SAND2016-3526PE

Update on Simulations of WIPP Room D Closure

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Sandia National Laboratories

Joint Project WEIMOS Workshop 1

Clausthal, April 21st-22nd, 2016

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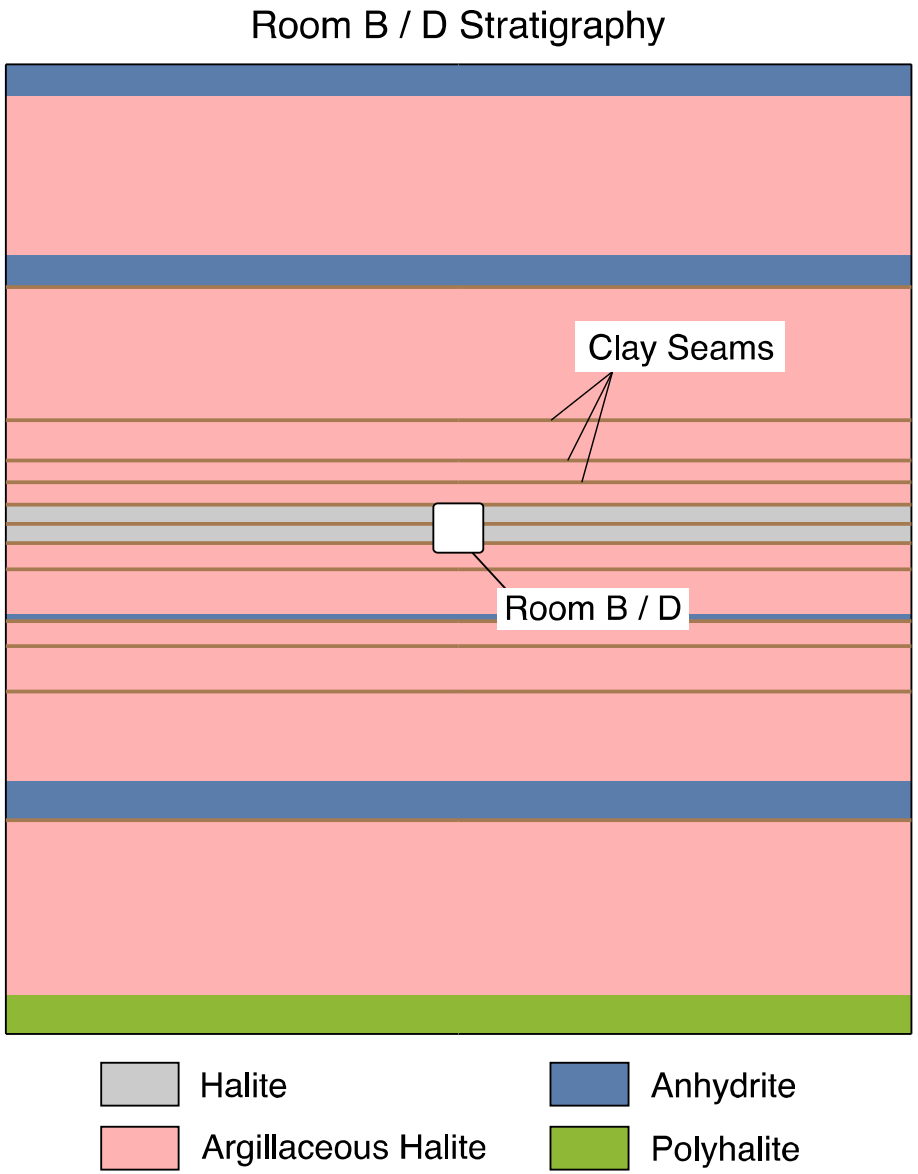
Outline

- Legacy simulations
- Resolving the legacy simulation numerics
- Joint Project III simulations
- Preliminary recalibration of the Munson-Dawson model
- Future Work



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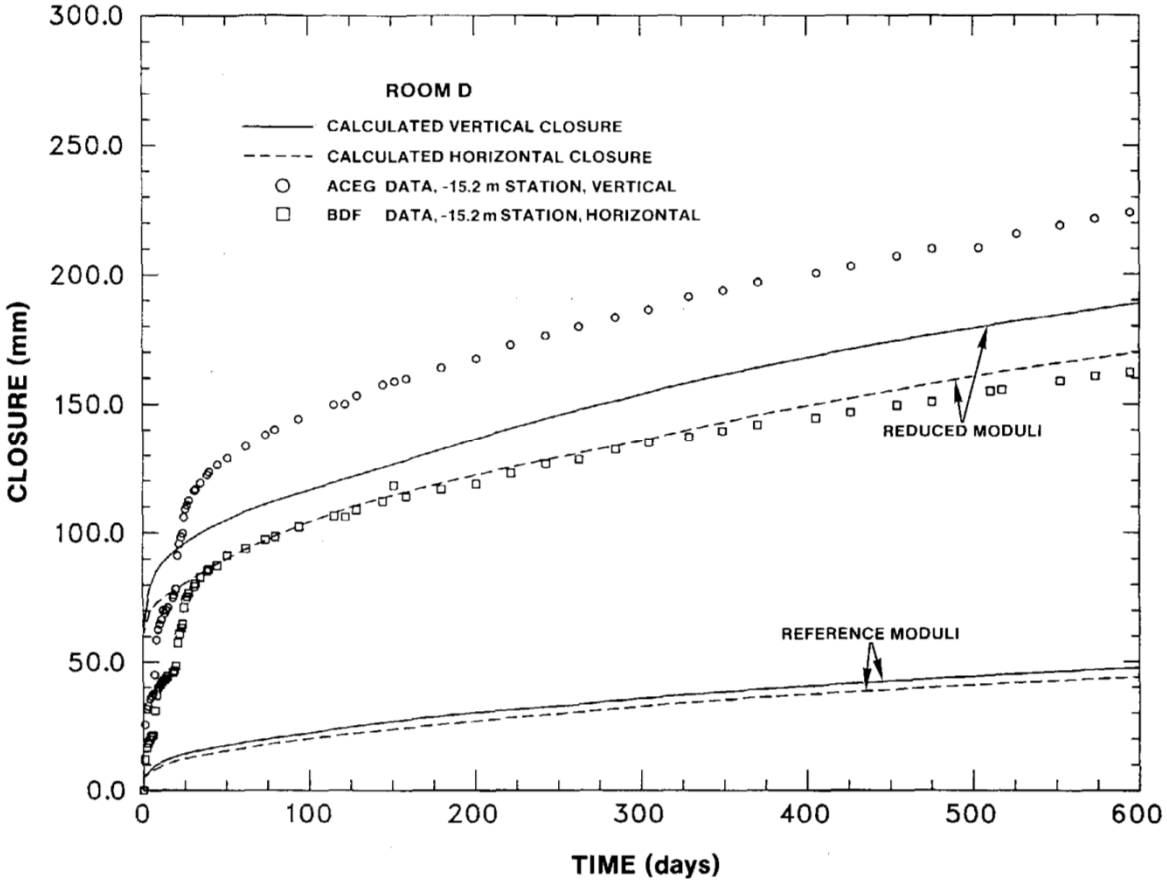
Legacy Simulations

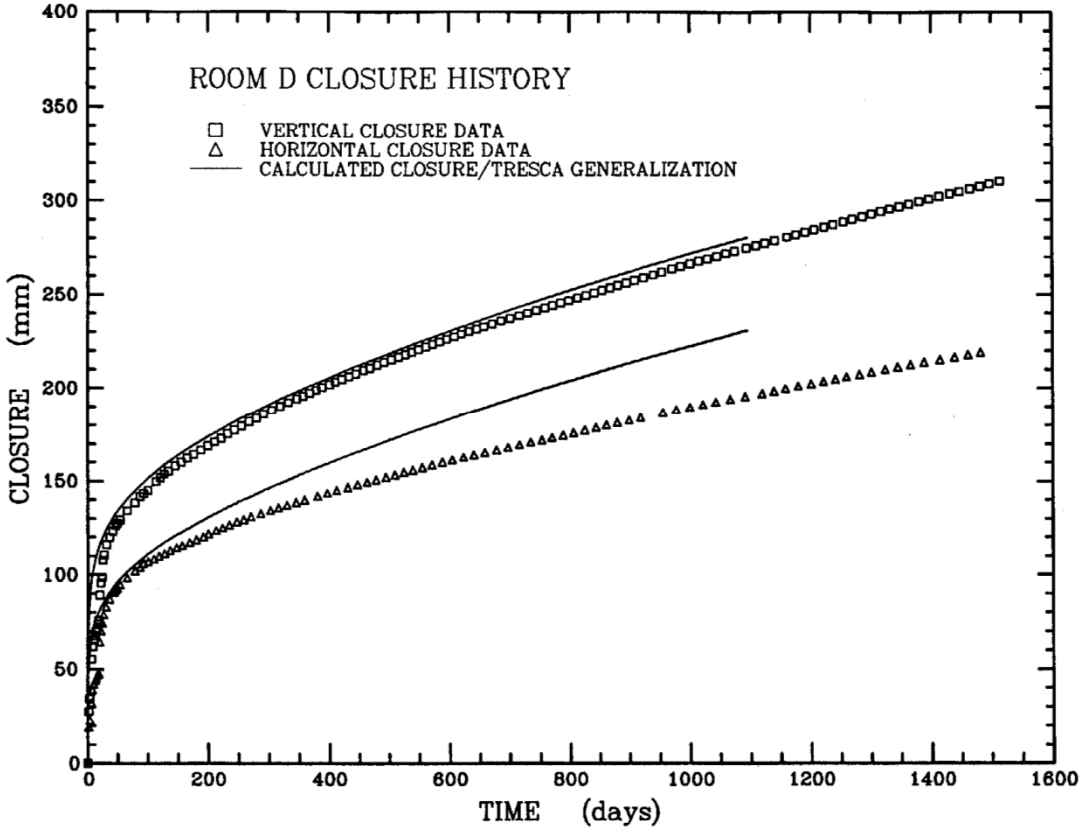
Legacy Simulations



Munson, D., Torres, T. Jones, R. Pseudostrain representation of multipass excavations in salt. 28th Symposium on Rock Mechanics. July 1987

Legacy Simulations

- Switched from von Mises to Tresca flow potential
- Switched from mostly clean salt to mostly argillaceous salt
- Altered the material model calibrations
  - Argillaceous transient strain limit treated as a free parameter
- Clay seam friction coefficient treated as a free parameter

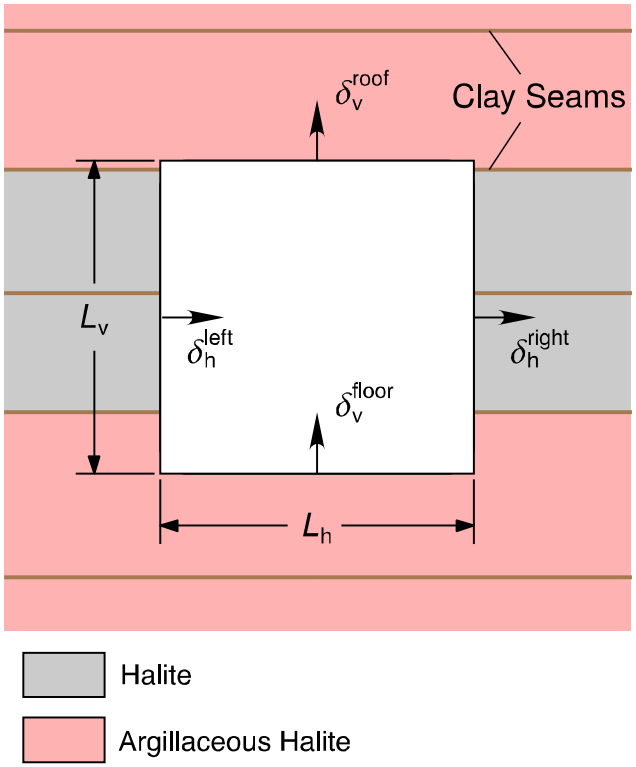


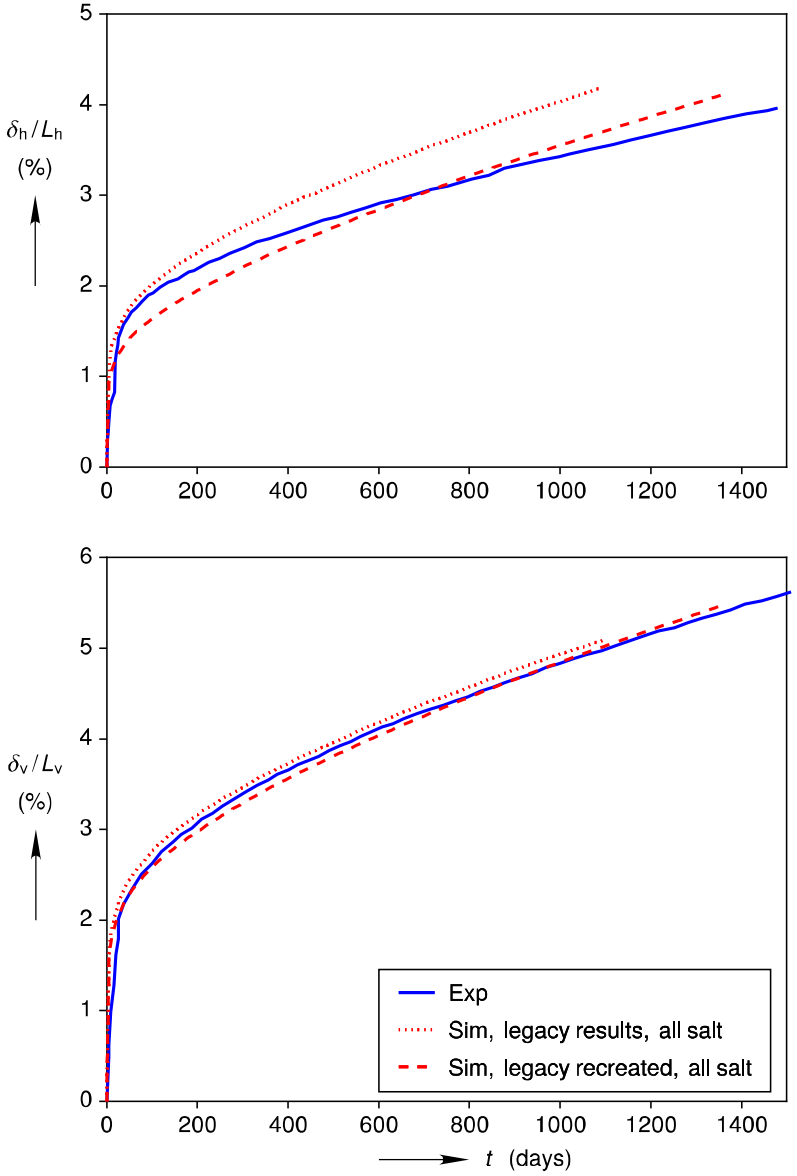
Munson, D., Fossum, A. Senseny, P., Advances in Resolution of Discrepancies Between Predicted and Measured In Situ WIPP Room Closures, SAND88-2948, 1988

Re-creation of Legacy Simulations

$$\delta_h = \delta_h^{right} - \delta_h^{left}$$

$$\delta_v = \delta_v^{floor} - \delta_v^{roof}$$





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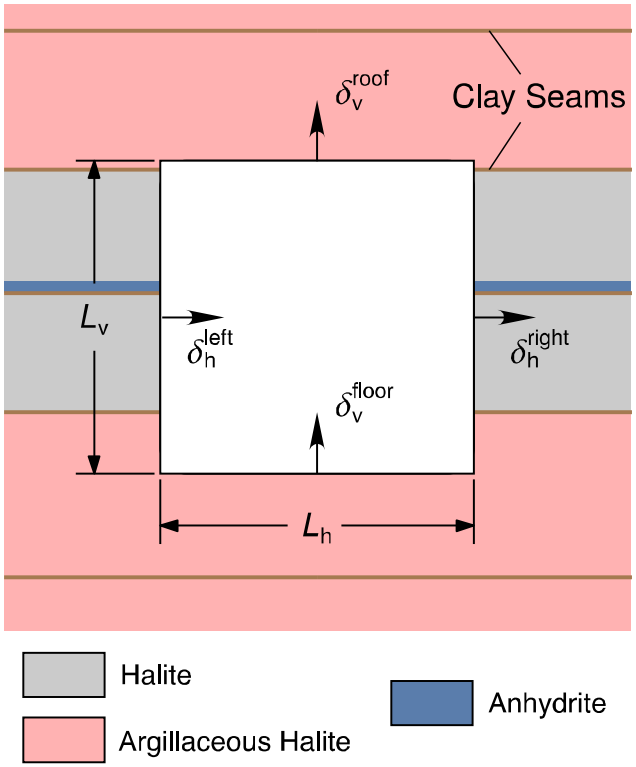

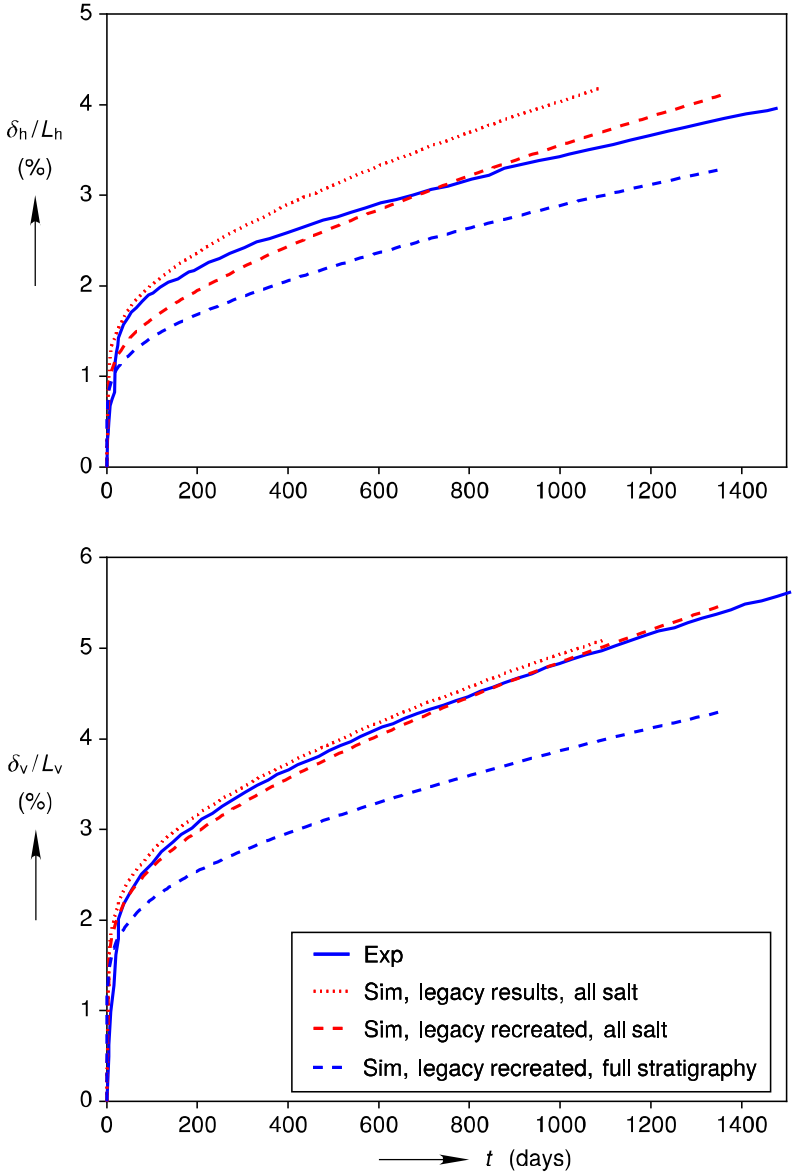

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Resolving the Legacy Simulation Numerics

