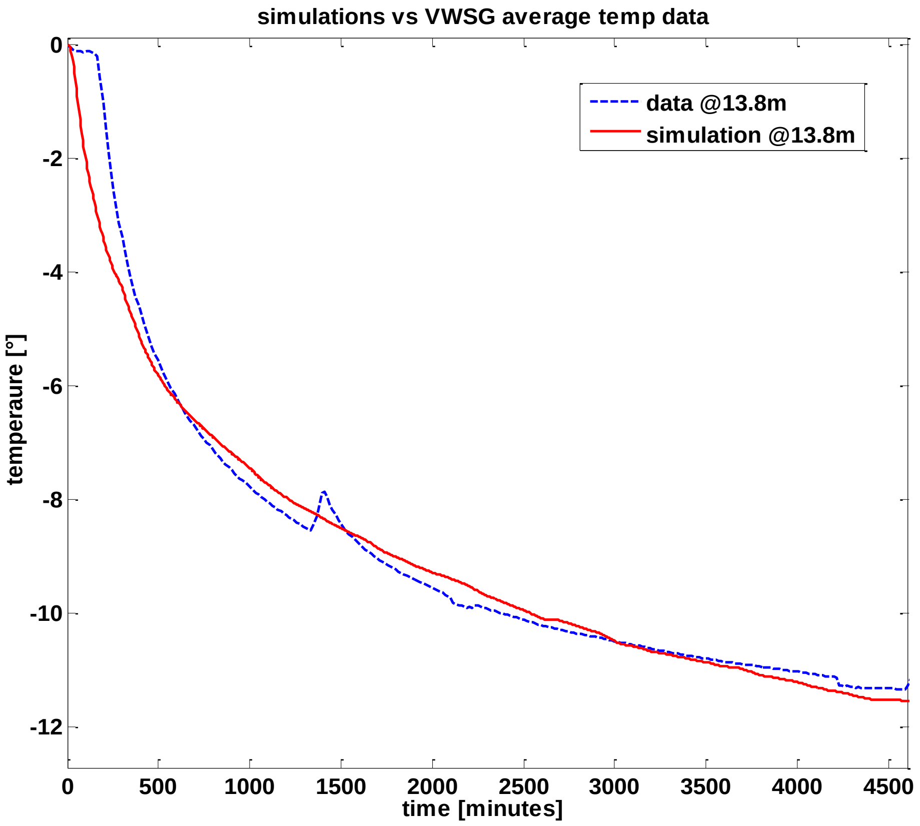
Numerical model validation
against field data

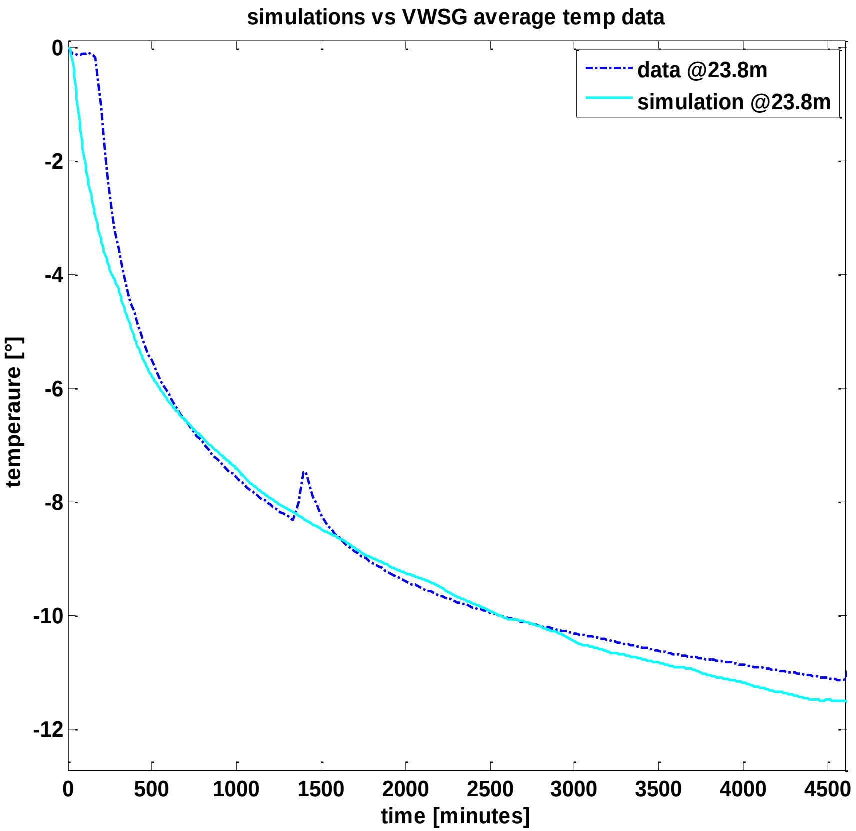
- Simulation of <u>outled fluid temperature</u> evolution compared to the measured one



