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Enhancements to the Munson-Dawson Model and Their Impact on Room D Closure Predictions

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Sandia National Laboratories

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Outline

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- Background
- Creep at low equivalent stresses
- Hosford equivalent stress
- Domain size convergence study
- Summary

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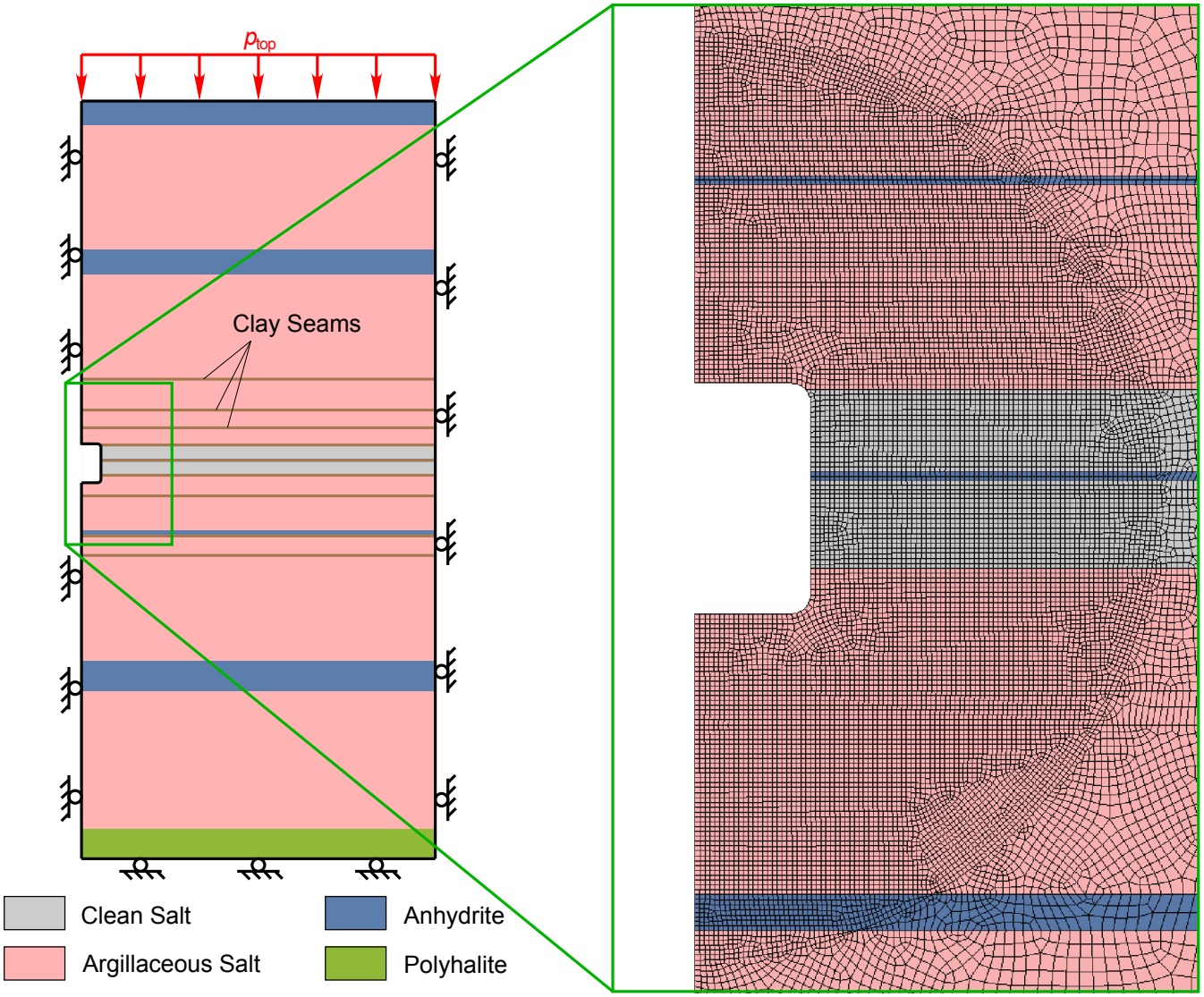
Background