Initial Mesh Convergence Study

$$\delta_h = \delta_h^{right} - \delta_h^{left}$$

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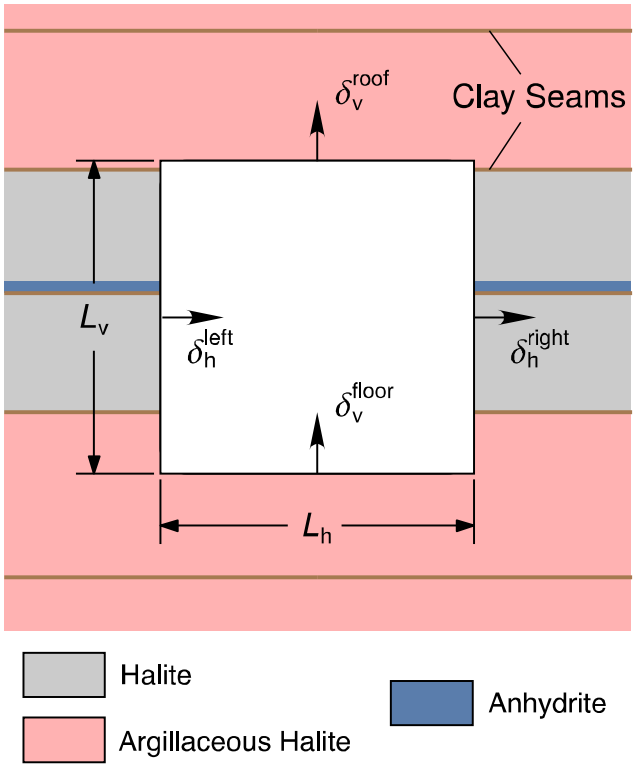
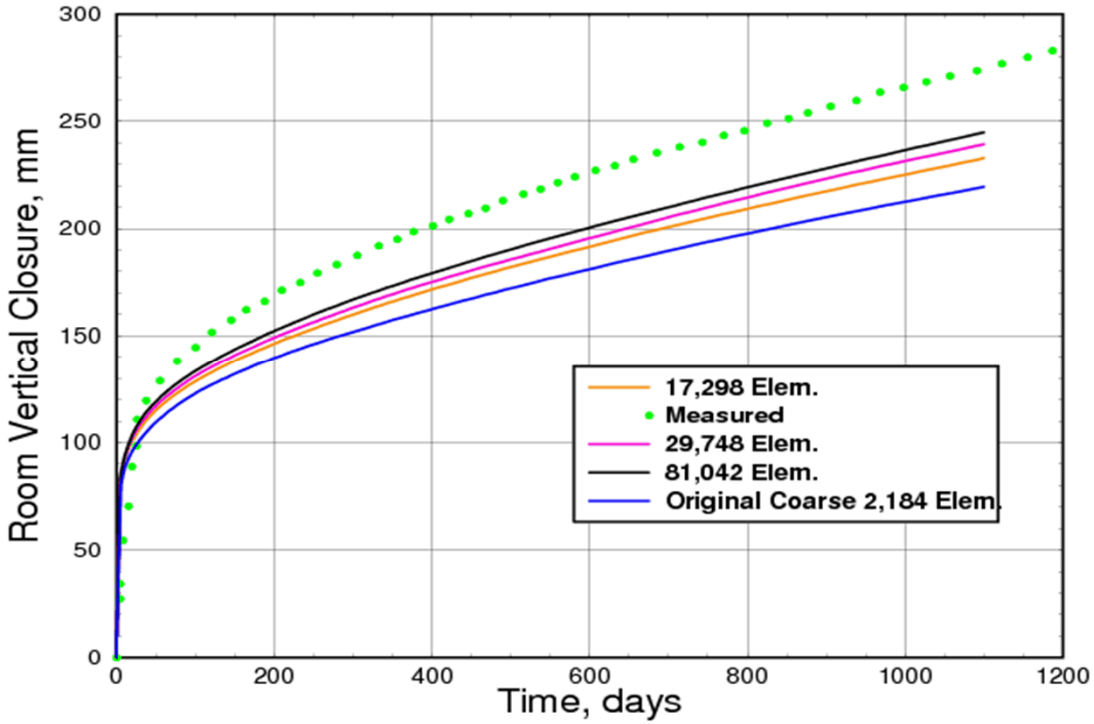
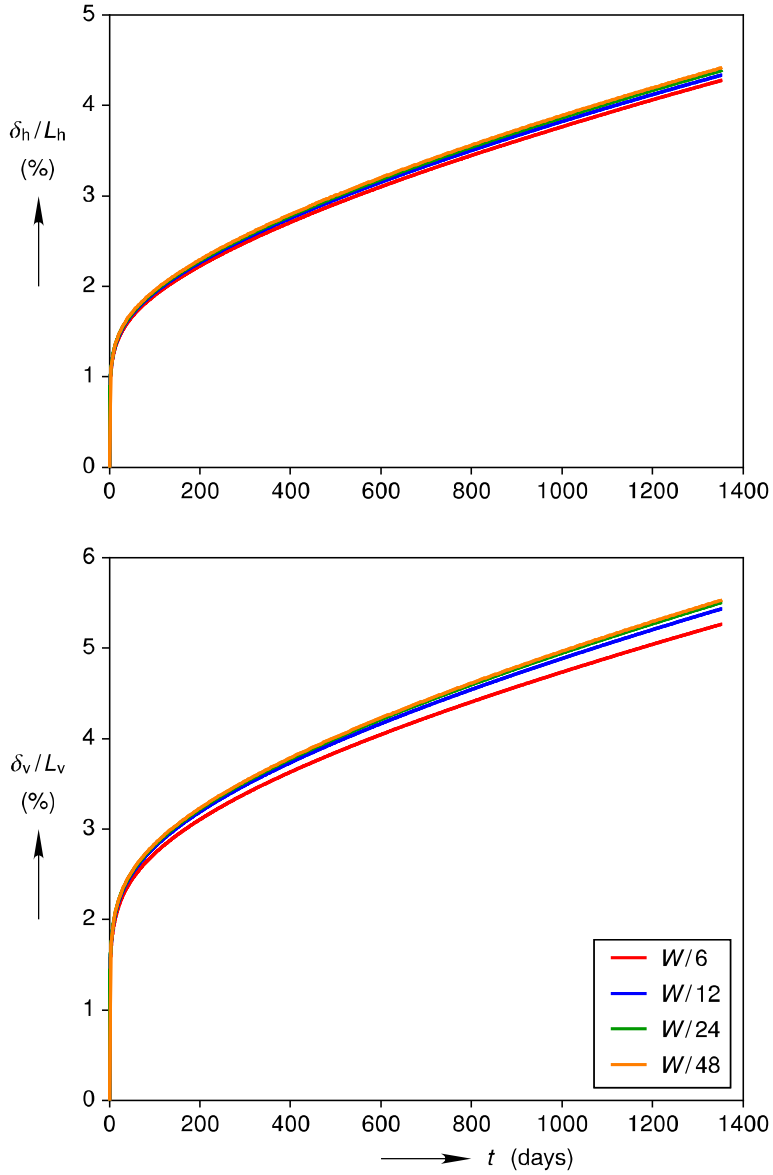




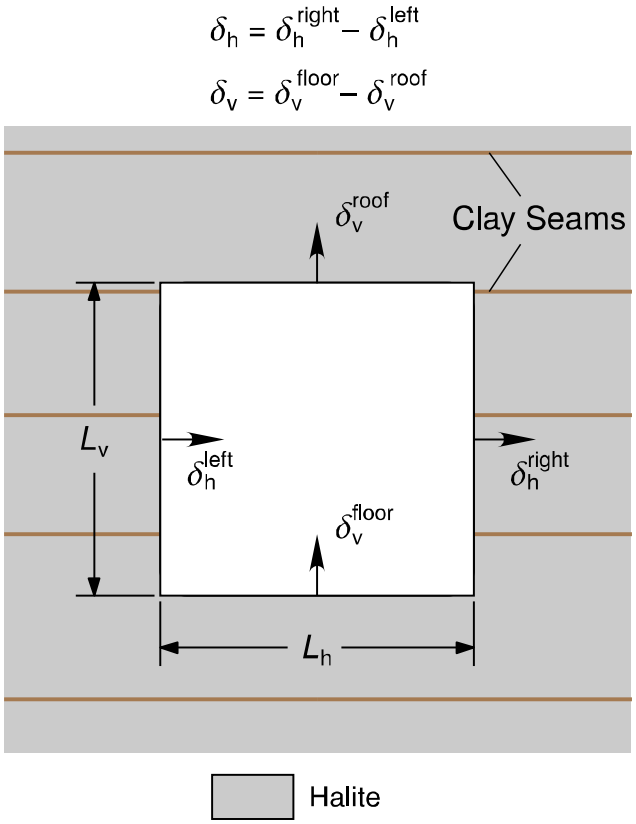
Arguello, J., Summary of FY15 Results of Benchmark Modeling Activities, SAND2015-6273, 2015

New Mesh Convergence Study

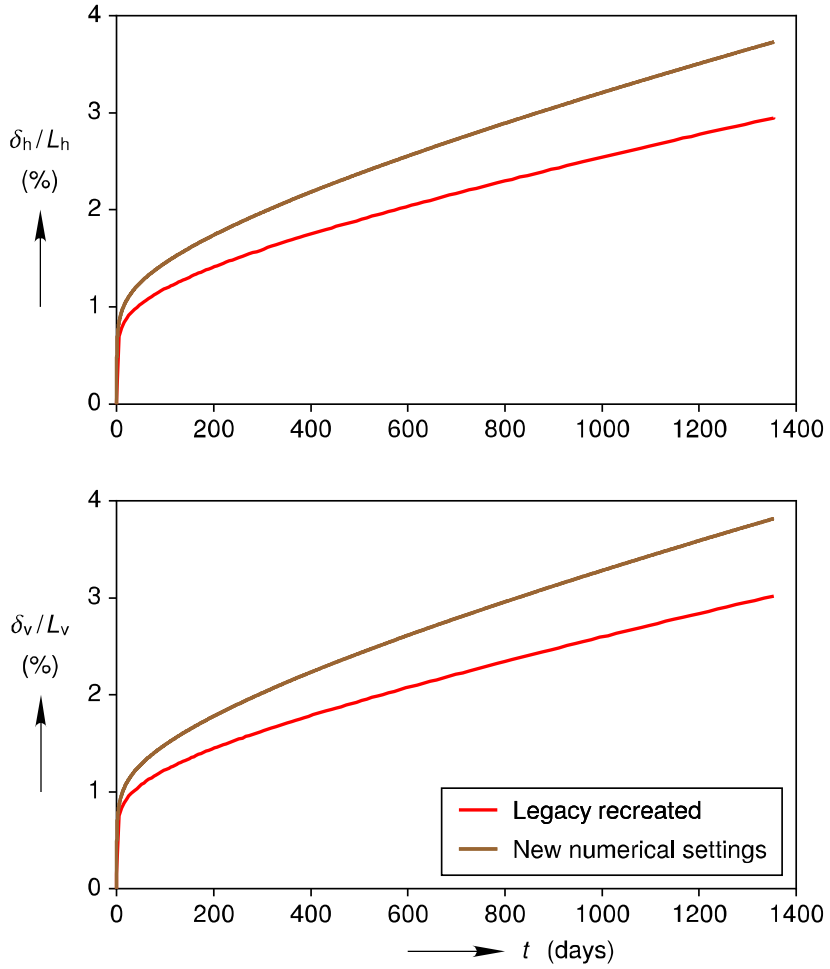
- Changed the mesh
- Changed R_{tol} =10^{-3} to R_{tol} =10^{-5}
- Switched from MQ to SD element
- Switched from Kinematic Contact to Augmented Lagrange Contact enforcement
- Added a pressure ramp down
- Switched to an associative flow rule for the anhydrite



Effects of Numerical Choices



Same mesh density at room



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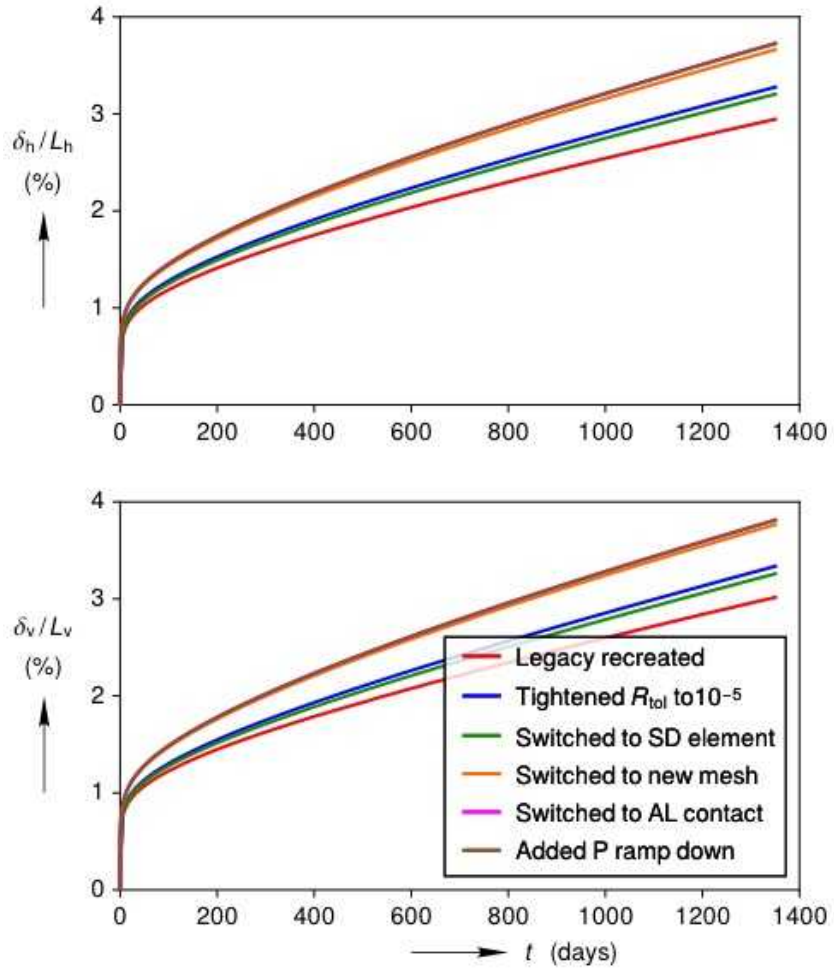
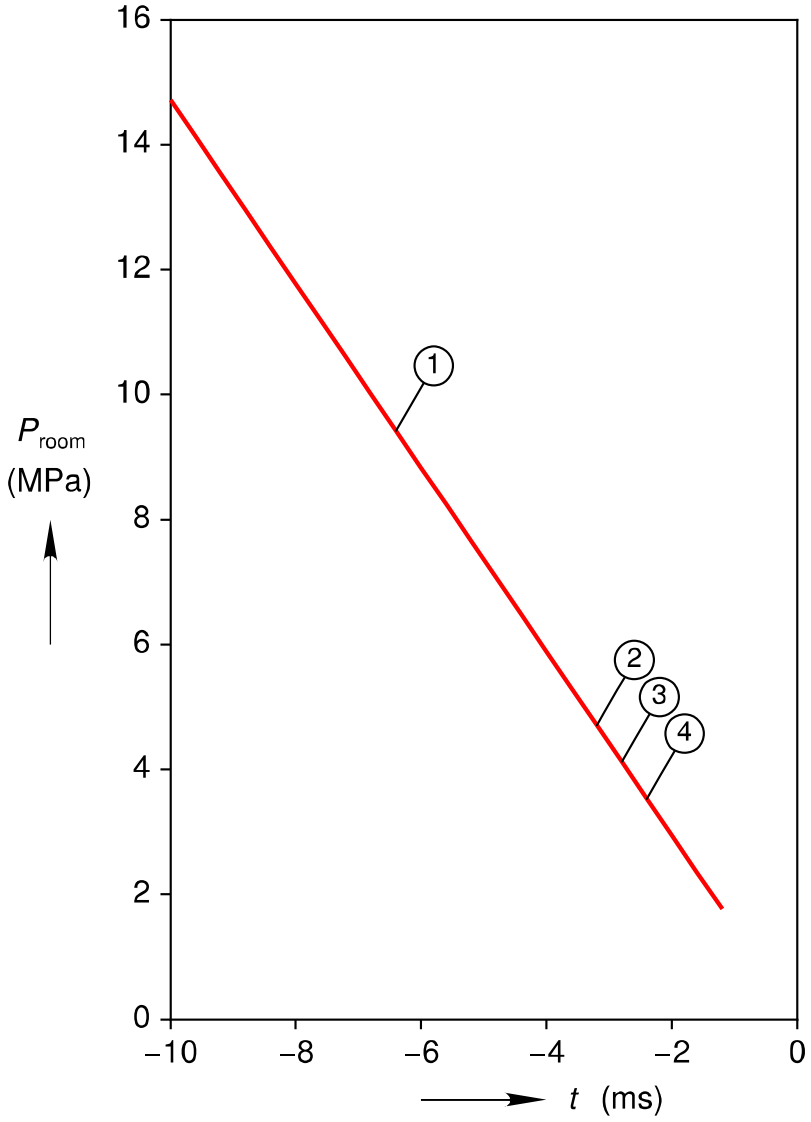
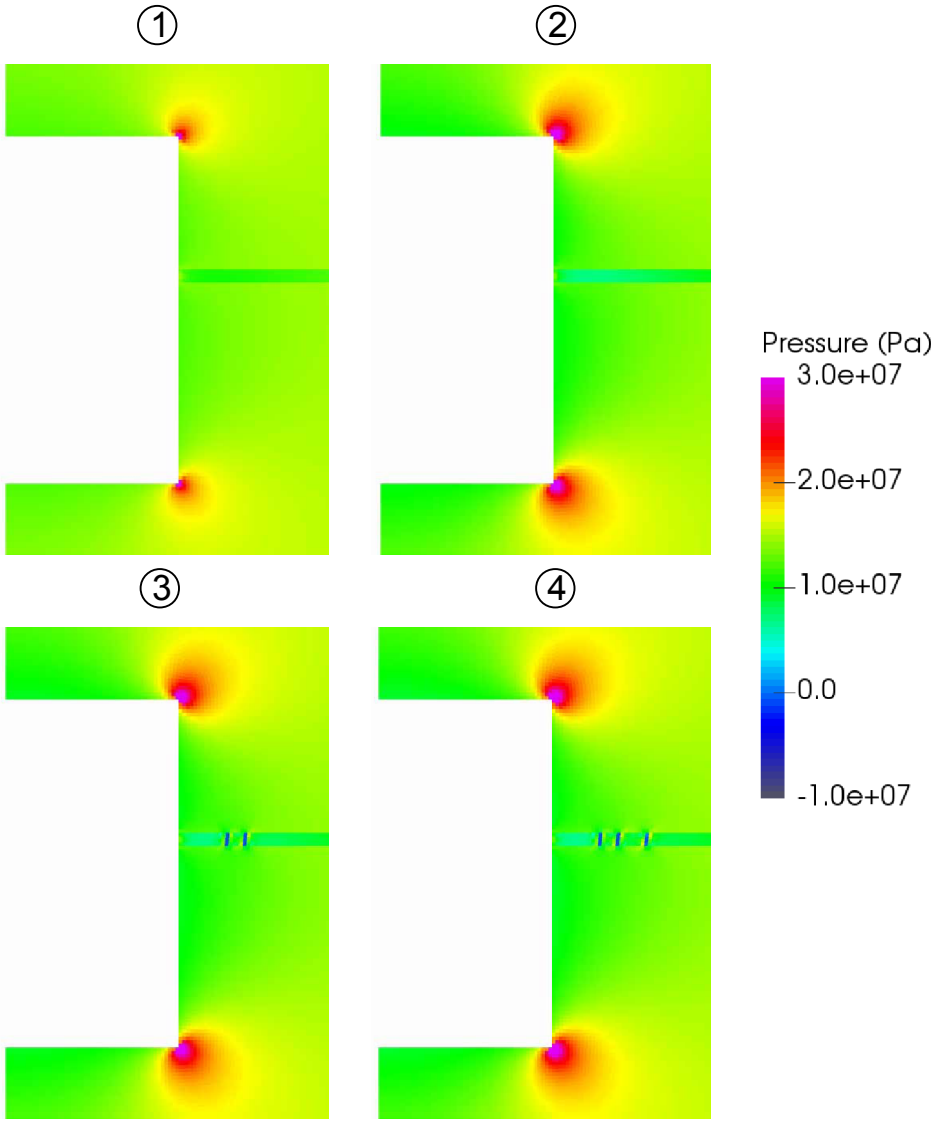
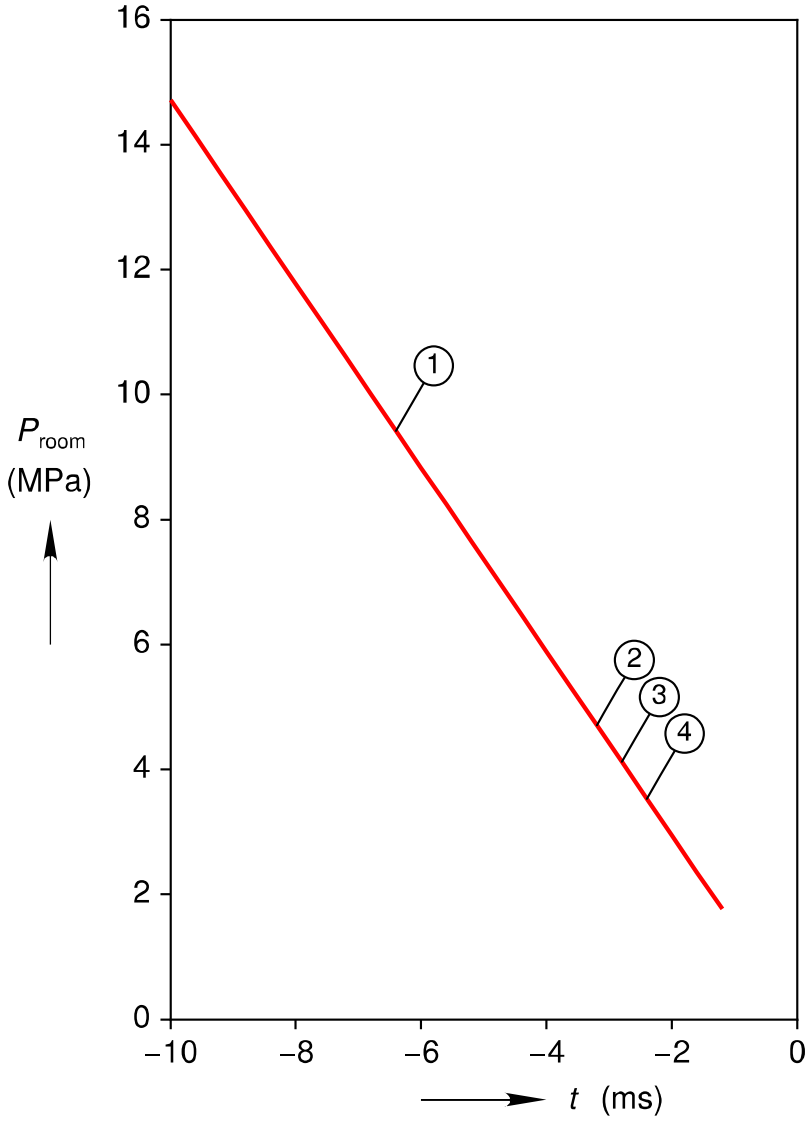


