The University of Texas Rio Grande Valley

Verifying Long Term Effect Of Heat Injection Using a Fully Coupled Thermo-Hydro-Mechanical Model

Luther Medina, Dr Ben Xu, Dr Thuy Vu

Outline

I. Abstract & Introduction
II. Model Geometry
III. Boundary Condition
IV. Mesh
V. Results
VI. Future Work

Abstract

- Ground Heat Exchangers (GHX)
- GHX in warmer climates experience unbalanced heat injection
- Long term effect unknown
- Finite element numerical model necessary

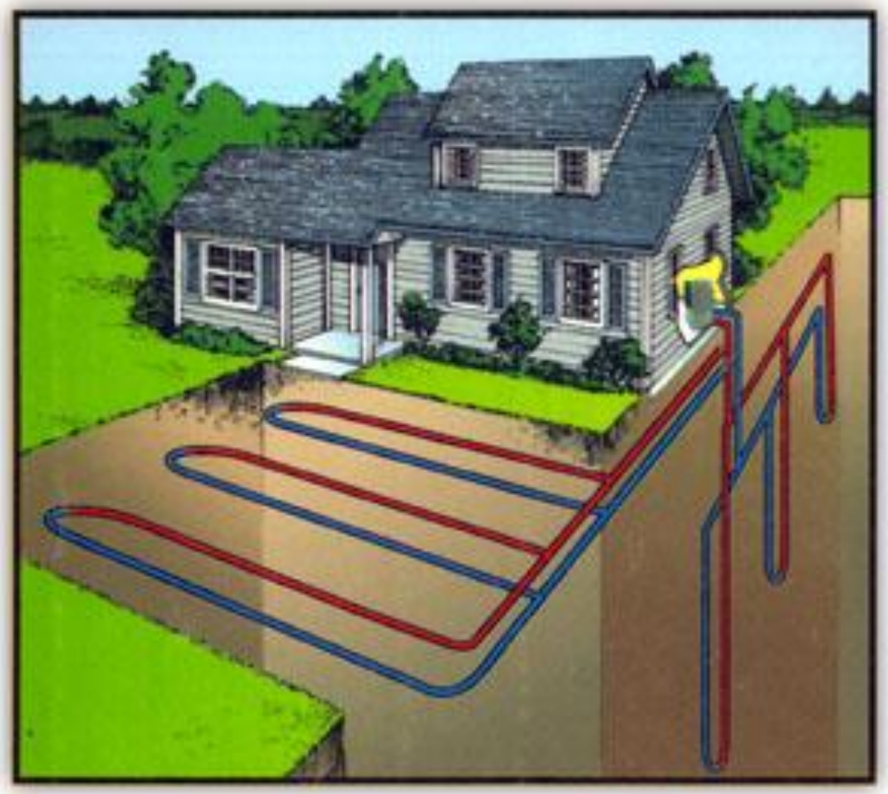


Figure 1. Vertical and Horizontal GHX

Introduction

- Geothermal Research
  - Site model in Mission, TX
  - Small scale box model
  - Finite element model

- Verify model using ATLAS III Boom Clay heat test in Mol, Belgium
  - Expansive clay soil
  - Step-wise heating cycle over 1 year
  - Measures change in temperature, Pore Water Pressure (pwp) and stress

