SAND2016-4348PE

A Re-Evaluation of the WIPP Room D Closure Predictions

Benjamin Reedlunn

Sandia National Laboratories

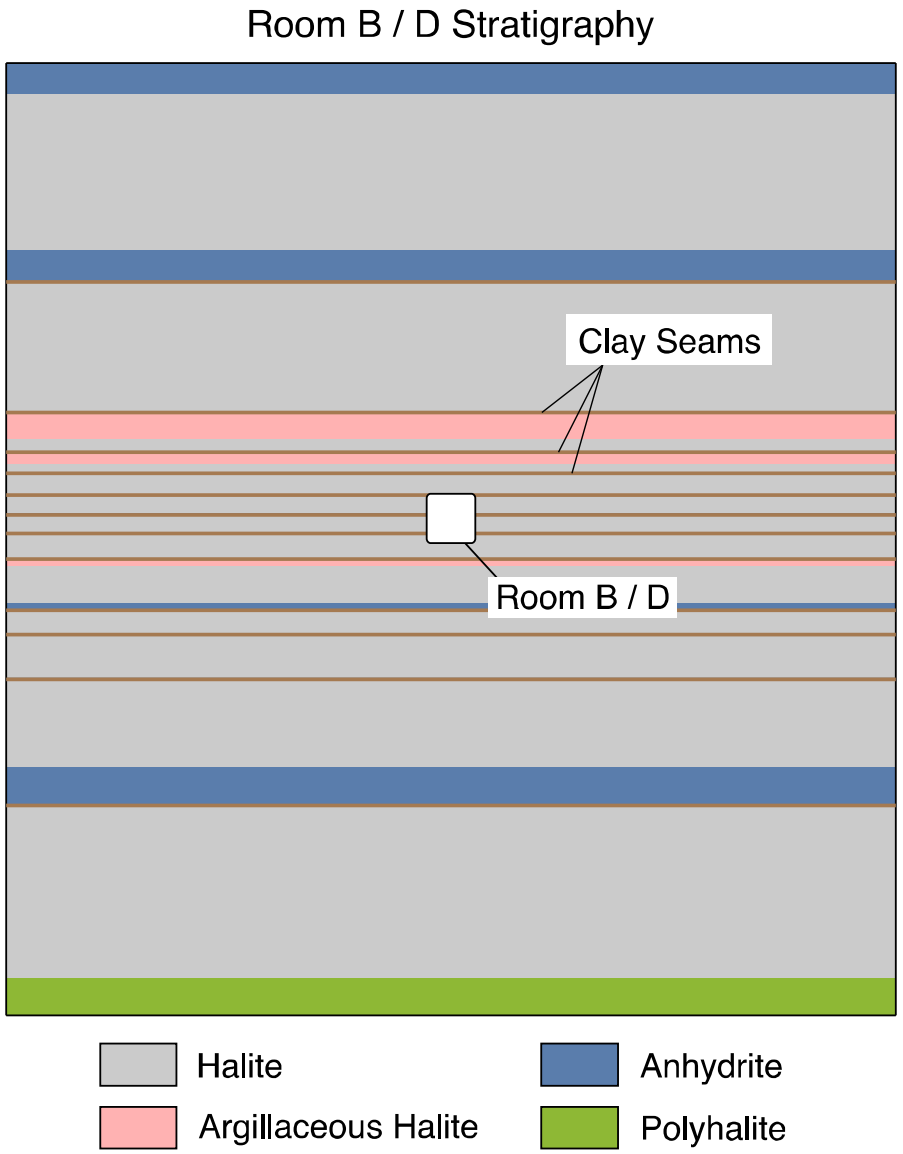
RESPEC Meeting

Rapid City, May 9th-10th, 2016

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2011-XXXXP

Outline

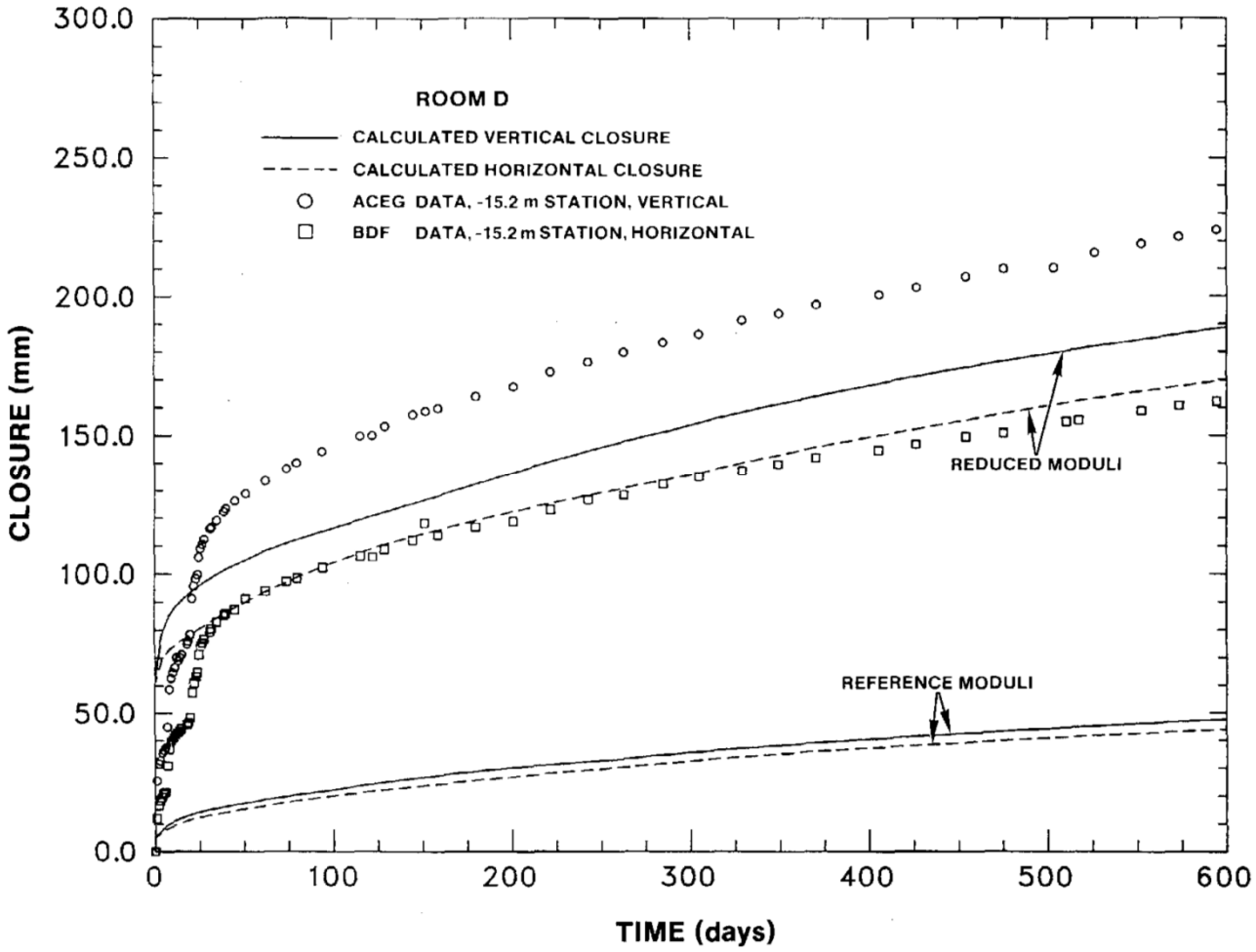
- Legacy simulations
- Resolving the legacy simulation numerics
- Joint Project III simulations
- Legacy Munson-Dawson model calibration
- Preliminary Munson-Dawson model recalibration



Sandia National Laboratories

Legacy Simulations

Legacy Simulations



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

Steady State Creep Rate

$$\dot{\bar{\varepsilon}}^{ss} \propto \left(\frac{\bar{\sigma}}{\mu}\right)^{n}$$

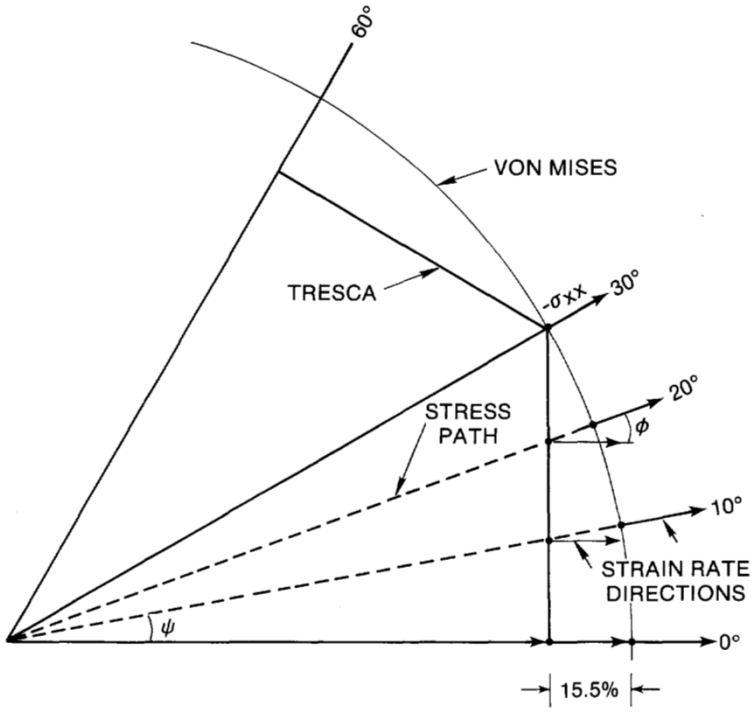
Transient Creep Strain Limit

$$\bar{\varepsilon}^{tr*} \propto \left(\frac{\bar{\sigma}}{\mu}\right)^{m}$$

Changed the Flow Potential

Sandia National Laboratories

π-Plane



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

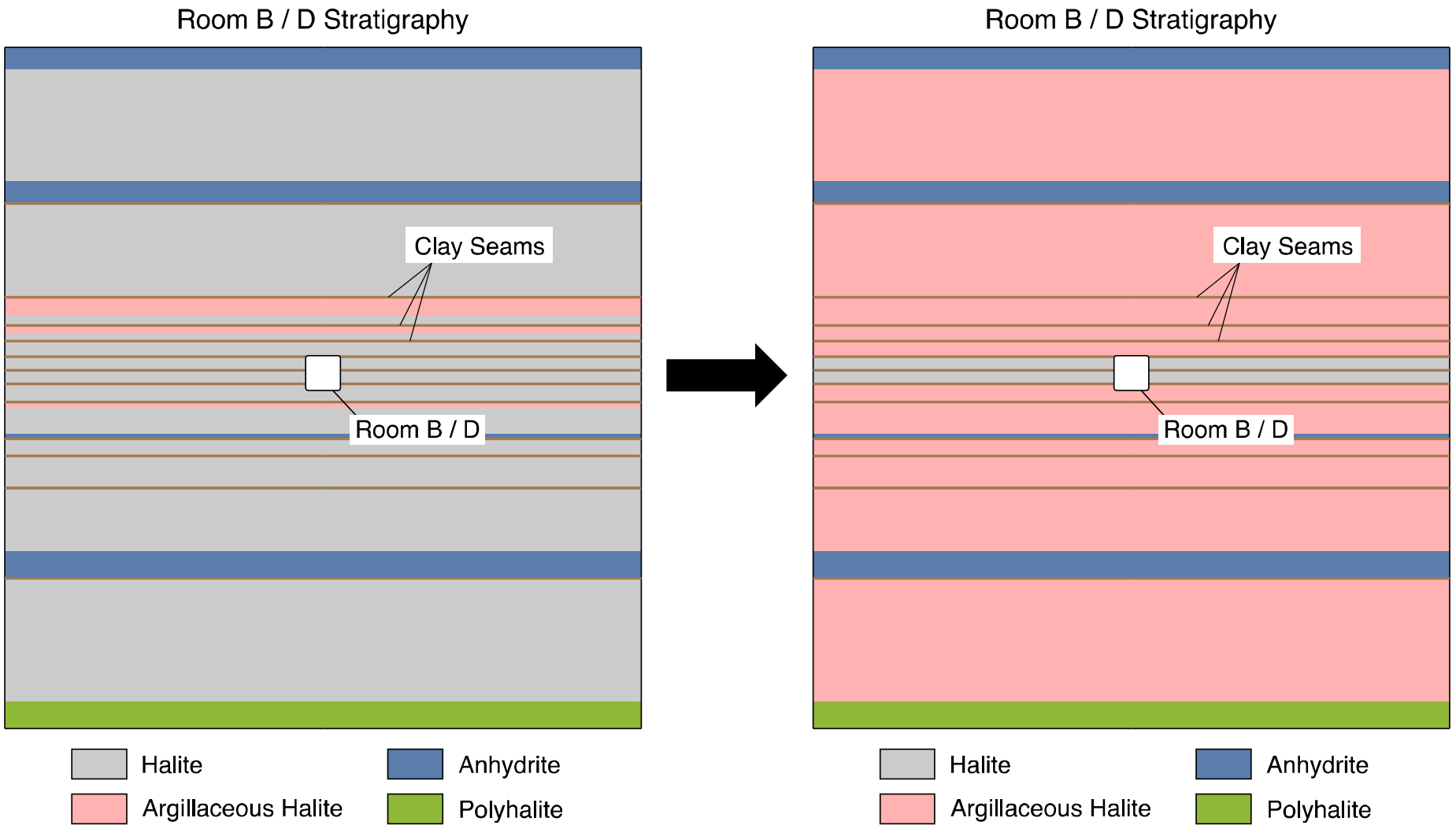
Steady State Creep Rate

$$\dot{\bar{\varepsilon}}^{ss} \propto \left(\frac{\bar{\sigma}}{\mu}\right)^{n}$$

Transient Creep Strain Limit

$$\bar{\varepsilon}^{tr*} \propto \left(\frac{\bar{\sigma}}{\mu}\right)^{m}$$

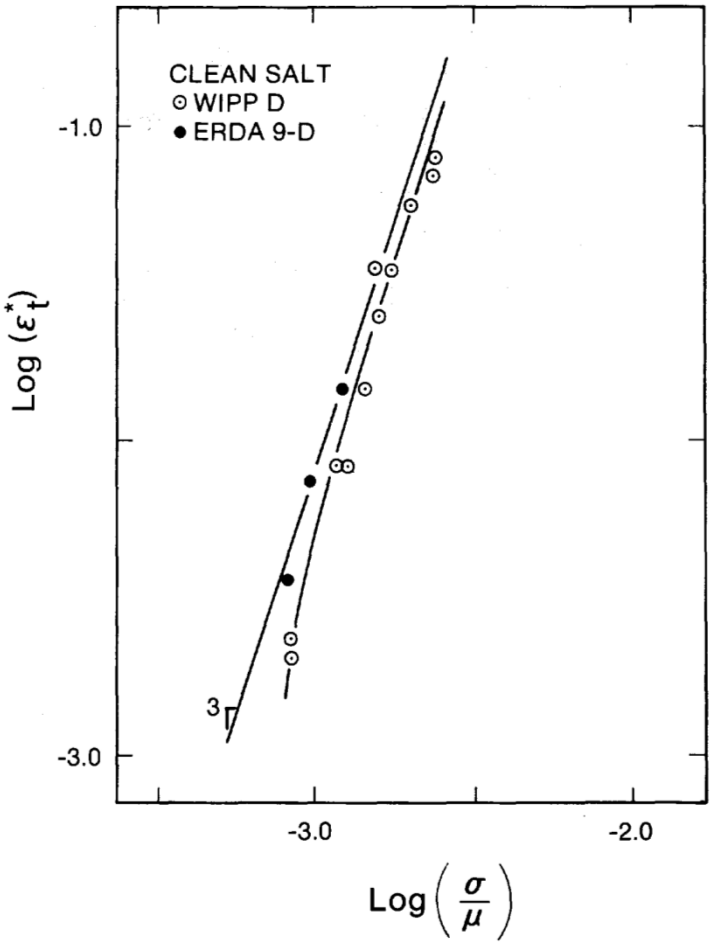
Changed the Stratigraphy



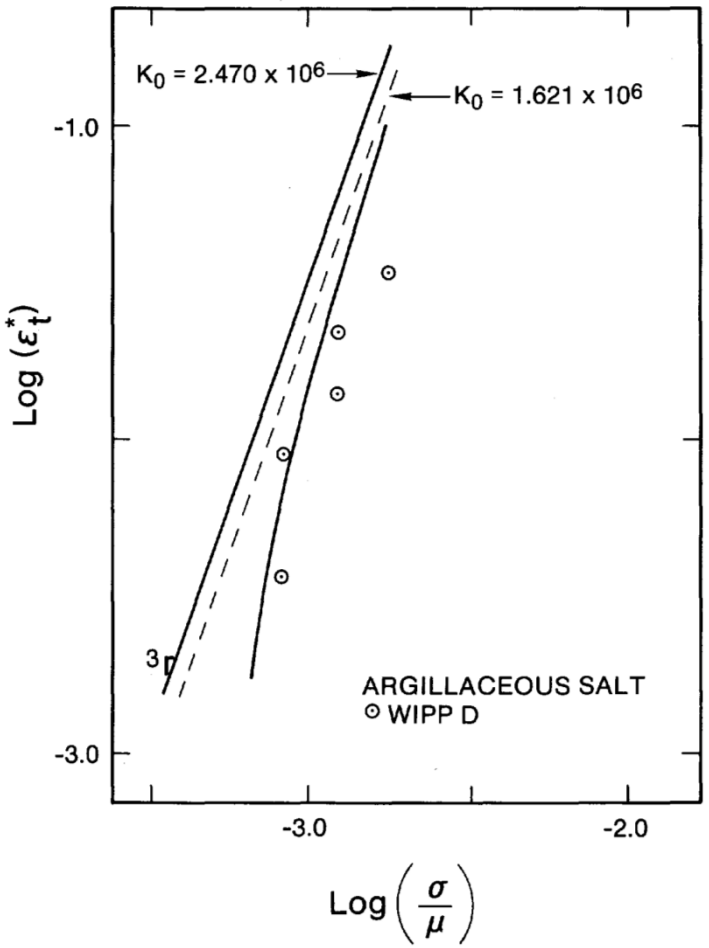
Changed the Material Model Calibrations

Sandia National Laboratories

Clean Salt



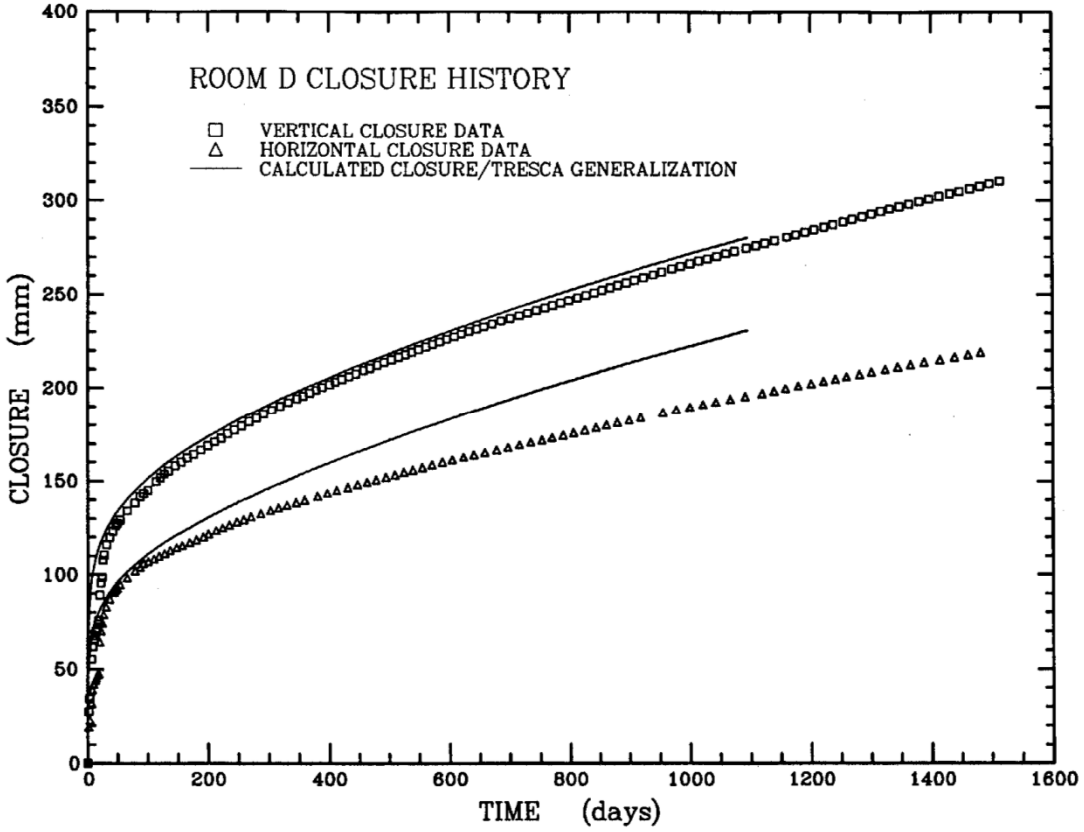
Argillaceous Salt



Argillaceous transient strain limit treated as a “free parameter”.

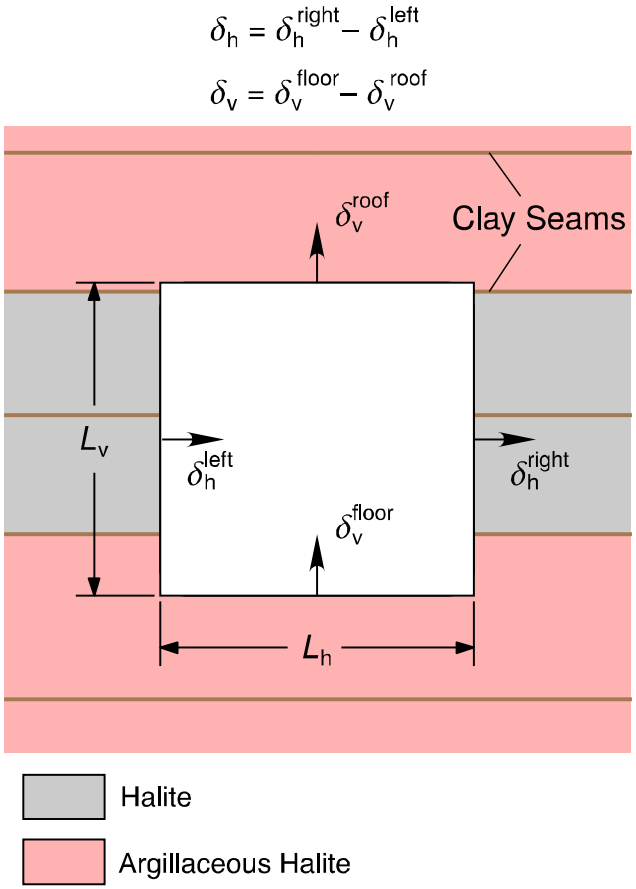
Legacy Simulations

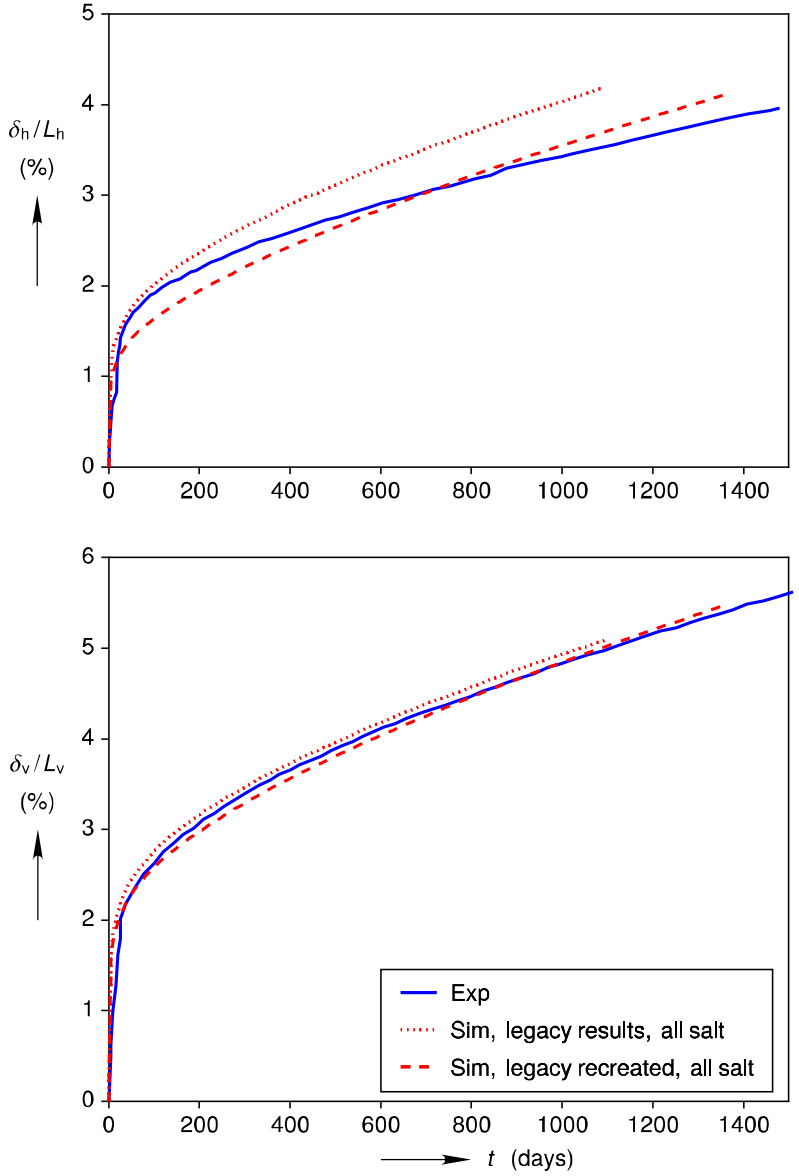
- Changed from von Mises to Tresca flow potential
- Changed from mostly clean salt to mostly argillaceous salt
- Changed the material model calibrations
  - Argillaceous transient strain limit treated as a free parameter
- Changed the clay seam friction coefficient from 0.2 to 0.4