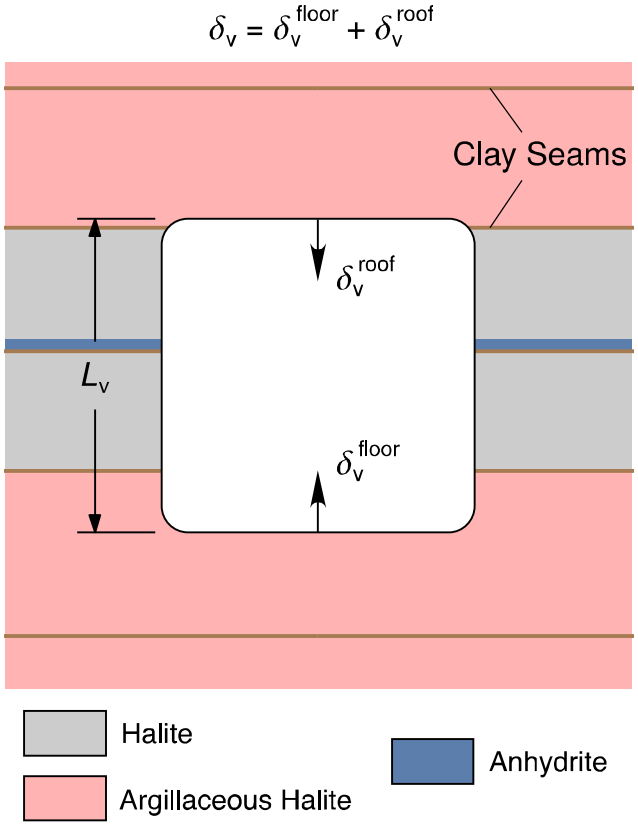
History of WIPP Creep Closure Modeling

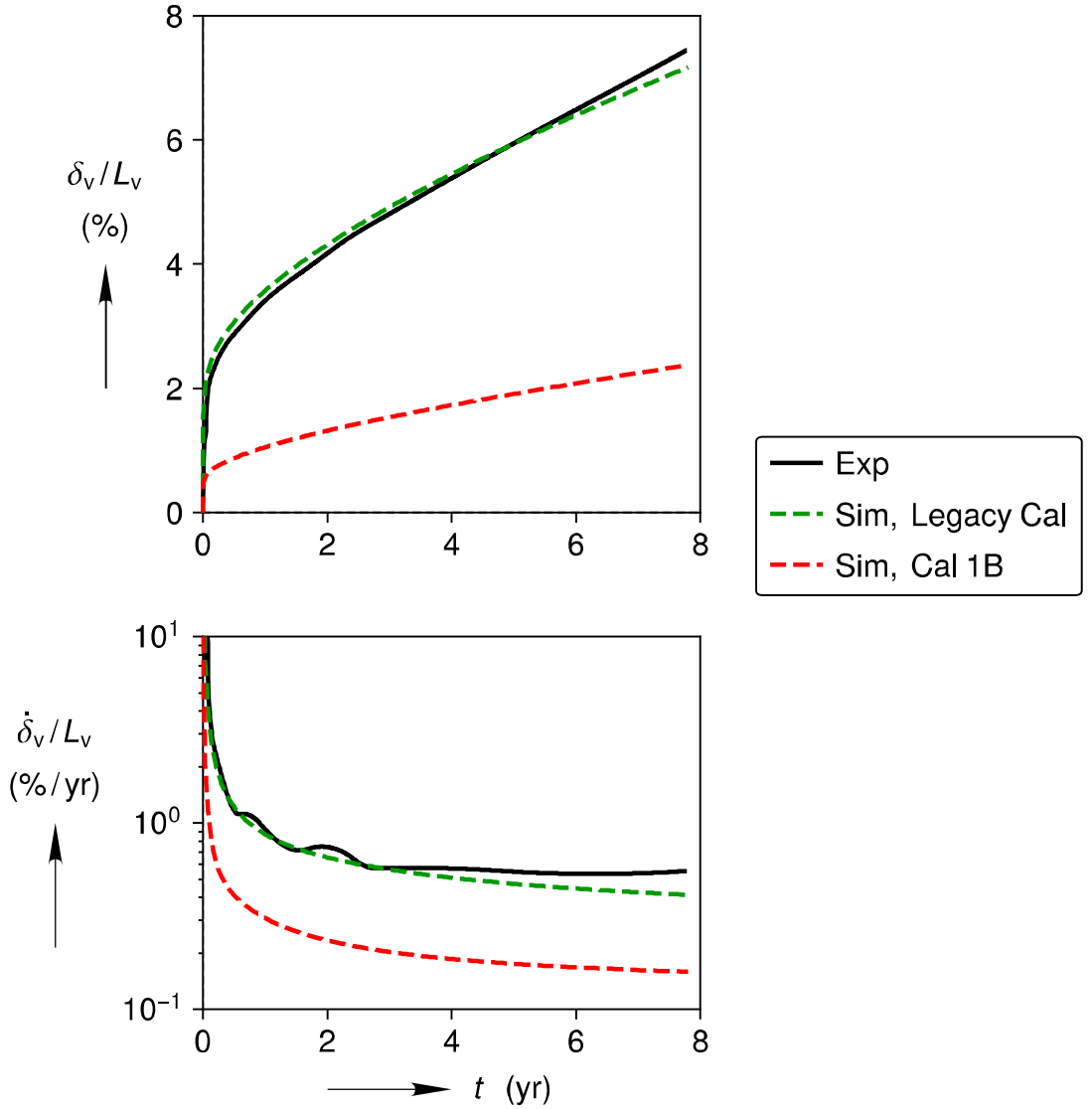
- In the 1980's, creep closure models calibrated against laboratory experiments under-predicted closure by roughly 3X.
  - Elastic stiffness reduced by 12.5X
- Munson et al. (1989) tuned the geomechanical model to match Room D's closure.
  - Six different changes to the model
- Further research into creep closure came to a halt in early 1990's.
- Interest in creep closure reignited recently by US/German Joint Projects on Salt Geomechanics.
  - Model under-predicts closure by roughly 3X.