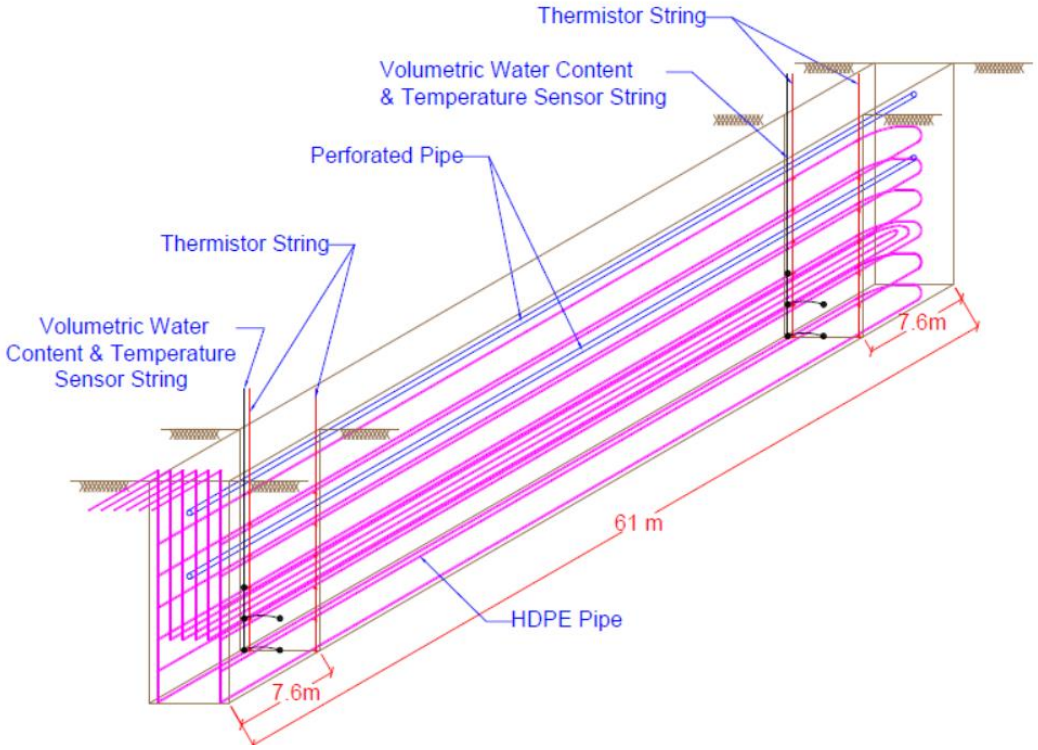
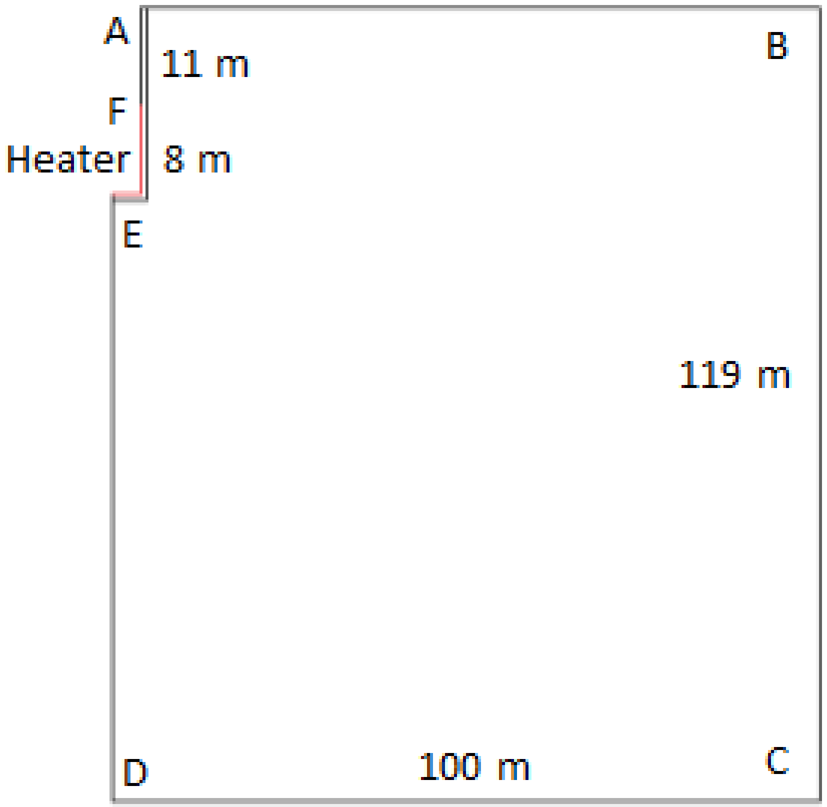


Figure 2. Site Geometry, Mission, TX

Model Geometry

- 2-D axisymmetric
  - Along ED boundary
- Soil domain is Boom Clay
  - R = 100m, Z = 119m
- Pipe domain is AISI 4340 steel
  - R = .095m, t = .015m, Z = 19m
  - Heater located at bottom 8m
- Measurements taken at (1.6, -14.6)