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

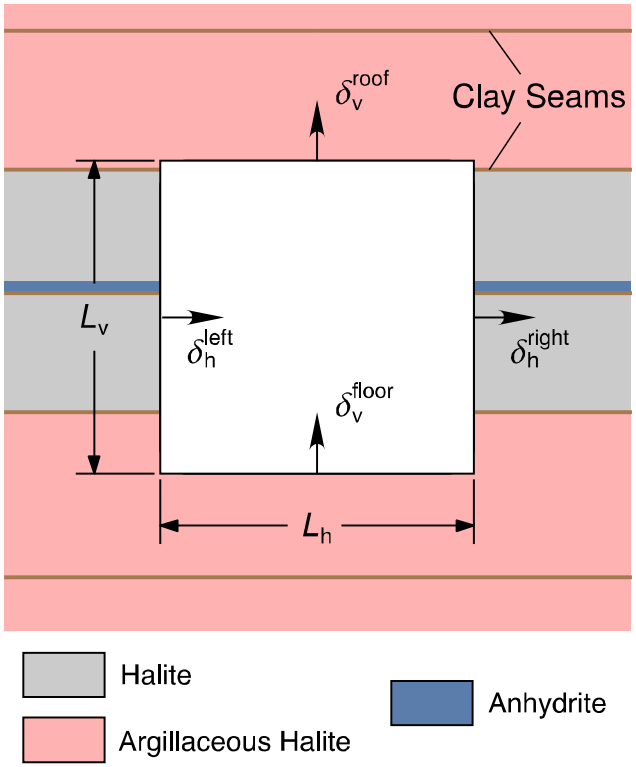


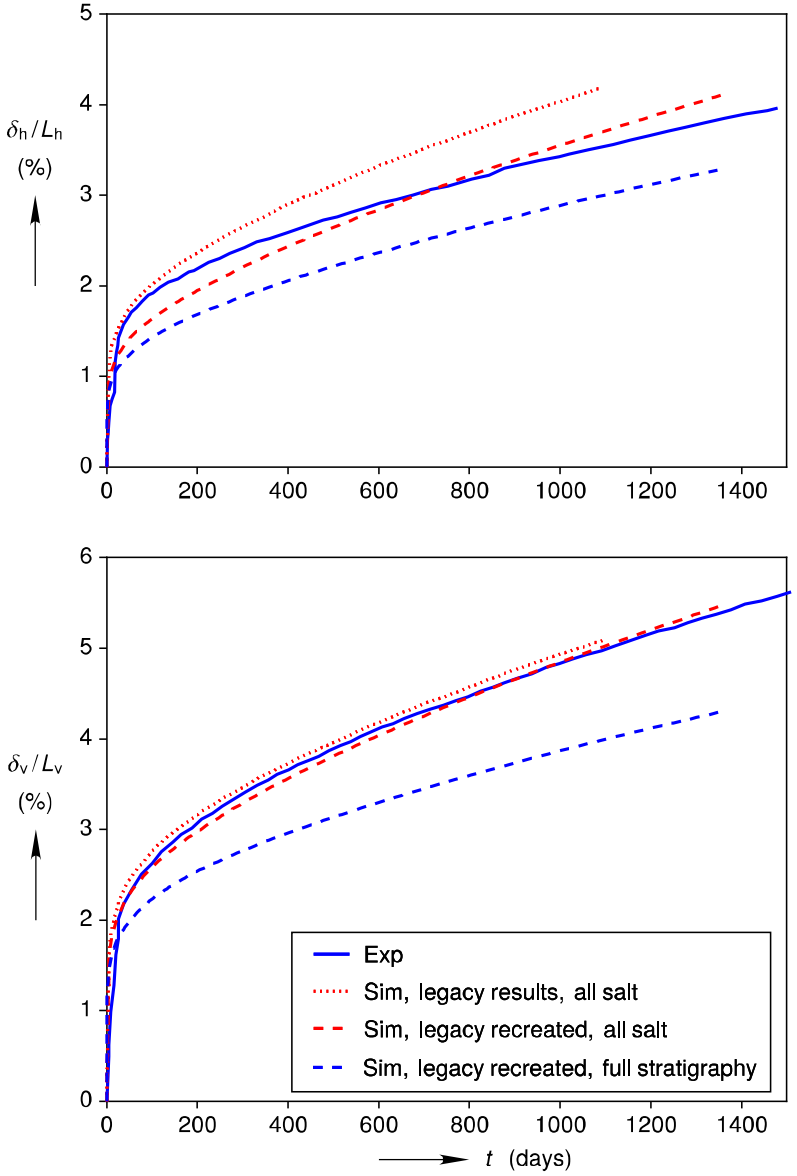


Re-creation of Legacy Simulations

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

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





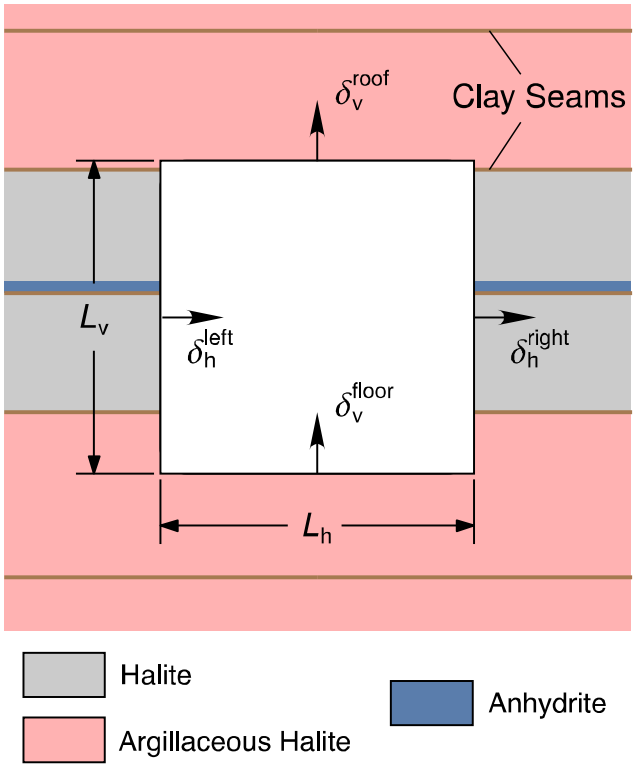
Sandia National Laboratories

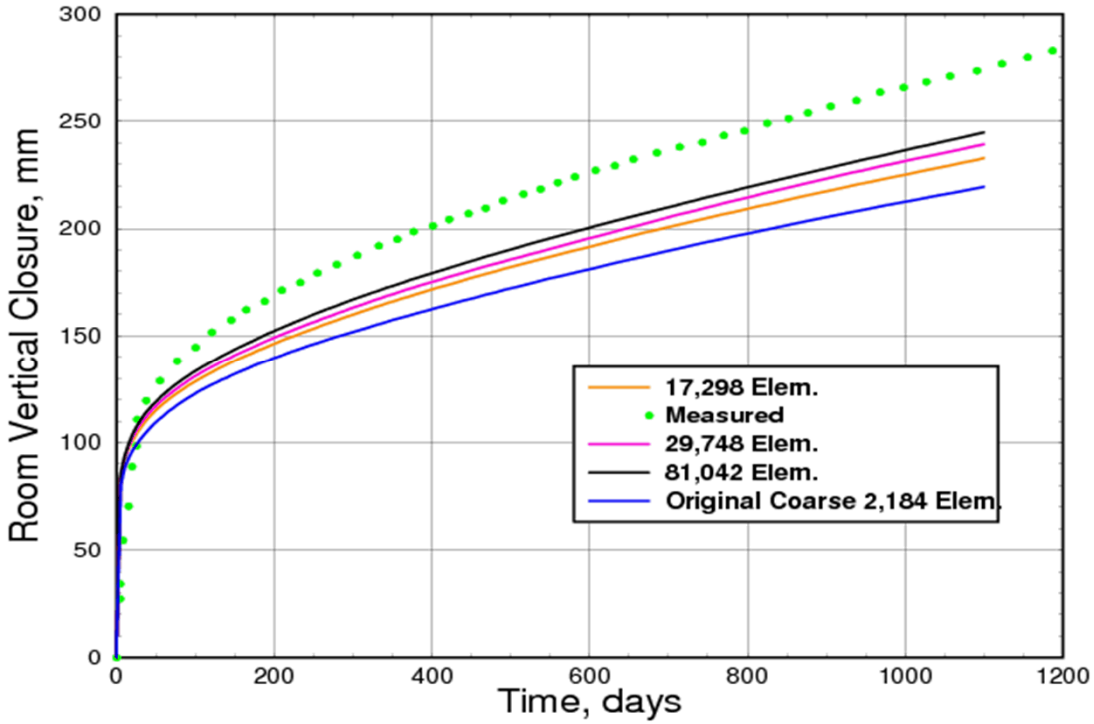
Resolving the Legacy Simulation Numerics

Initial Mesh Convergence Study

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

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





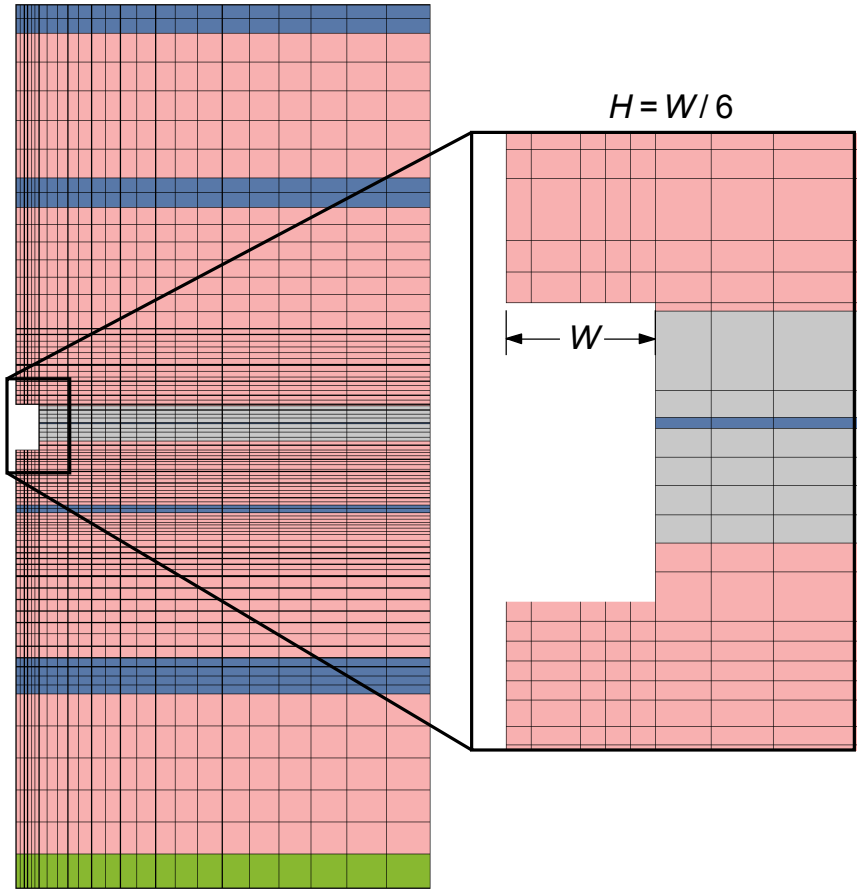
Arguello, J., Summary of FY15 Results of Benchmark Modeling Activities, SAND2015-6273, 2015