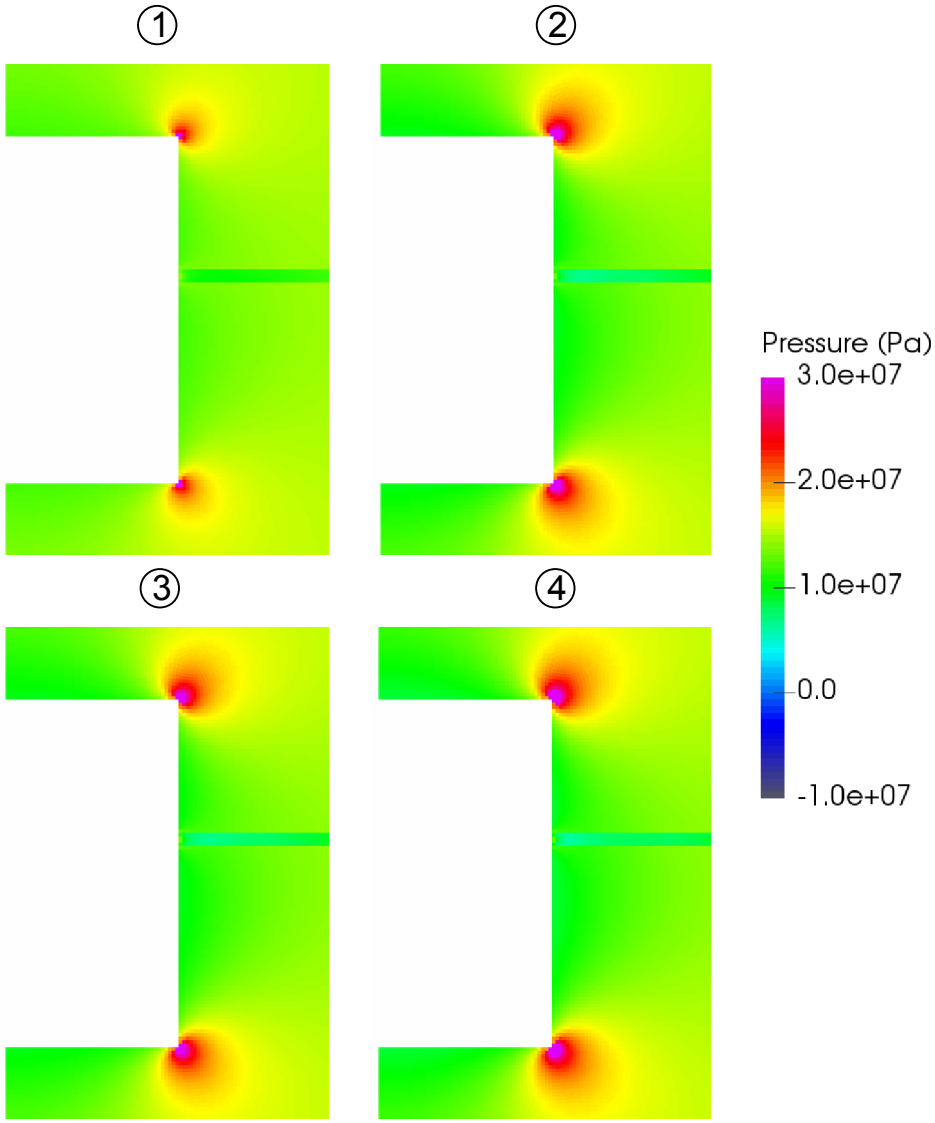
Anhydrite Issue



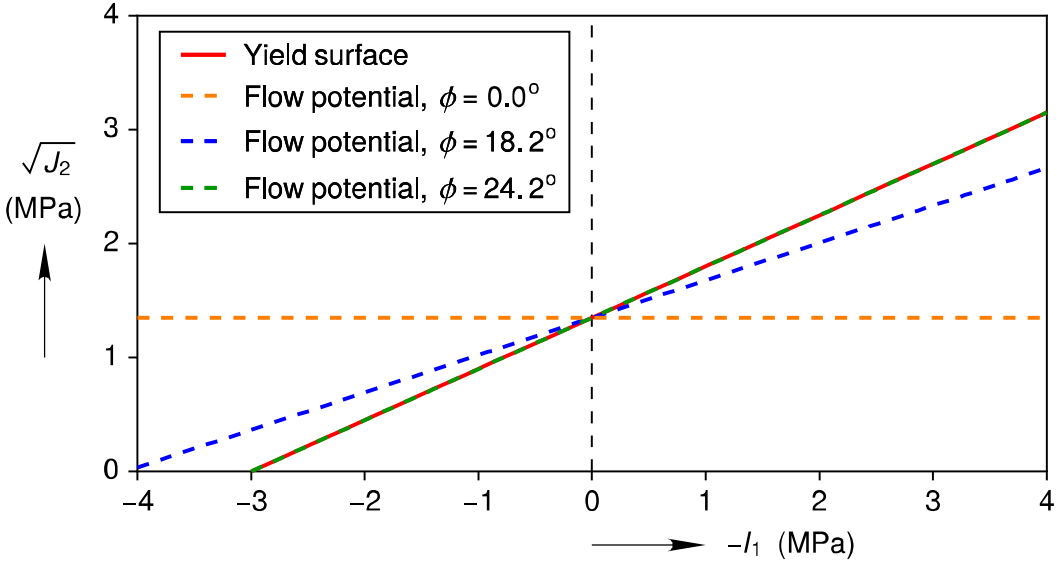


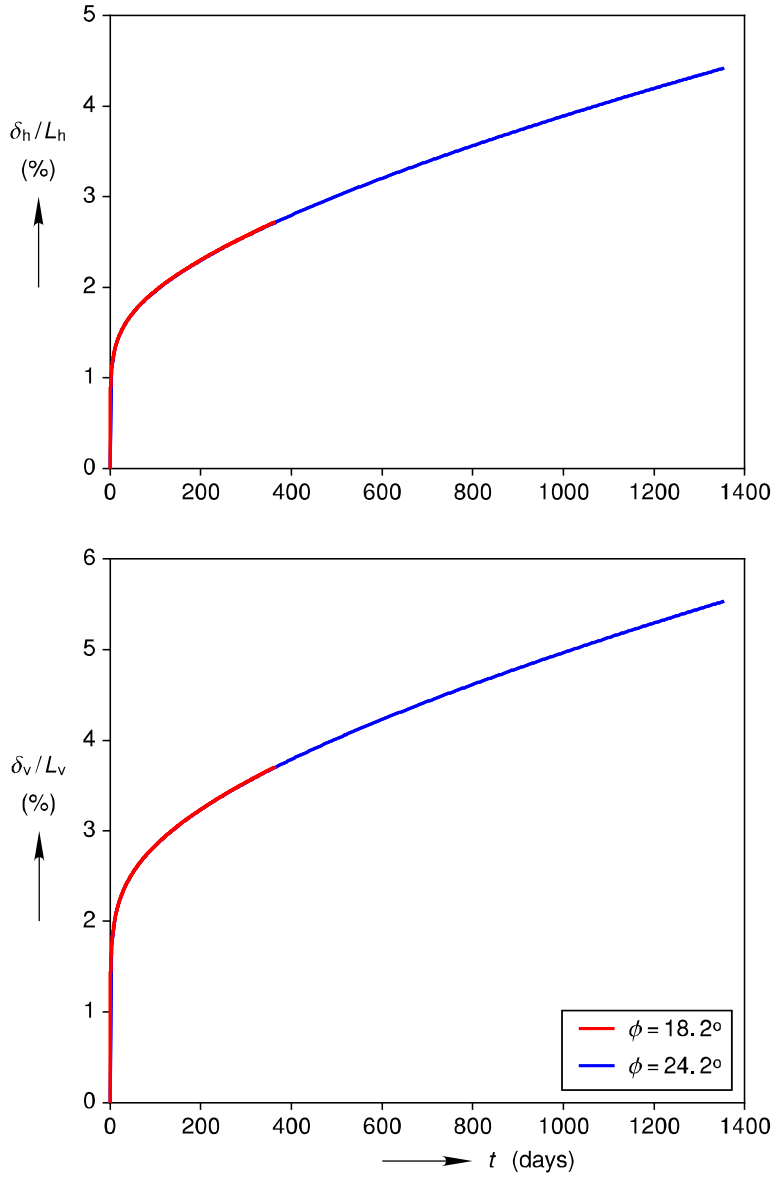
Anhydrite Issue Resolved





Anhydrite Dilatation Angle Sensitivity





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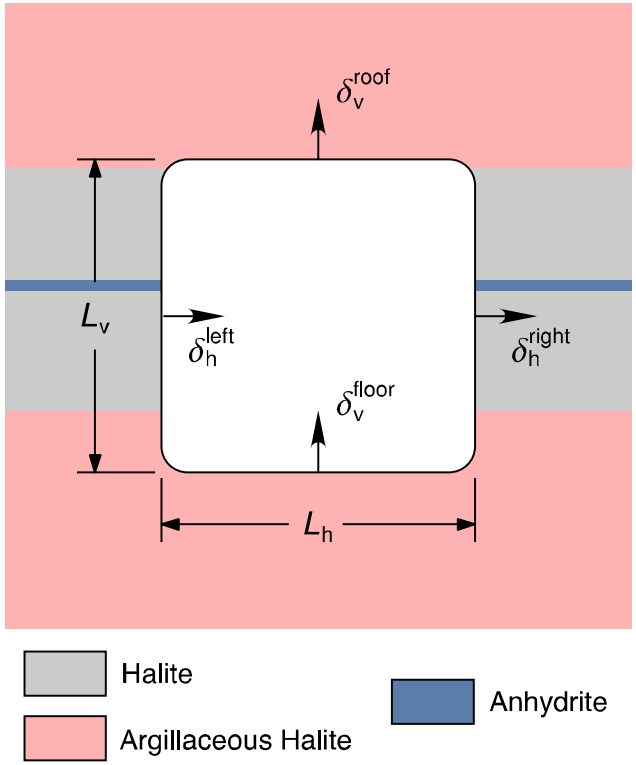
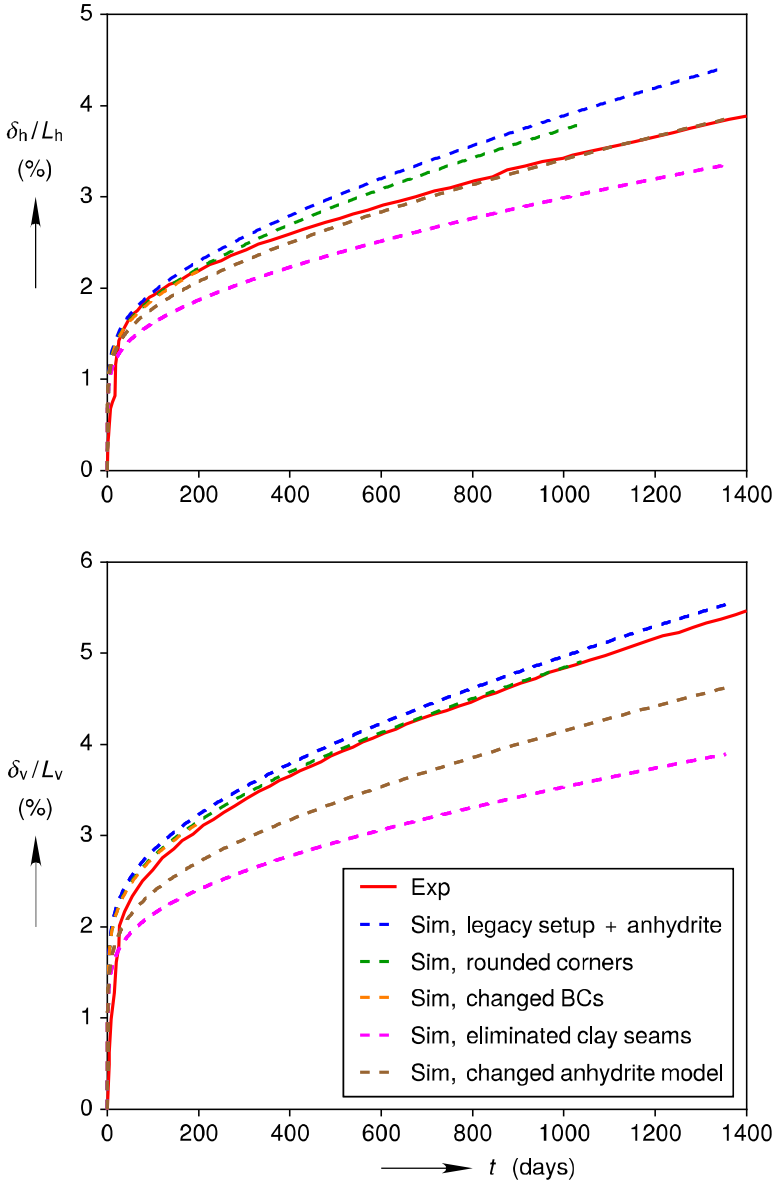
Joint Project III Simulations