Room D Simulation Setup



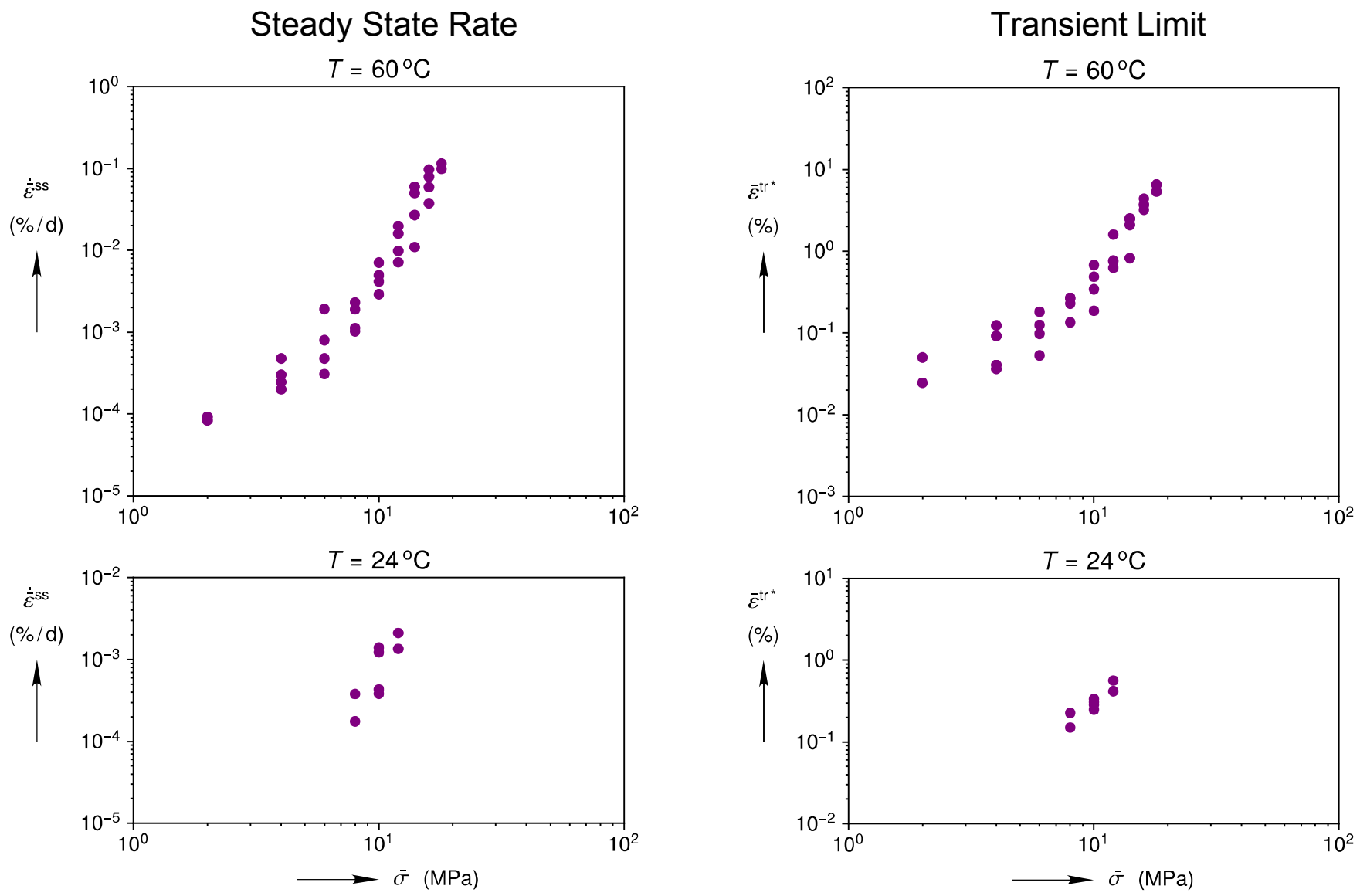
Room D Simulations





Creep at Low Equivalent Stresses

MD Model Calibration



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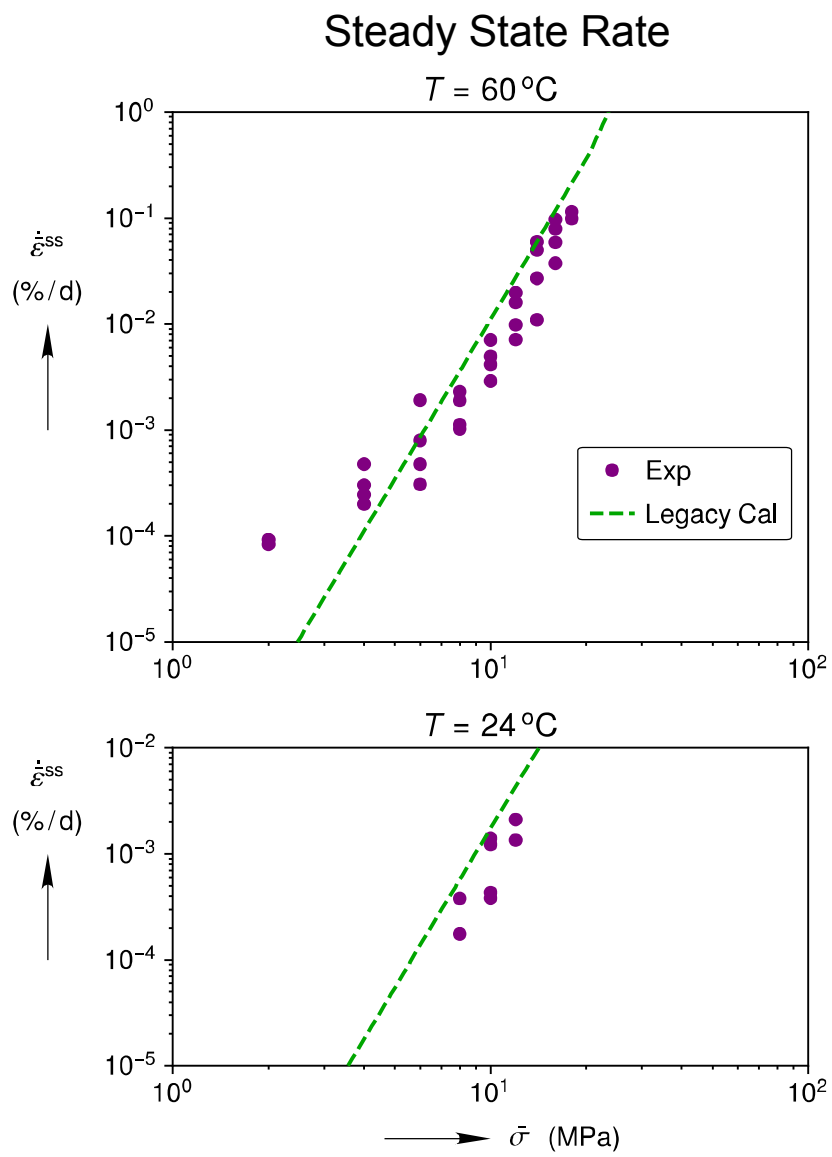