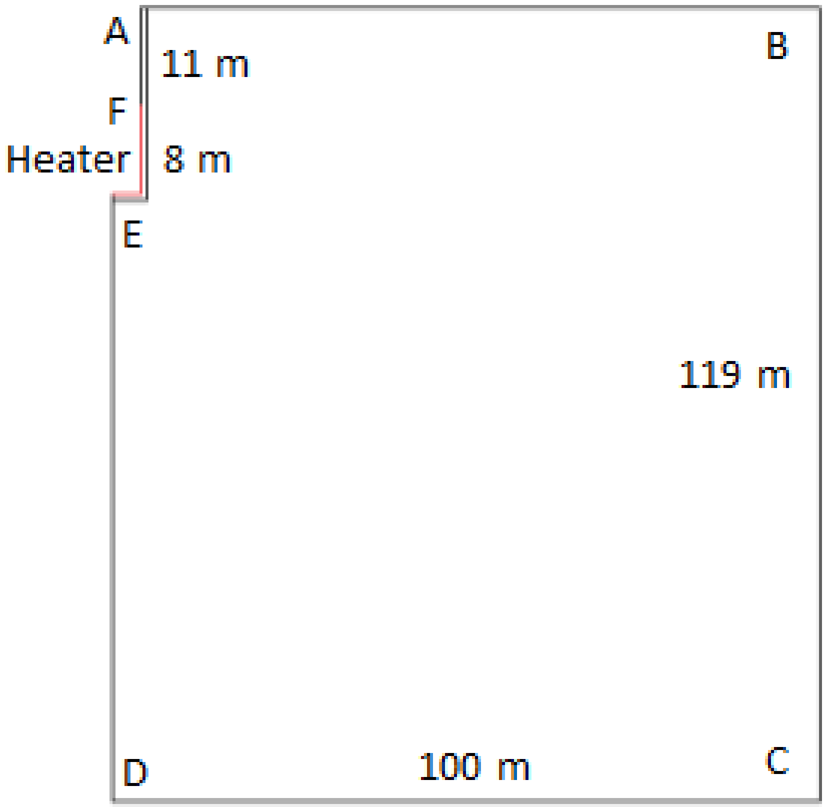
Boundary Condition

- Heat Transfer in Porous Media *(ht)*
  - Porous Medium 1
  - Initial Values 1
  - Axial Symmetry 1
  - Thermal Insulation 1
  - Solid 1
  - Heat Flux 1
  - Heat Flux 2

$$\boldsymbol{i}_c = -\lambda \nabla T$$

Day no.	P(t)
0-4	$-25(t-4)^2+400$
4-49	400
49-54	$-10(t-54)^2+900$
54-120	900
120-125	$-10(t-25)^2+1400$
125-381	1400
381-945	0

Heating and cooling cycle as function of time, in Watts and Days



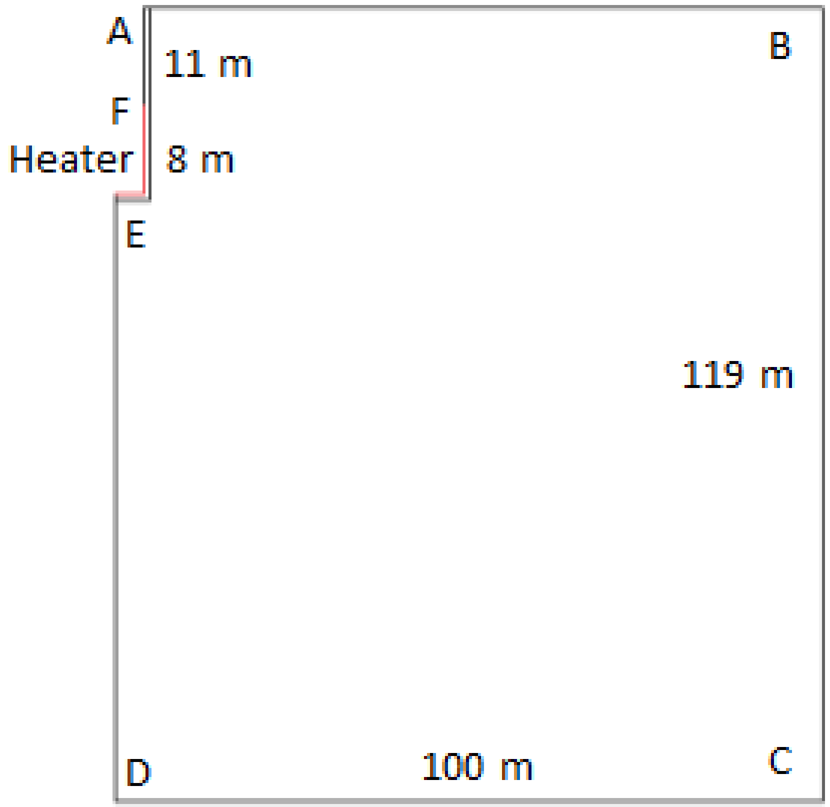
Boundary Condition (cont.)

- Darcy's Law *(dl)*
  - Fluid and Matrix Properties 1
  - Axial Symmetry 1
  - No Flow 1
  - Initial Values 1
  - Mass Source 1
  - Poroelastic Storage 1
  - Pressure 1

$$q_l = -\frac{k}{\mu_l}(\nabla p_l - \rho_l \mathbf{g})$$

$$\mu_l(T) = 2.1 \times 10^{-12} \exp \frac{1808.5}{273.15+T}$$

$$\rho_l(T, p_l) = \rho_0 \cdot \exp(\beta(p_1 - p_0) + \alpha T)$$



Boundary Condition (cont.)