Transition to Joint Project III Setup

$$\delta_h = \delta_h^{right} - \delta_h^{left}$$

$$\delta_v = \delta_v^{floor} - \delta_v^{roof}$$





Joint Project III Simulations

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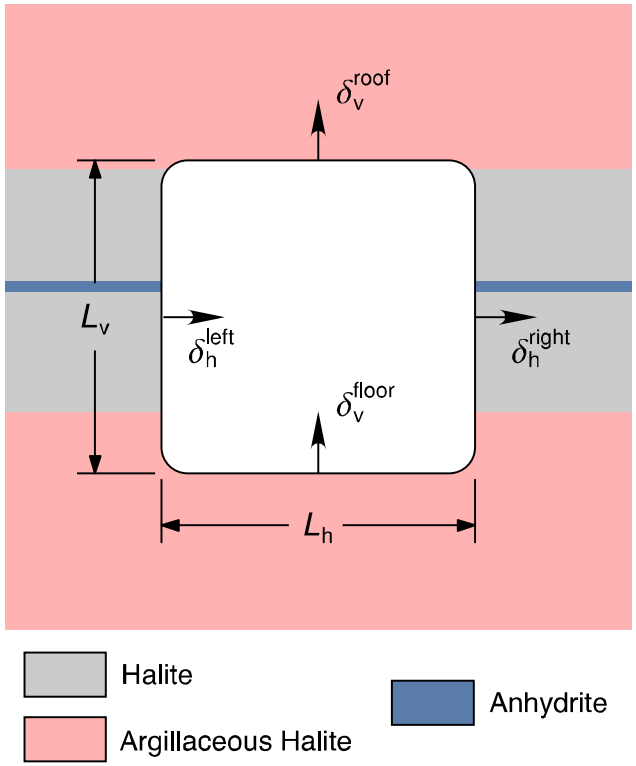
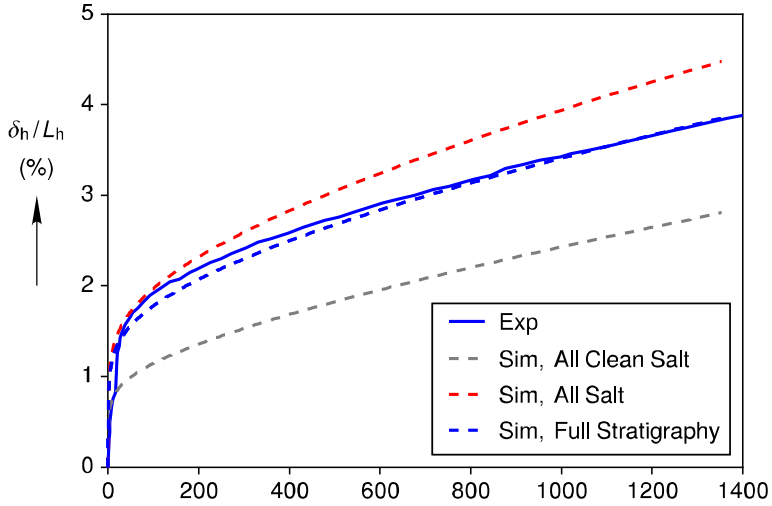
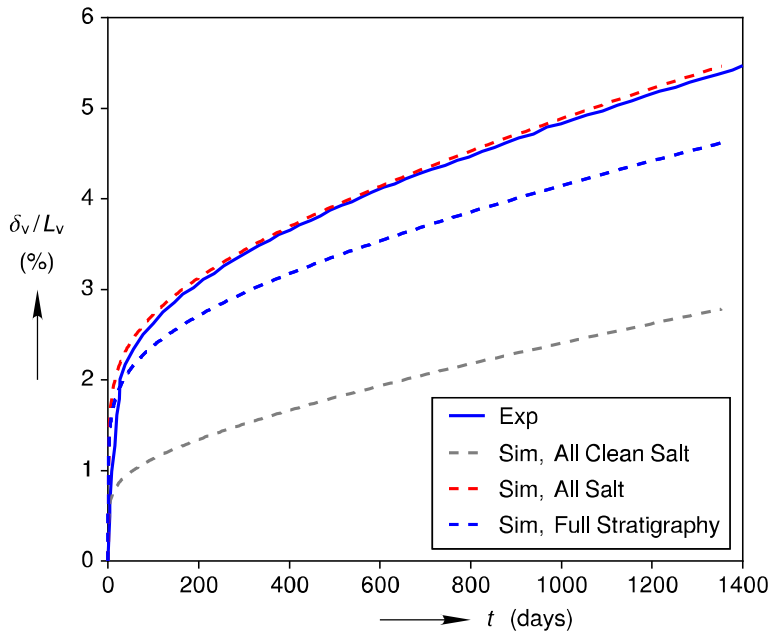






Preliminary Munson-Dawson Recalibration

Triaxial Creep Exp

Additive Decomposition

$$\dot{\varepsilon}_{zz} = \dot{\varepsilon}^{\mathrm{e}}_{zz} + \dot{\bar{\varepsilon}}^{\mathrm{ss}} + \dot{\bar{\varepsilon}}^{\mathrm{tr}}$$

Strain Definitions

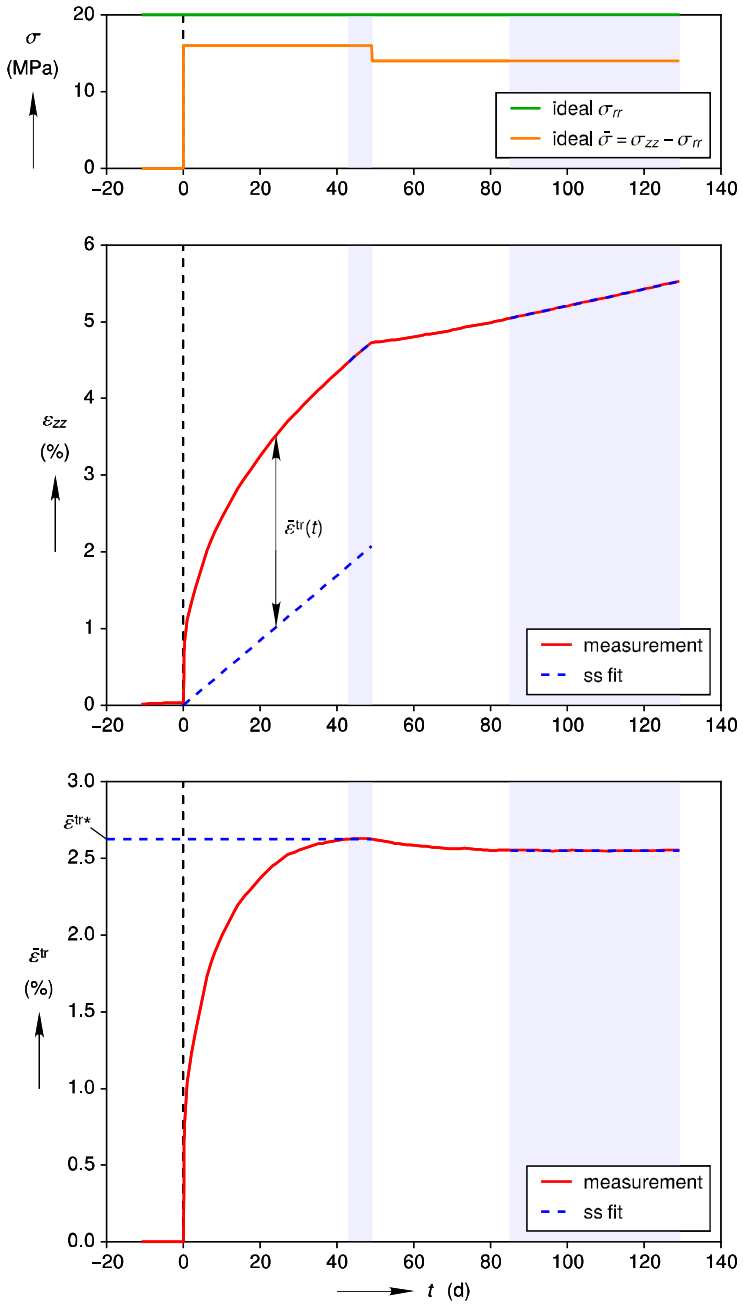
ε_{zz} = total axial strain

ε^{e}_{zz} = axial elastic strain

$\bar{\varepsilon}^{\mathrm{ss}}$ = steady state equivalent strain

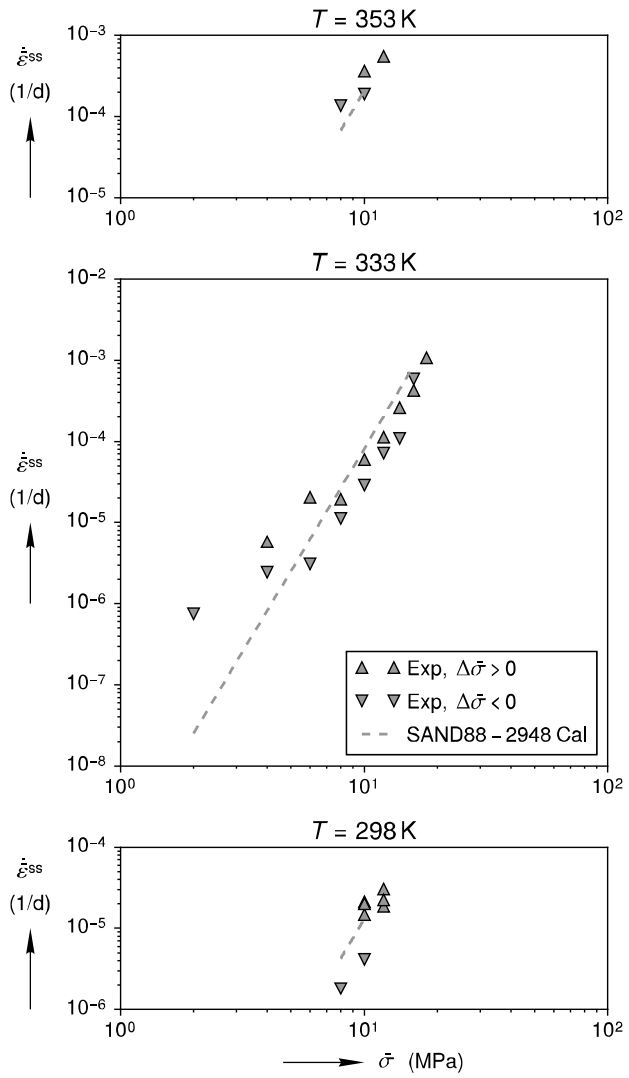
$\bar{\varepsilon}^{\mathrm{tr}}$ = transient equivalent strain