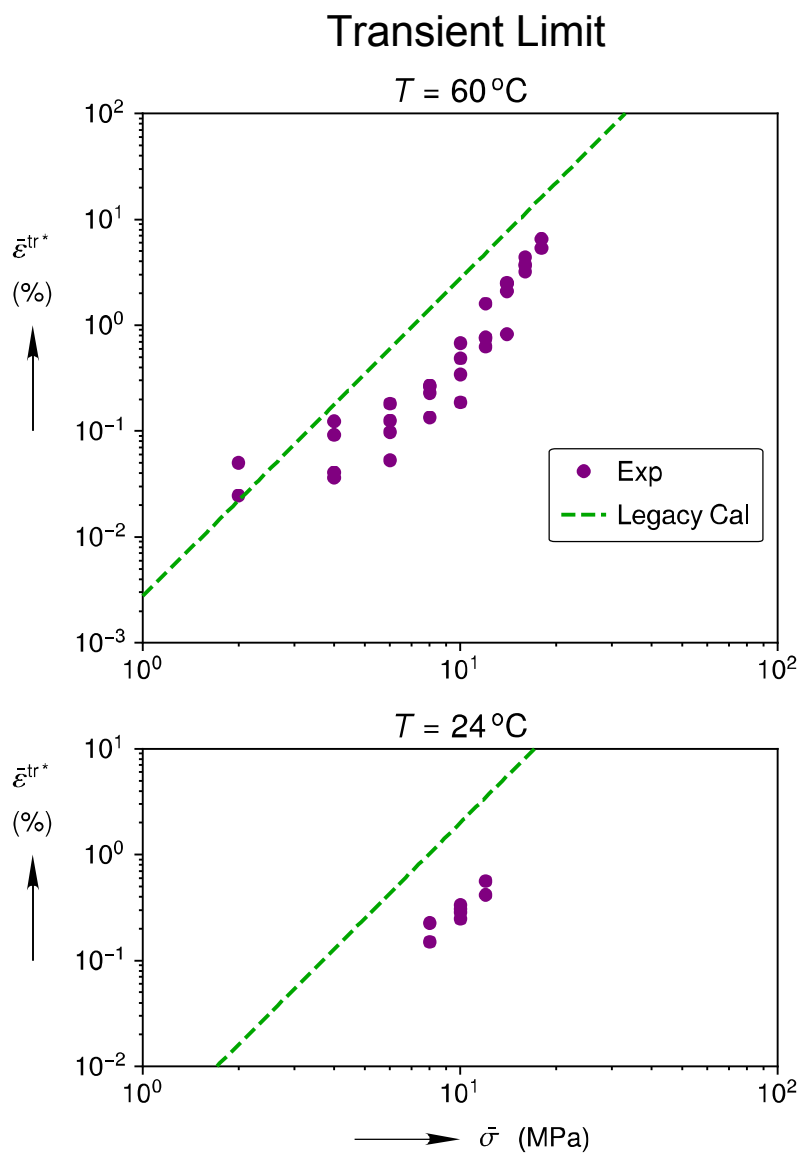

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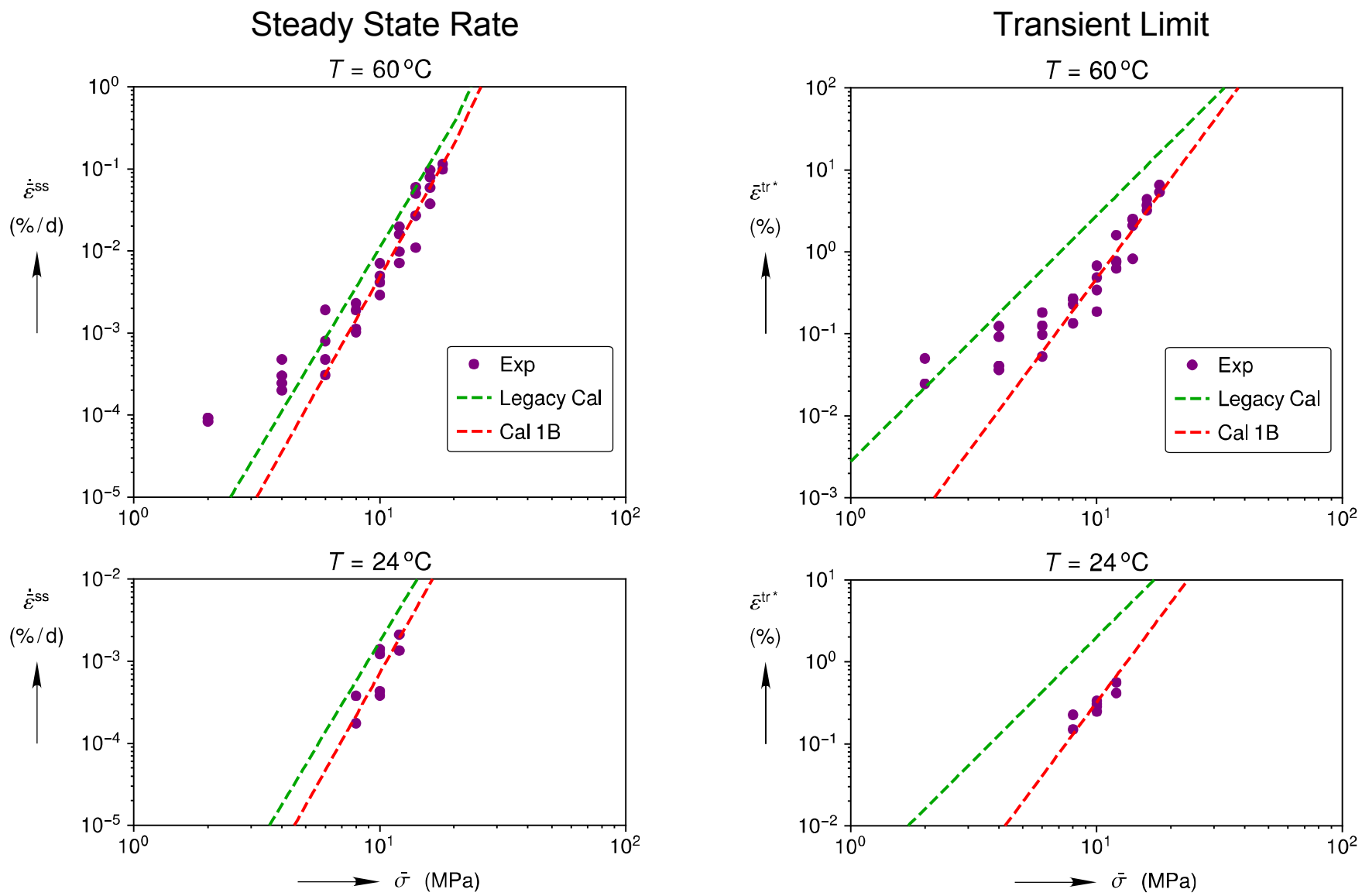