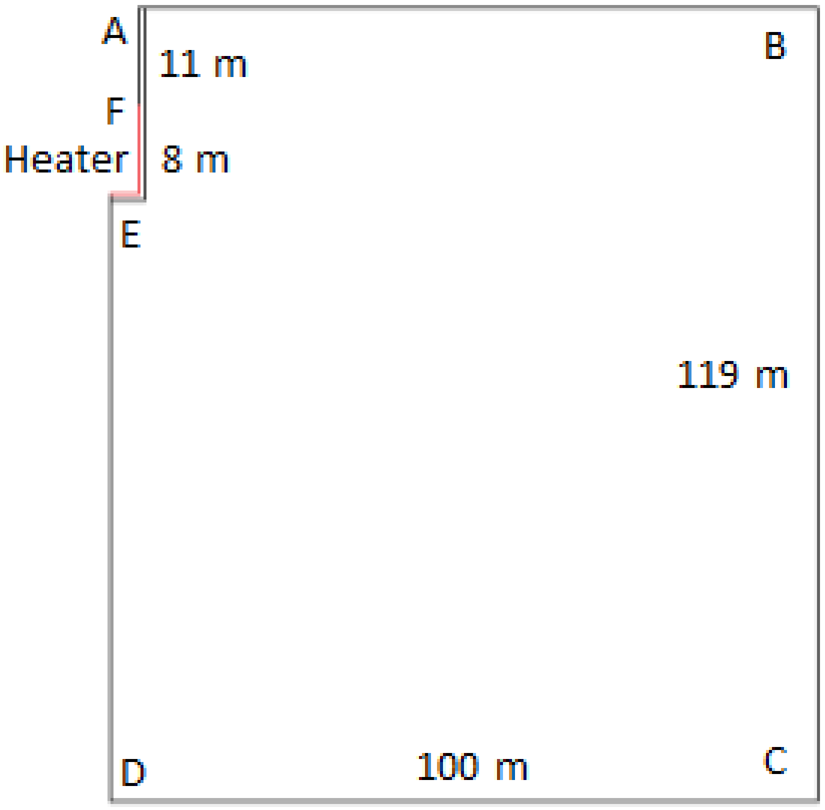
- Solid Mechanics *(solid)*
  - Linear Elastic Material 1
    - Soil Plasticity 1
    - External Stress 1
    - Initial Stress and Strain 1
    - Thermal Expansion 1
  - Axial Symmetry 1
  - Free 1
  - Initial Values 1
  - Roller 1
  - Fixed Constraint 1
  - Boundary Load 1

$$\nabla \cdot \boldsymbol{\sigma} + \mathbf{b} = 0$$

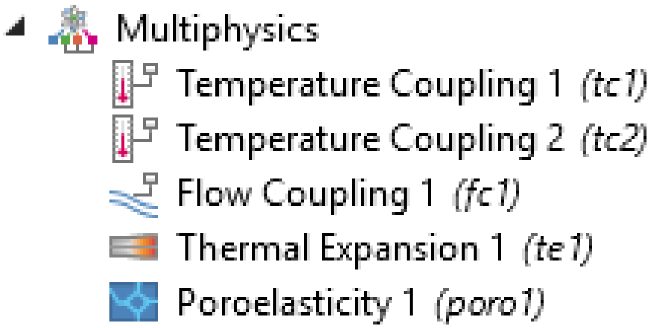
$$F = \sqrt{J_2} + \alpha I_1 + k$$

$$\alpha = \frac{2 sin\phi}{\sqrt{3}(3 - sin\phi)}$$

$$k = \frac{2\sqrt{3} c cos\phi}{(3 - sin\phi)}$$



Multiphysics



Mesh

- Free Triangular
- 65687 Elements
- Max element size: 1m
- Min element size: .001m
- Element growth rate: 1.1
- 228390 degrees of freedom