Numerical model validation
against field data

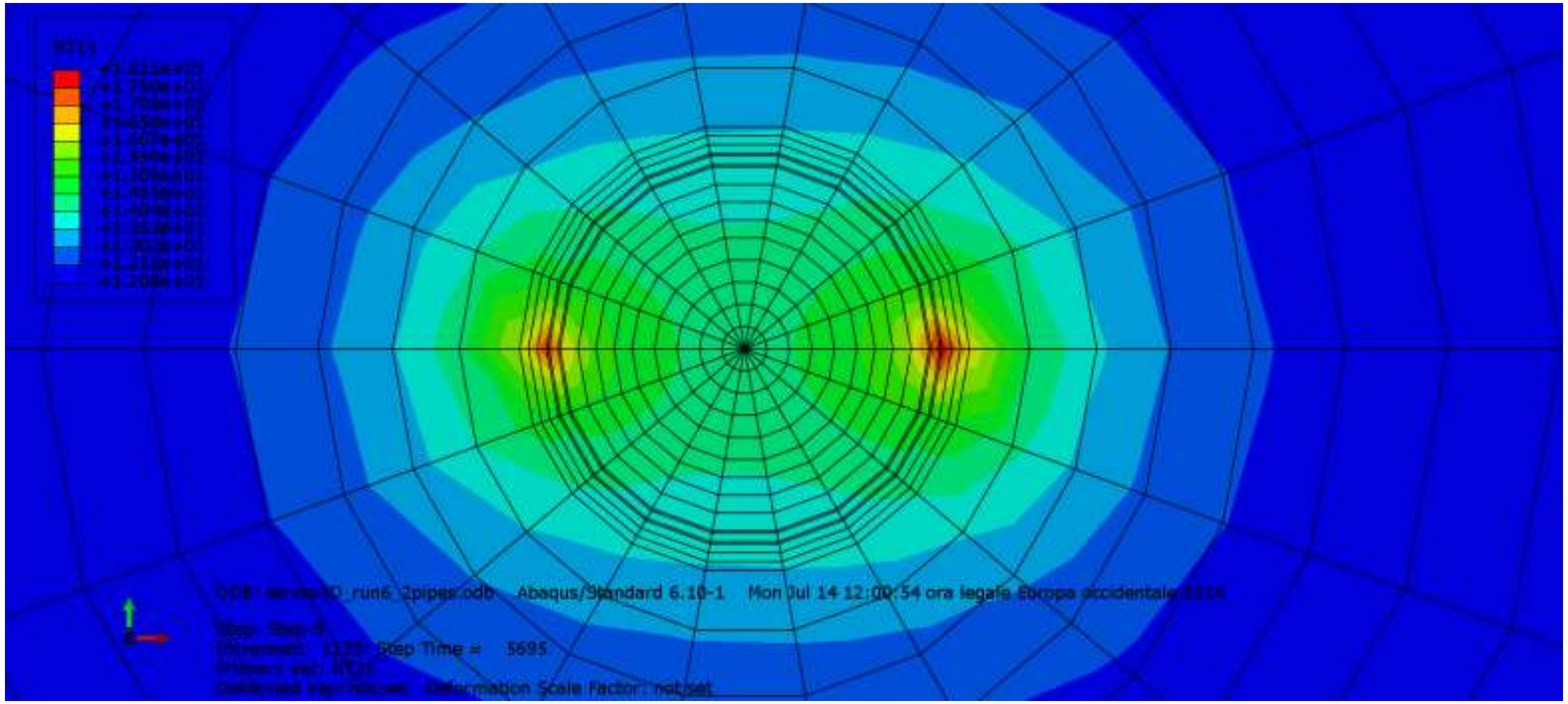
- Simulation of <u>concrete temperature</u> evolution compared to the measured one