MD Model Modifications

Steady State Rate

$$\dot{\bar{\varepsilon}}^{ss} = \sum_{i=0}^{2} A_i \exp\left(-\frac{Q_i}{R\,T}\right)\left(\frac{\bar{\sigma}}{\mu}\right)^{n_i}$$

$$+ H(\bar{\sigma} - \bar{\sigma}_g) \sum_{i=0}^{2} B_i \exp\left(-\frac{Q_i}{R\,T}\right) \sinh\left(q\frac{(\bar{\sigma} - \bar{\sigma}_g)}{\mu}\right)$$

Transient Limit

$$\dot{\bar{\varepsilon}}^{tr*} = \sum_{i=0}^{1} K_i \exp(c_i\,T)\left(\frac{\bar{\sigma}}{\mu}\right)^{m_i}$$

MD Model Calibration

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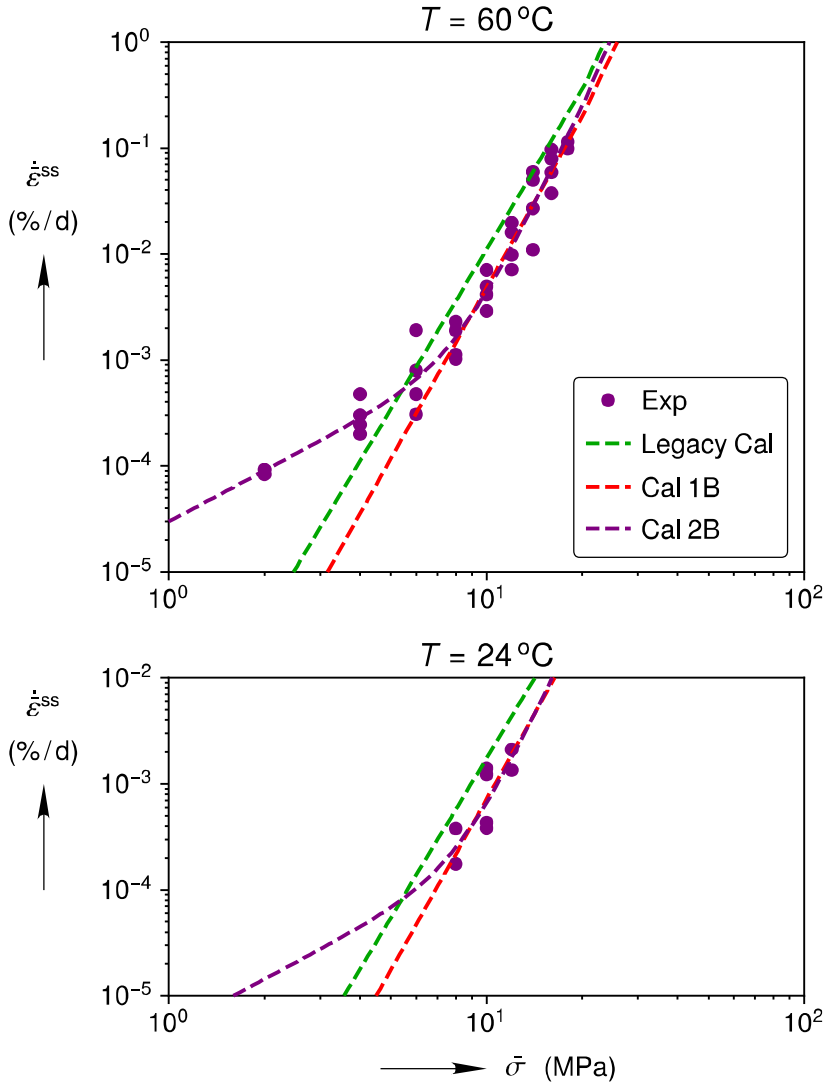
Steady State Rate