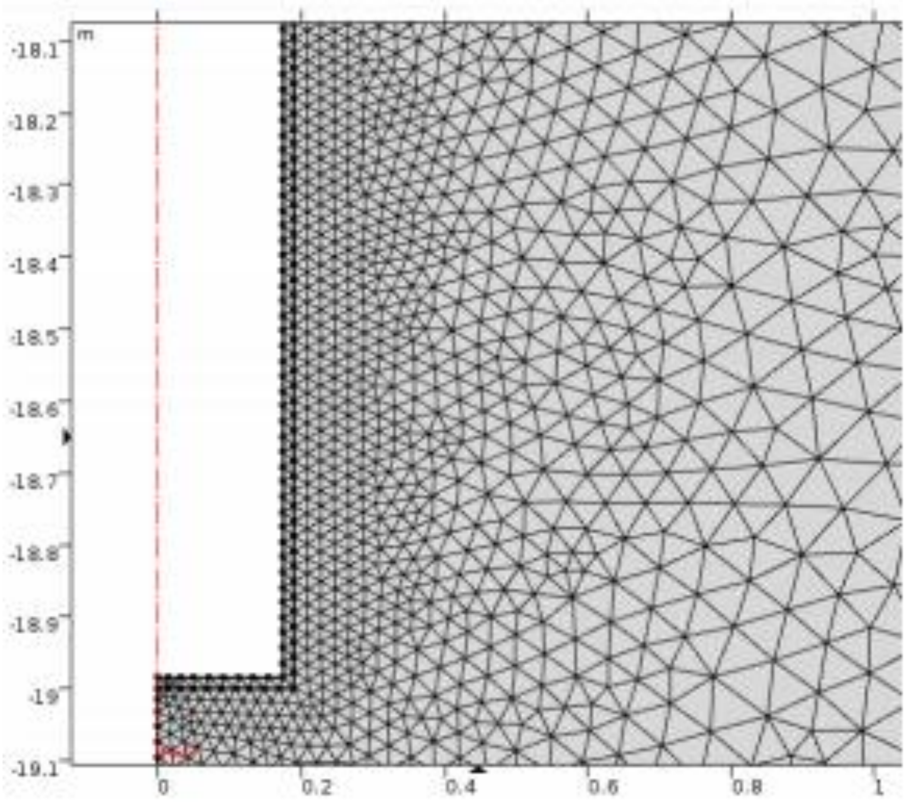


Figure 3. Mesh geometry at pipe

Results

- Temperature change due to heating cycle
- Vicinity of pipe retains temperature

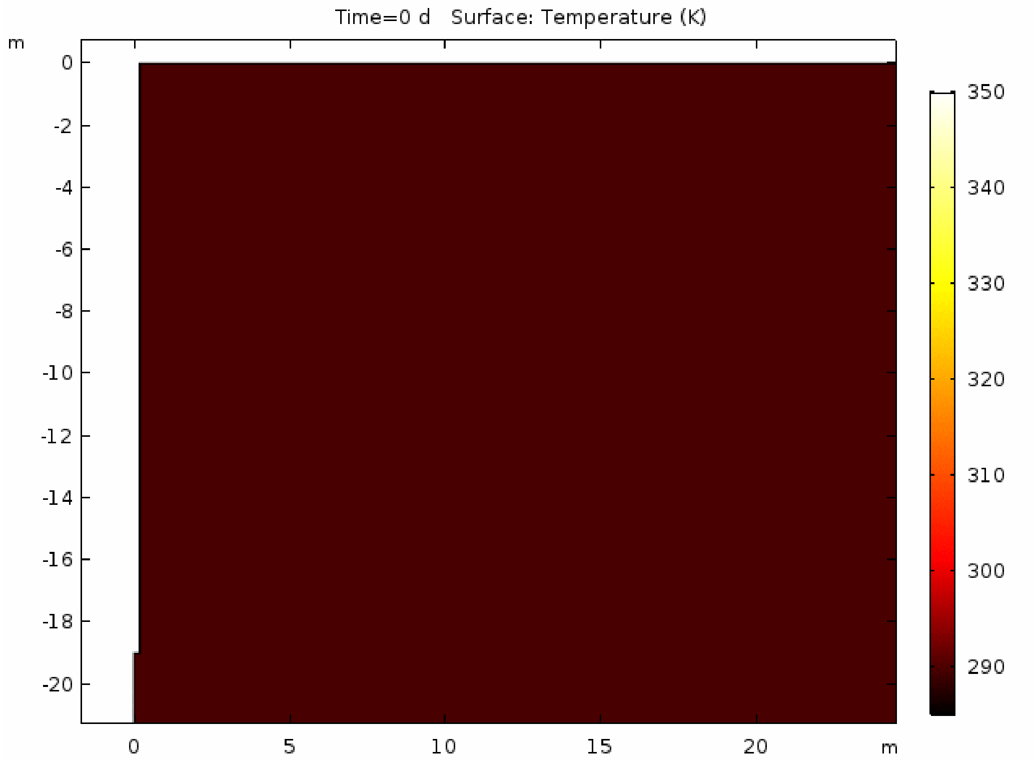


Figure 4. Change in Temperature over time

Results (Cont.)