Changed the Mesh

Sandia National Laboratories

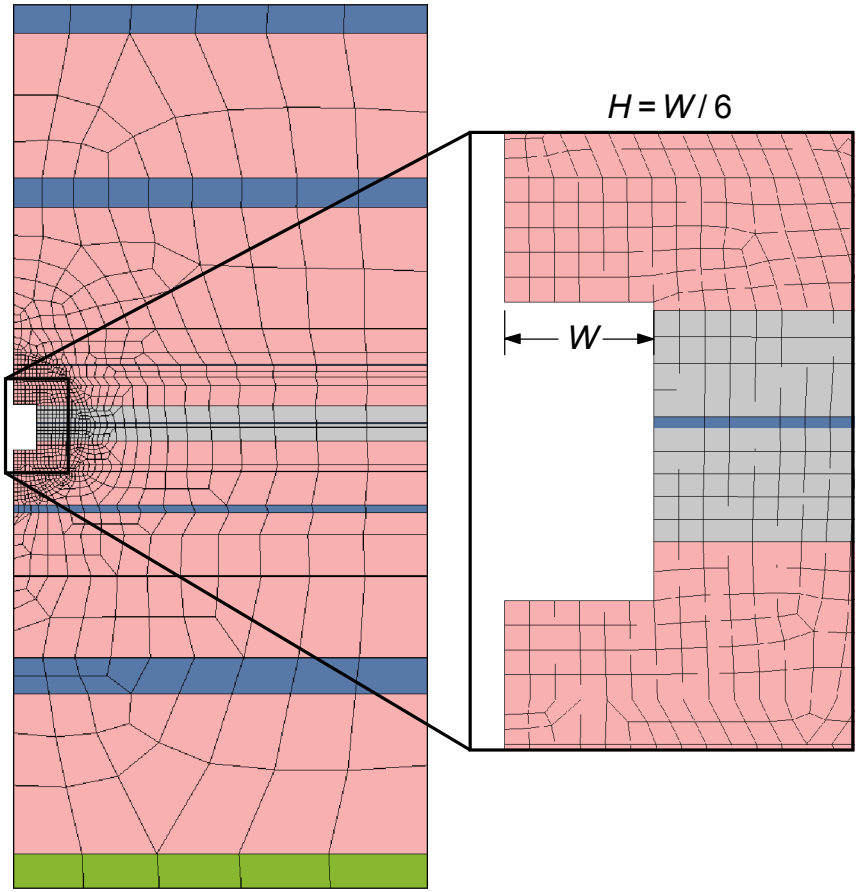
Legacy Coarse Mesh

2184 Elements



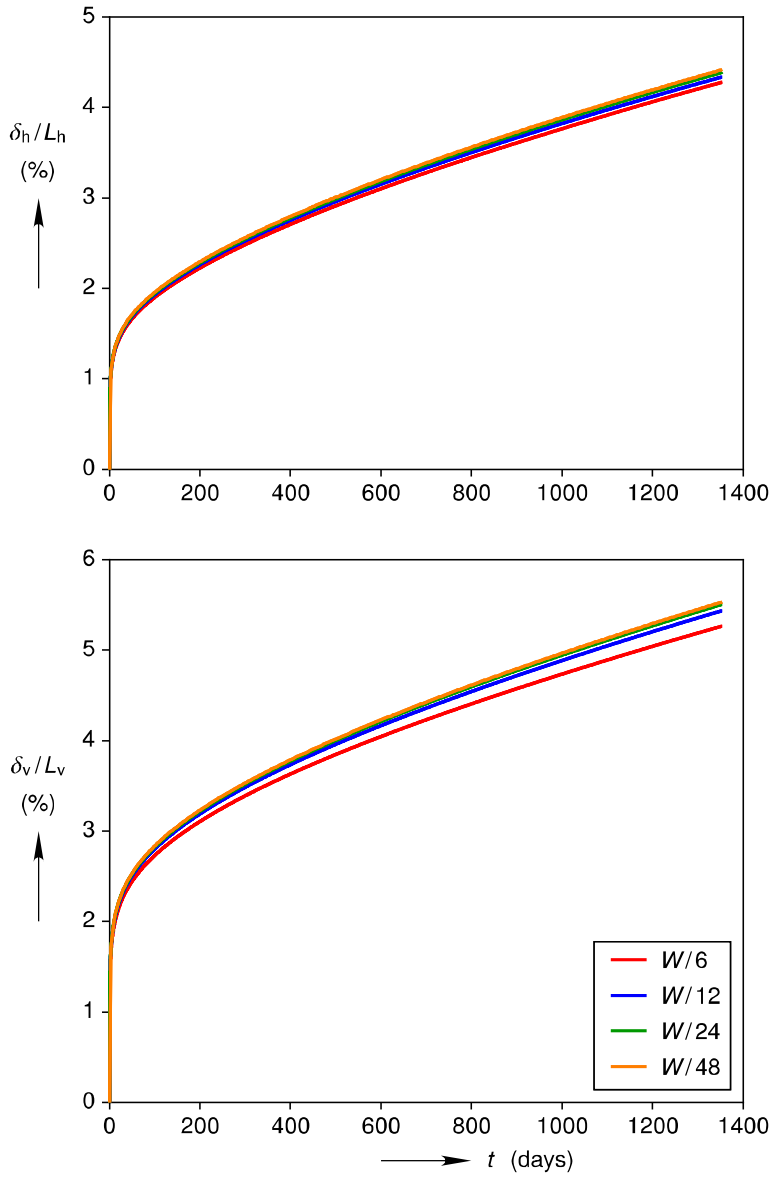
New Coarse Mesh

1139 Elements

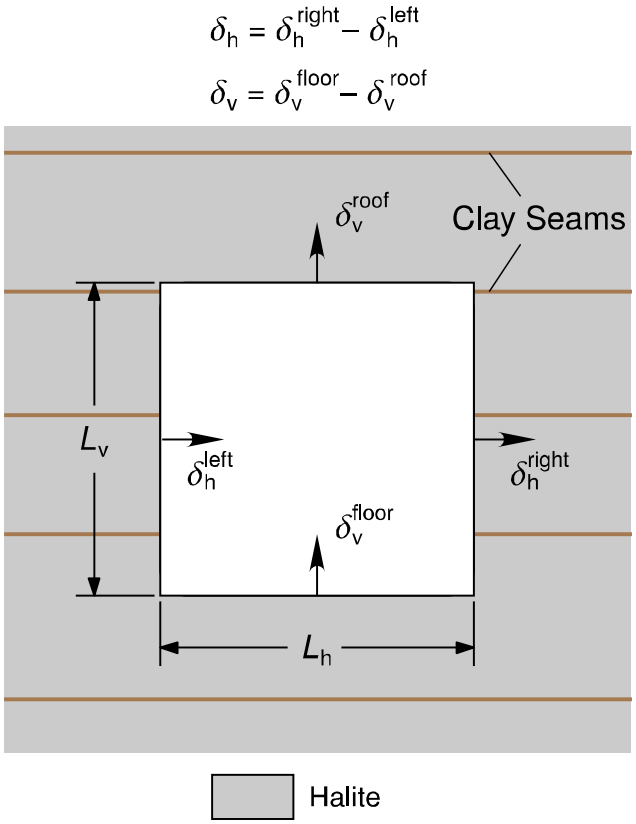


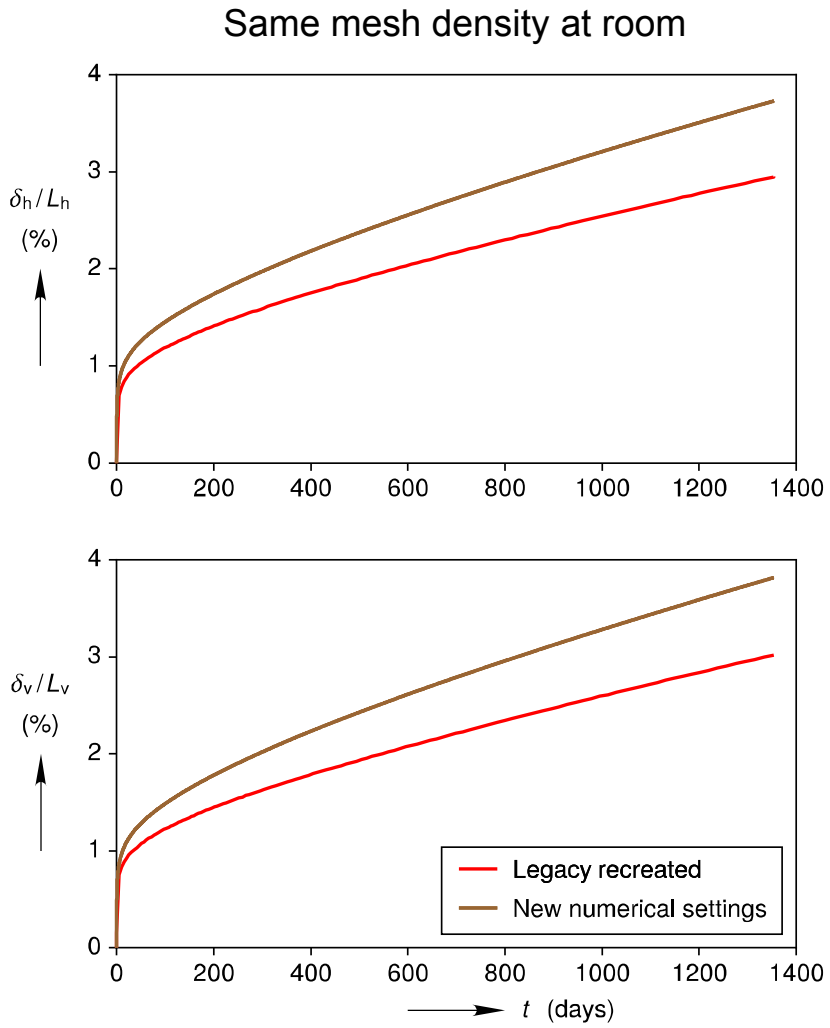
New Mesh Convergence Study

- 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

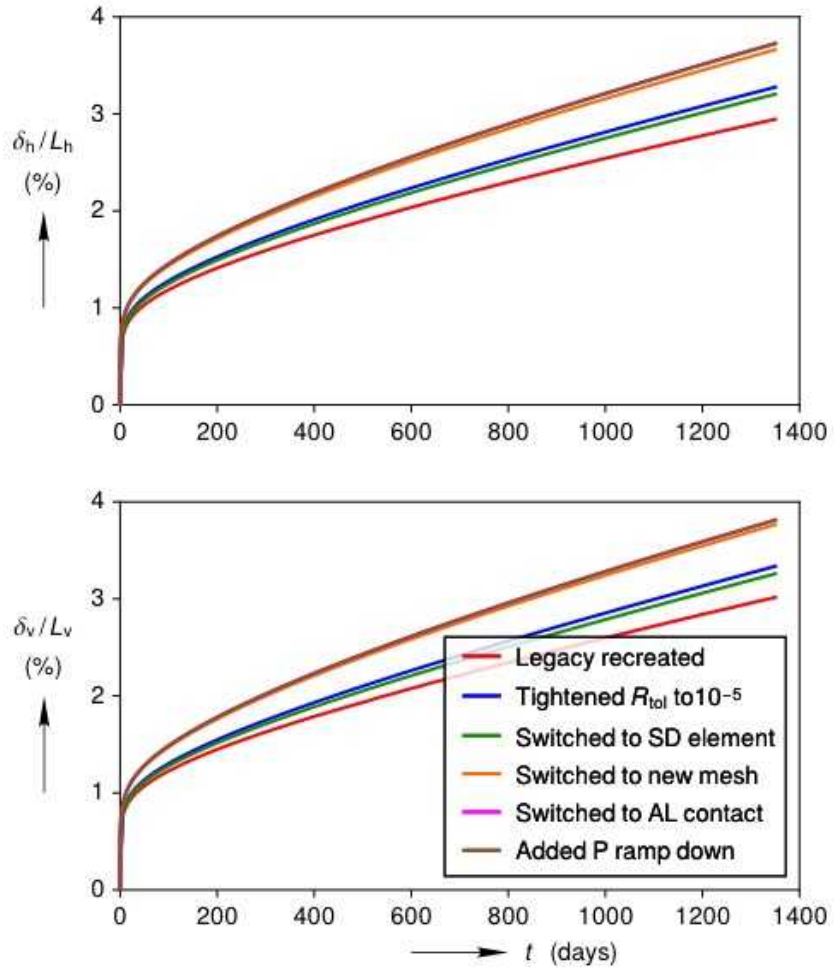




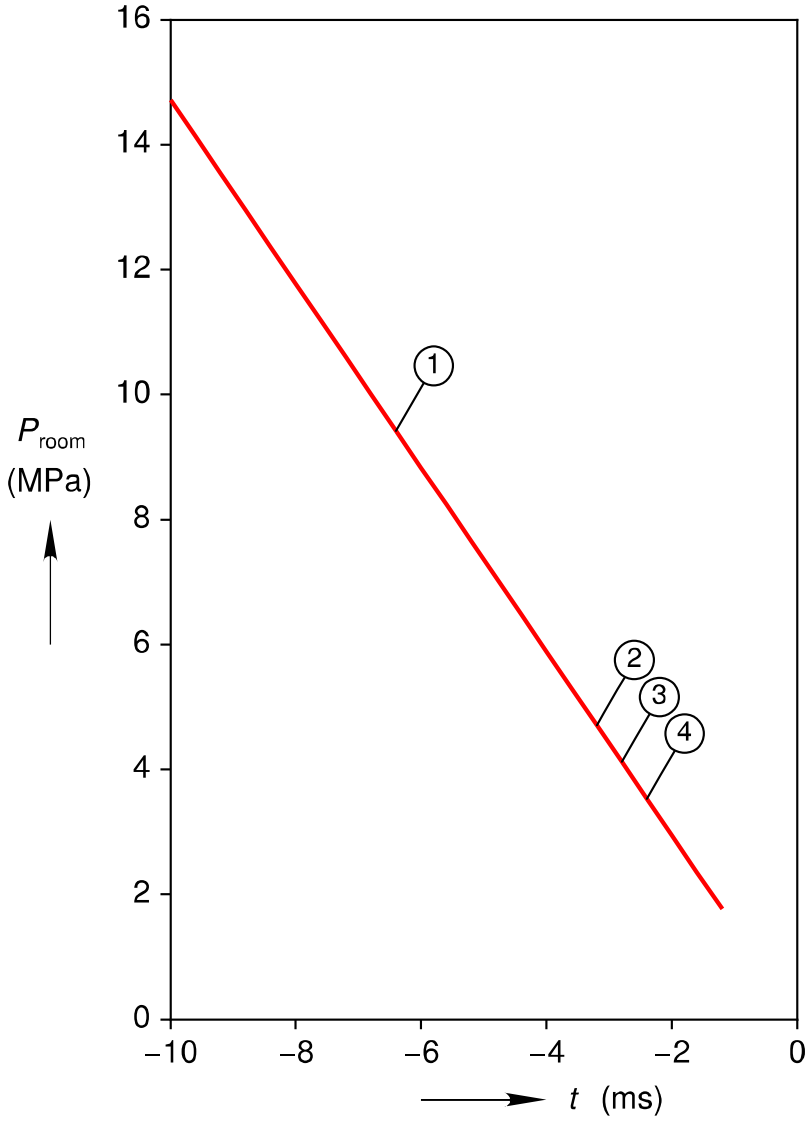
Effects of Numerical Choices

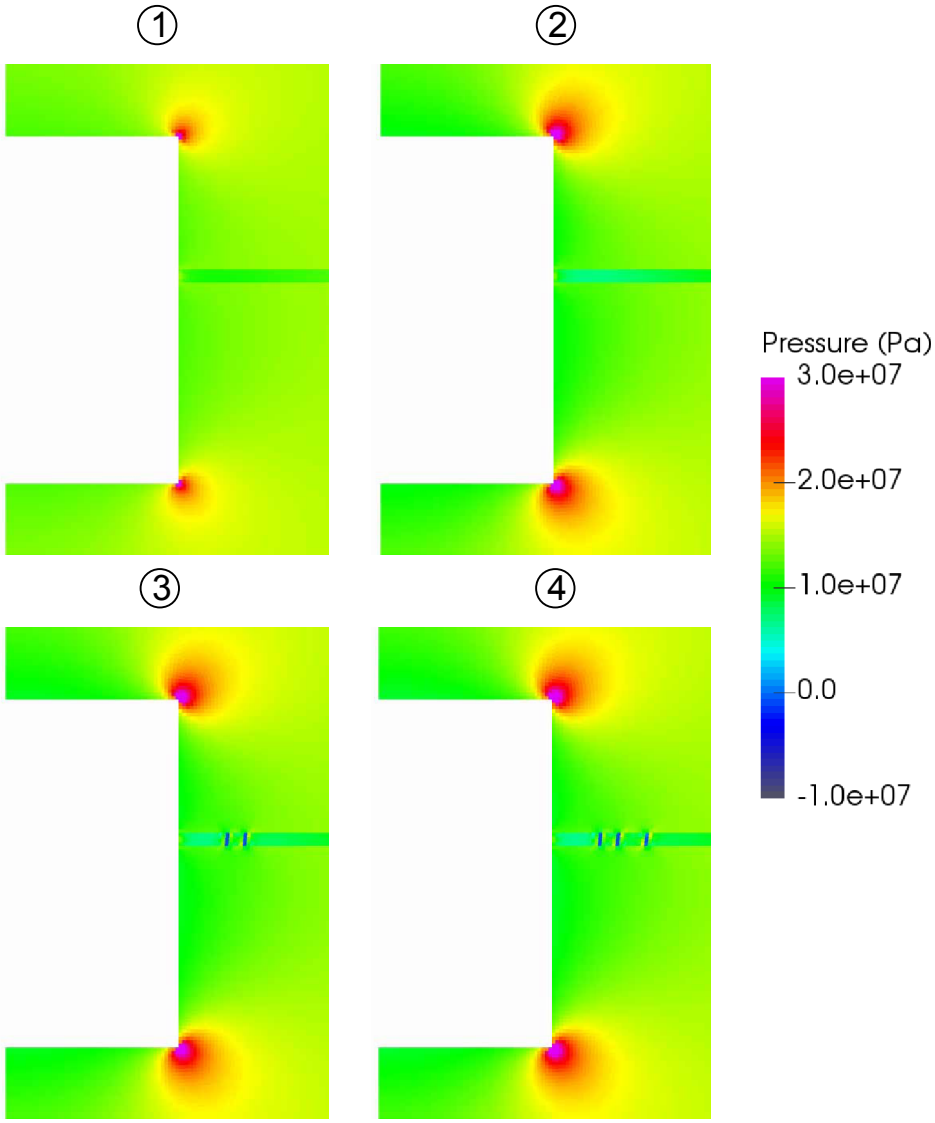
- Changed the mesh
- Changed R_{tol} =10^{-3} to R_{tol} =10^{-5}
- Switched from MQ to SD element
- Switched from Kinematic Contact to Augmented Lagrange Contact enforcement
- Added a pressure ramp down