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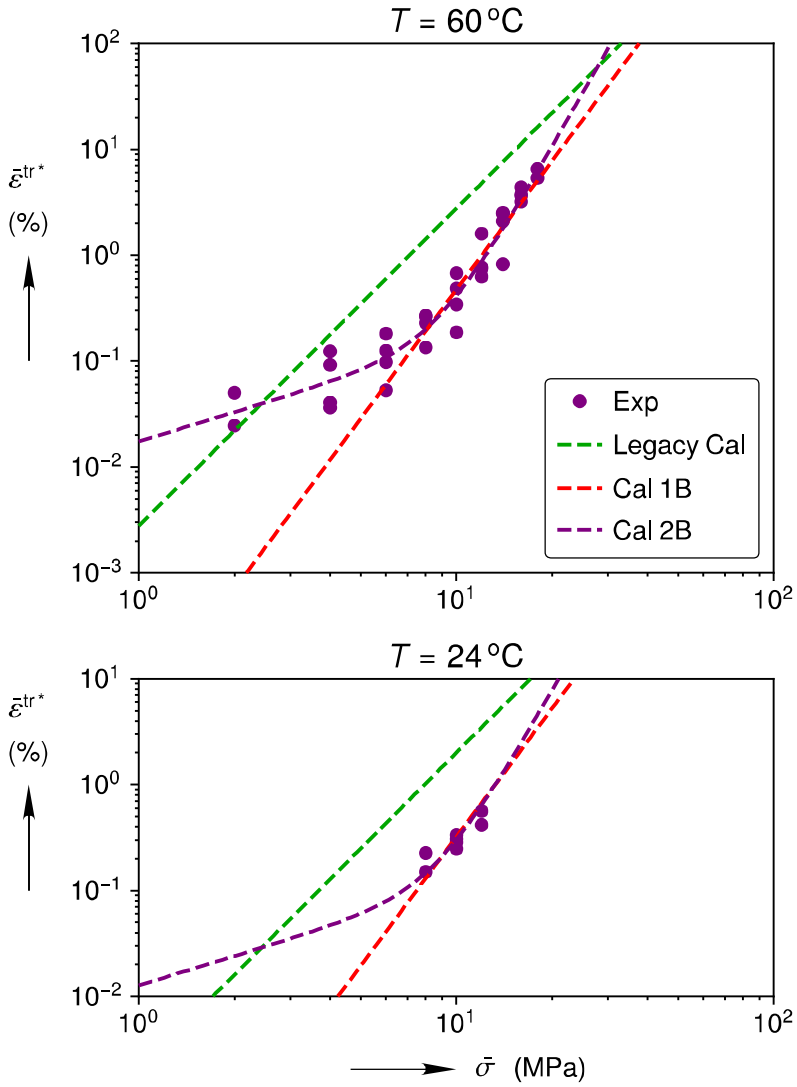