- Similar trends observed as power increases and heater is shutoff
- Model temperature changes prematurely relative to heat cycle

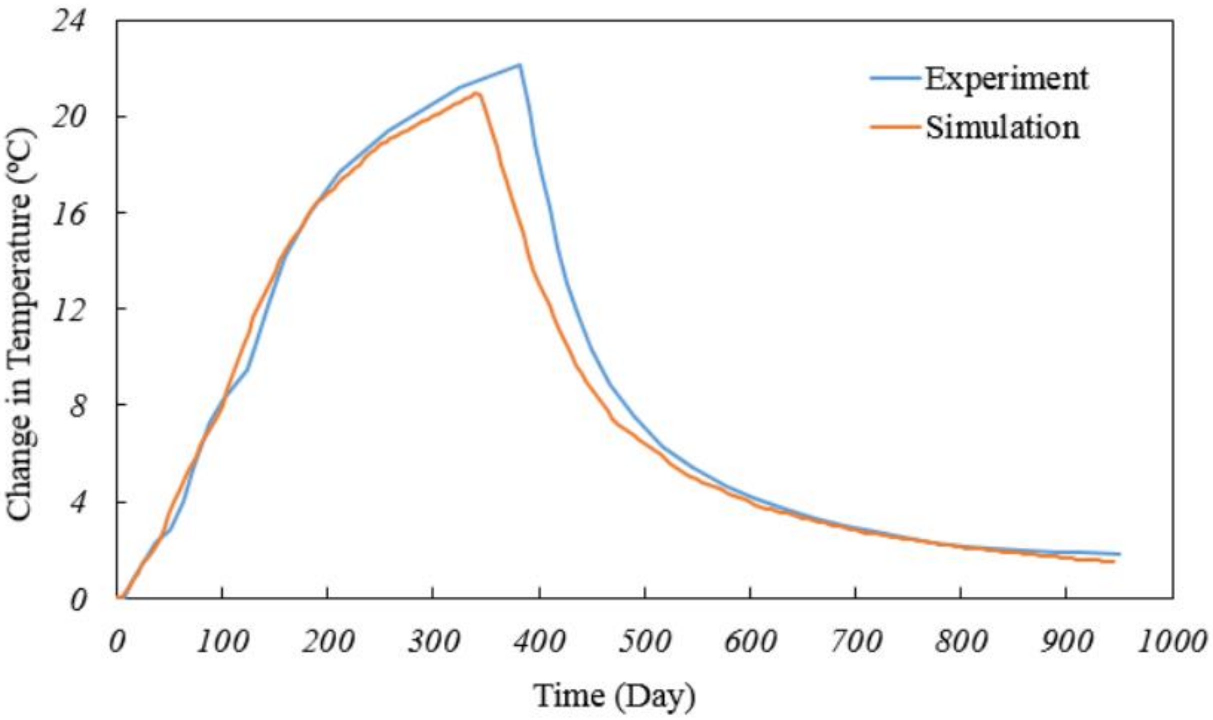


Figure 5. Change in Temperature over time at point (1.6, -14.6)

Results (Cont.)

- As temperature increases, PWP also increases
  - Experiences momentary decrease in pwp during heating phase