Same mesh density at room

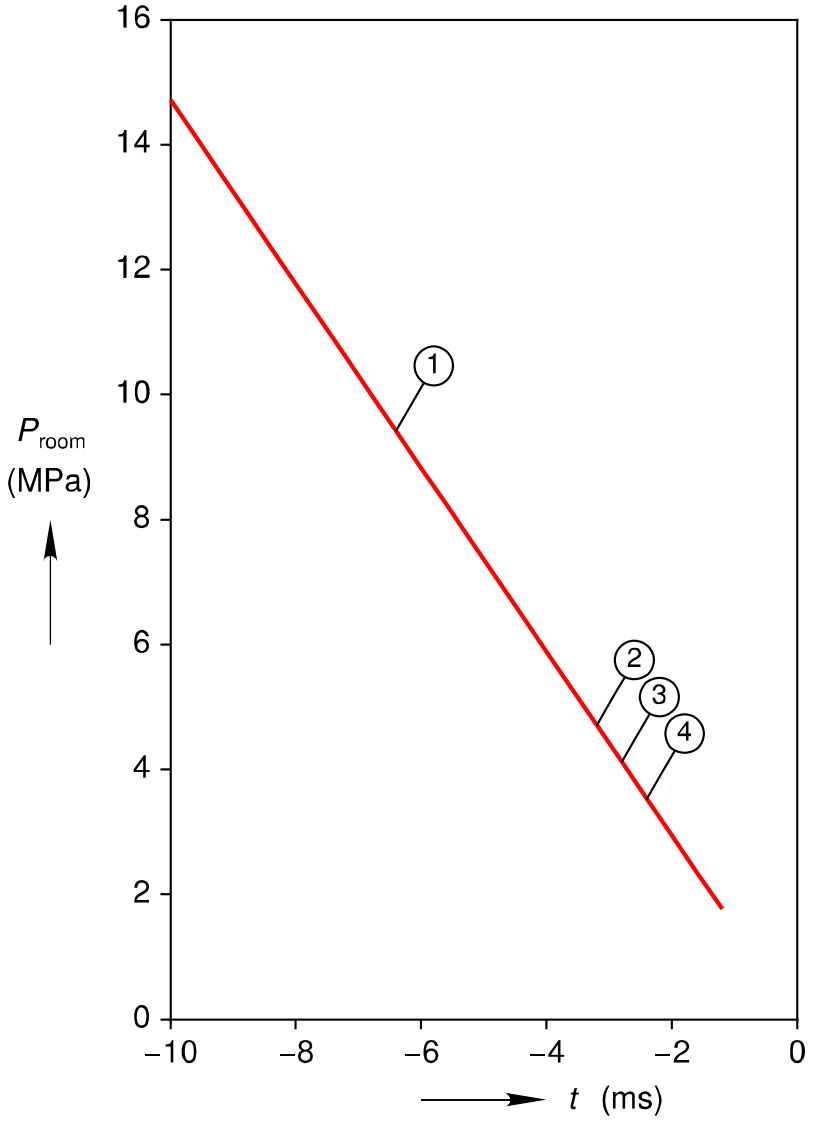


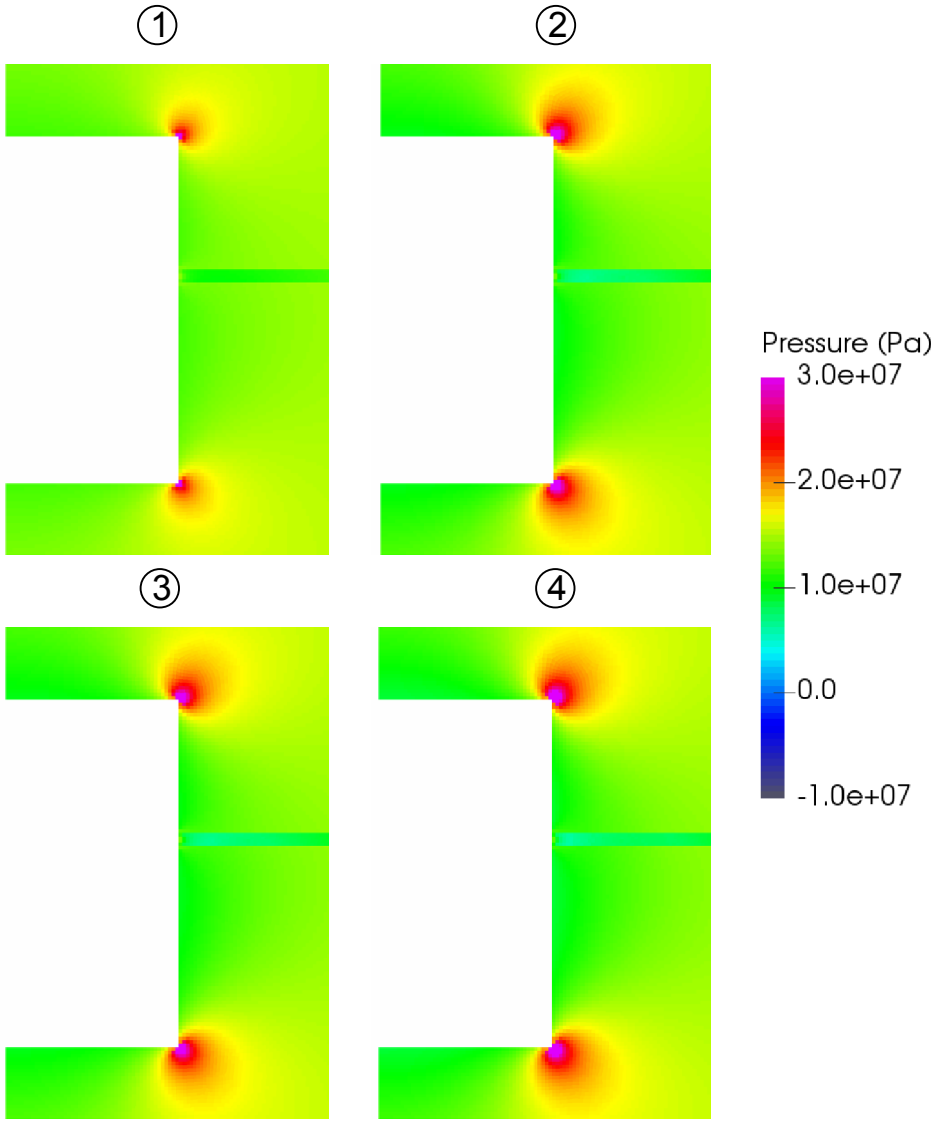
Anhydrite Issue



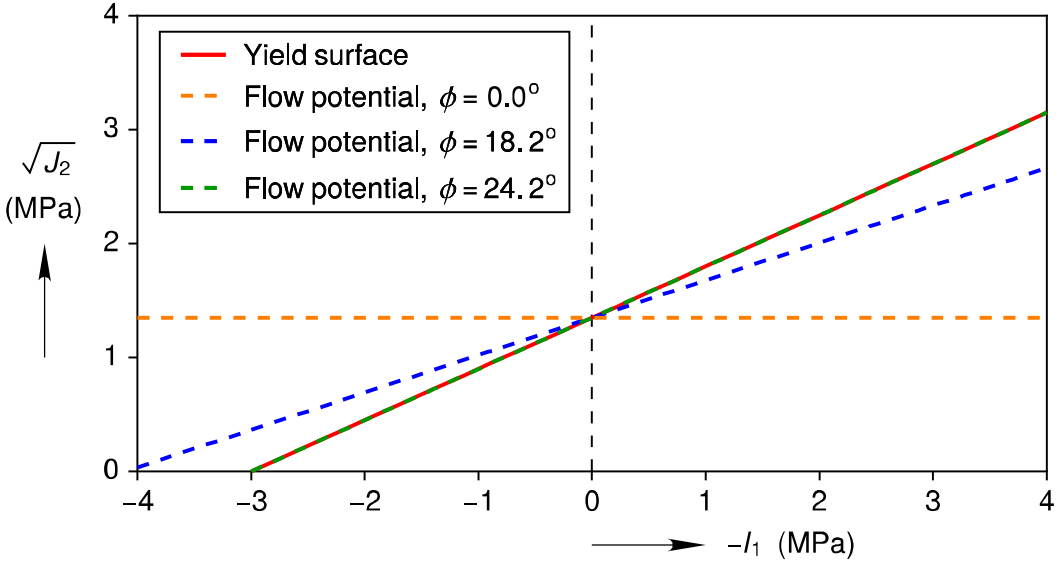


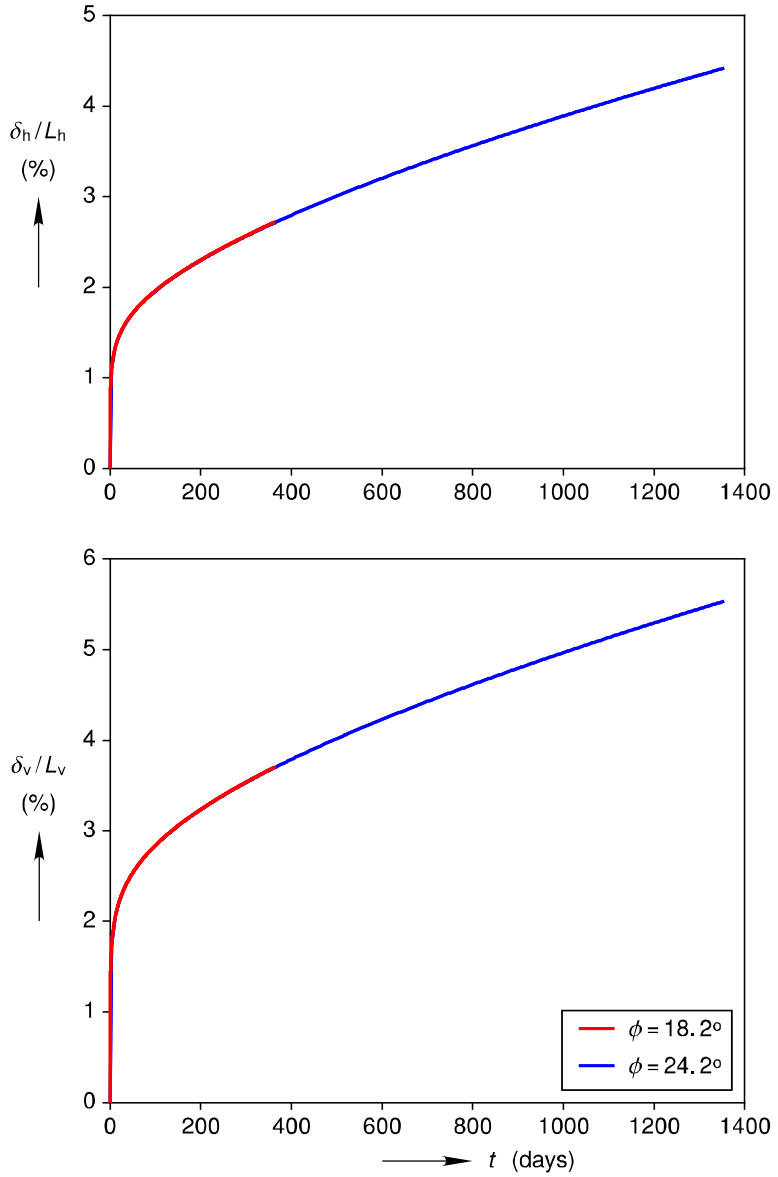
Anhydrite Issue Resolved





Anhydrite Dilatation Angle Sensitivity

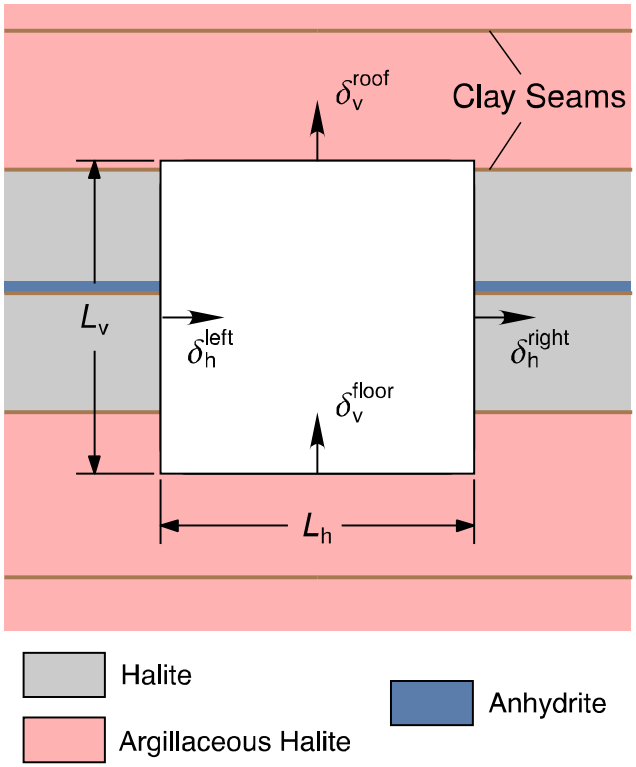


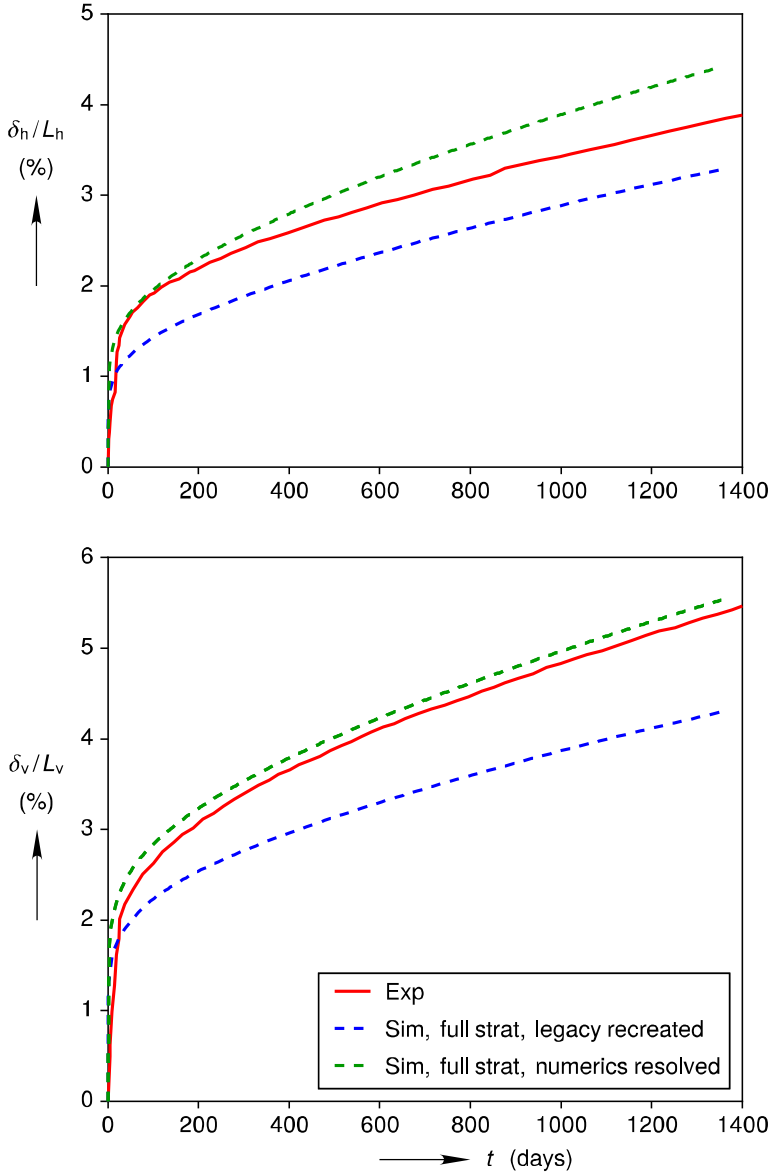


Impact of Resolving the Numerics

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

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



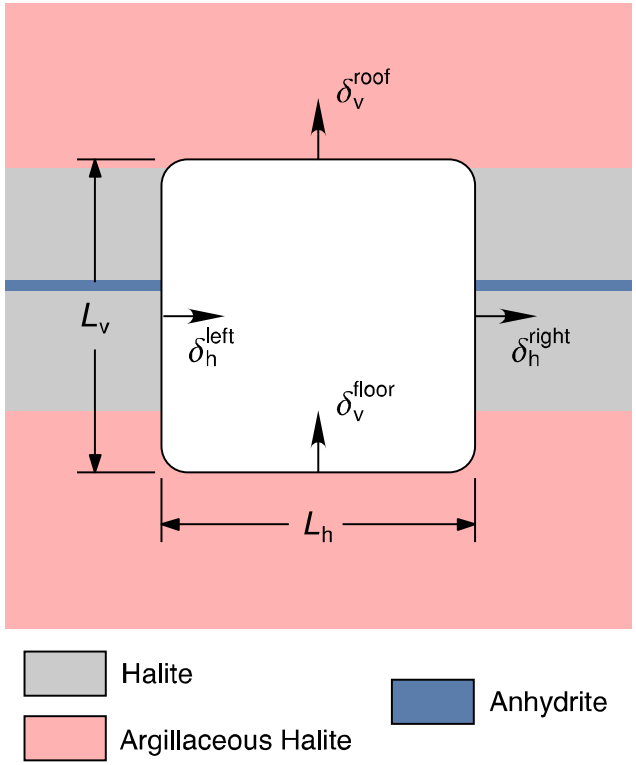


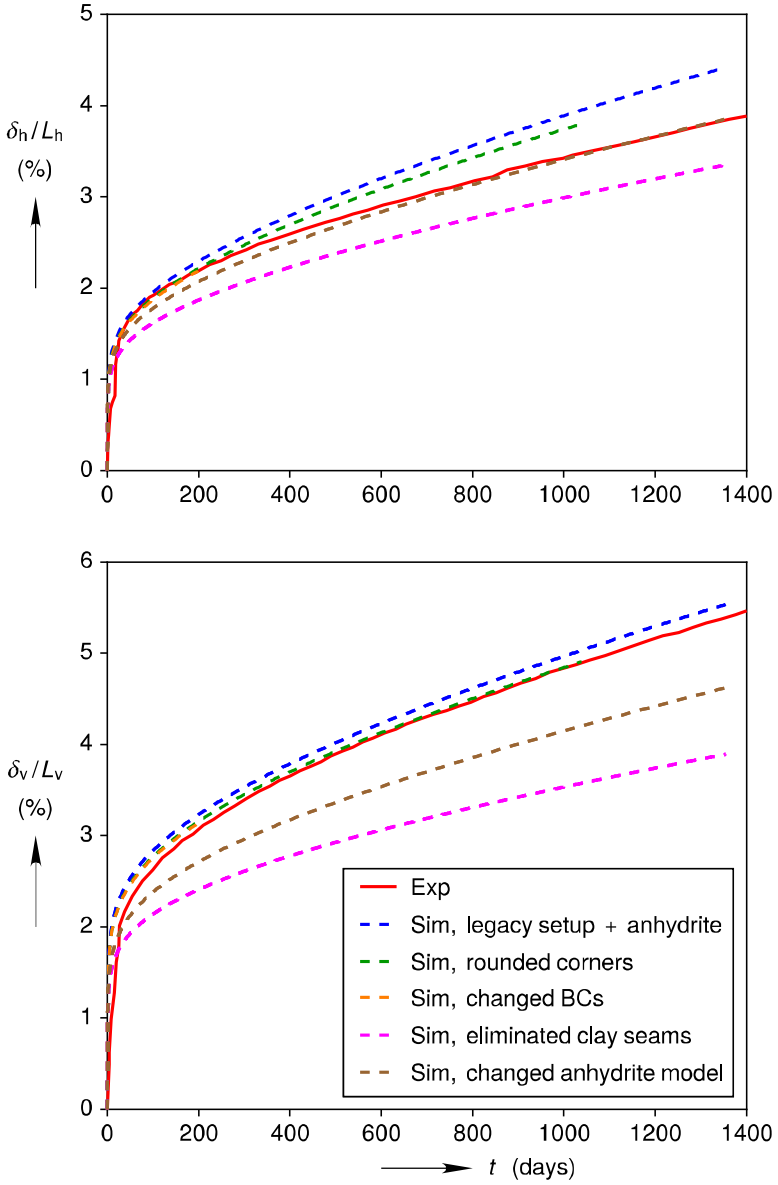
Joint Project III Simulations

Transition to Joint Project III Setup

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

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

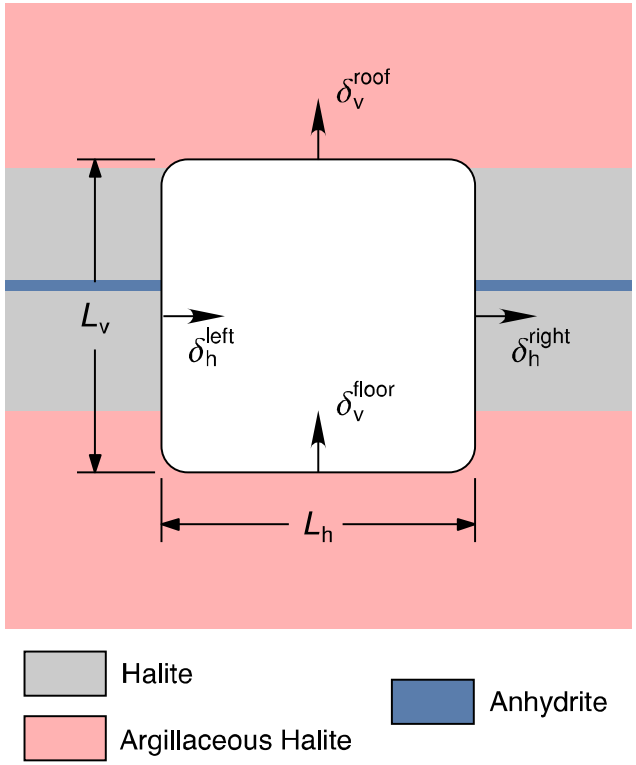


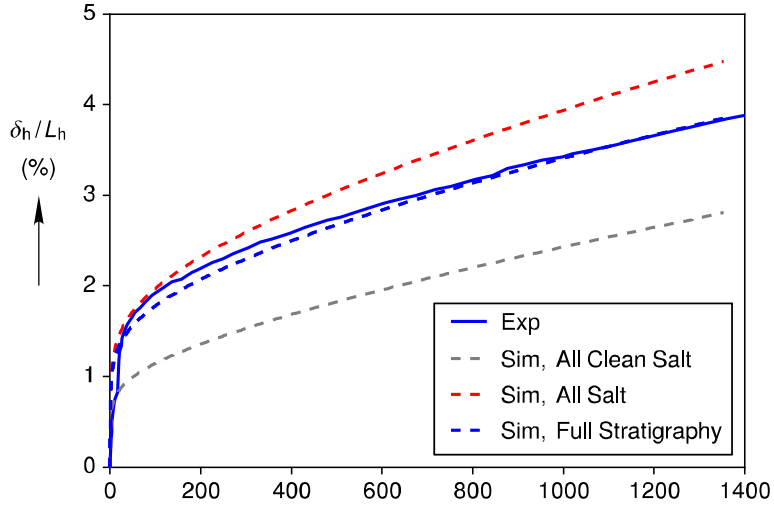


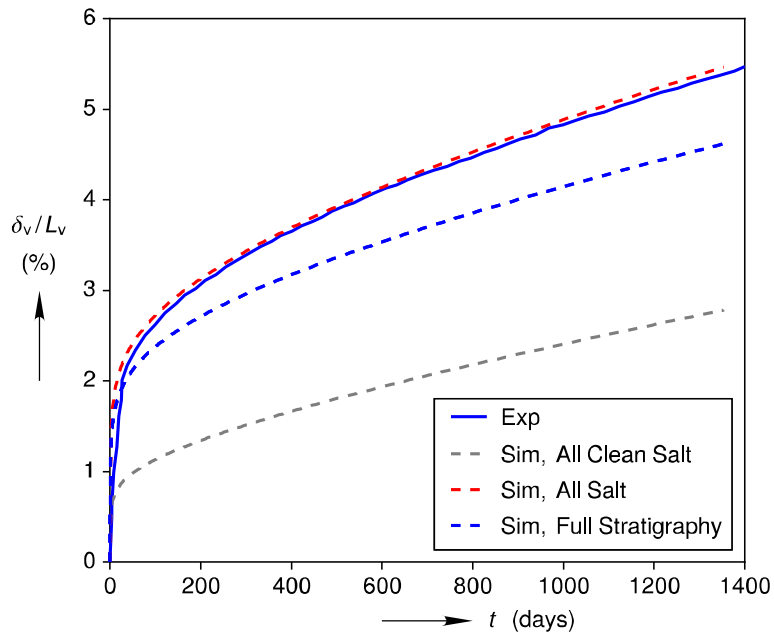
Joint Project III Simulations

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

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

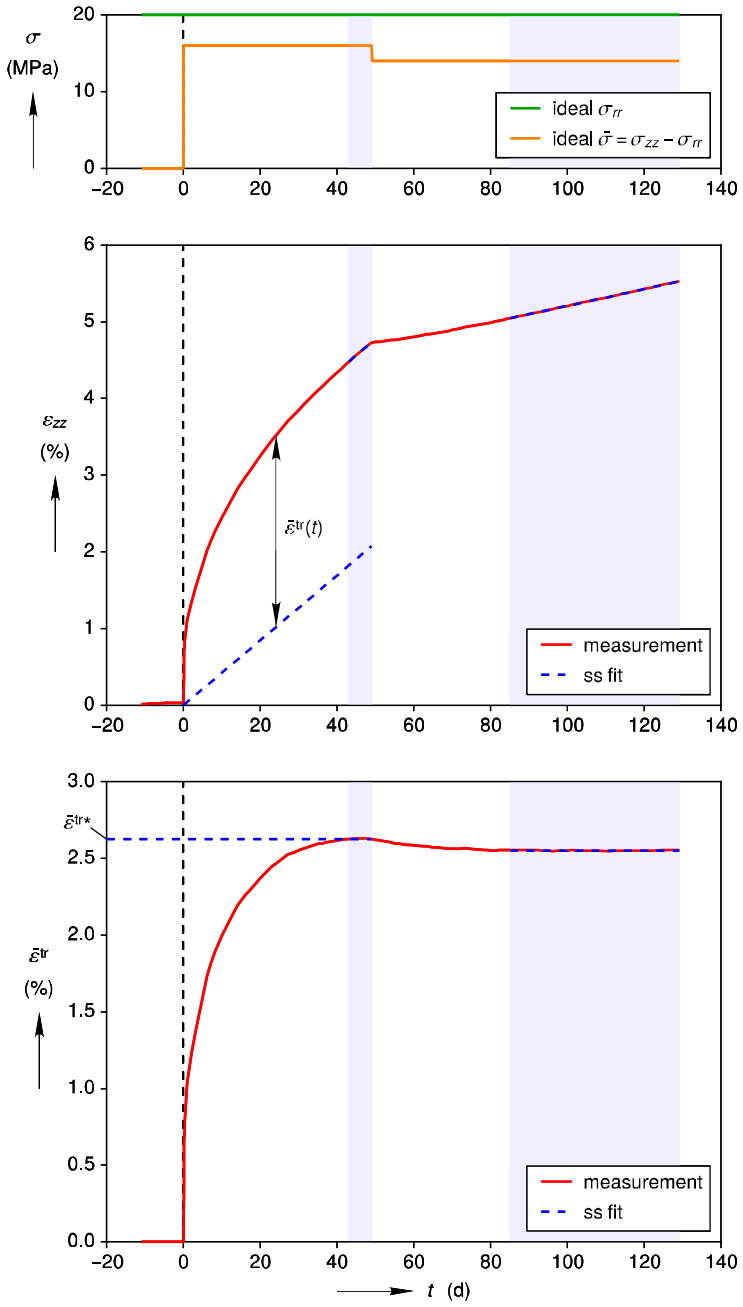






Legacy Munson-Dawson Calibration

Triaxial Creep Exp



Additive Decomposition

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

Strain Definitions

ε_{zz} = total axial strain

ε^{e}_{zz} = axial elastic strain

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

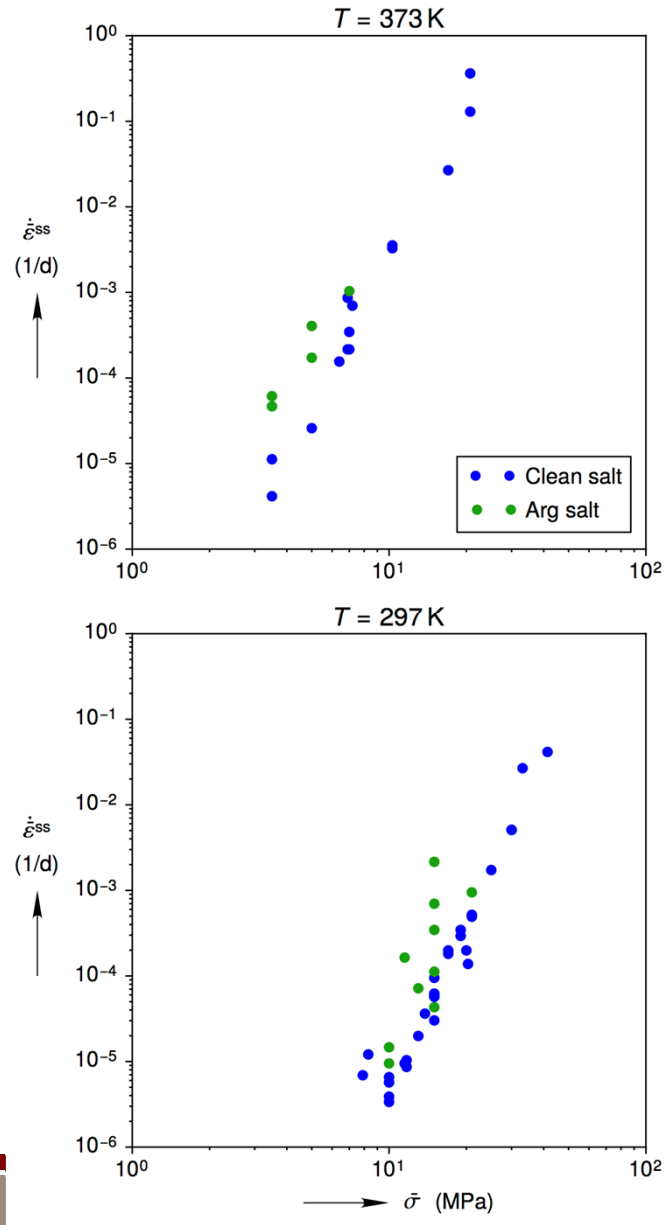
$\bar{\varepsilon}^{tr}$ = transient equivalent creep strain

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

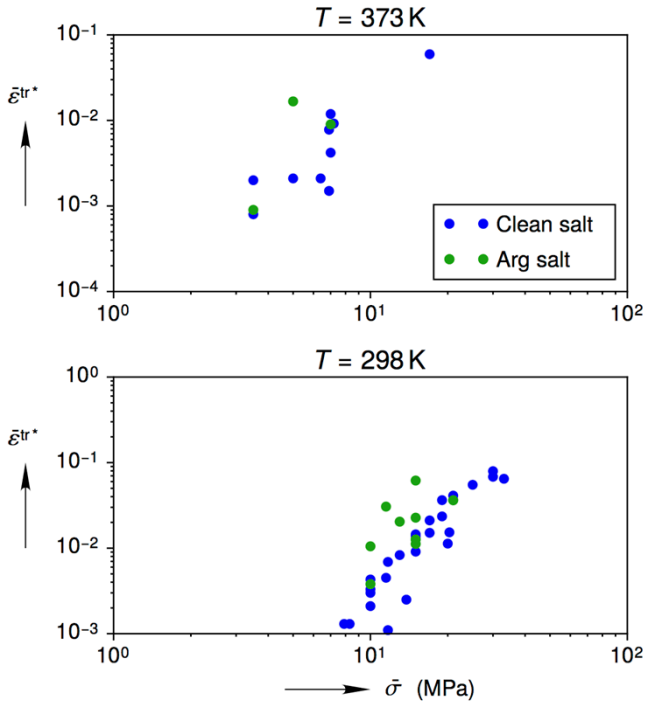
Clean vs. Argillaceous: Legacy Experiments

Sandia National Laboratories

Steady State Rate



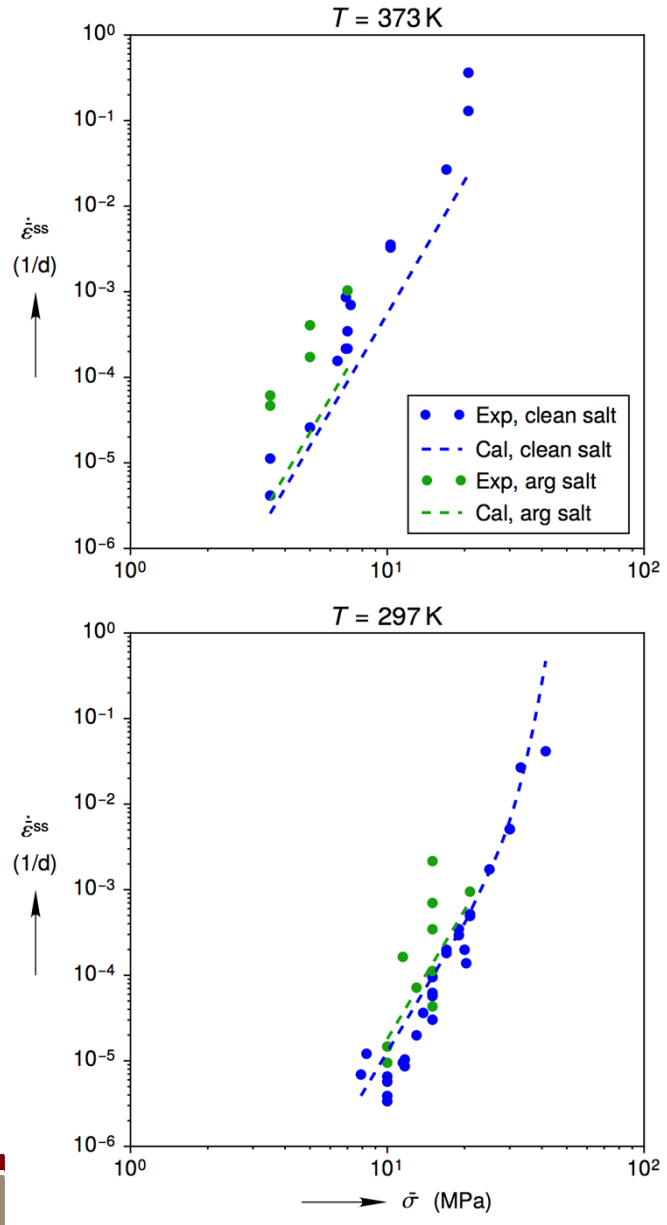
Transient Limit



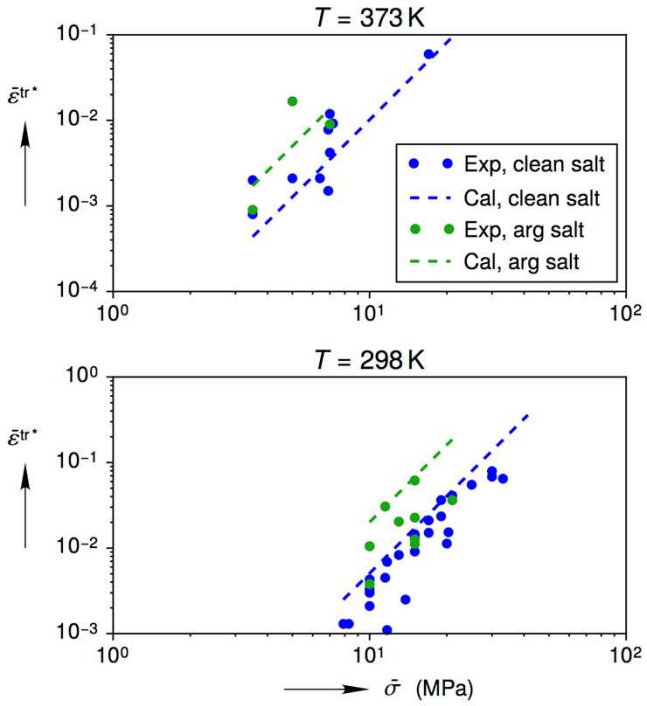
Legacy experimental data copied verbatim from Table 4-1 and 4-2 in Mellegard, K. and Pfeifle, T., Creep tests on clean and argillaceous salt from the Waste Isolation Pilot Plant, SAND92-7291, 1993

Legacy Exp vs. Legacy Cal

Steady State Rate

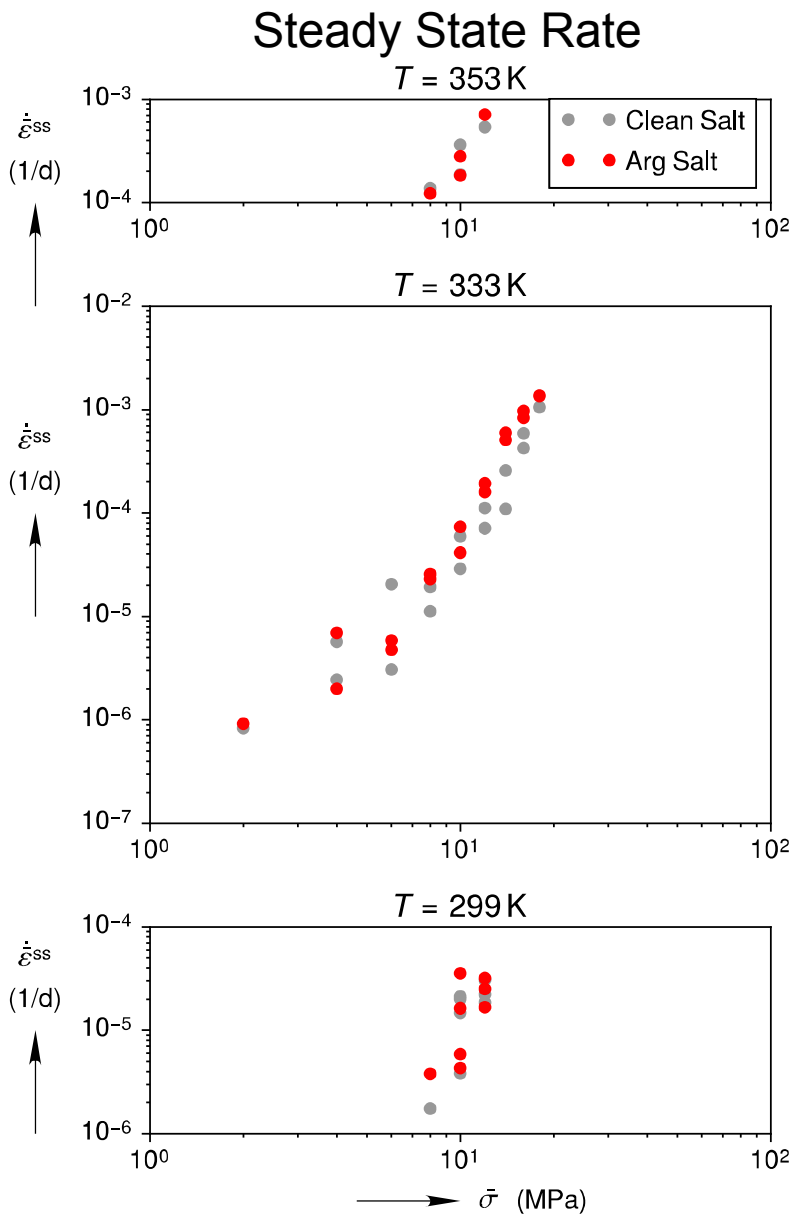


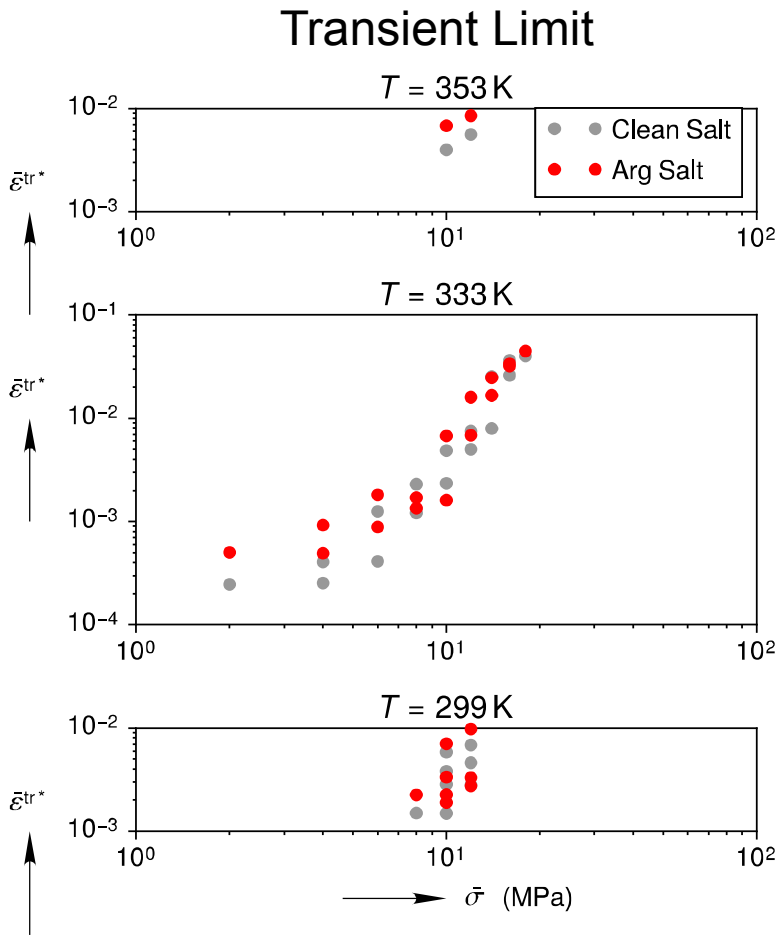
Transient Limit



Legacy experimental data copied verbatim from Table 4-1 and 4-2 in Mellegard, K. and Pfeifle, T., Creep tests on clean and argillaceous salt from the Waste Isolation Pilot Plant, SAND92-7291, 1993