Example of simulation output

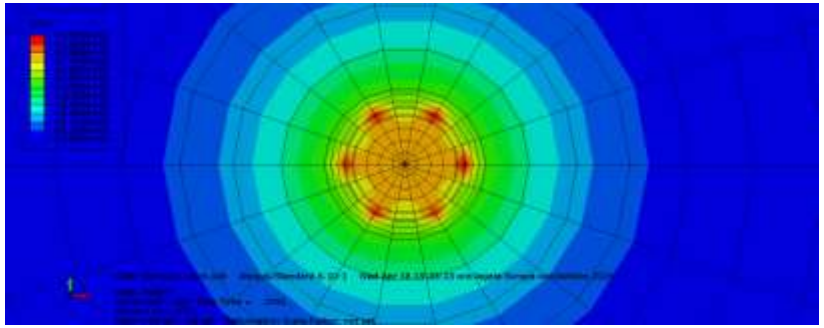
- Temperature contour lines evolution after 4 days of heat injection, cross-section view at pile mid-height

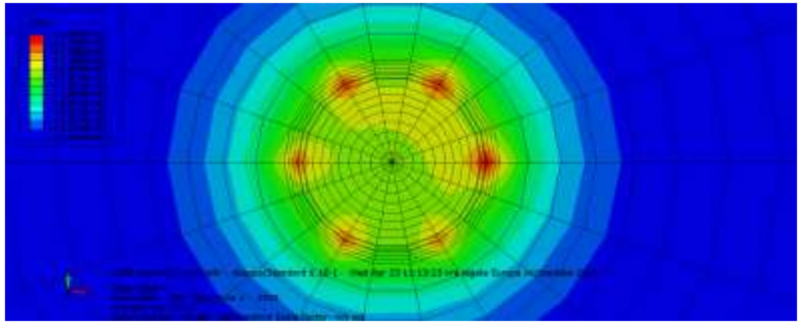


- Pile ∅=1 m, Single U-pipe

Design applications

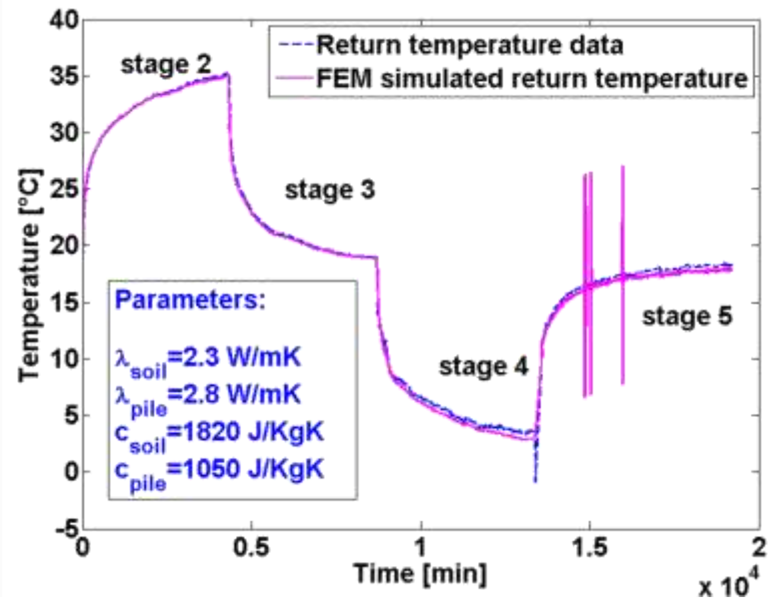
- Improved estimation of thermal properties during TRTs
  (back-calculating λ & c of soil & concrete by fitting measured T curves)
- Identification of the most important design parameters in enhancing energy efficiency, yet complying with geotechnical design
- Assessment of thermo-mechanical couplings that could interfere with the structural/geotechnical behaviour of the system (e.g. alteration of lateral bearing capacity)
- Application to other geothermal structures
  (e.g. tunnel linings, diaphragm walls…)





Example of design application/1:
Improved parameter estimation during TRTs

- Sensitivity analysis to identify best-fit values of thermal parameters for different TRT stages.