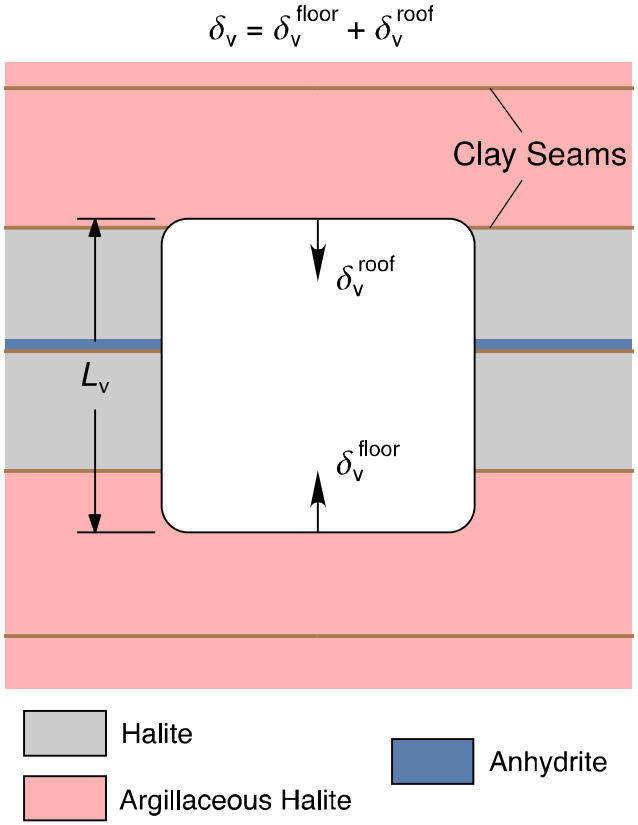
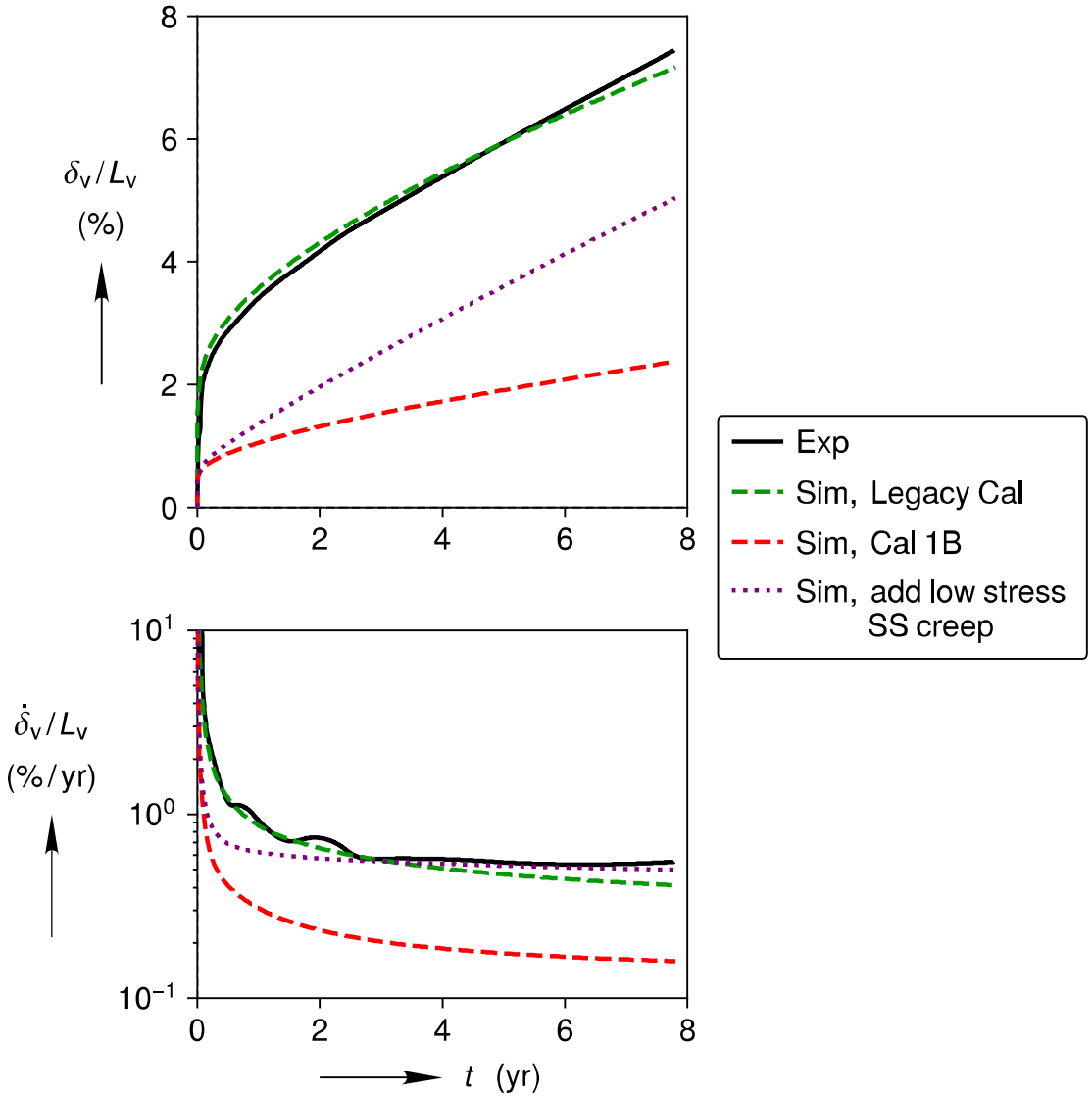