Clean vs. Argillaceous: JPIII Experiments





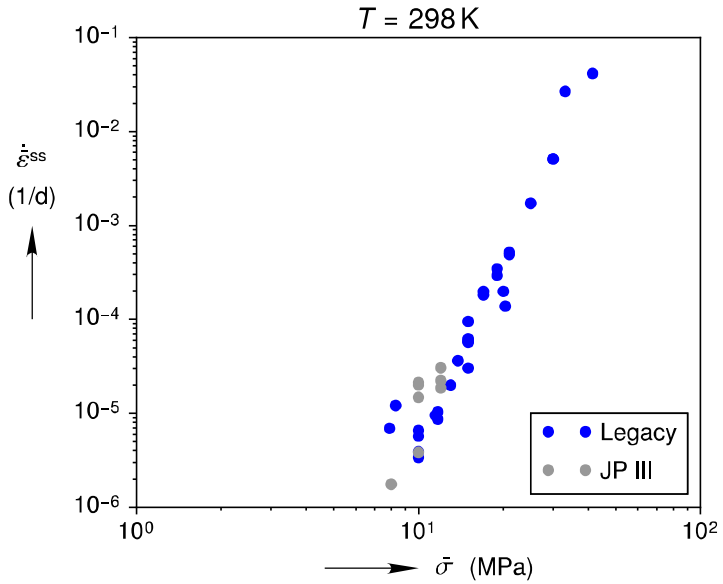
Legacy vs. JPIII Experiments

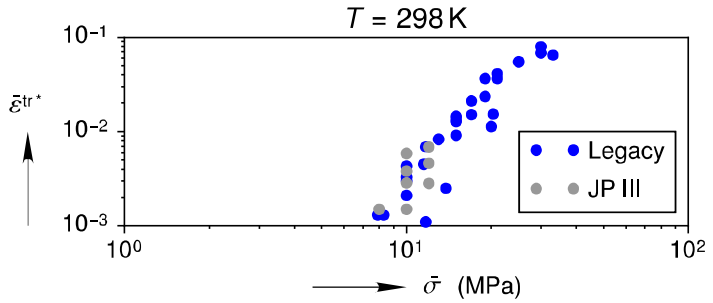
Sandia National Laboratories

Steady State Rate

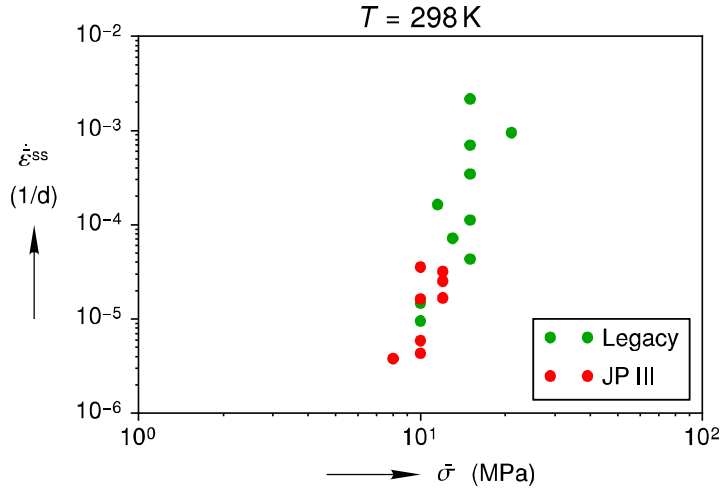
Transient Limit

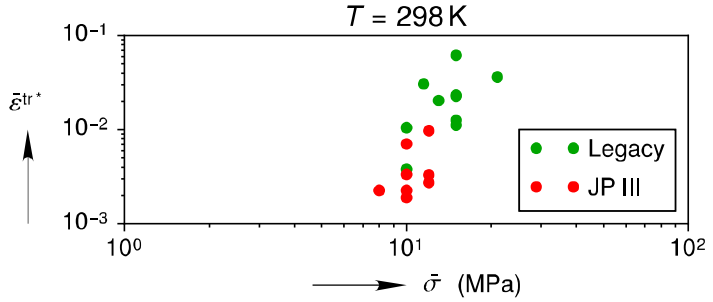
Clean Salt





Argillaceous Salt



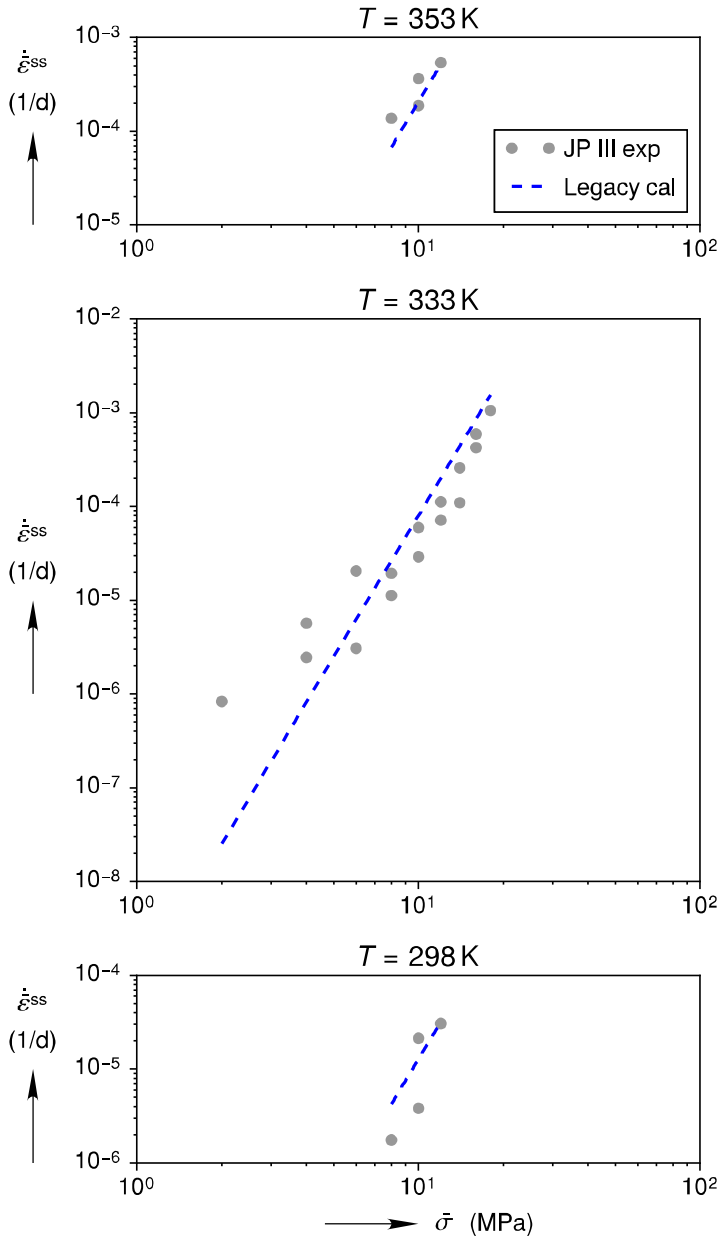


Legacy experimental data copied verbatim from Table 4-1 and 4-2 in
Mellegard, K. and Pfeifle, T., Creep tests on clean and argillaceous salt from the Waste Isolation Pilot Plant, SAND92-7291, 1993

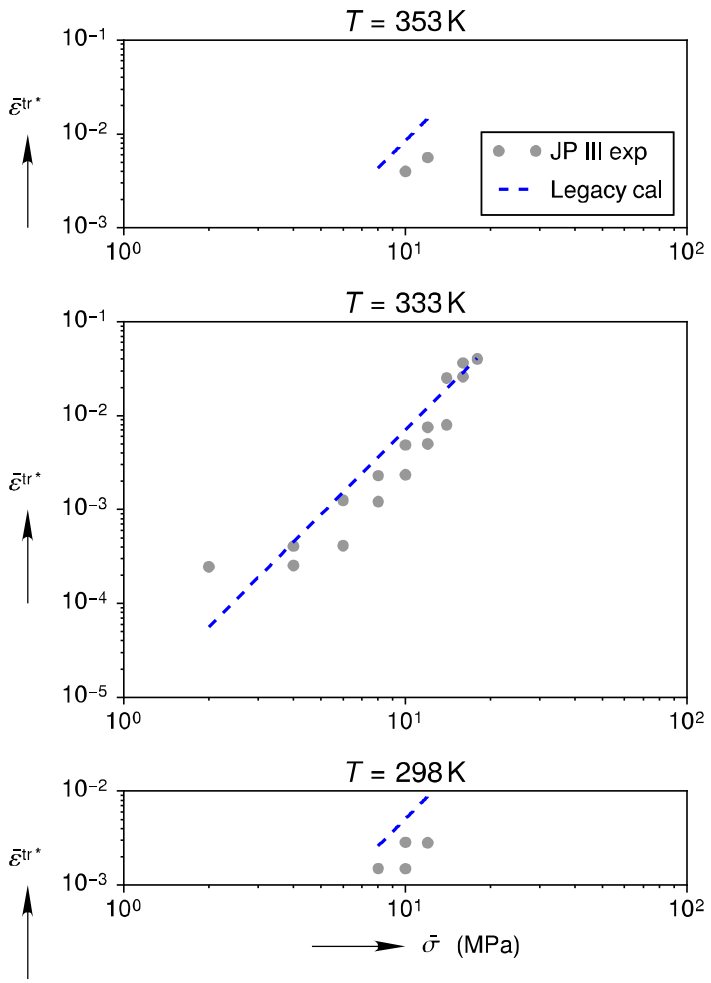
Clean Salt: JPIII Exp vs. Legacy Cal

Sandia National Laboratories

Steady State Rate



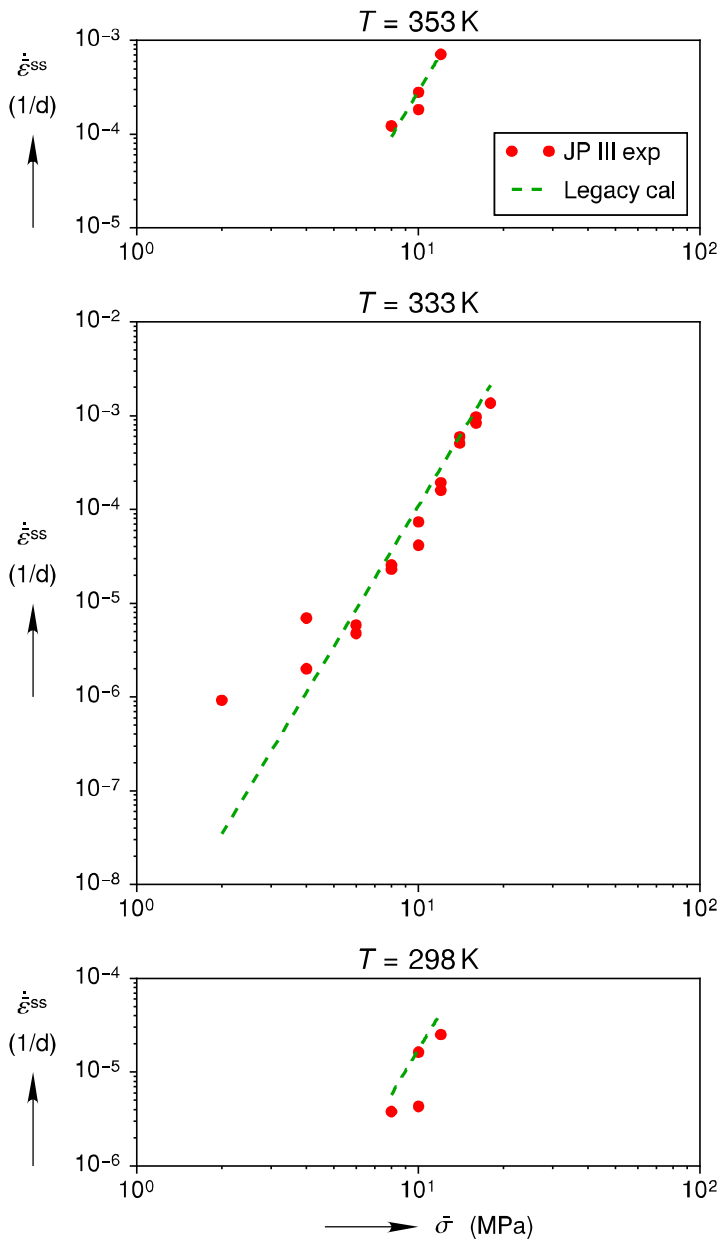
Transient Limit



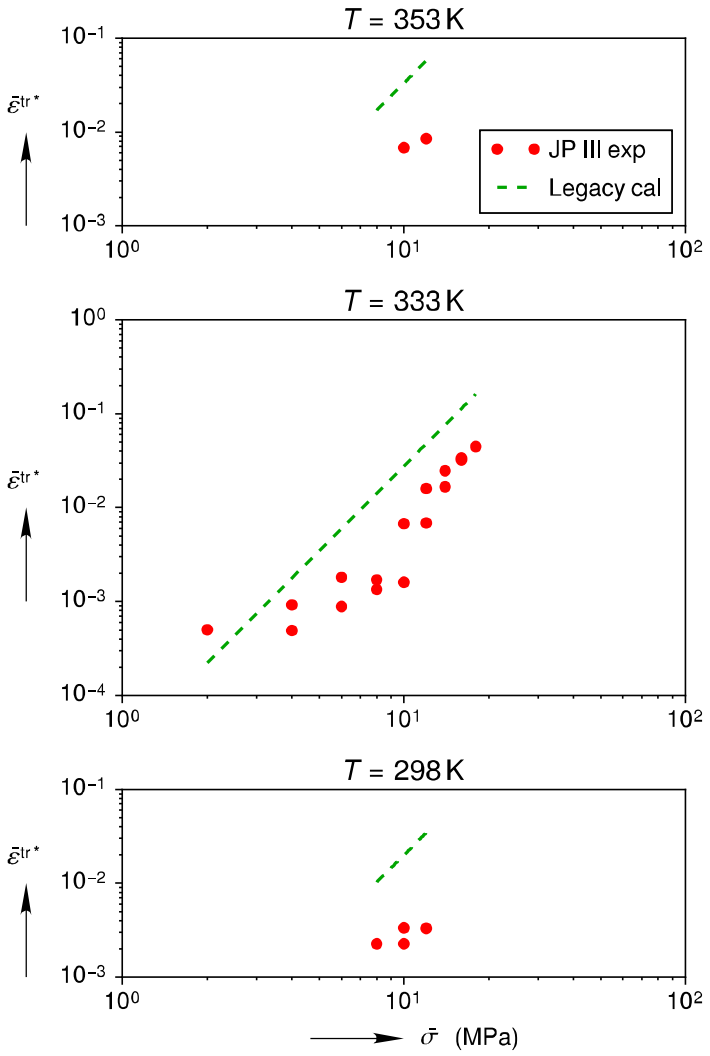
Argillaceous Salt: JPIII Exp vs. Legacy Cal

Sandia National Laboratories

Steady State Rate



Transient Limit



Preliminary Munson-Dawson Re-Calibration

Munson Dawson Model

Sandia National Laboratories

Steady State Rate

$$\dot{\bar{\varepsilon}}^{ss} = \sum_{i=1}^{3} \dot{\bar{\varepsilon}}_i^{ss}$$

$$\dot{\bar{\varepsilon}}_1^{ss} = A_1 \exp\left(-\frac{Q_1}{R\,T}\right)\left(\frac{\bar{\sigma}}{\mu}\right)^{n_1}$$

$$\dot{\bar{\varepsilon}}_2^{ss} = A_2 \exp\left(-\frac{Q_2}{R\,T}\right)\left(\frac{\bar{\sigma}}{\mu}\right)^{n_2}$$

$$\dot{\bar{\varepsilon}}_3^{ss} = H(\bar{\sigma} - \bar{\sigma}_0)\left[B_1 \exp\left(-\frac{Q_1}{R\,T}\right) + B_2 \exp\left(-\frac{Q_2}{R\,T}\right)\right] \sinh\left(q\frac{(\bar{\sigma} - \bar{\sigma}_0)}{\mu}\right)$$

Transient Limit

$$\bar{\varepsilon}^{tr*} = K_0 \exp(c\,T)\left(\frac{\bar{\sigma}}{\mu}\right)^{m}$$

Transient Creep ODE

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

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

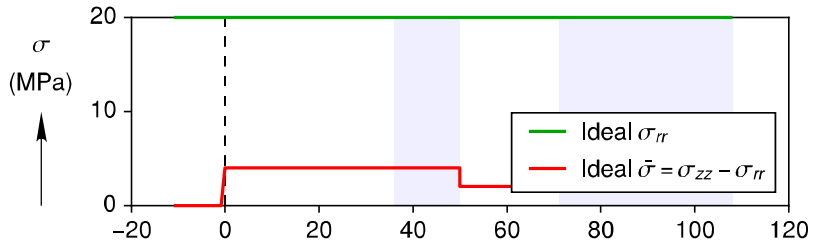
$$\delta_h = \alpha_h + \beta_h \log_{10}\left(\frac{\bar{\sigma}}{\mu}\right)$$

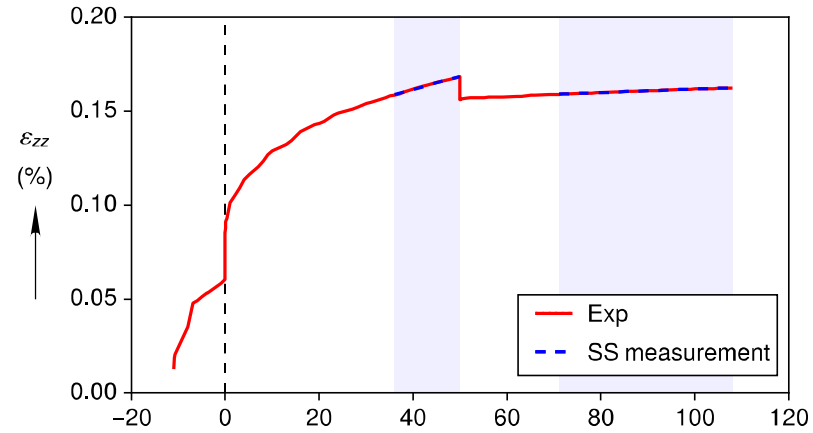
$$\delta_r = \alpha_r + \beta_r \log_{10}\left(\frac{\bar{\sigma}}{\mu}\right)$$