$\bar{\varepsilon}^{\mathrm{tr}*}$ = transient equivalent strain limit

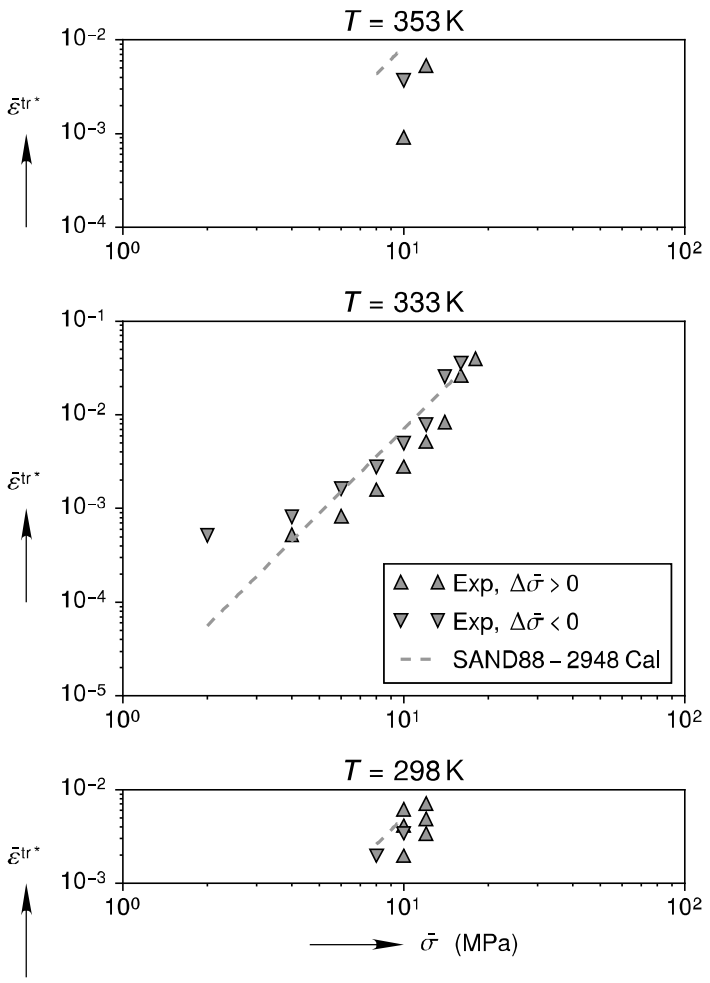


Clean Salt

Steady State Rate

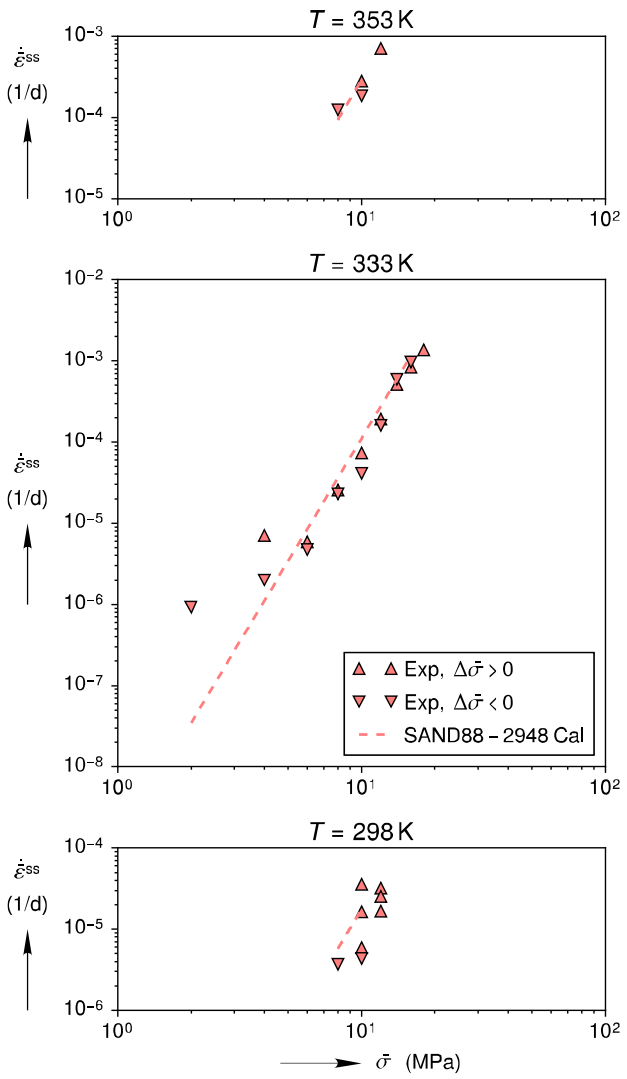


Transient Limit

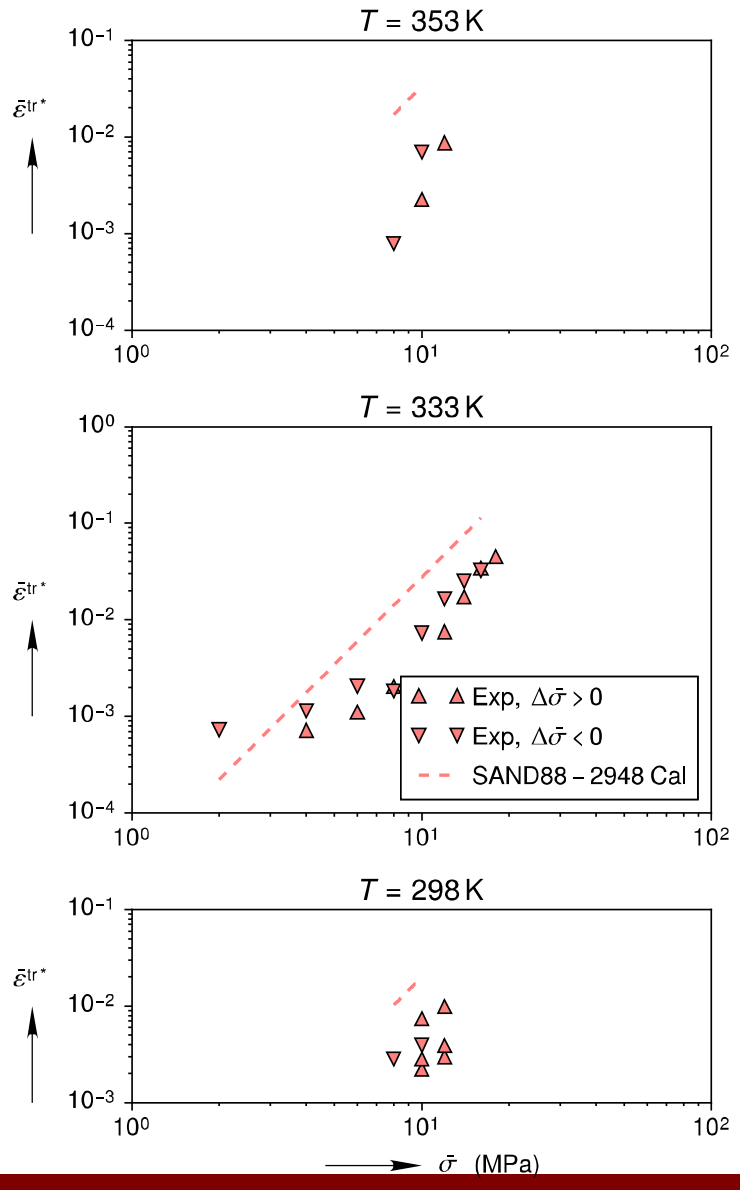


Argillaceous Salt

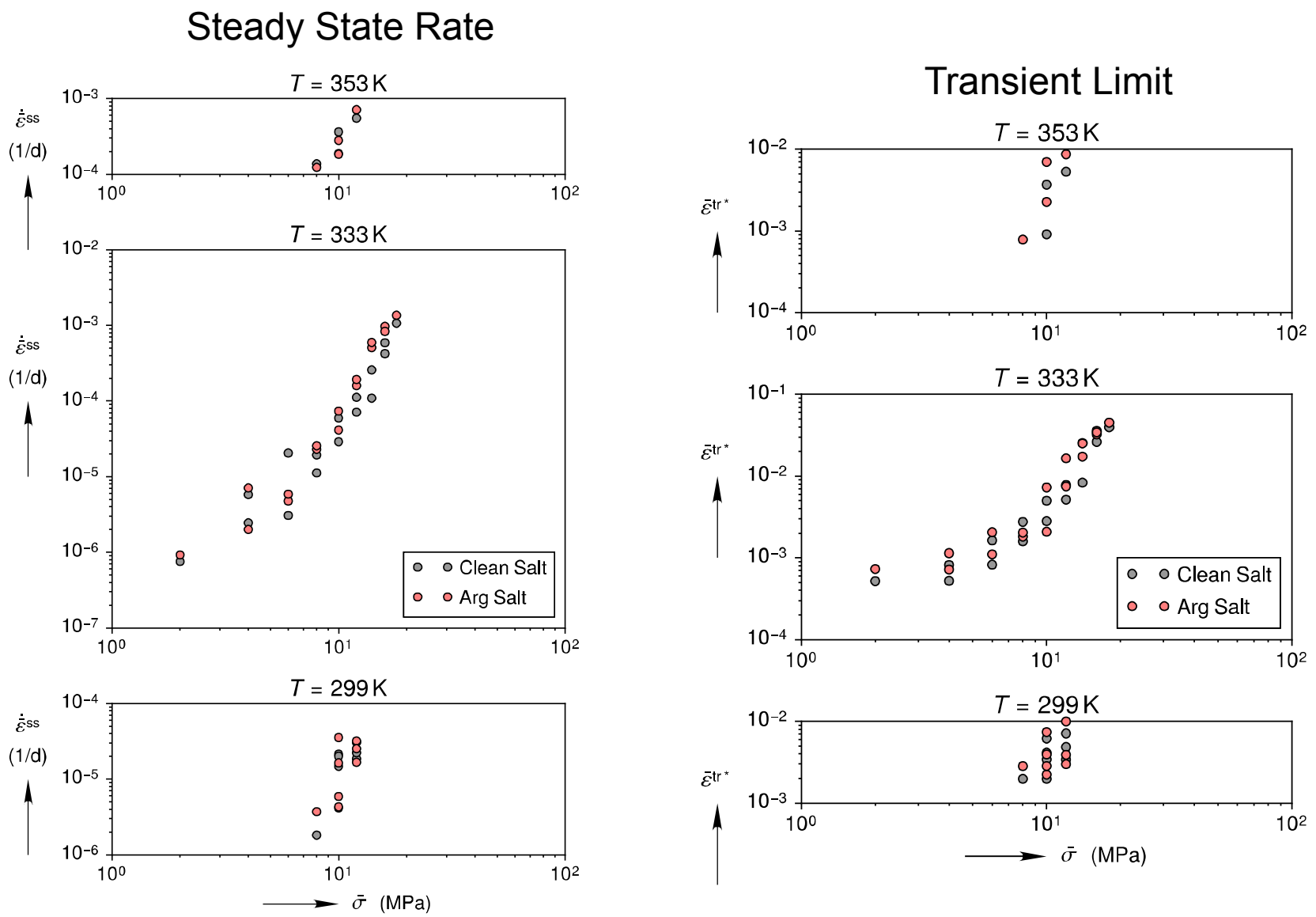
Steady State Rate



Transient Limit



Clean vs. Argillaceous Salt



Preliminary New Calibration

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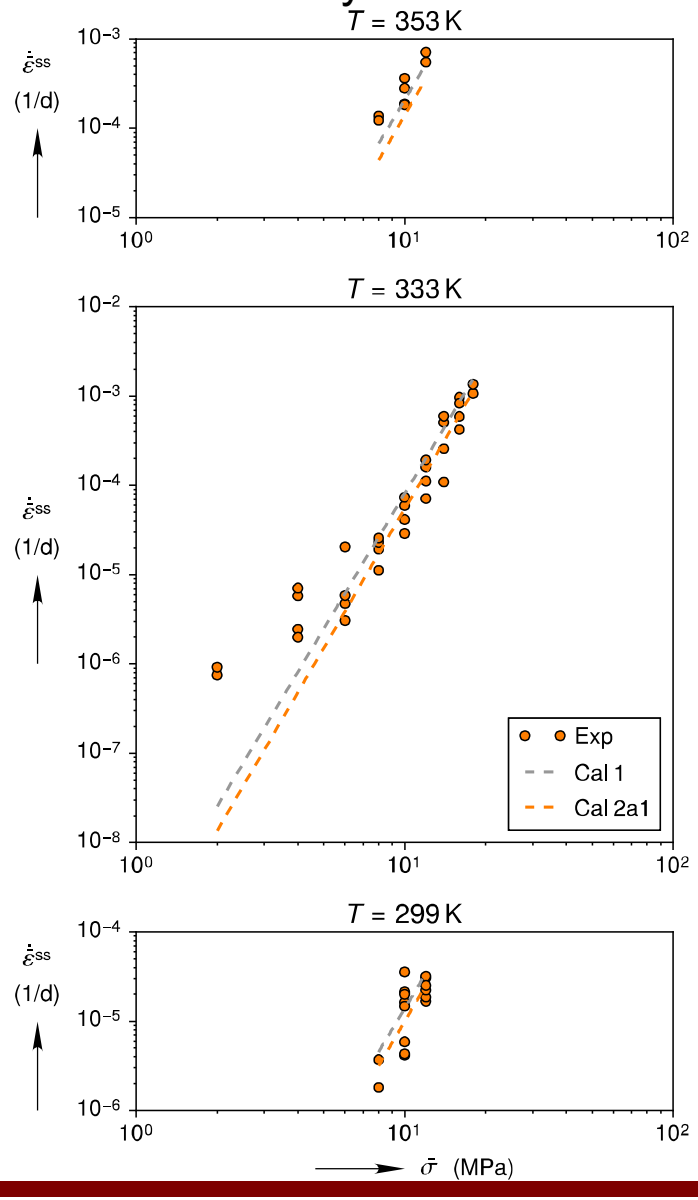
Steady State Rate



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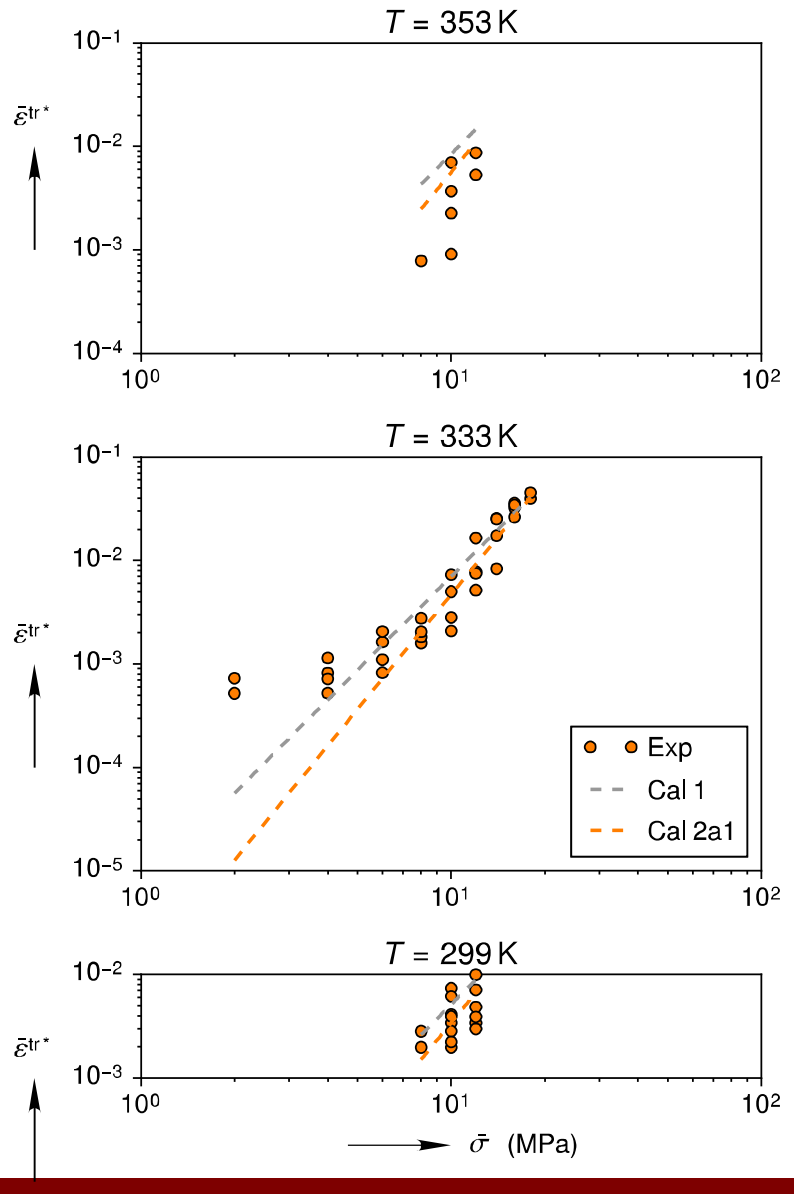

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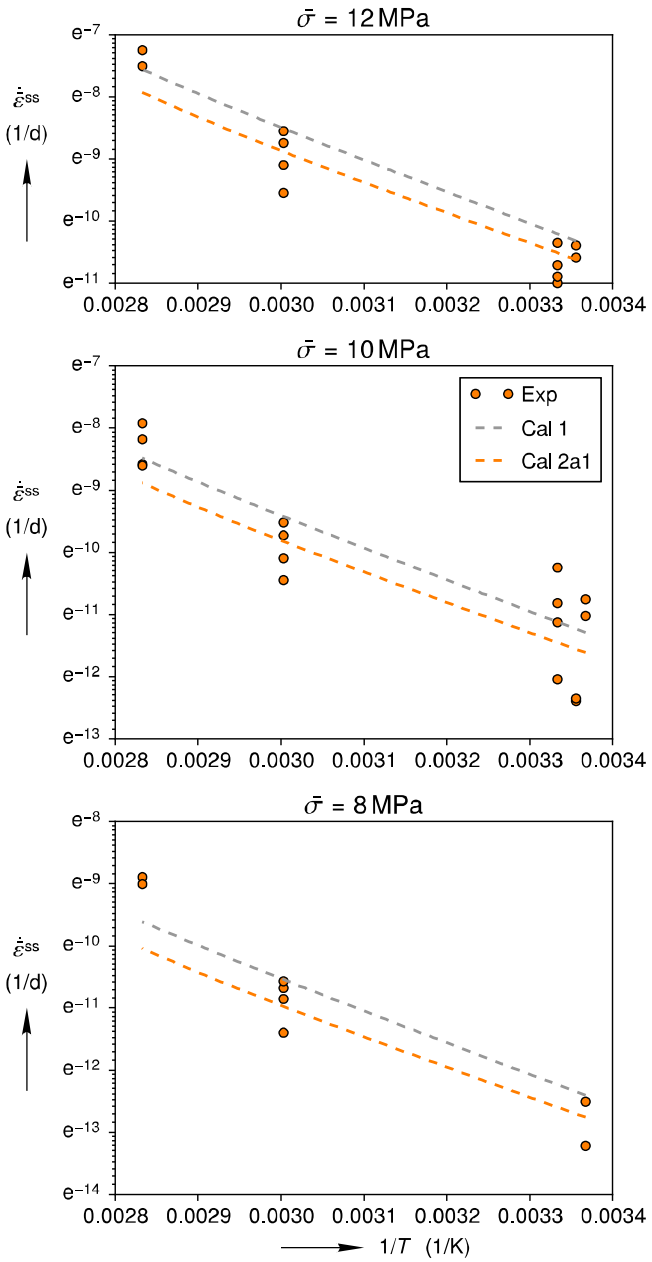

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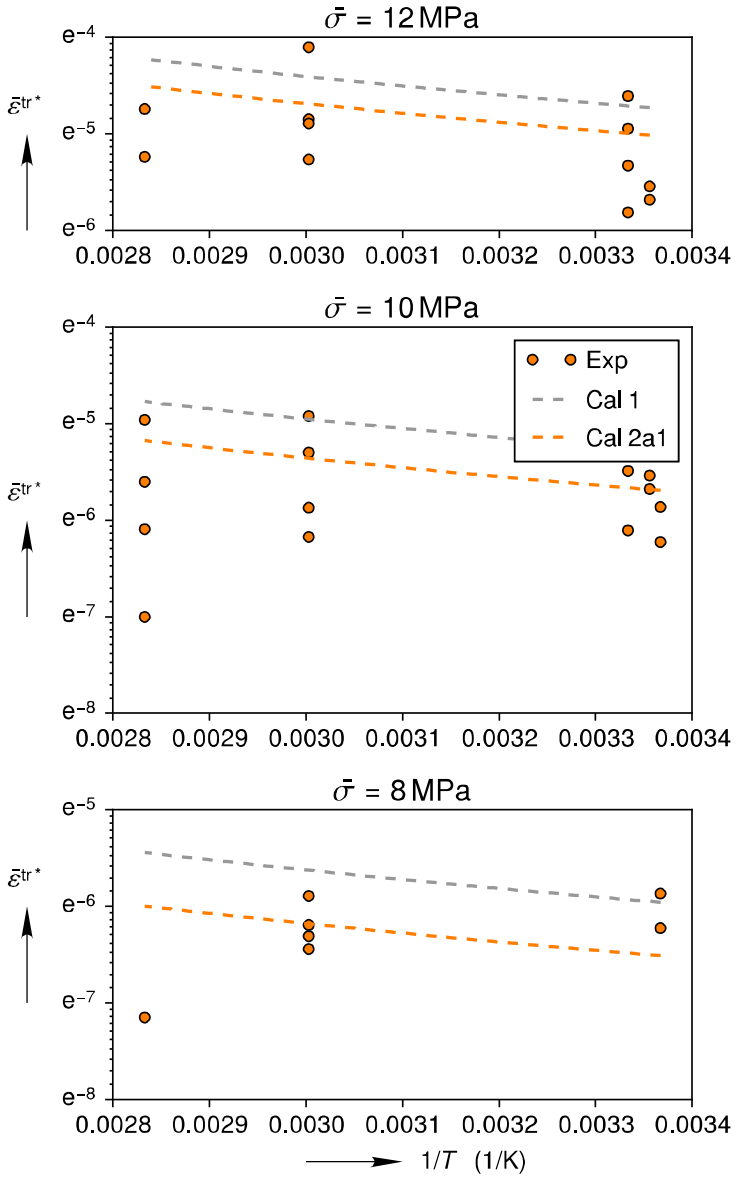
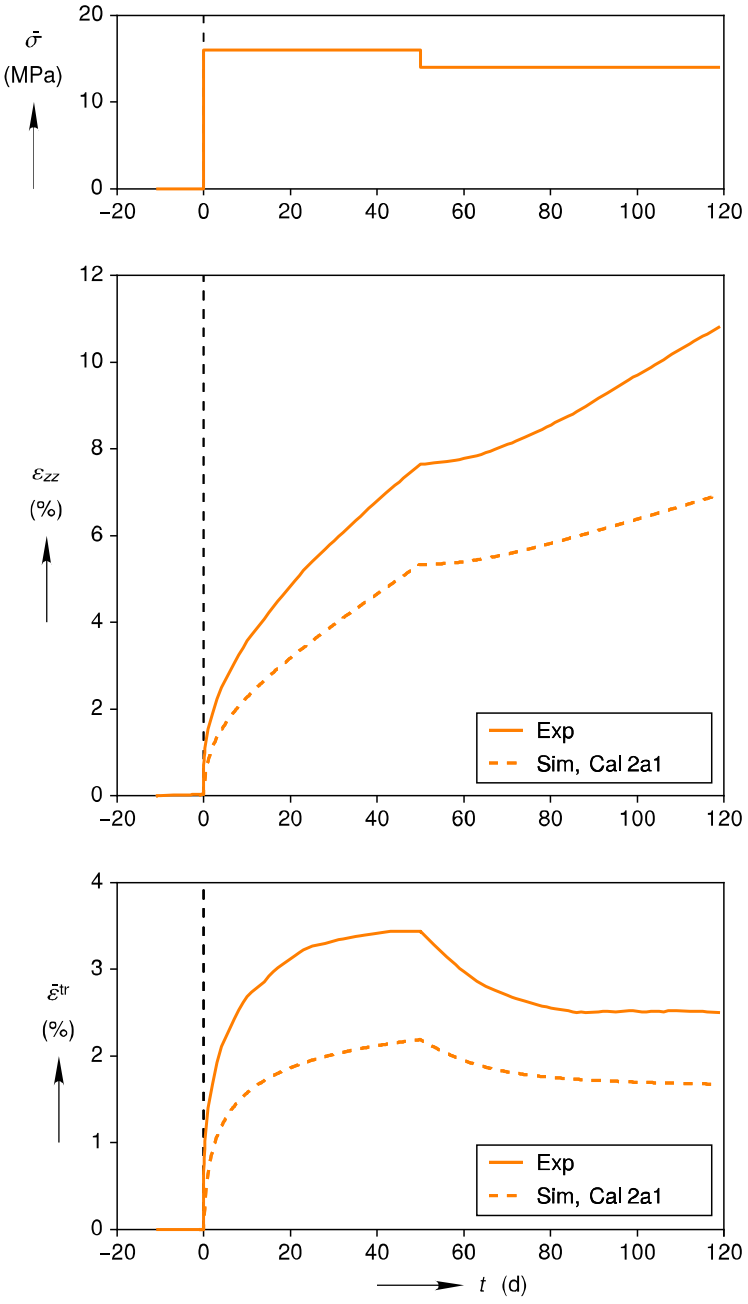


Transient Creep Rate Parameters Not Calibrated Yet

Transient Creep ODE

$$\dot{\bar{\varepsilon}}^{tr} = (F - 1)\ \dot{\bar{\varepsilon}}^{ss}$$

$$F = \begin{cases} \exp\left[\delta_w \left(1 - \frac{\bar{\varepsilon}^{tr}}{\bar{\varepsilon}^{tr*}}\right)^2\right] & \bar{\varepsilon}^{tr} \le \bar{\varepsilon}^{tr*} \\ \exp\left[-\delta_r \left(1 - \frac{\bar{\varepsilon}^{tr}}{\bar{\varepsilon}^{tr*}}\right)^2\right] & \bar{\varepsilon}^{tr} > \bar{\varepsilon}^{tr*} \end{cases}$$