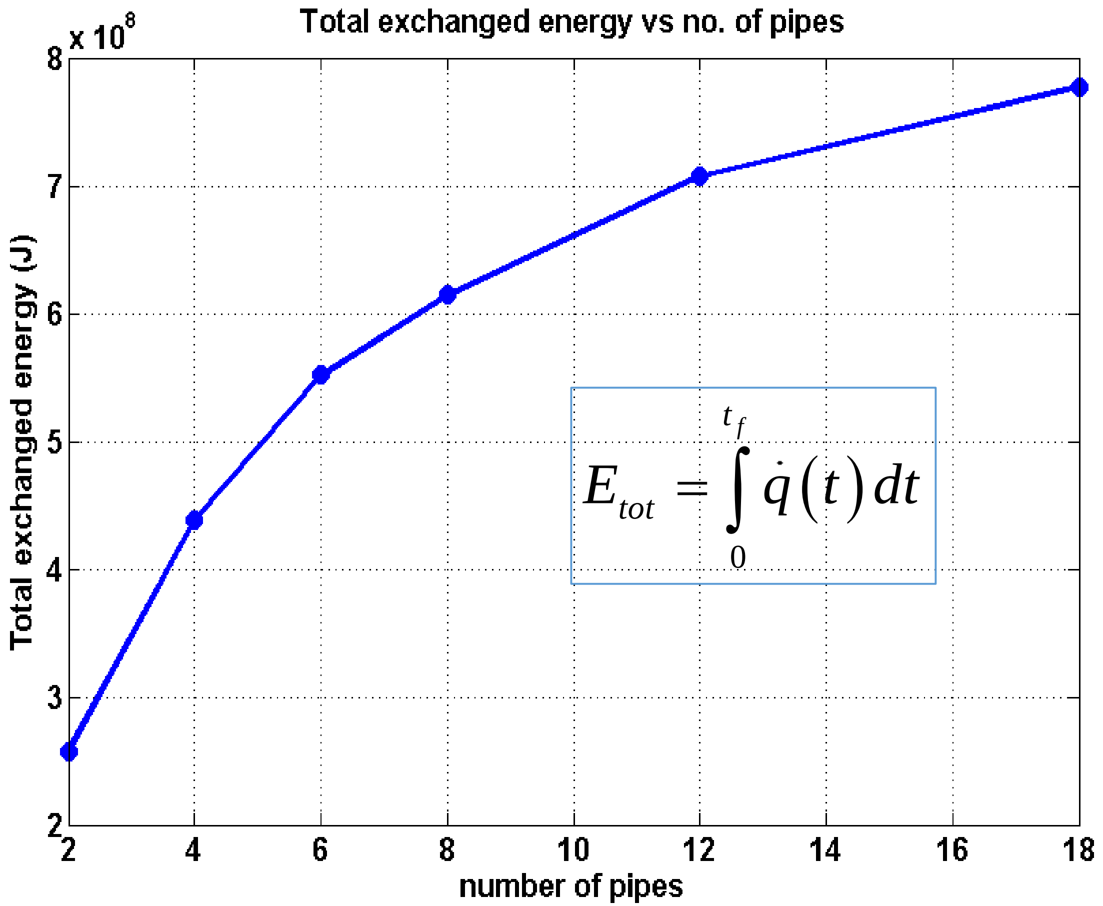


Simulation #	TRT stages	λ_c	λ_g	c_c	c_g	RMSE	Global RMSE
1	*2&3*	*2.8*	*2.3*	*1050*	*1820*	*0.2308*	*0.659*
	4&5	*2.8*	*2.3*	*1050*	*1820*	*0.8653*	
2	2&3	2.5	2.3	1050	1820	0.2826	0.670
	4&5	2.5	2.3	1050	1820	0.8686	
3	**2&3**	**2.8**	**2.2**	**1000**	**2100**	**0.2312**	**0.652**
	4&5	**2.8**	**2.2**	**1000**	**2100**	**0.8557**	
4	2&3	2.6	2.3	1050	2100	0.2532	0.669
	4&5	2.6	2.3	1050	2100	0.8750	
5	2&3	2.55	2.6	1000	2100	0.2917	0.666
	4&5	2.55	2.6	1000	2100	0.8635	

- More direct and accurate determination (compared to analytical and semi-empirical methods) of pile and ground physical properties λ_c, λ_g, c_c and c_g

Example of design application/2:
Energy efficiency vs no. of pipes installed

- Total exchanged energy after 4 days' heat injection simulation (initial ΔT=8°C) for a 1m diameter pile



Conclusions

- An innovative 3D model to accurately reproduce the main features of heat transfer in geothermal systems was developed.
- Validation against field data shows the model's good prediction capabilities.
- The model can be used to gain further insight into thermal and thermo-mechanical aspects of geothermal systems, leading to improved design criteria.