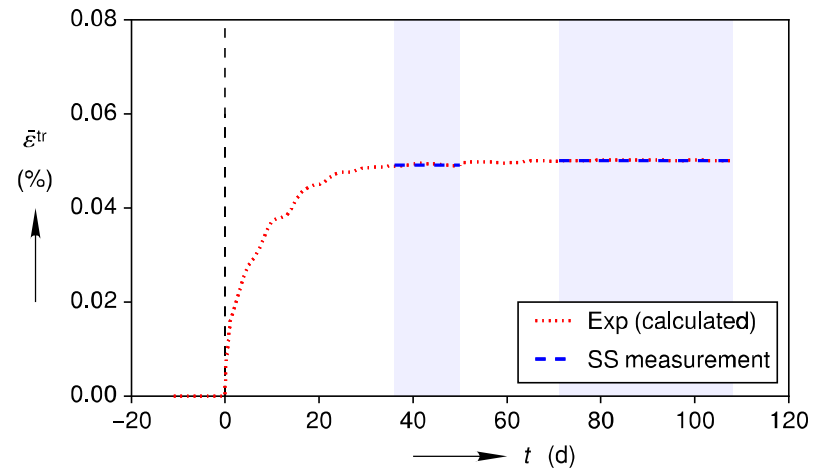
Calibration Techniques Compared

Sandia National Laboratories

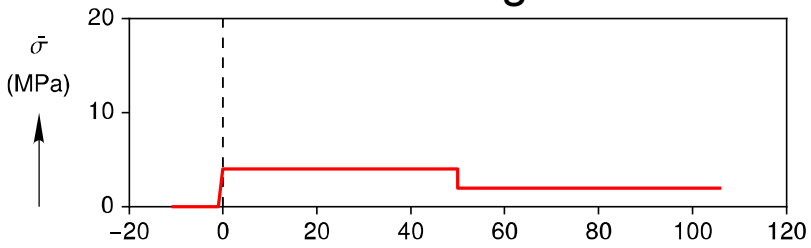
Measurements

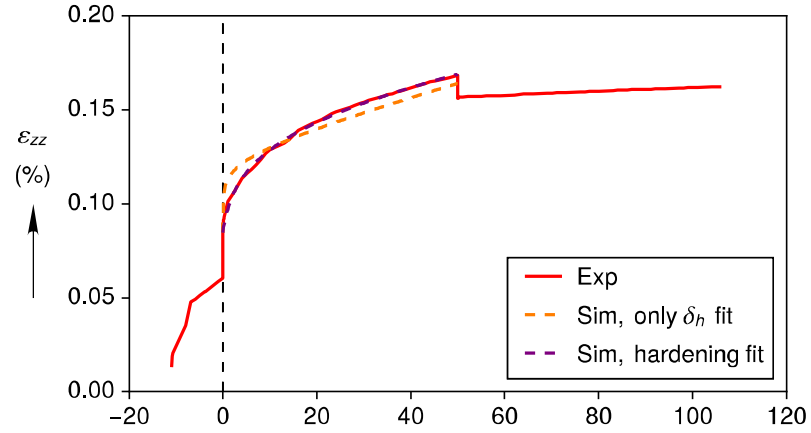


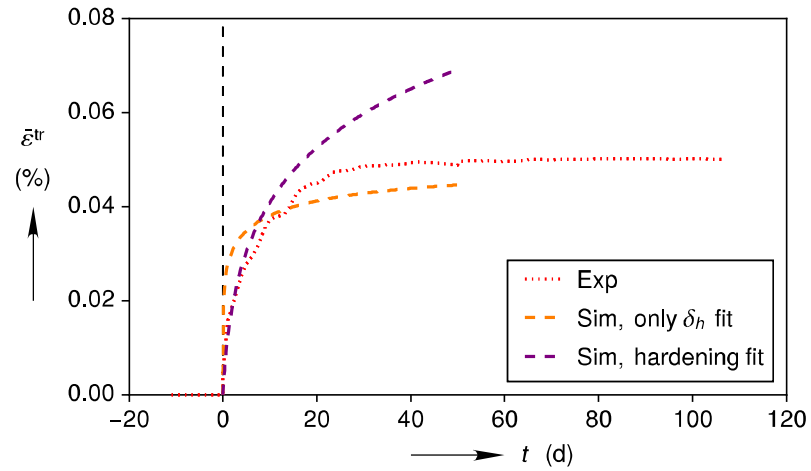




Fitting



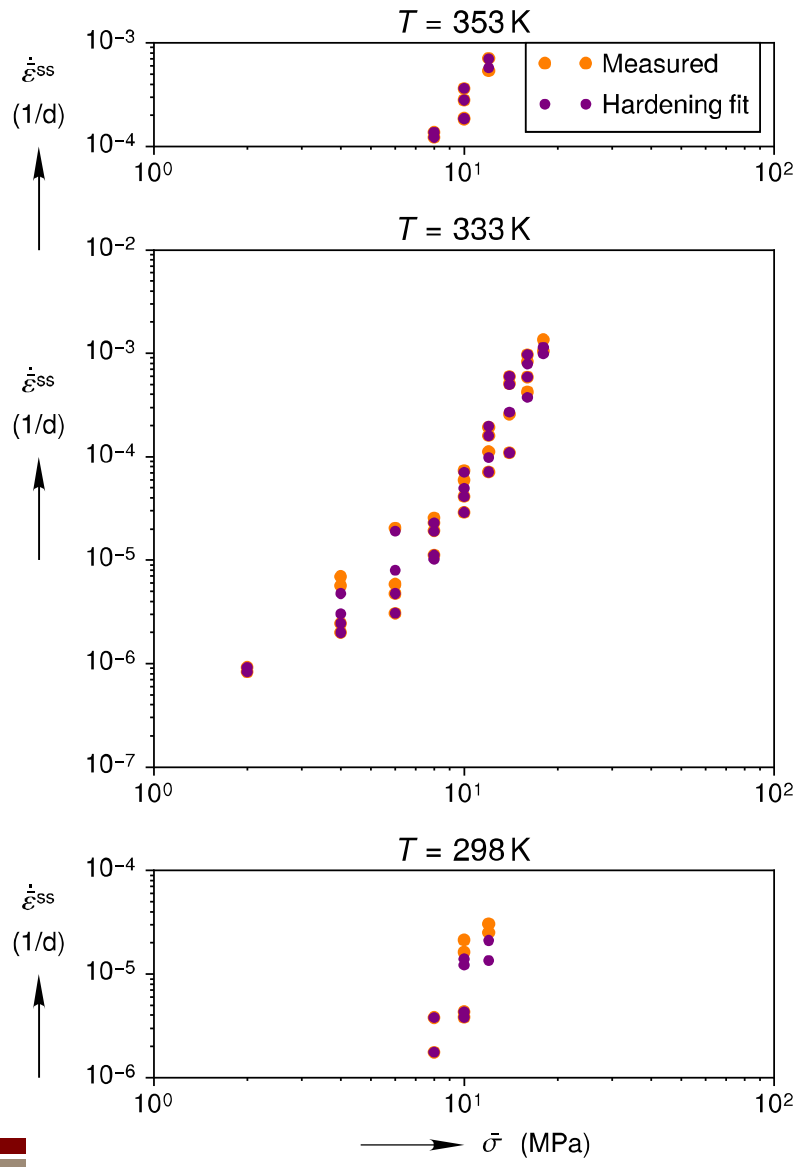




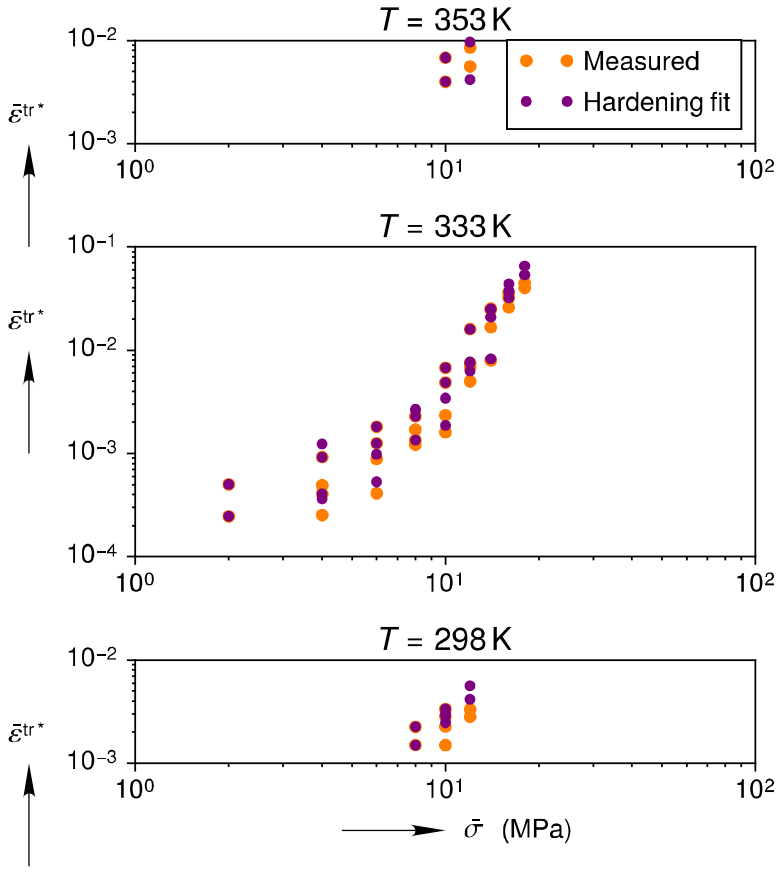
Calibration Techniques Compared

Sandia National Laboratories

Steady State Rate



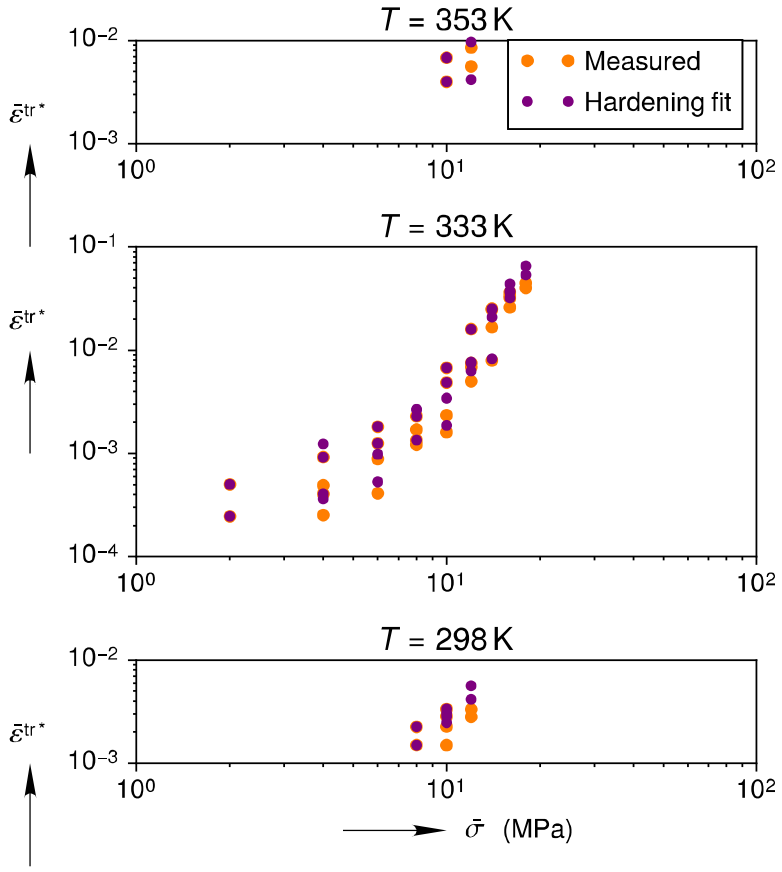
Transient Limit



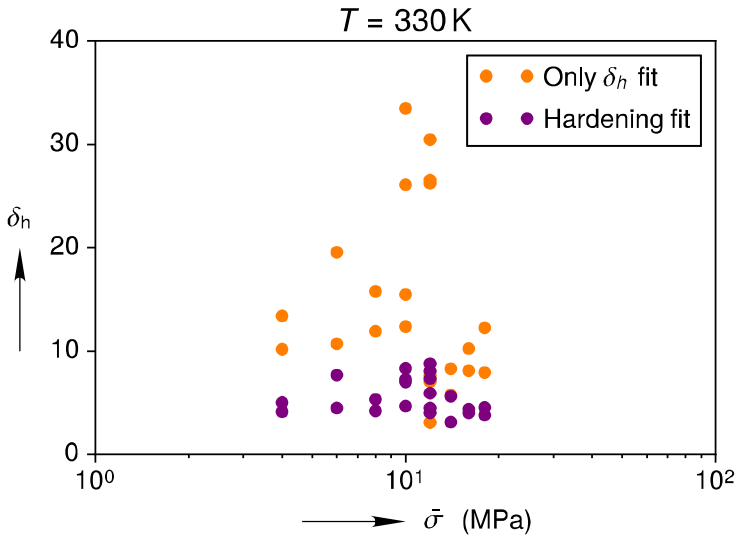
Extraction Techniques Compared

Sandia National Laboratories

Transient Limit

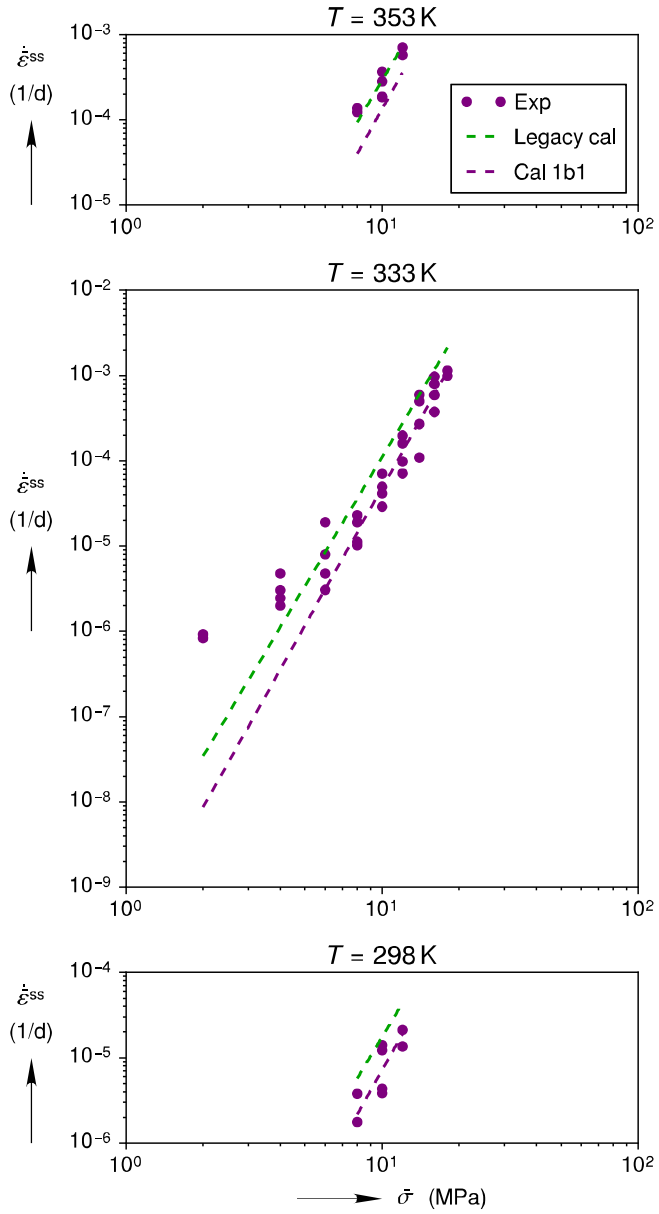


Hardening Rate Parameter

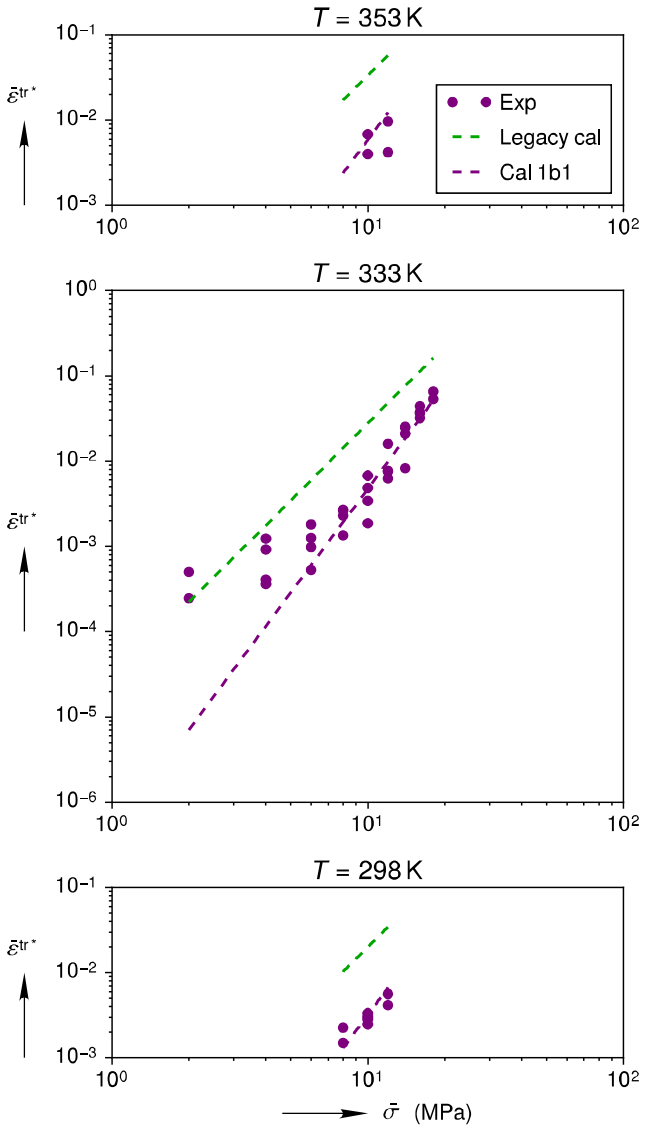


Preliminary New Calibration

Steady State Rate

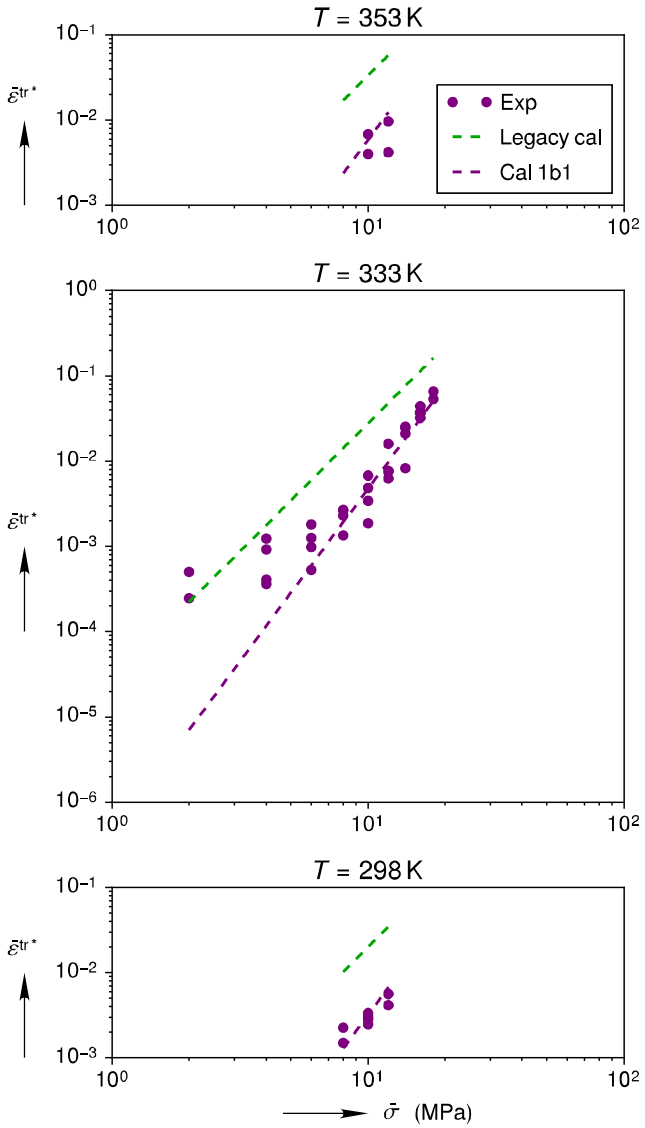


Transient Limit

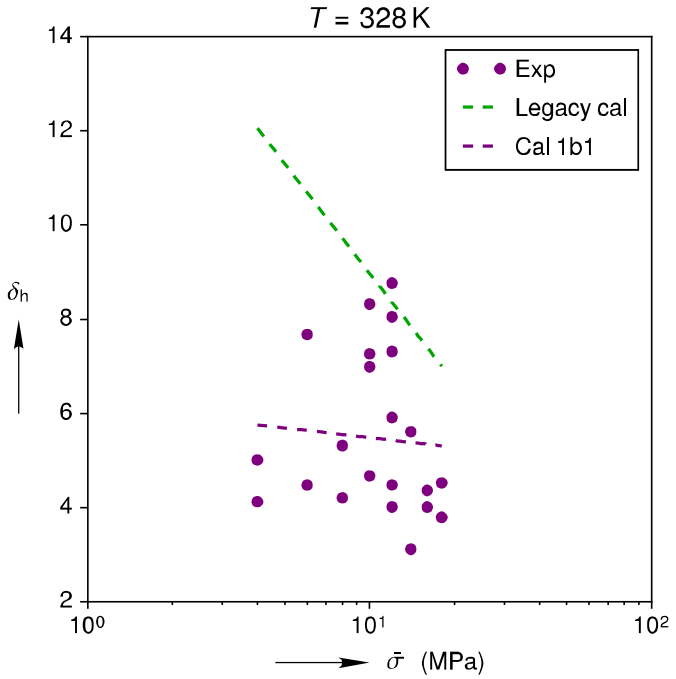


Preliminary New Calibration

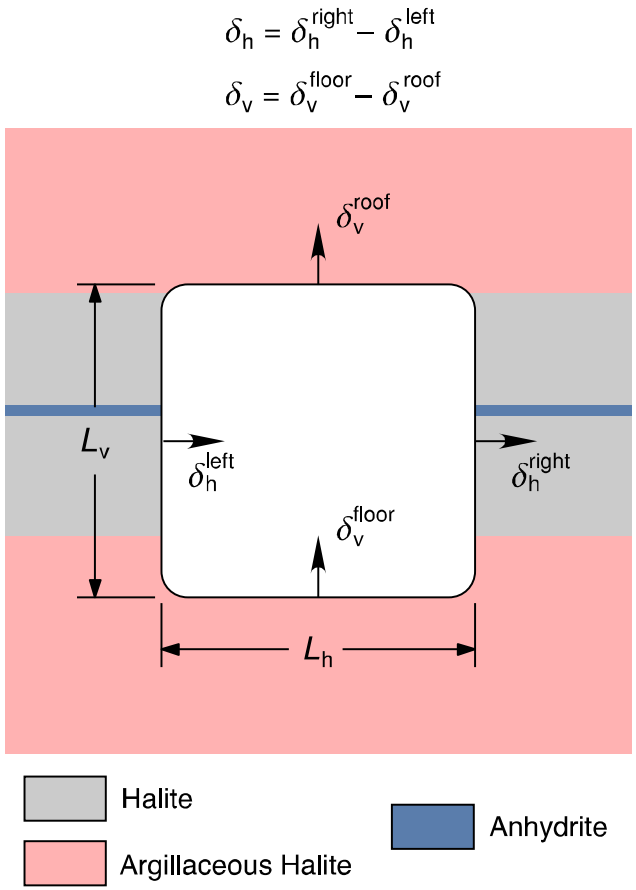
Transient Limit

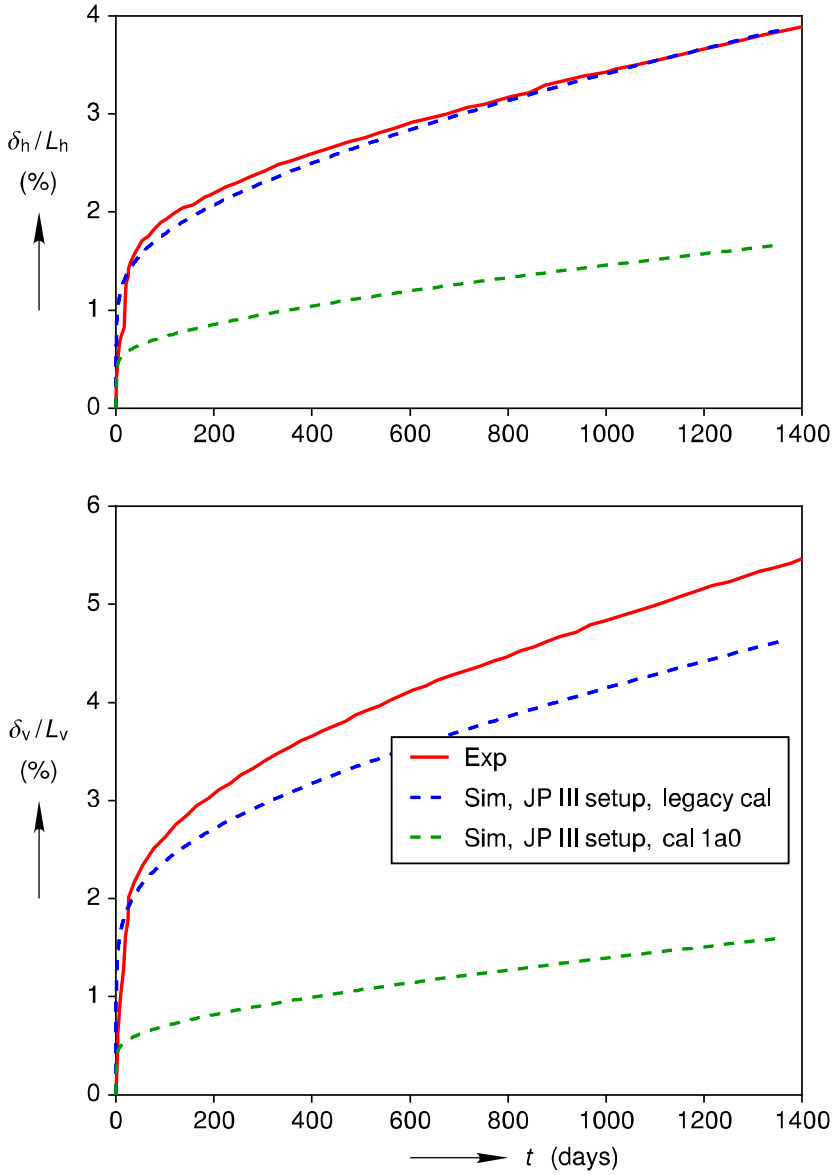


Hardening Rate Parameter



Closure Predictions with Preliminary Calibration





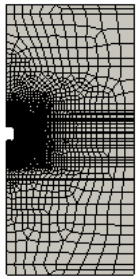
Sandia National Laboratories

Future Work: Simulation Boundary

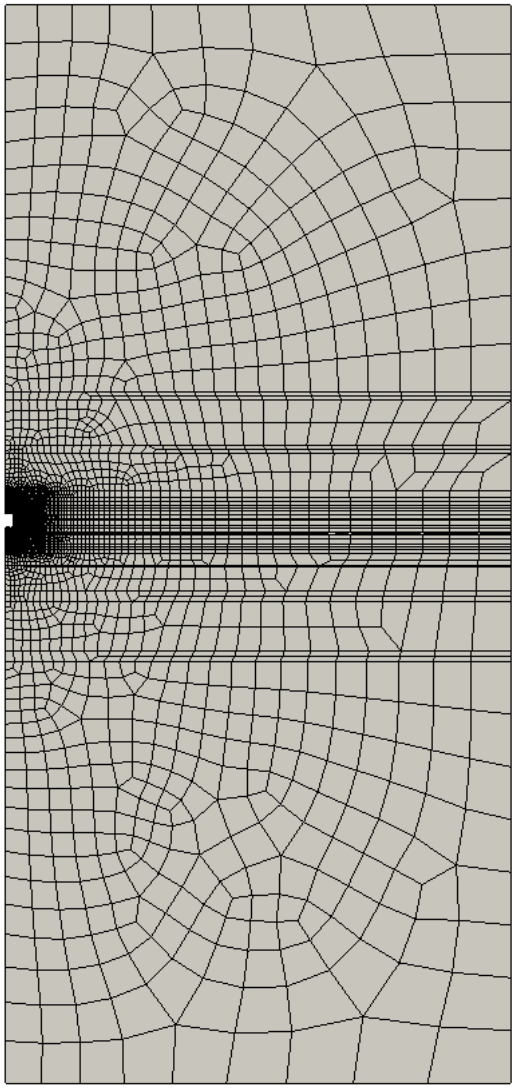
Somewhat Coarse Meshes (All Clean Salt)