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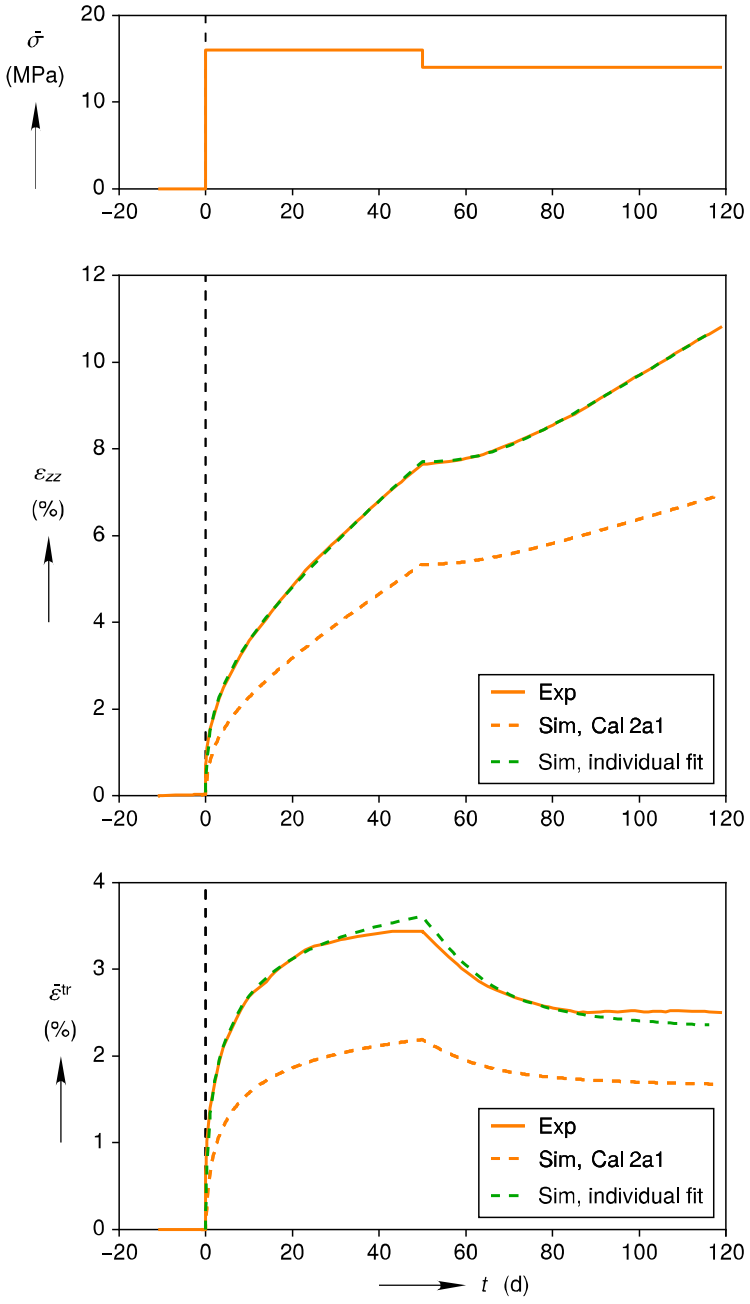
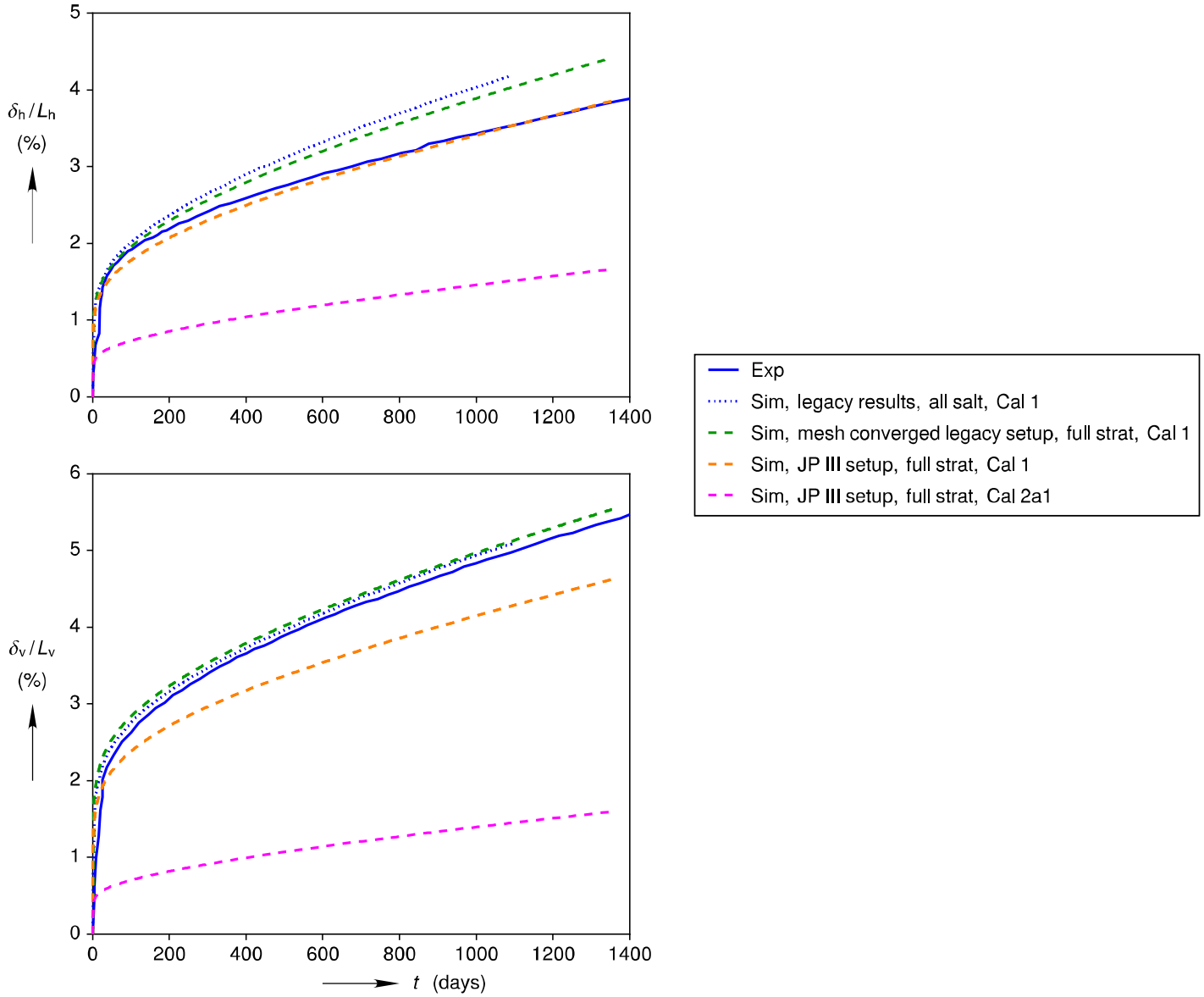
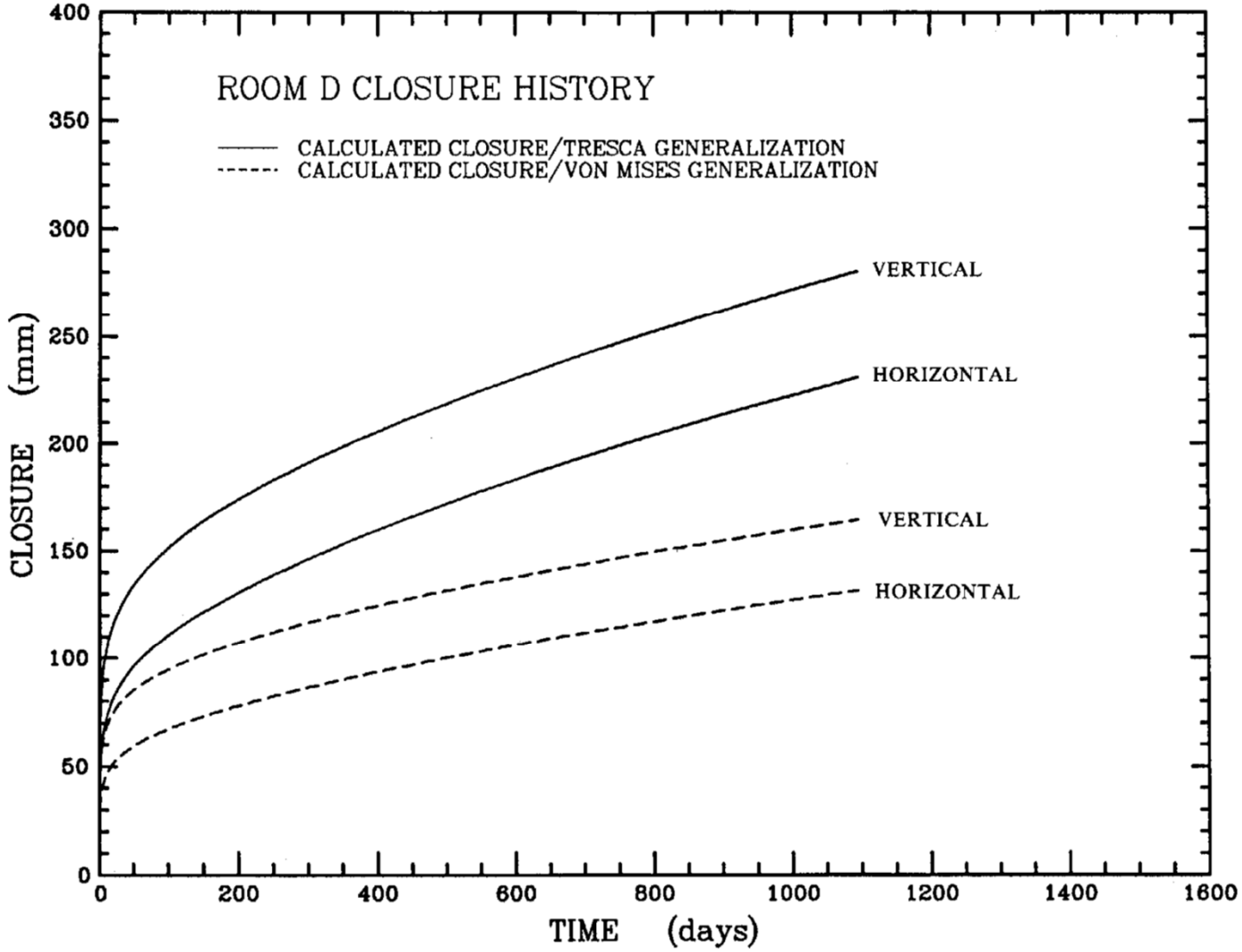


Closure Predictions with Preliminary Calibration



Future Work:
Flow Potential

Flow Potential



Munson, D., Fossum, A. Senseny, P., Advances in Resolution of Discrepancies Between Predicted and Measured In Situ WIPP Room Closures, SAND88-2948, 1988

Flow Potential

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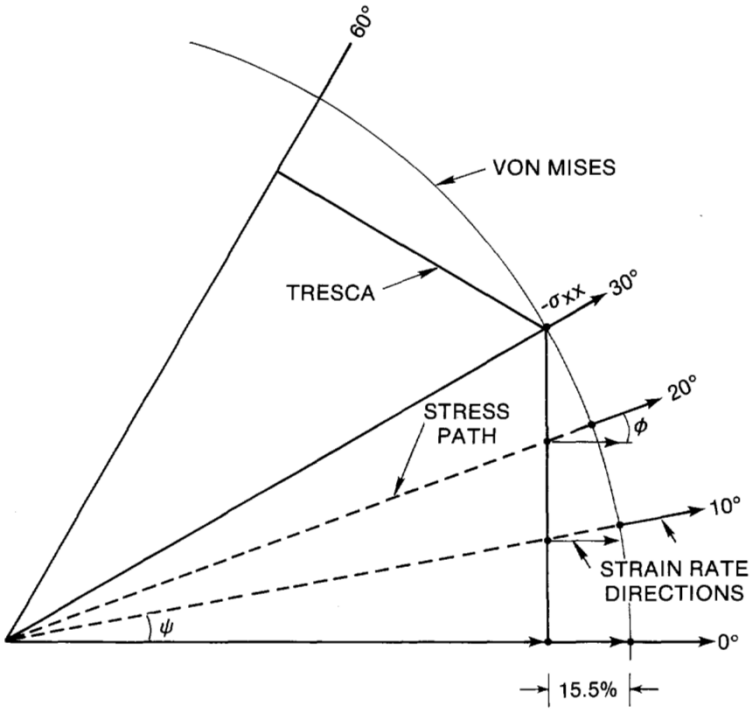
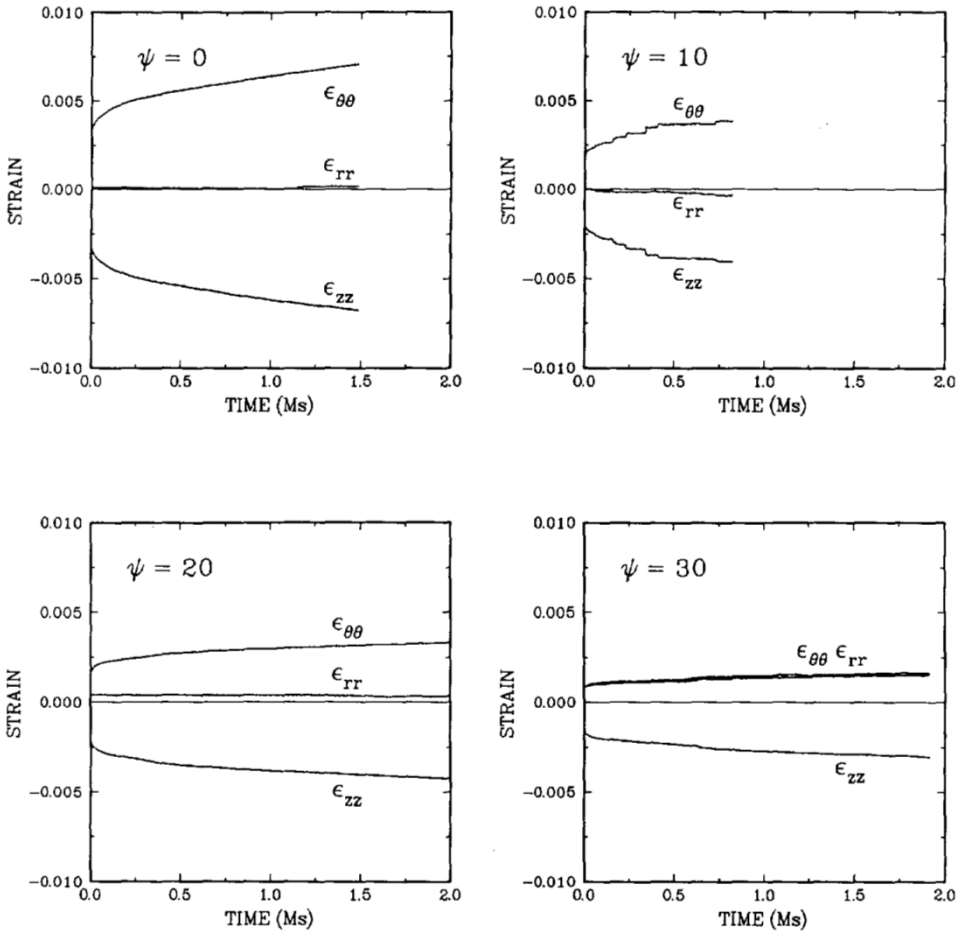
π-Plane



Thin Walled Tube Results



Munson, D., Fossum, A. Senseny, P., Advances in Resolution of Discrepancies Between Predicted and Measured In Situ WIPP Room Closures, SAND88-2948, 1988

Hosford (1972): $$f = \left(\frac{1}{2} |s_1 - s_2|^\eta + \frac{1}{2} |s_2 - s_3|^\eta + \frac{1}{2} |s_3 - s_1|^\eta \right)^{1/\eta}$$

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Future Work: Simulation Boundary

Somewhat Coarse Meshes (All Clean Salt)

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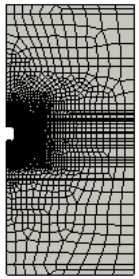
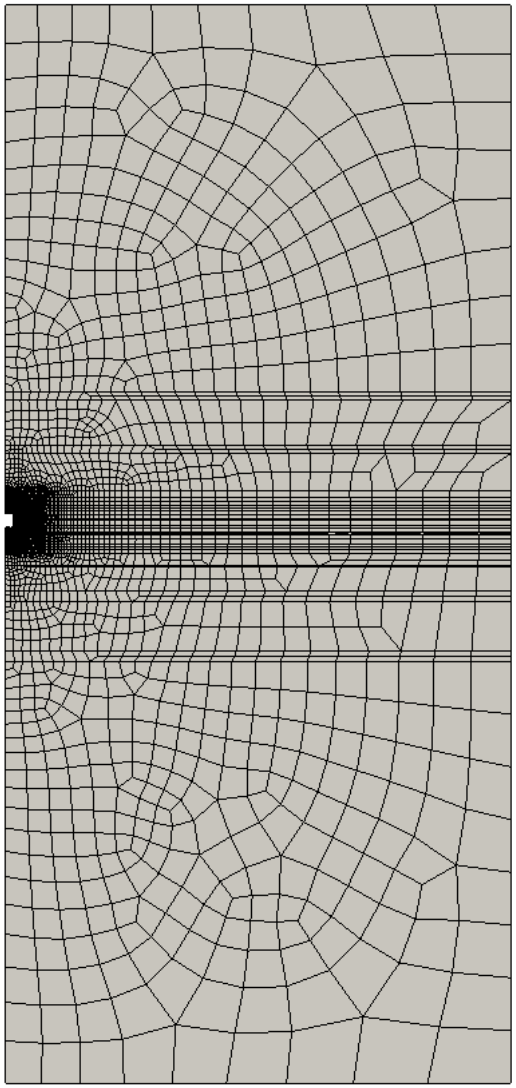
Legacy (50 m) Boundary



200 m Boundary



Impact of Simulation Boundary on Room Closure

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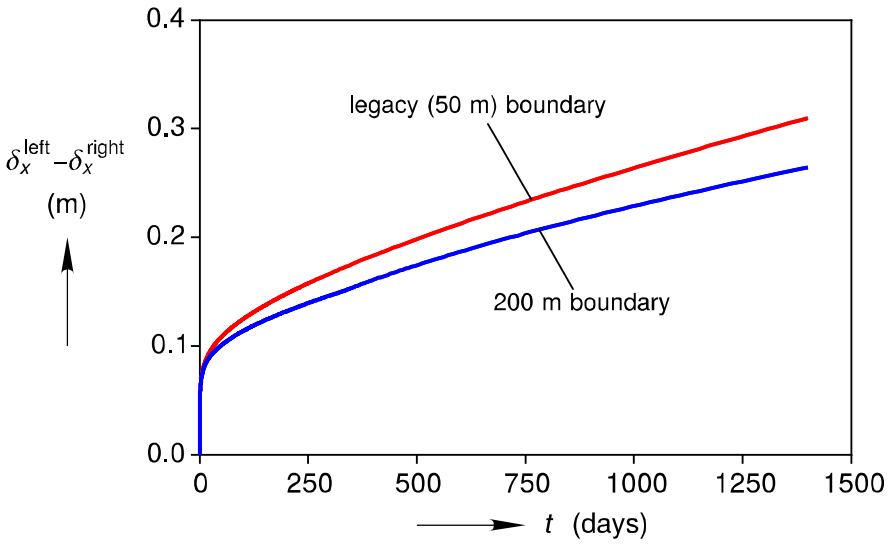
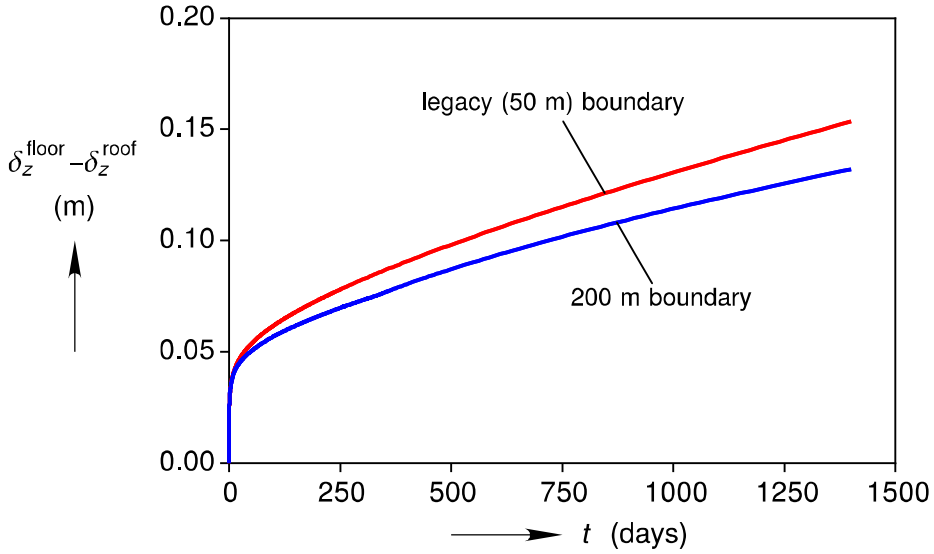
Horizontal Closure