References

- Cecinato, F., Loveridge, A. (2015). "Influences on the thermal efficiency of energy piles". Energy (82) : 1021-1033. [doi:10.1016/j.energy.2015.02.001]
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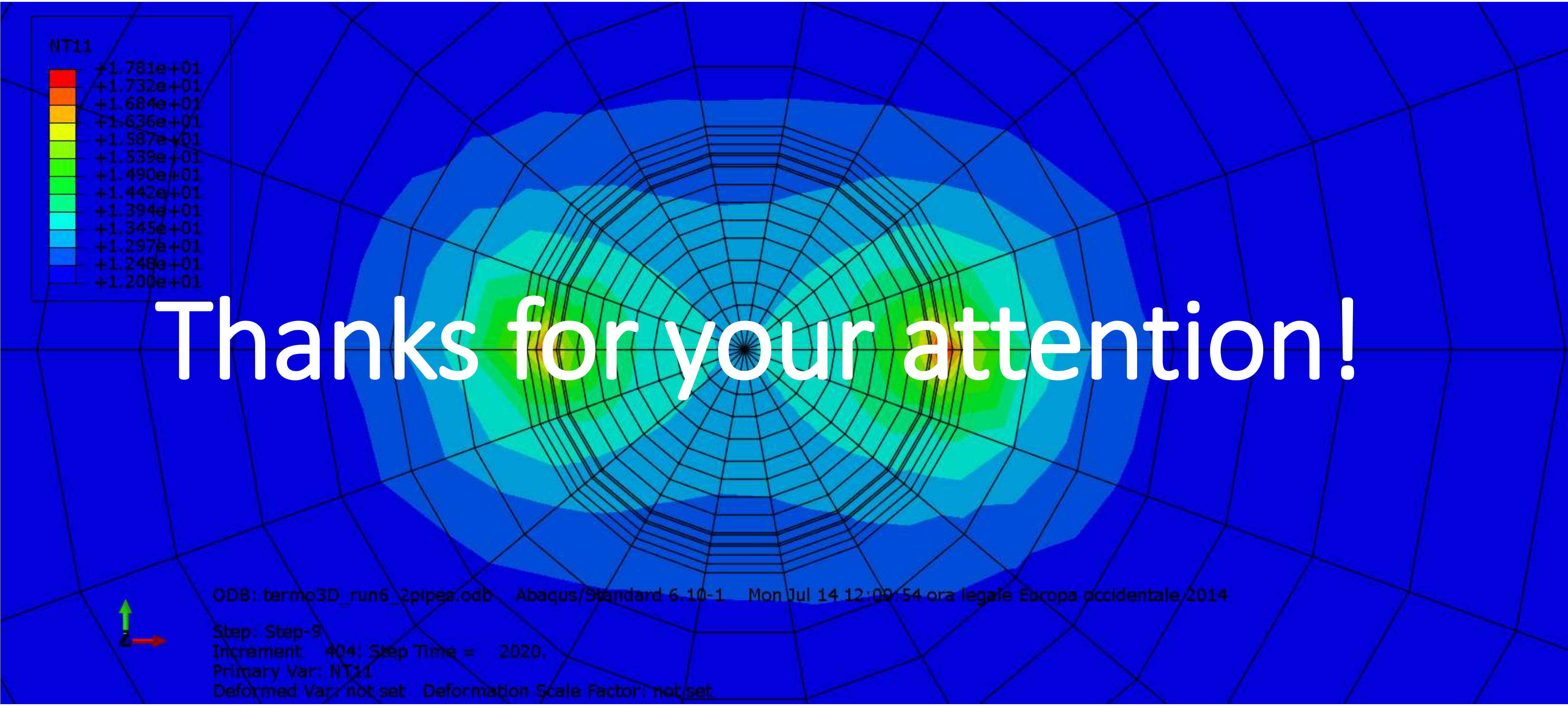

Thanks for your attention!