Sandia National Laboratories

Legacy (50 m) Boundary



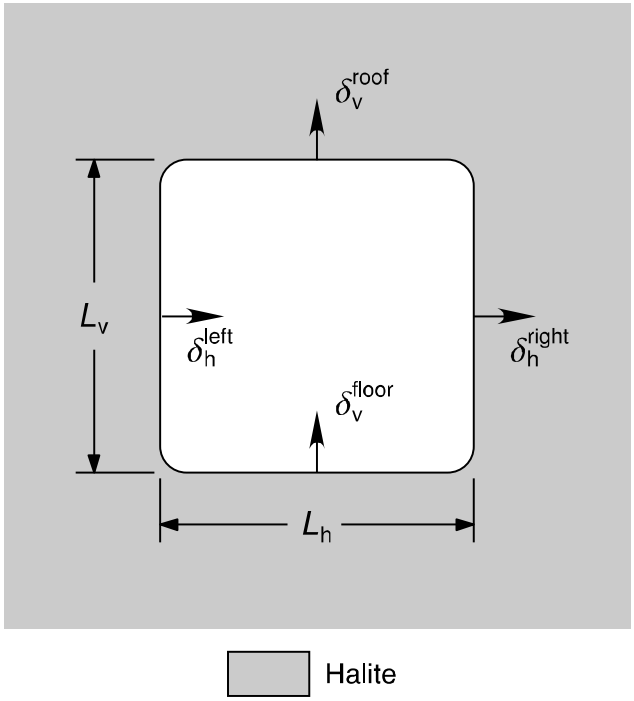
200 m Boundary

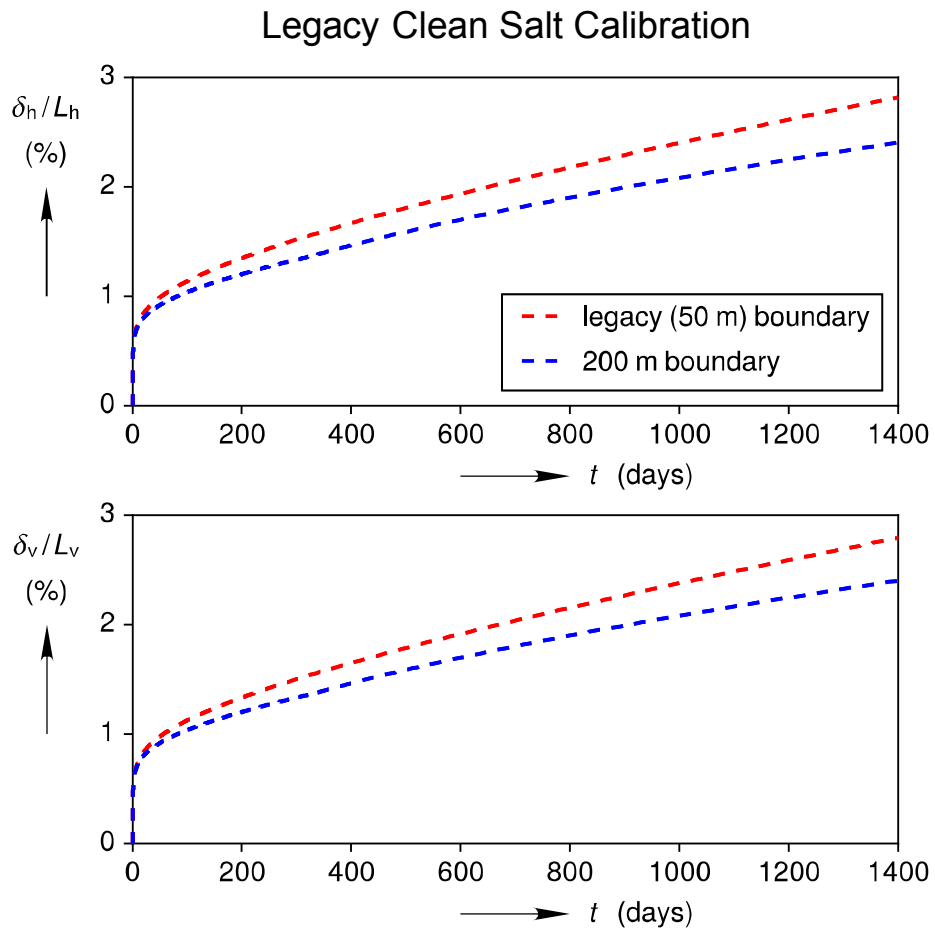


Impact of Simulation Boundary on Room Closure

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

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

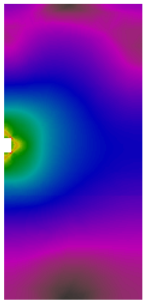




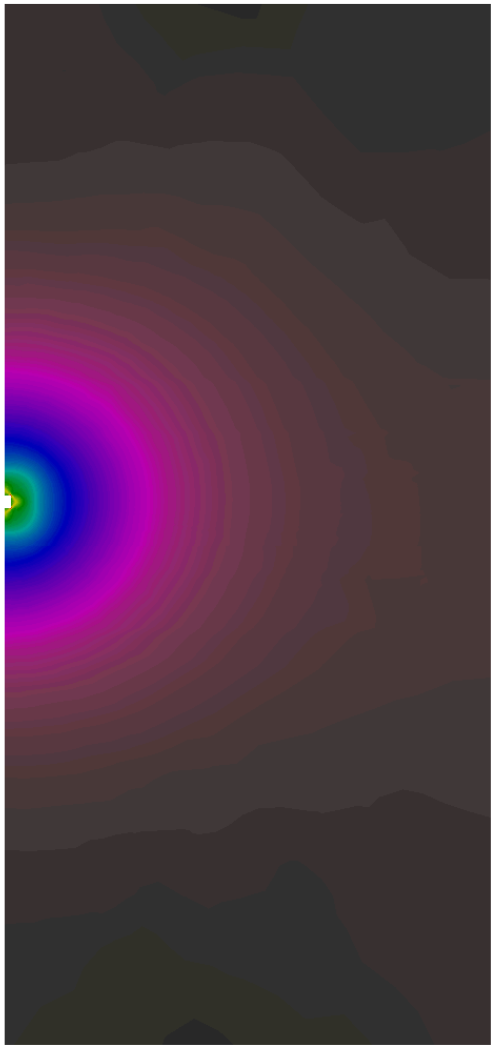
Compare von Mises Stress Fields

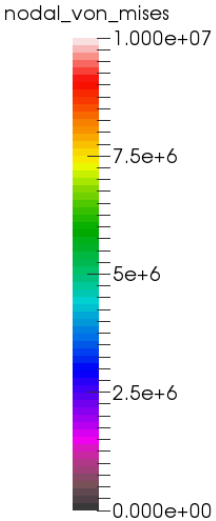
Sandia National Laboratories

Legacy (50 m) Boundary



200 m Boundary

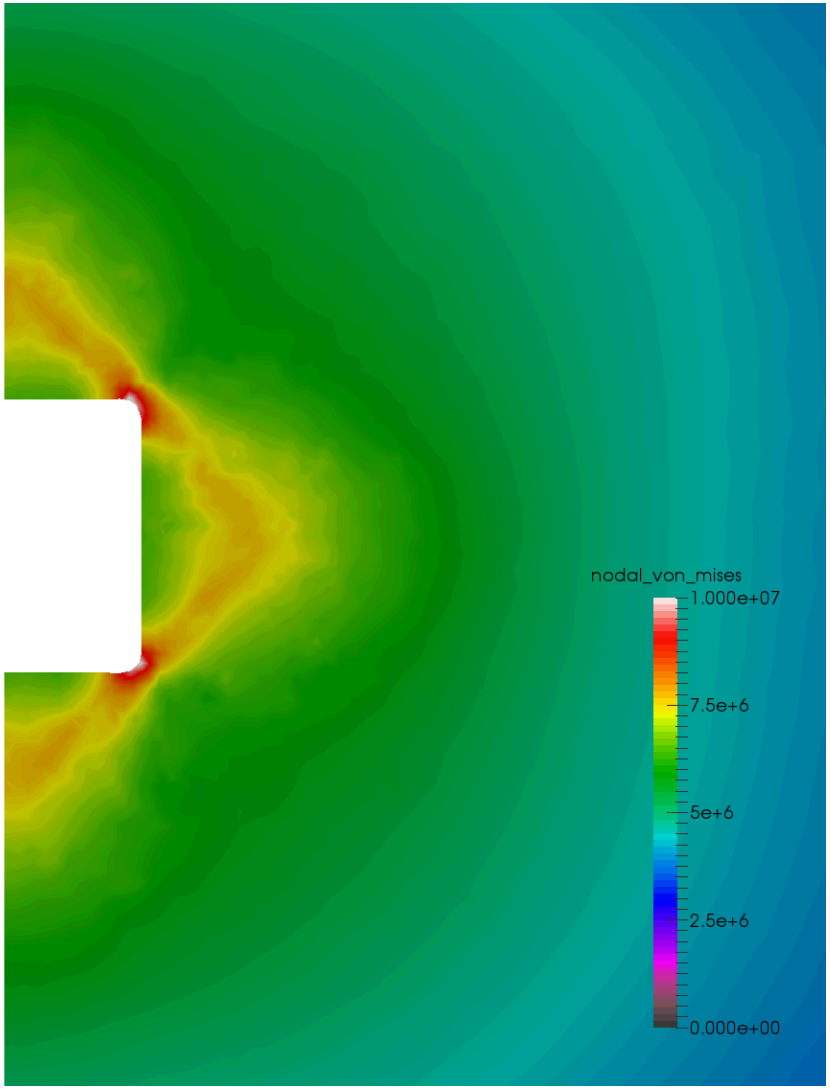




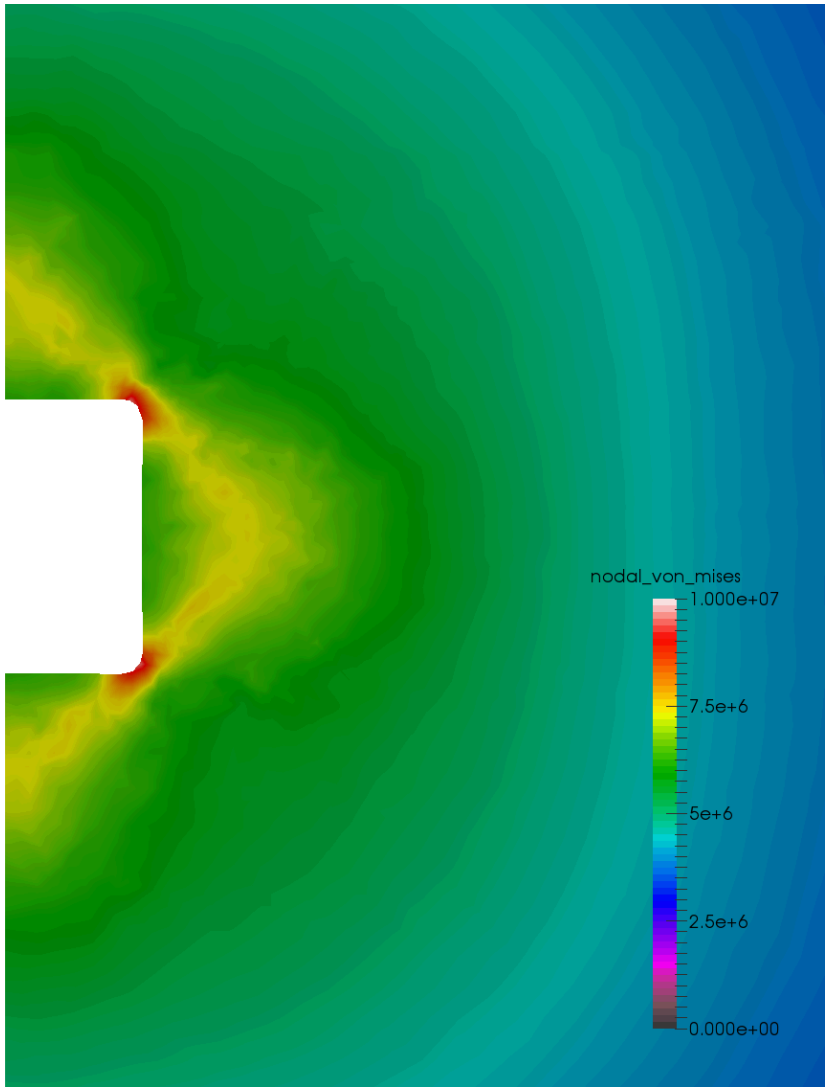
Compare von Mises Stress Fields

Sandia National Laboratories

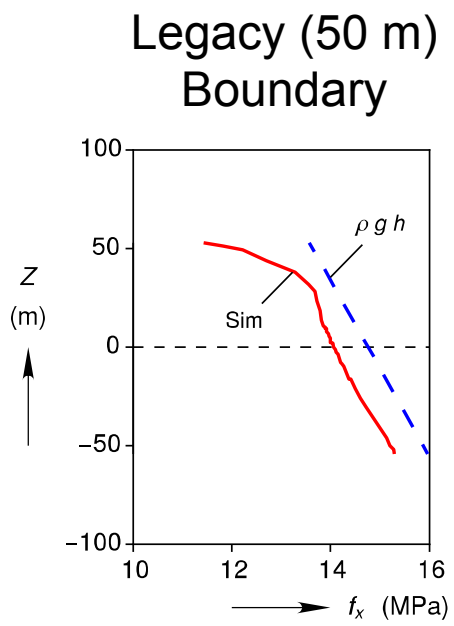
Legacy (50 m) Boundary

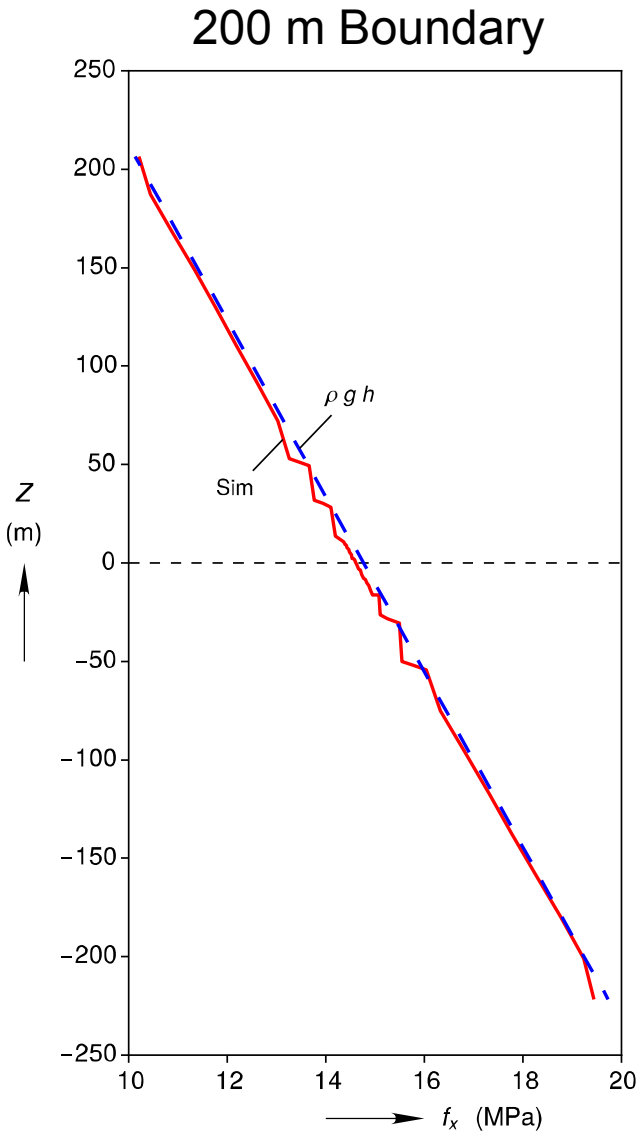


200 m Boundary

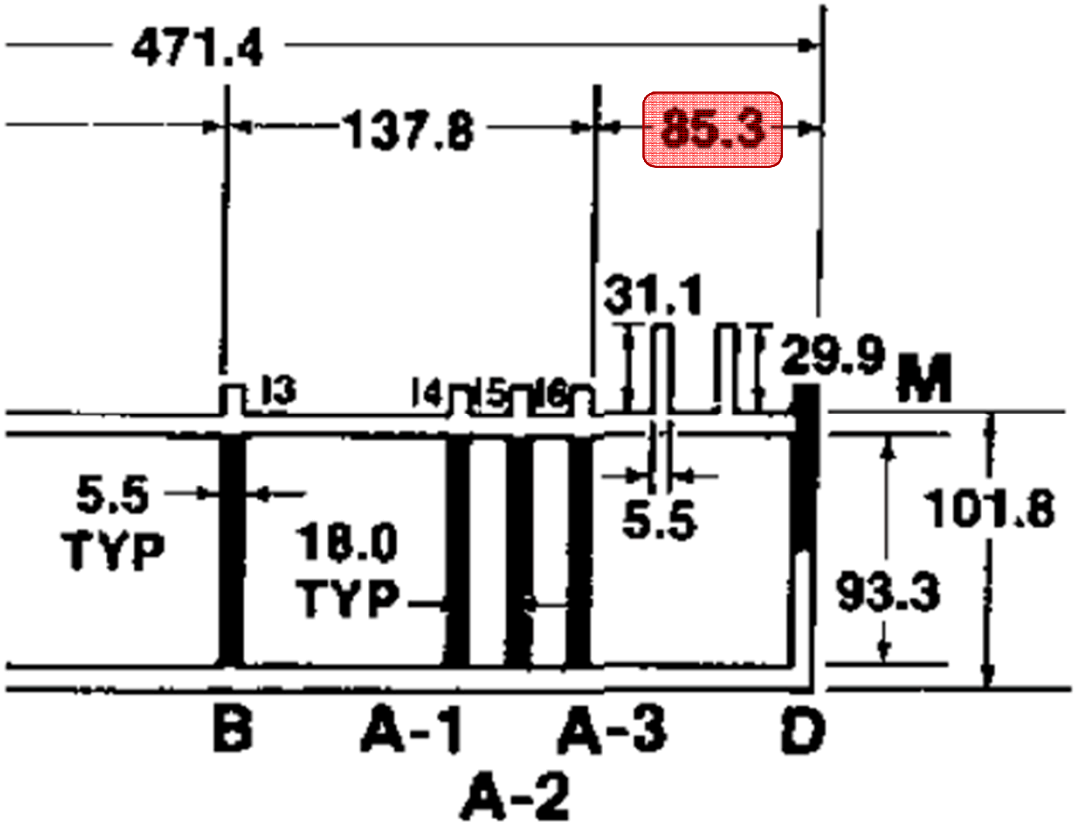


Traction distribution on the right boundary





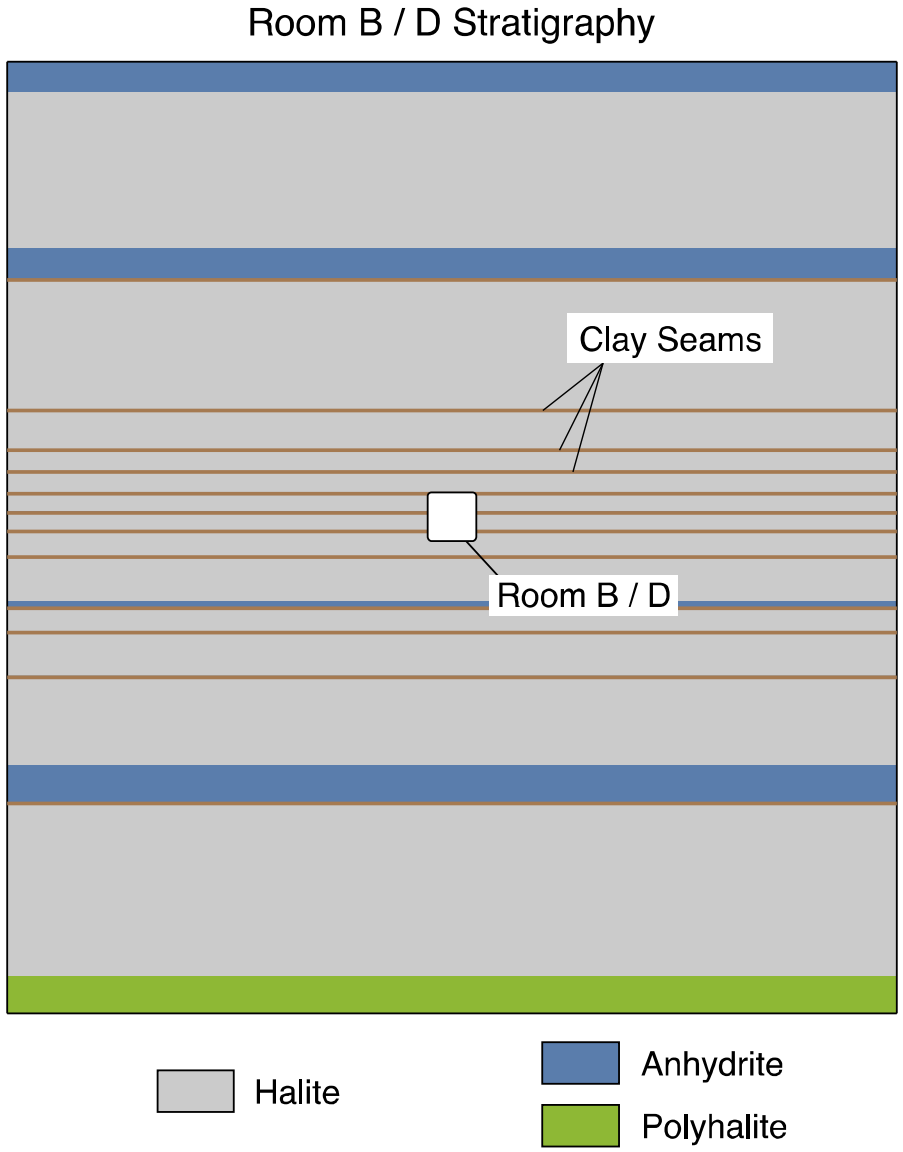
Room Spacing



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
  - Low deviatoric stresses
  - Flow potential
  - Calibrate high temp behavior
- 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 simulation of room D with the preliminary calibration roughly agrees with the partners
- Simulation boundary may be too close