Vertical Closure



Compare von Mises Stress Fields

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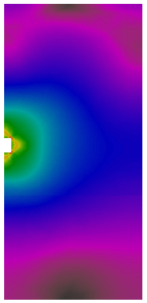
Legacy (50 m) Boundary



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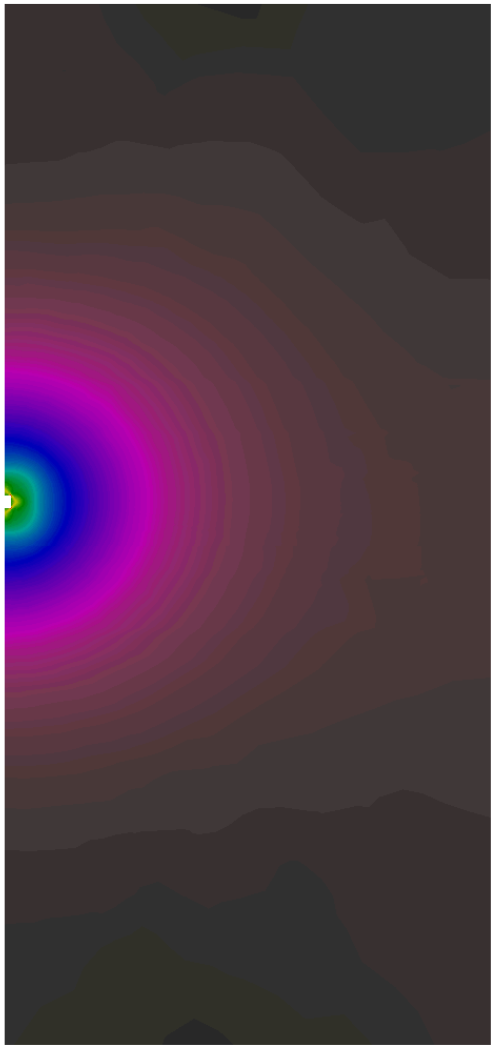

Compare von Mises Stress Fields

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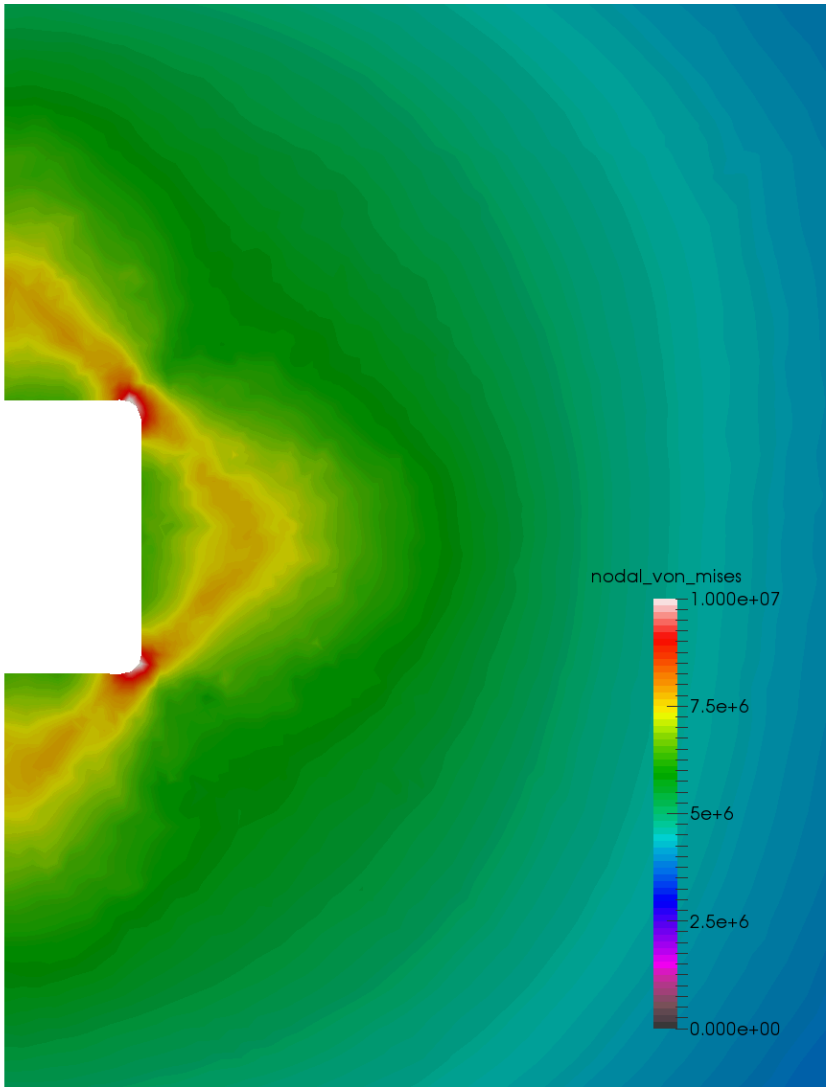

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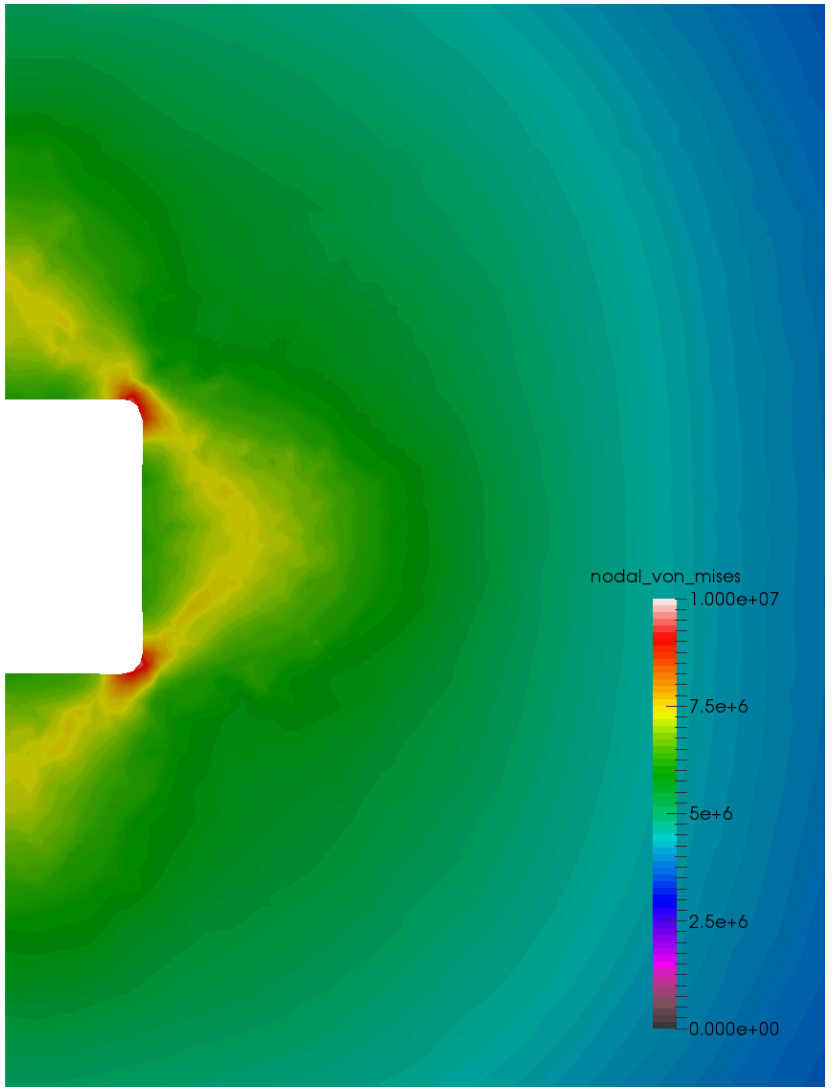
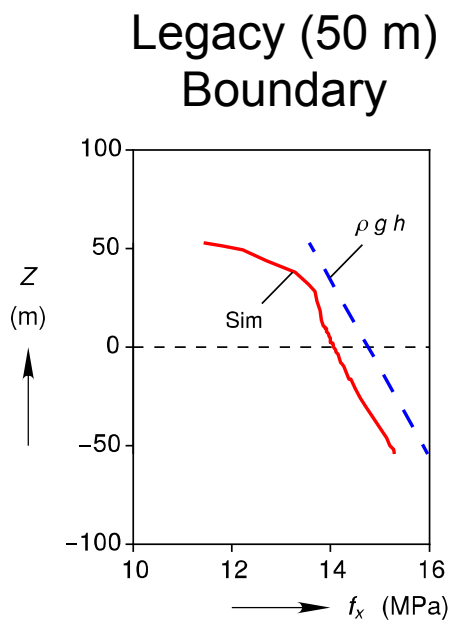
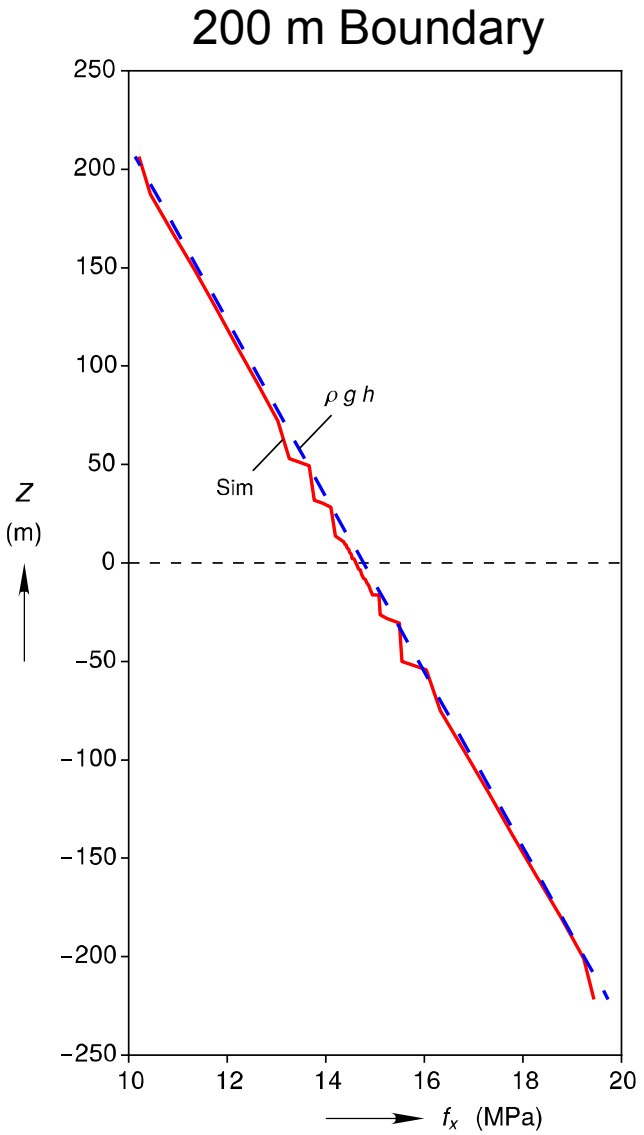
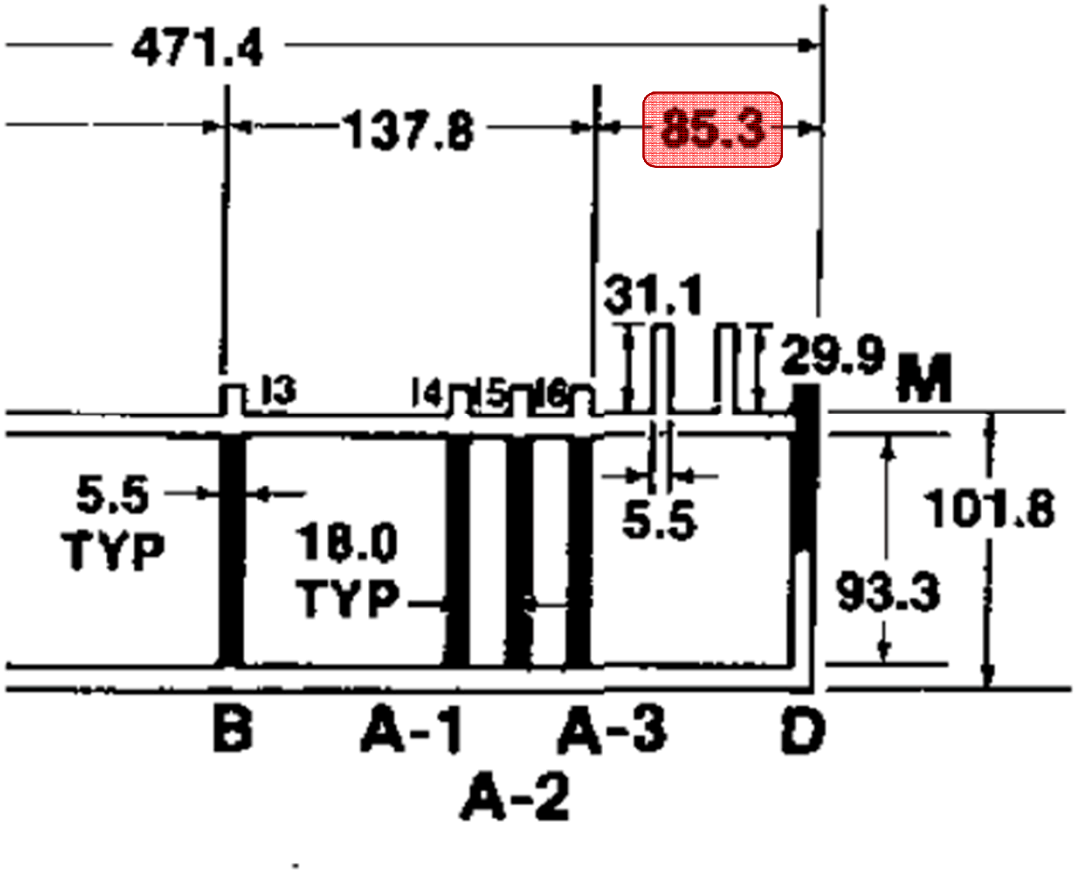


Traction distribution on the right boundary





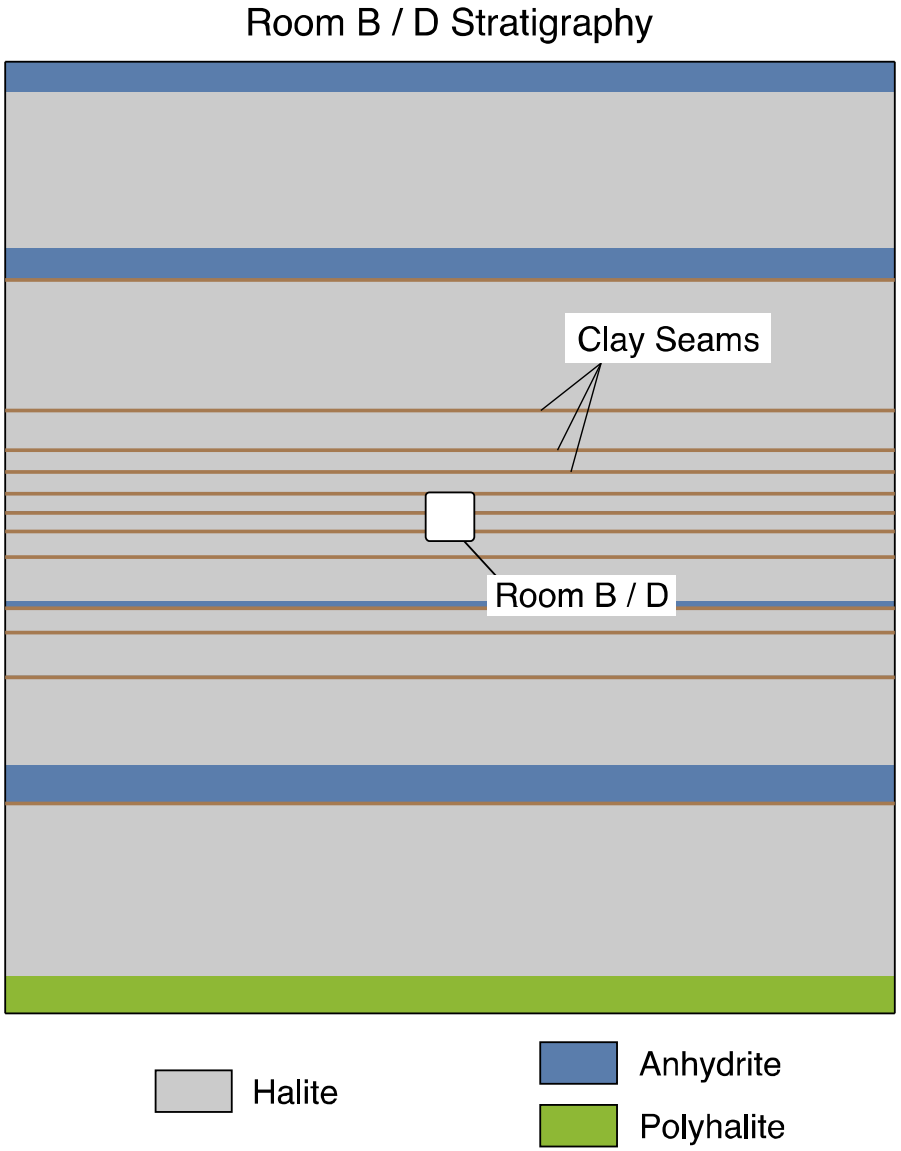
Room Spacing



Munson, D., Fossum, A., Senseny, P., Advances in Resolution of Discrepancies Between Predicted and Measured In Situ WIPP Room Closures, SAND88-2948, 1988 (Modified)

Future Work

- Salt material model
  - Calibrate high temp behavior
  - Calibrate transient creep rate
  - Low deviatoric stresses
  - Flow potential
- Simulation boundary
- Anhydrite material model
- Size effects
- Friction in triaxial experiment



Summary

- Quite difficult to resolve the legacy simulation numerics
  - New mesh
  - Tighter residual tolerance
  - Switched contact algorithm
  - Changed to associated flow for anhydrite material model
- Completed Room D simulations with the legacy Munson-Dawson model calibration
- Recalibration of the Munson-Dawson model is in process
  - The legacy transient limit does not match the JPIII experiments
  - The argillaceous and clean salt are virtually identical, so only one calibration will be pursued
  - The transient limit temperature dependence needs further study
  - The simulation of room D with the preliminary calibration roughly agrees with the partners
- Simulation boundary may be too close