- Experiences drop in pwp, when heater shut off

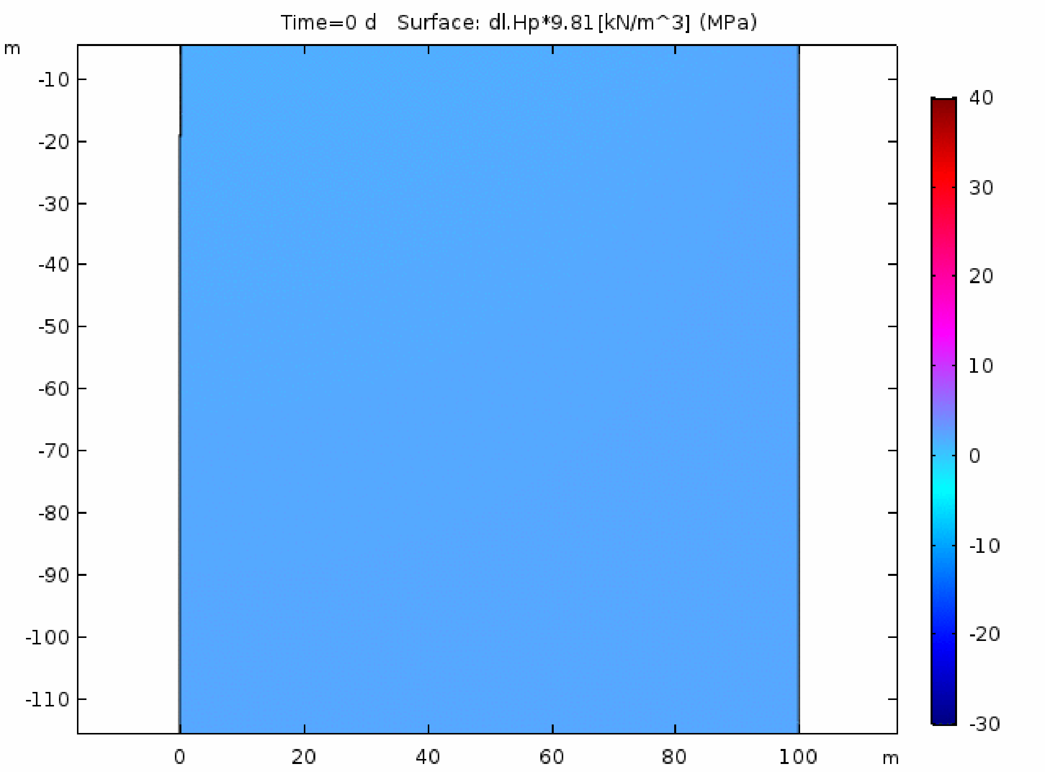


Figure 6. Change in Pore Water Pressure over time

Results (Cont.)

- Model and experiment experience similar trend
- Range of values for experiment is inaccurate

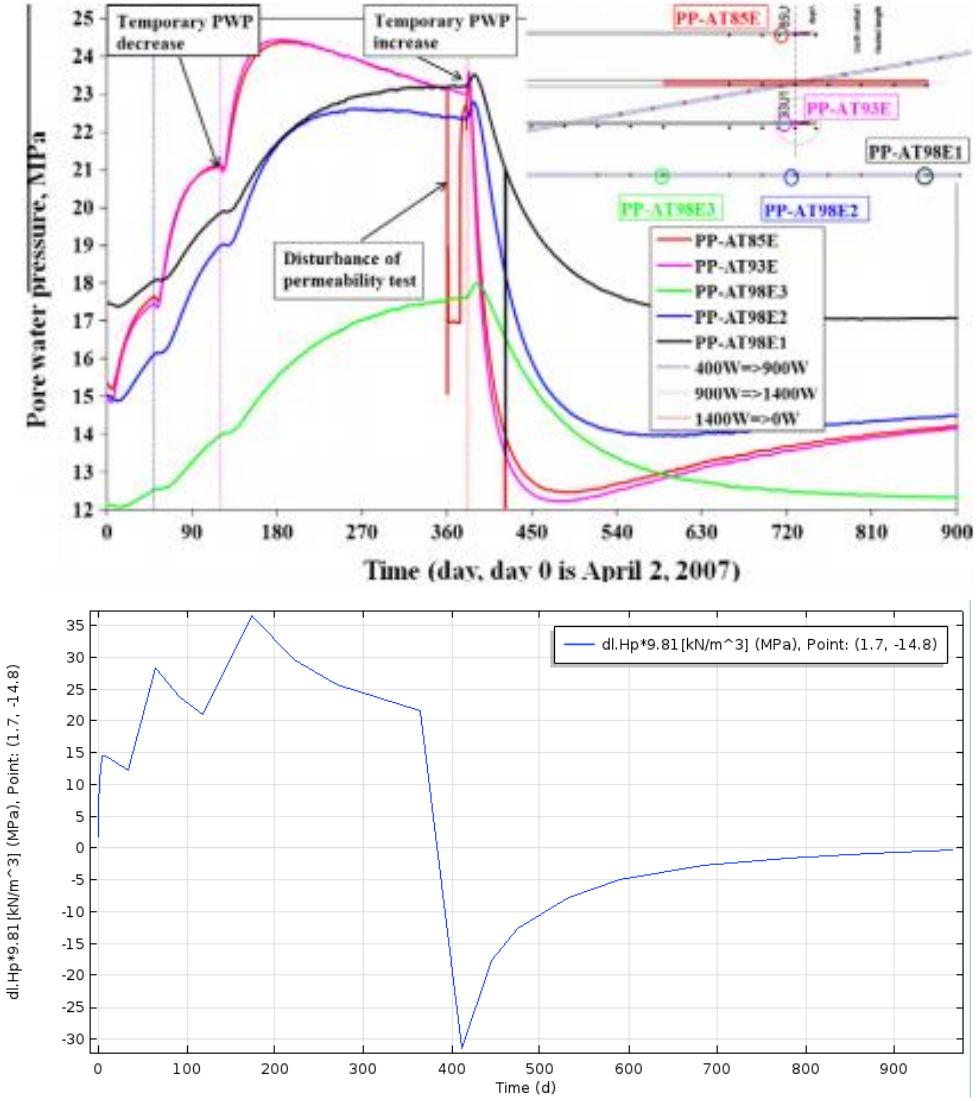


Figure 6. Change in Pore Water Pressure over time comparison

Results (Cont.)