Sandia National Laboratories

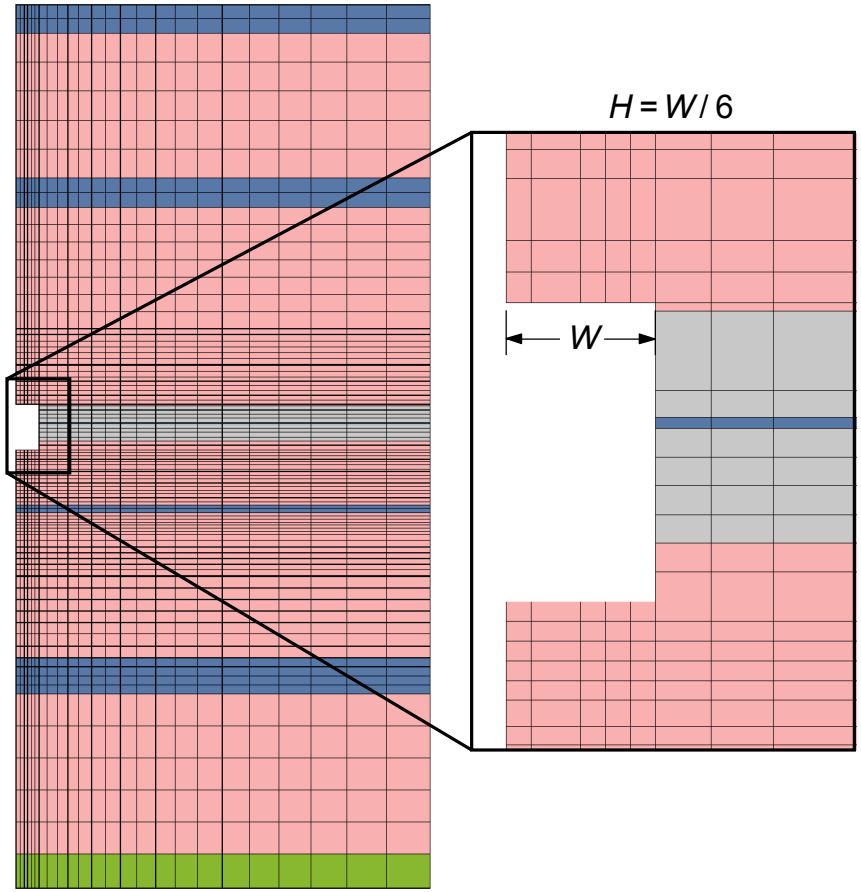
Extra Slides

Initial Mesh Convergence Study

Sandia National Laboratories

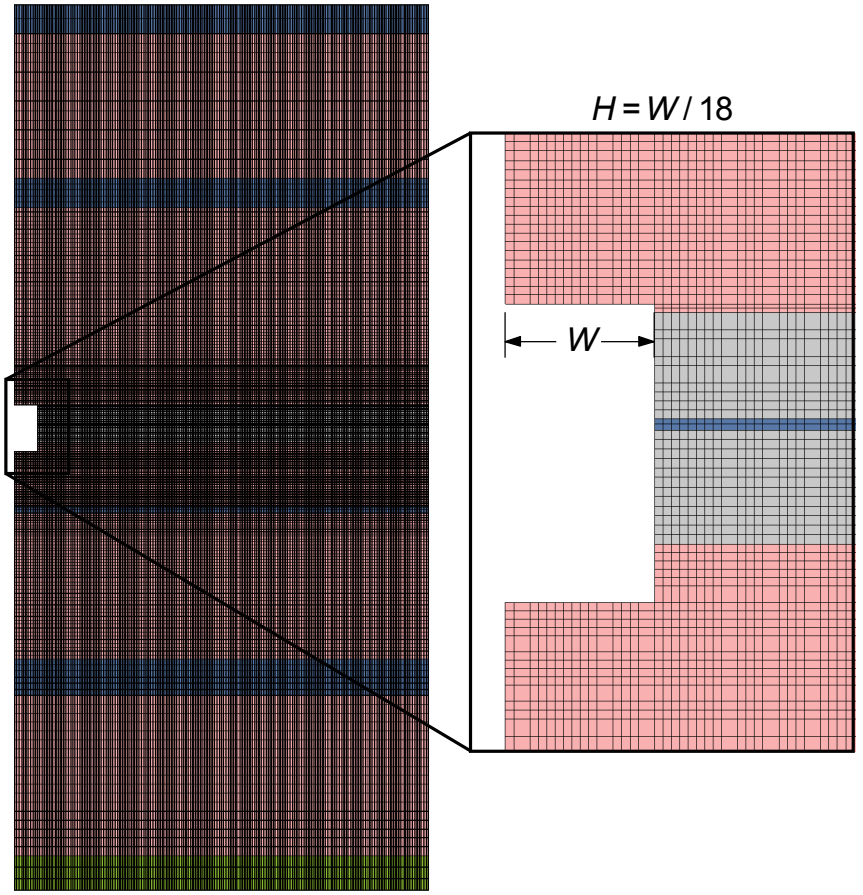
Coarsest Mesh

2184 Elements



Finest Mesh

81042 Elements

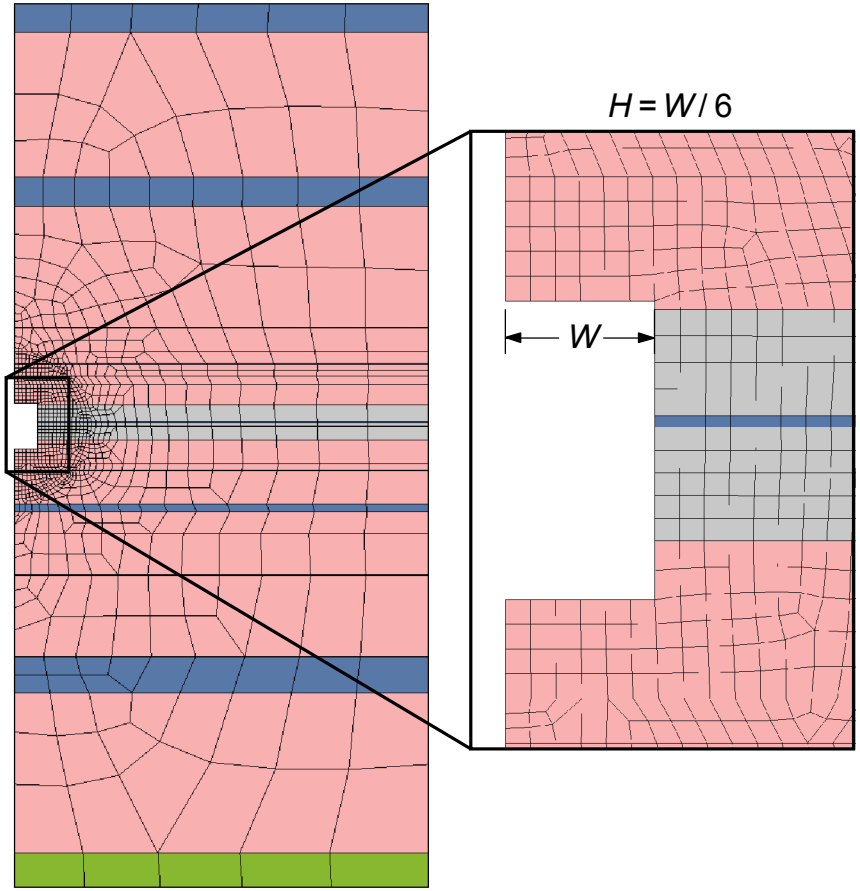


New Meshes

Sandia National Laboratories

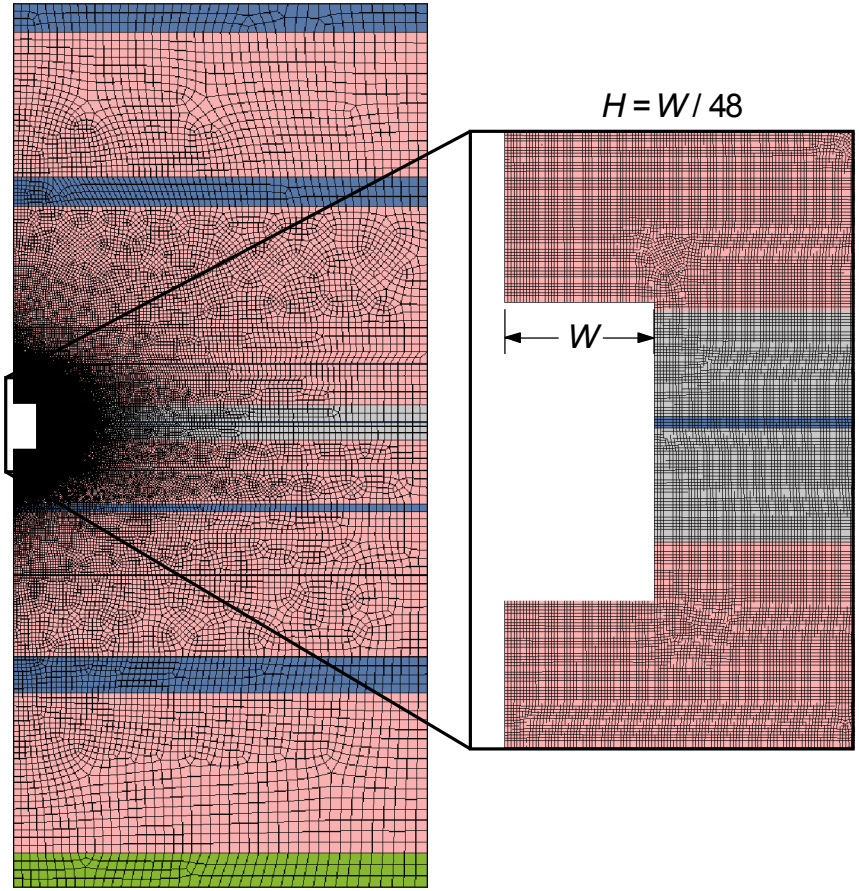
Coarsest Mesh

1139 Elements

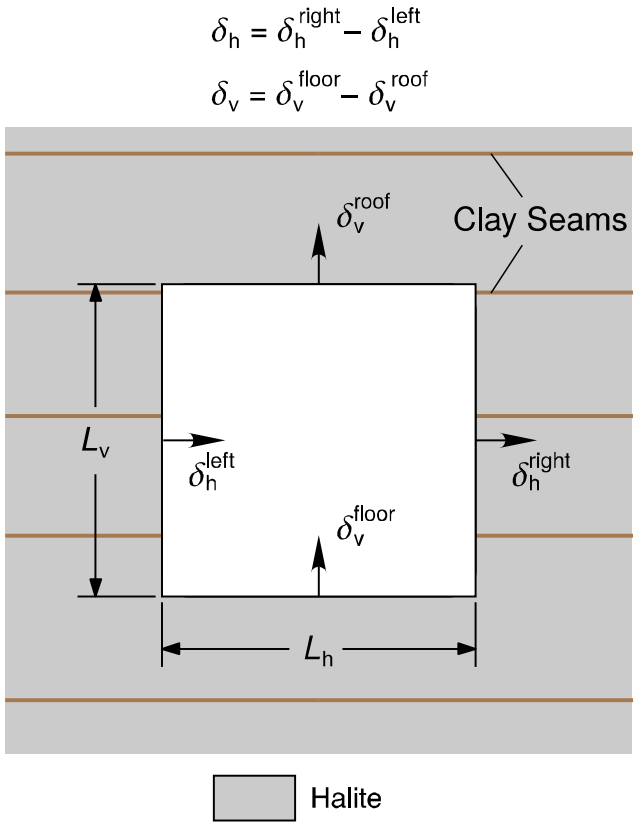


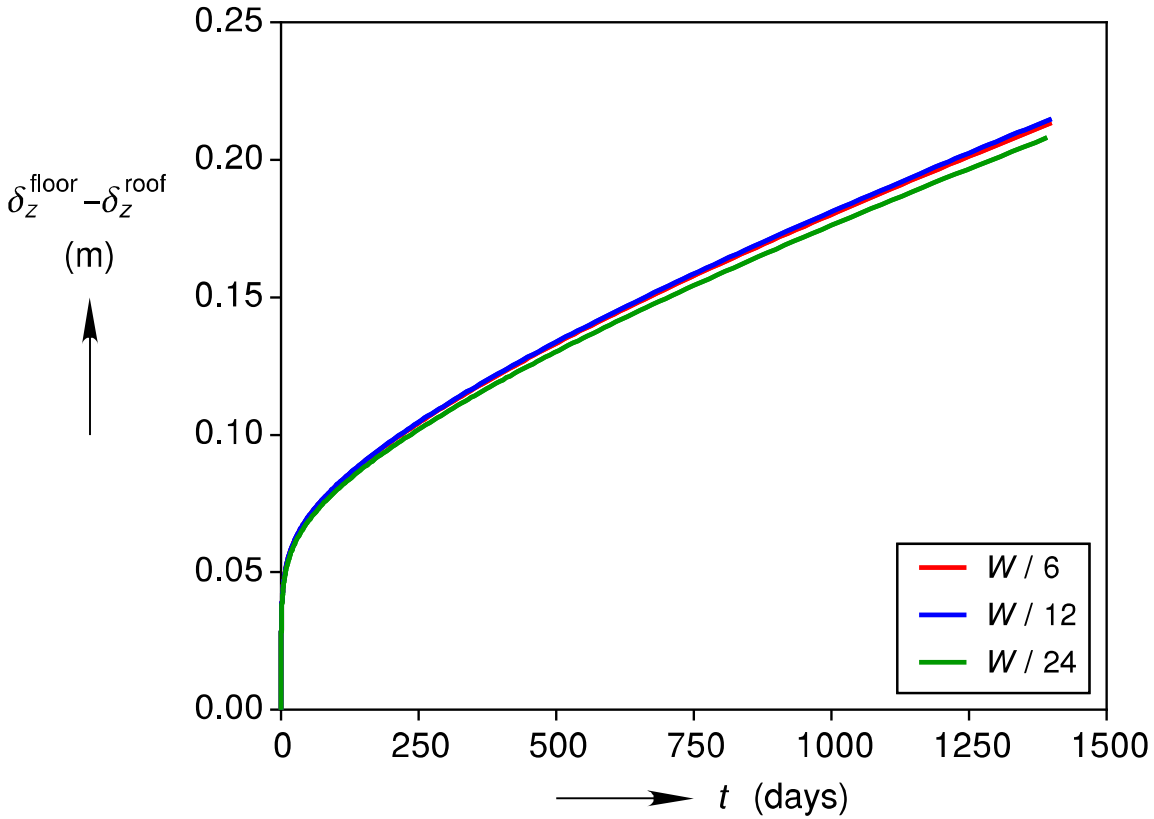
Finest Mesh

57849 Elements

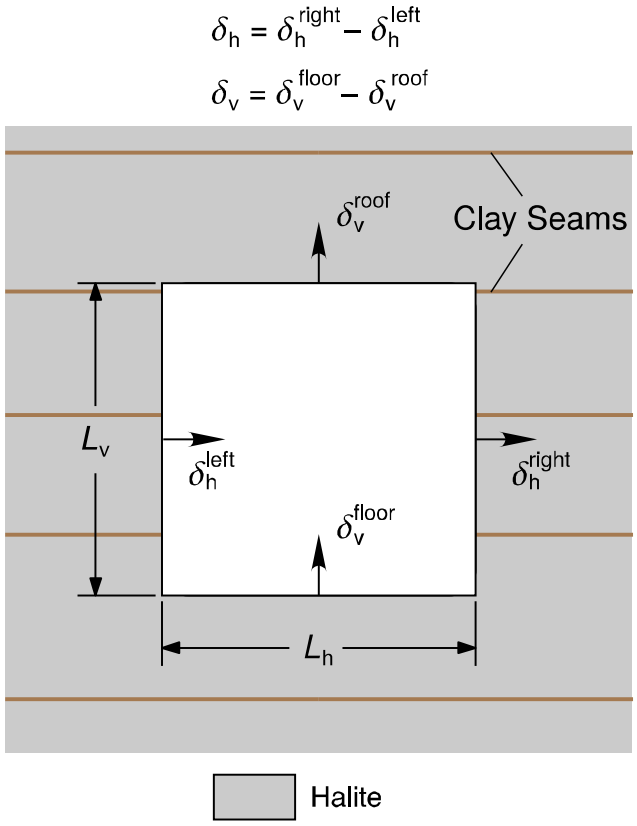


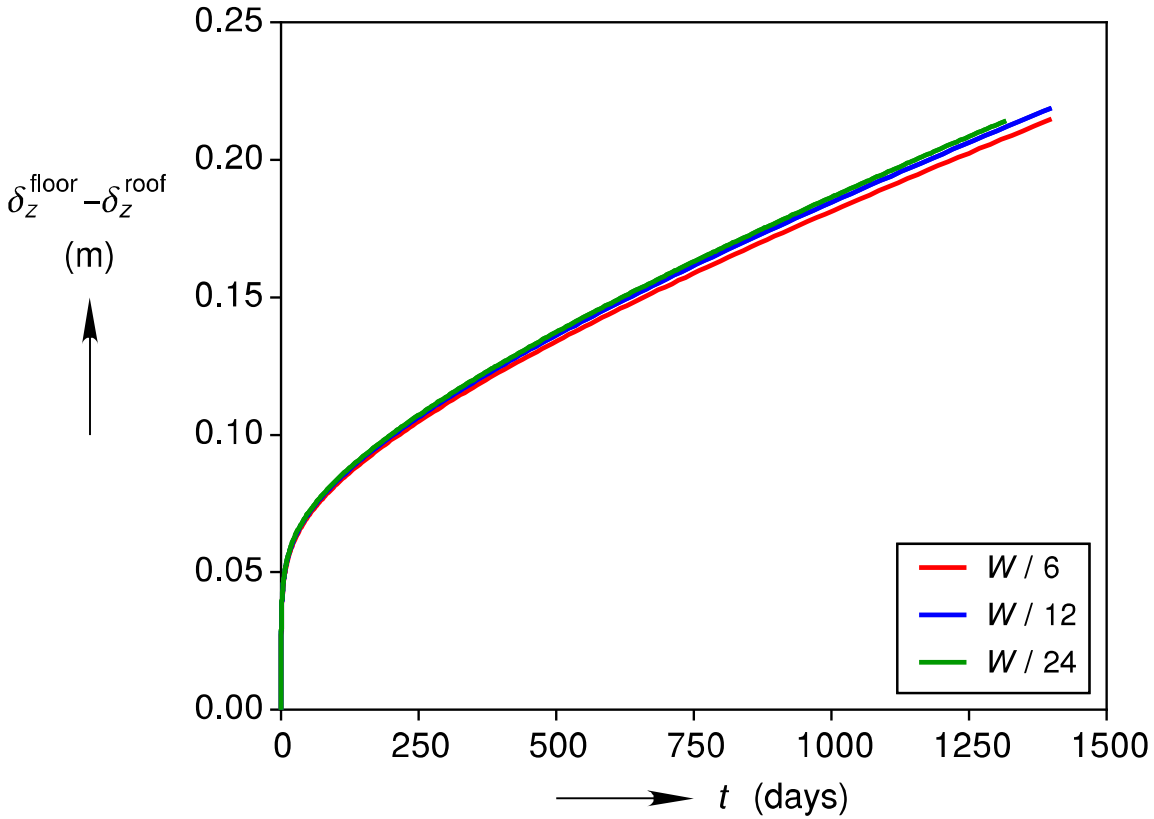
Kinematic Contact Enforcement Issue





Augmented Lagrange Contact Enforcement

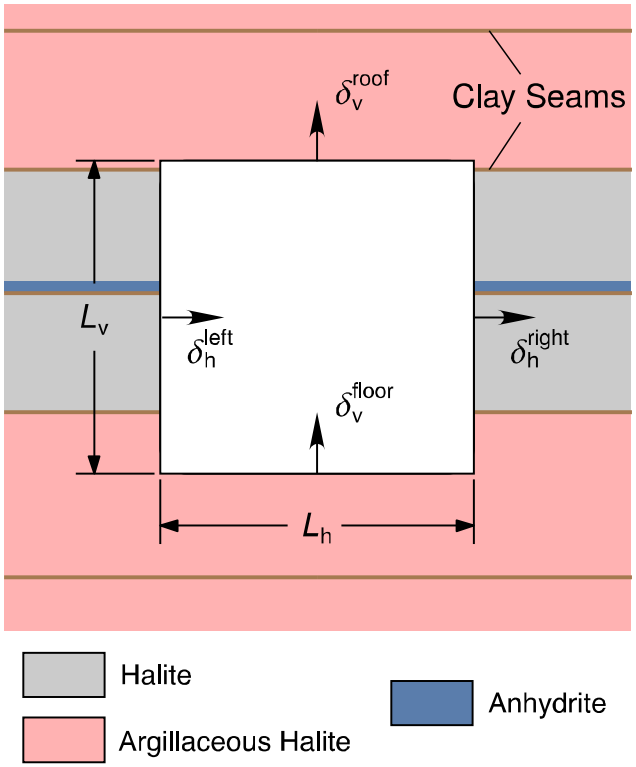


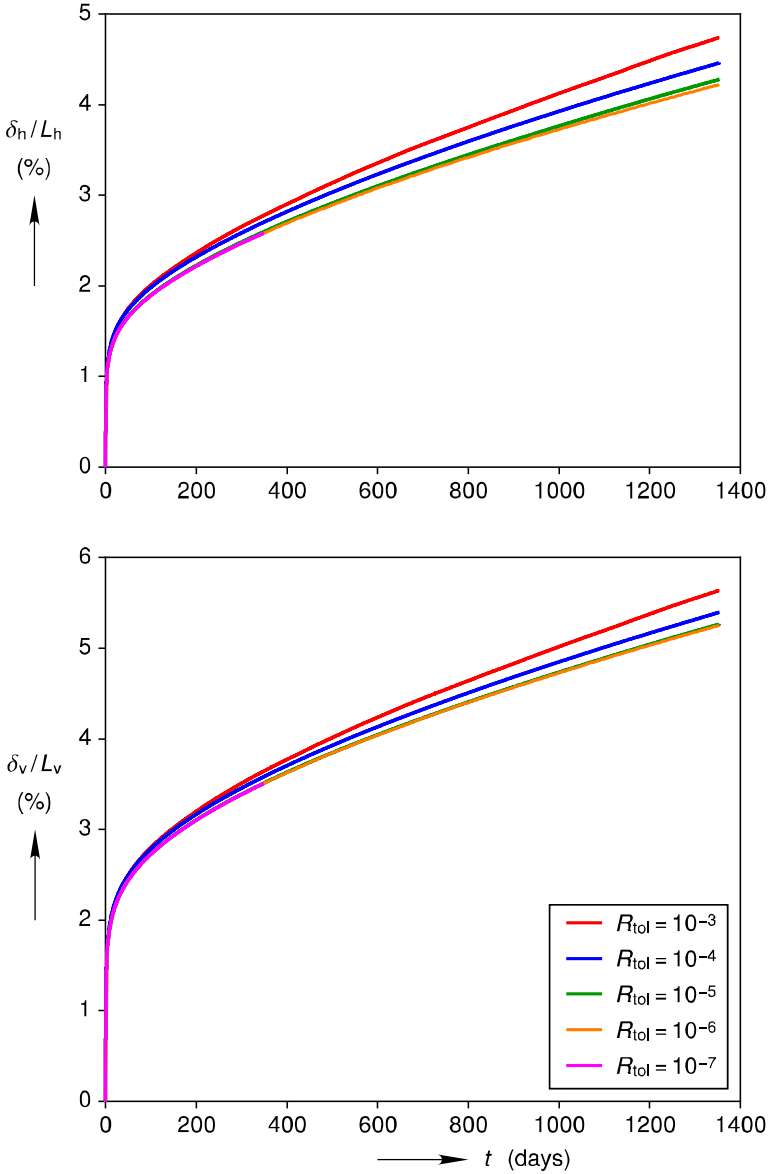


Residual Tolerance

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

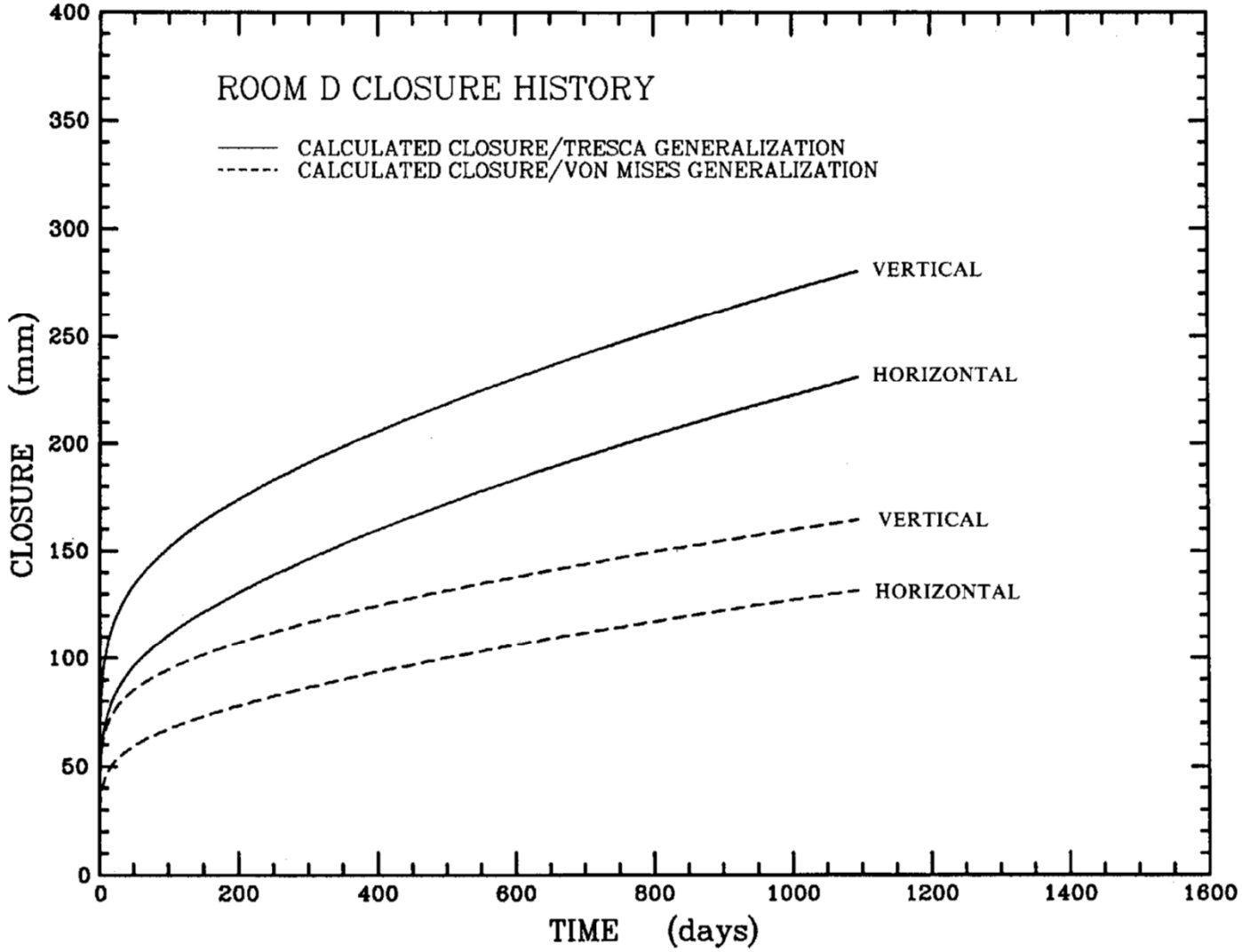
$$\delta_v = \delta_v^{floor} - \delta_v^{roof}$$





Future Work:
Flow Potential

Flow Potential

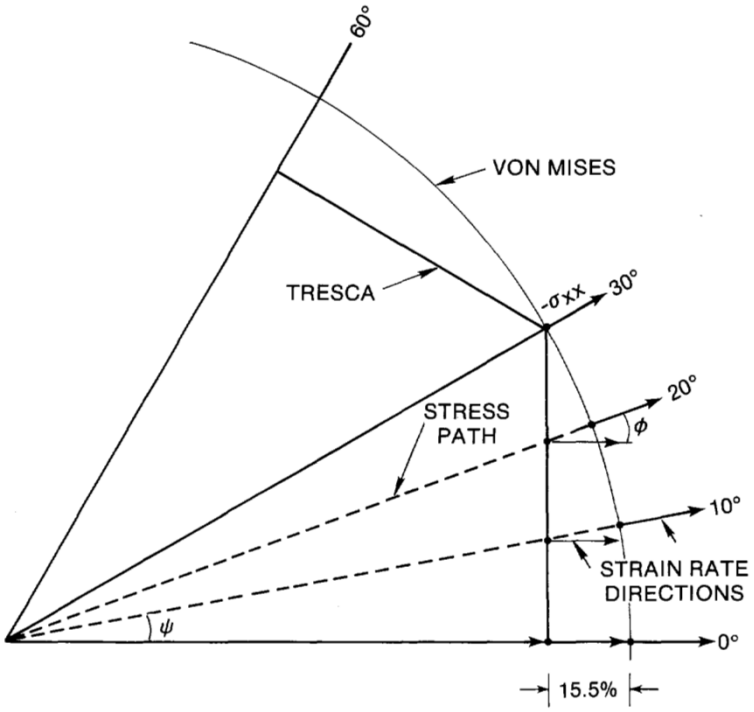


Munson, D., Fossum, A. Senseny, P., Advances in Resolution of Discrepancies Between Predicted and Measured In Situ WIPP Room Closures, SAND88-2948, 1988

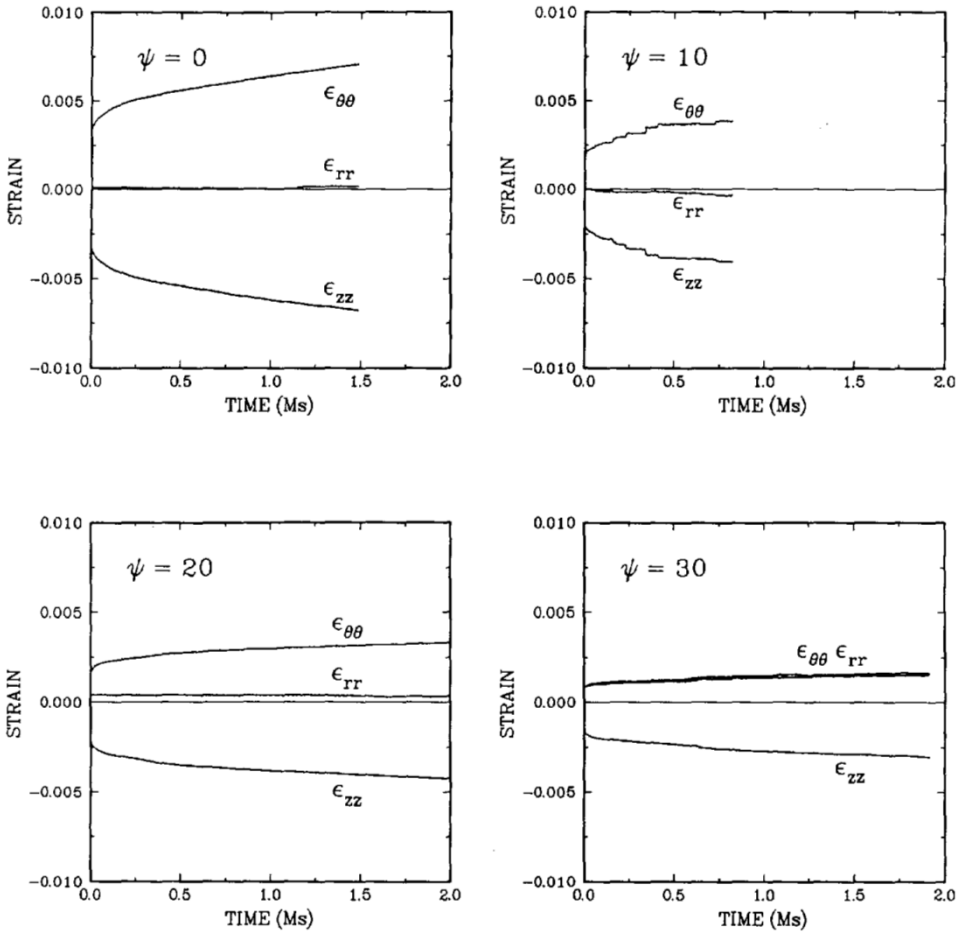
Flow Potential

Sandia National Laboratories

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