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Extra Slides

Initial Mesh Convergence Study

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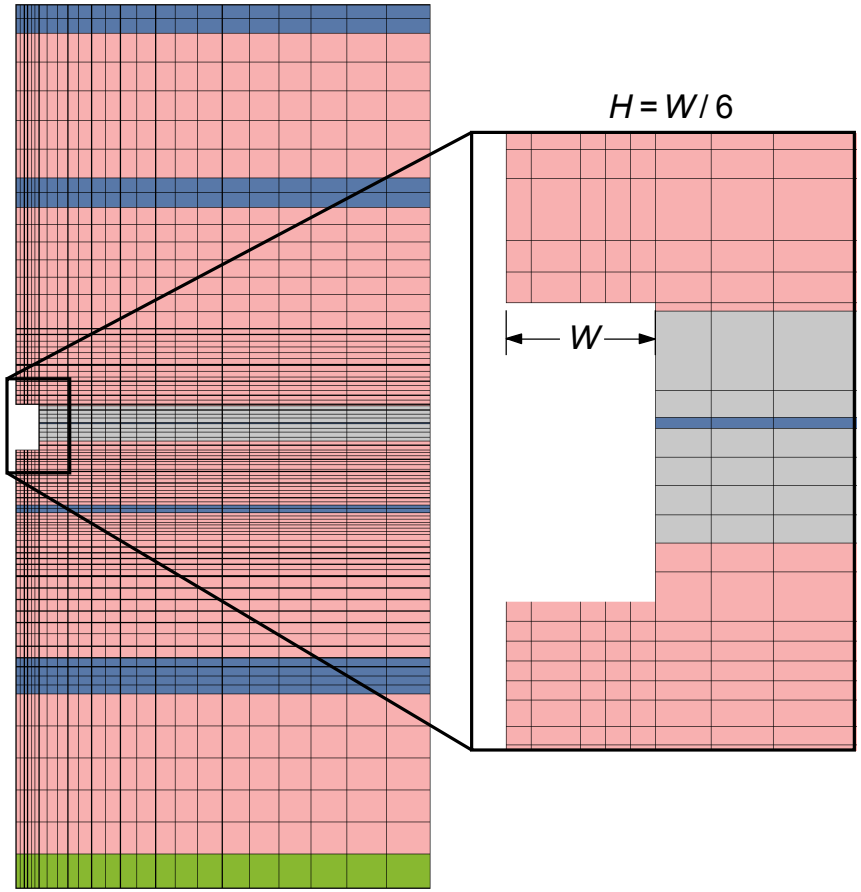
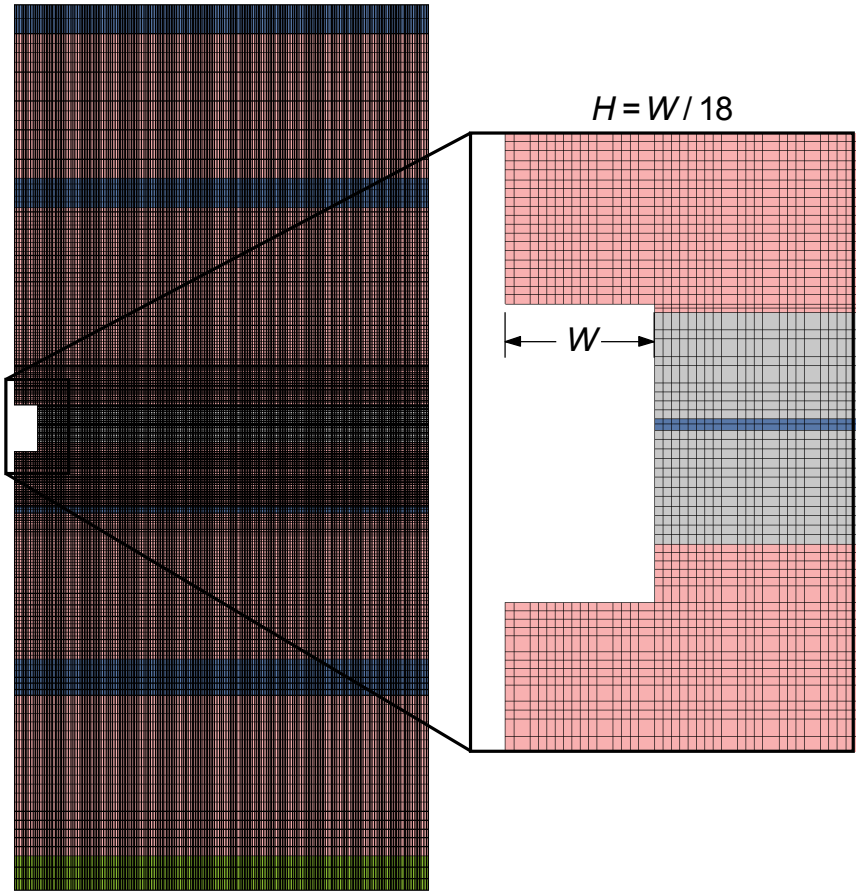
Coarsest Mesh

2184 Elements



Finest Mesh

81042 Elements



New Meshes

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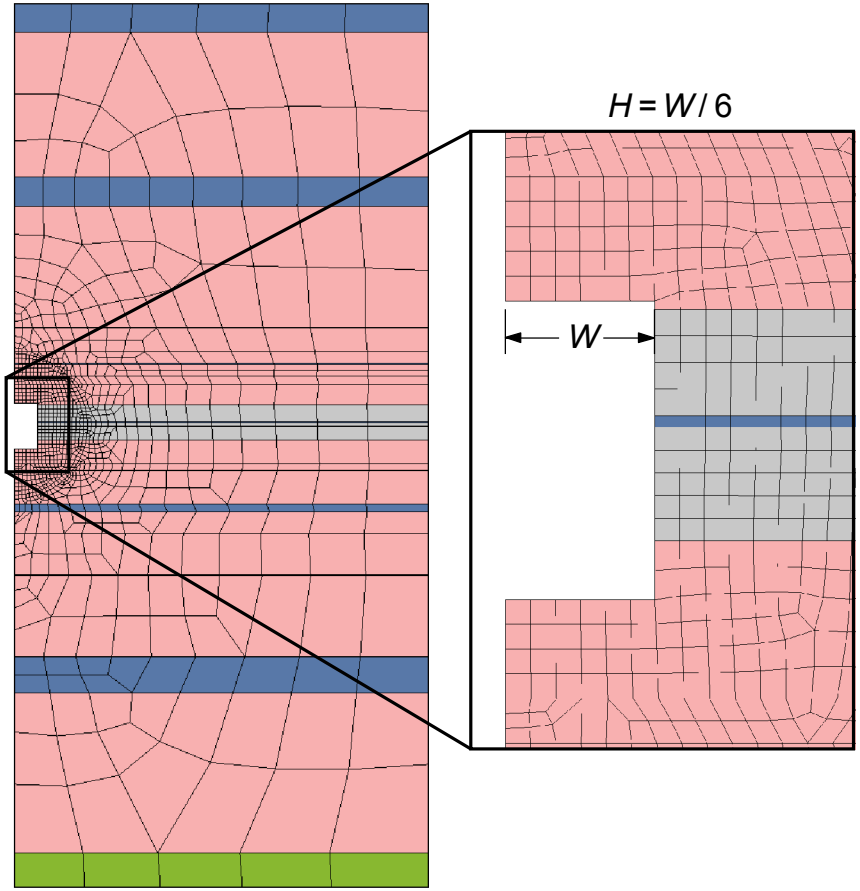
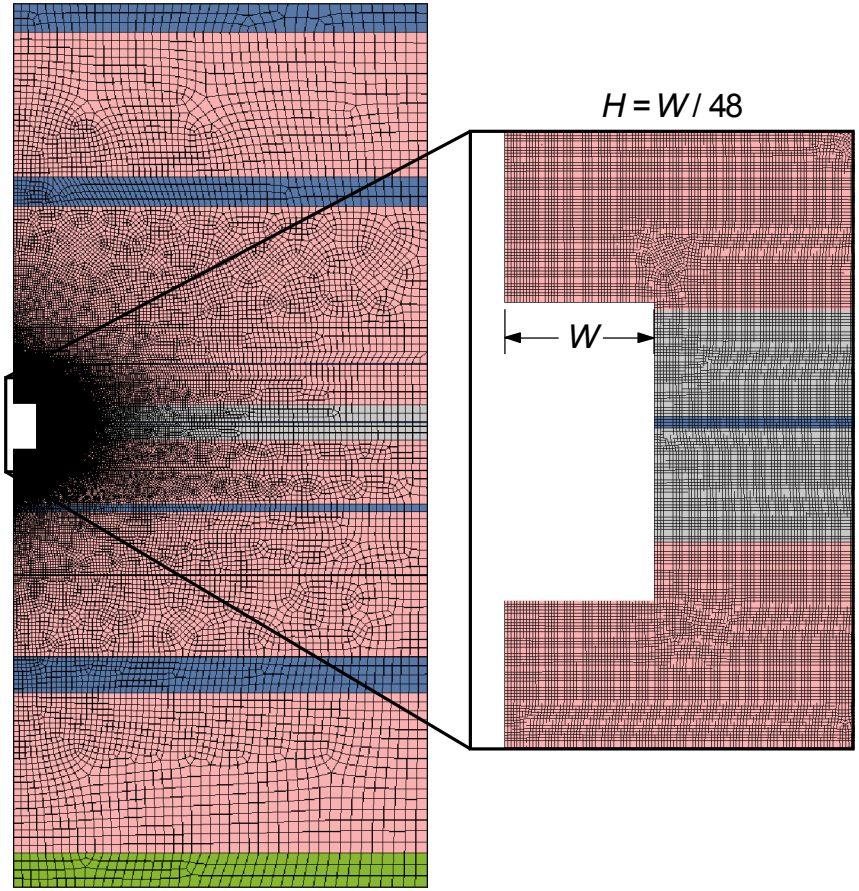
Coarsest Mesh

1139 Elements

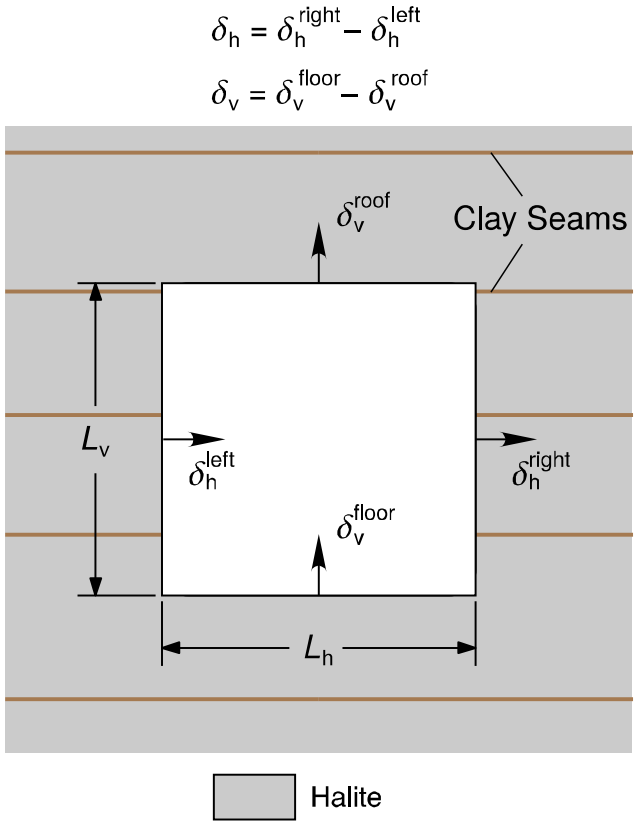


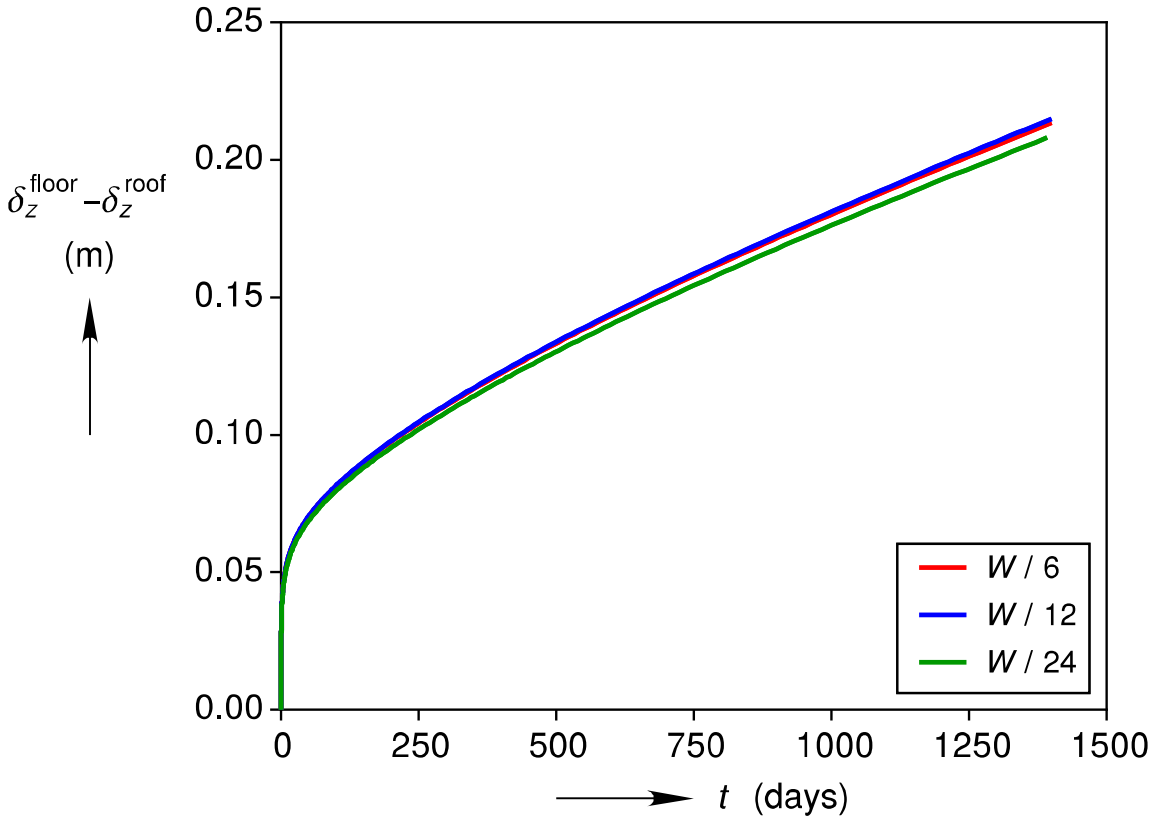
Finest Mesh

57849 Elements

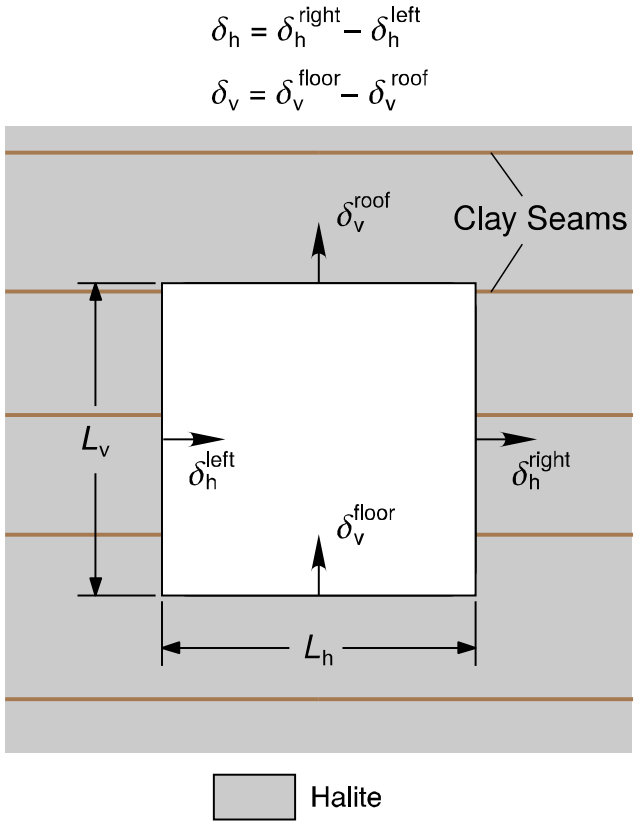


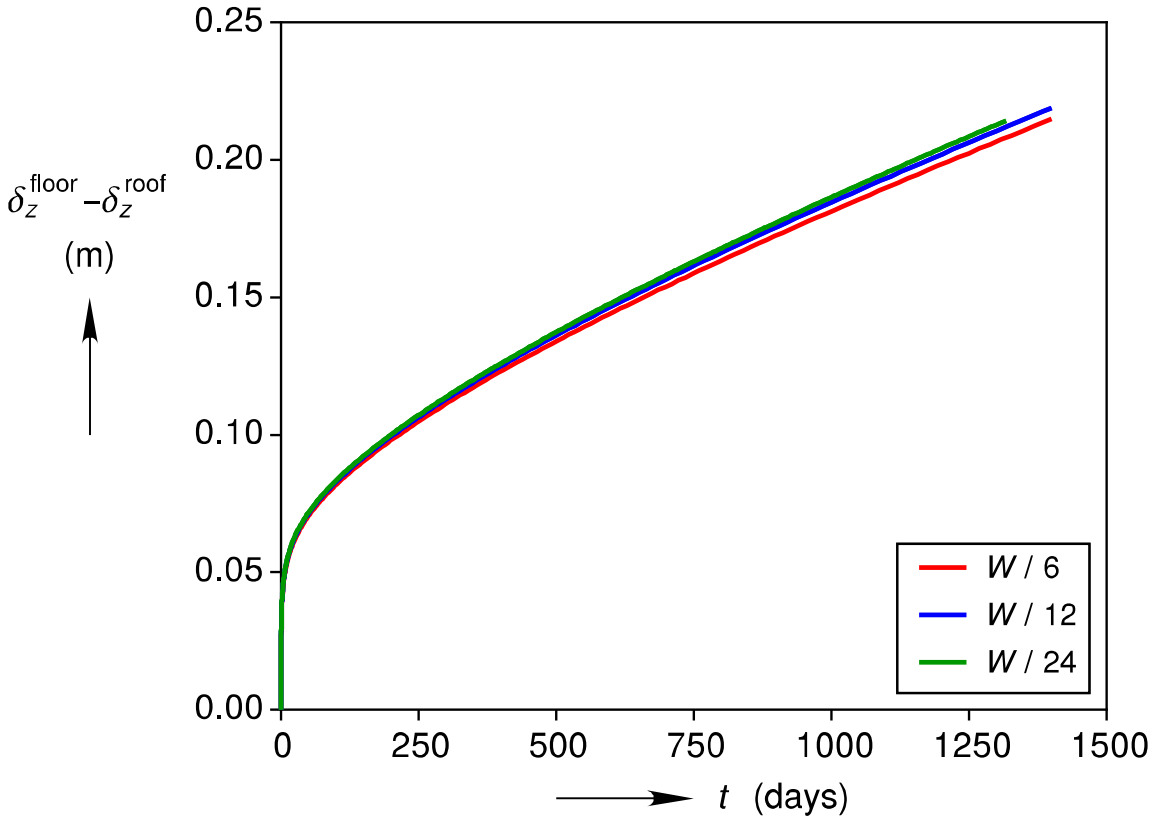
Kinematic Contact Enforcement Issue





Augmented Lagrange Contact Enforcement





Residual Tolerance

$$\delta_h = \delta_h^{right} - \delta_h^{left}$$

$$\delta_v = \delta_v^{floor} - \delta_v^{roof}$$