- Geomechanics module currently unstable
  - Initial stress/strain values do not converge

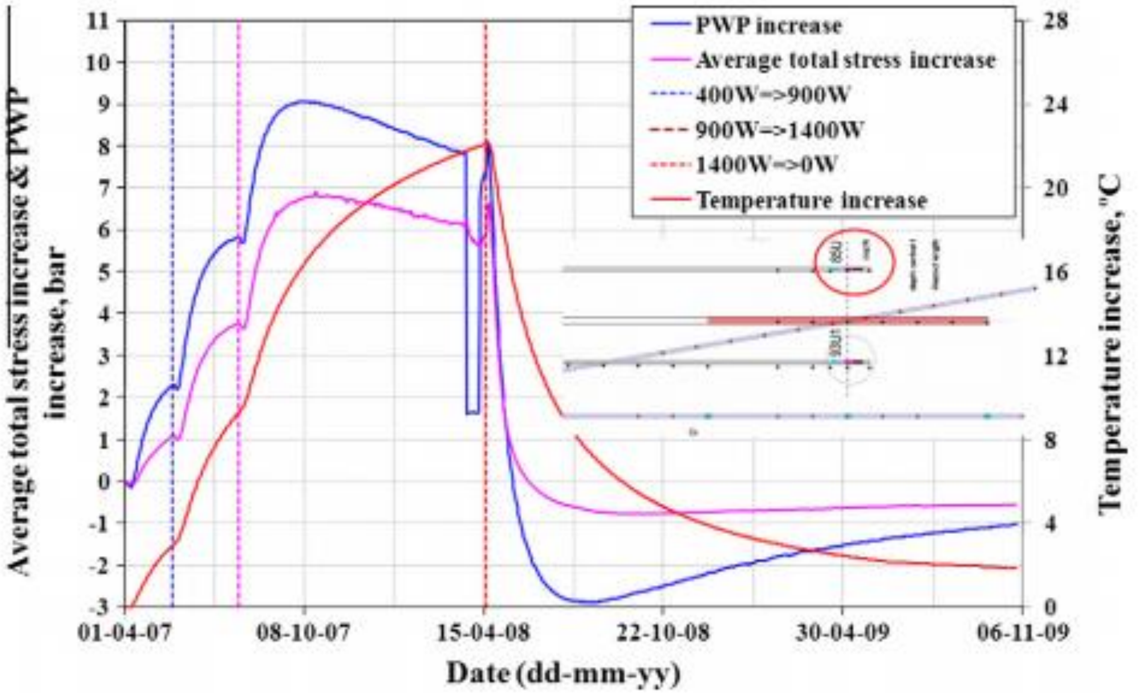


Figure 6. Experimental values for total stress change over time

Conclusion

- Heat transfer module produces similar results
  - Heat cycle function requires revision
  - Possible issues with volume fraction (assumed to be 1)
- Darcys Law module recreates trends in pwp change
  - Major improvement necessary to fix data range
- Geomechanics module is not functional
  - Revision need for boundary condition as well as initial stress/strain values

Future Works

- Improvement of modules and application of Anisotropic THM parameters
- Recreation of site model and validation based on measured data
- Long term study (40+ years)

Acknowledgements

- The University of Texas Rio Grande Valley college of Engineering and Computer Science undergraduate research program
- Department of Civil Engineering
- Department of Mechanical Engineering

References

- Chen, G., Sillen, X., Verstricht, J. & Li, X. ATLAS III in situ heating test in boom clay: Field data, observation and interpretation. Computers and Geotechnics 38, 683–696 (2011).
- Han, C., Ellett, K. M., Naylor, S. and Yu, X. (B.: Influence of local geological data on the performance of horizontal ground-coupled heat pump system integrated with building thermal loads, Renewable Energy, 113, 1046–1055.
- Li, W., Li, X., Wang, Y. and Tu, J.: An integrated predictive model of the long-term performance of ground source heat pump (GSHP) systems, Energy and Buildings, 159, 309–318.
- Zhao, Z., Shen, R., Feng, W., Zhang, Y. and Zhang, Y.: Soil Thermal Balance Analysis for a Ground Source Heat Pump System in a Hot-Summer and Cold-Winter Region, Energies, 11(5), 1206.