Impact of Low Stress Creep





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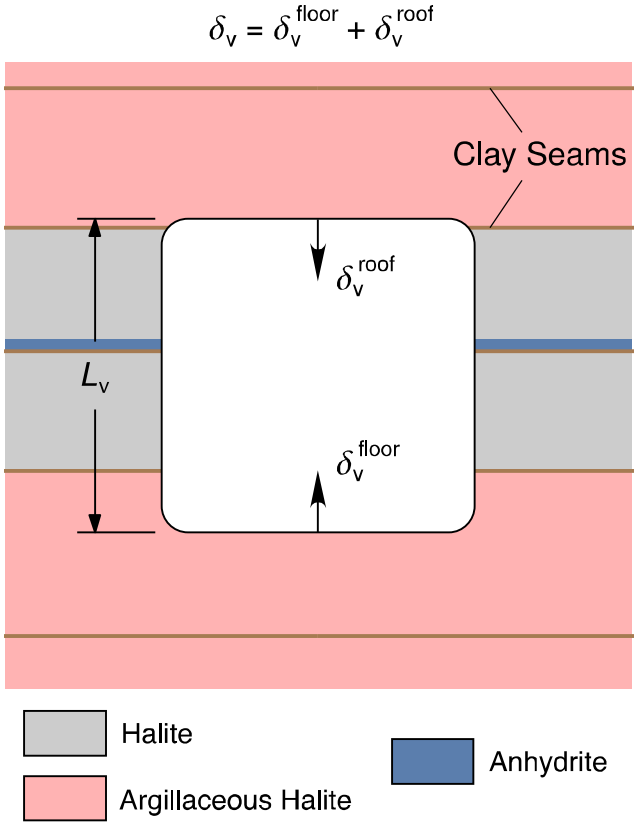
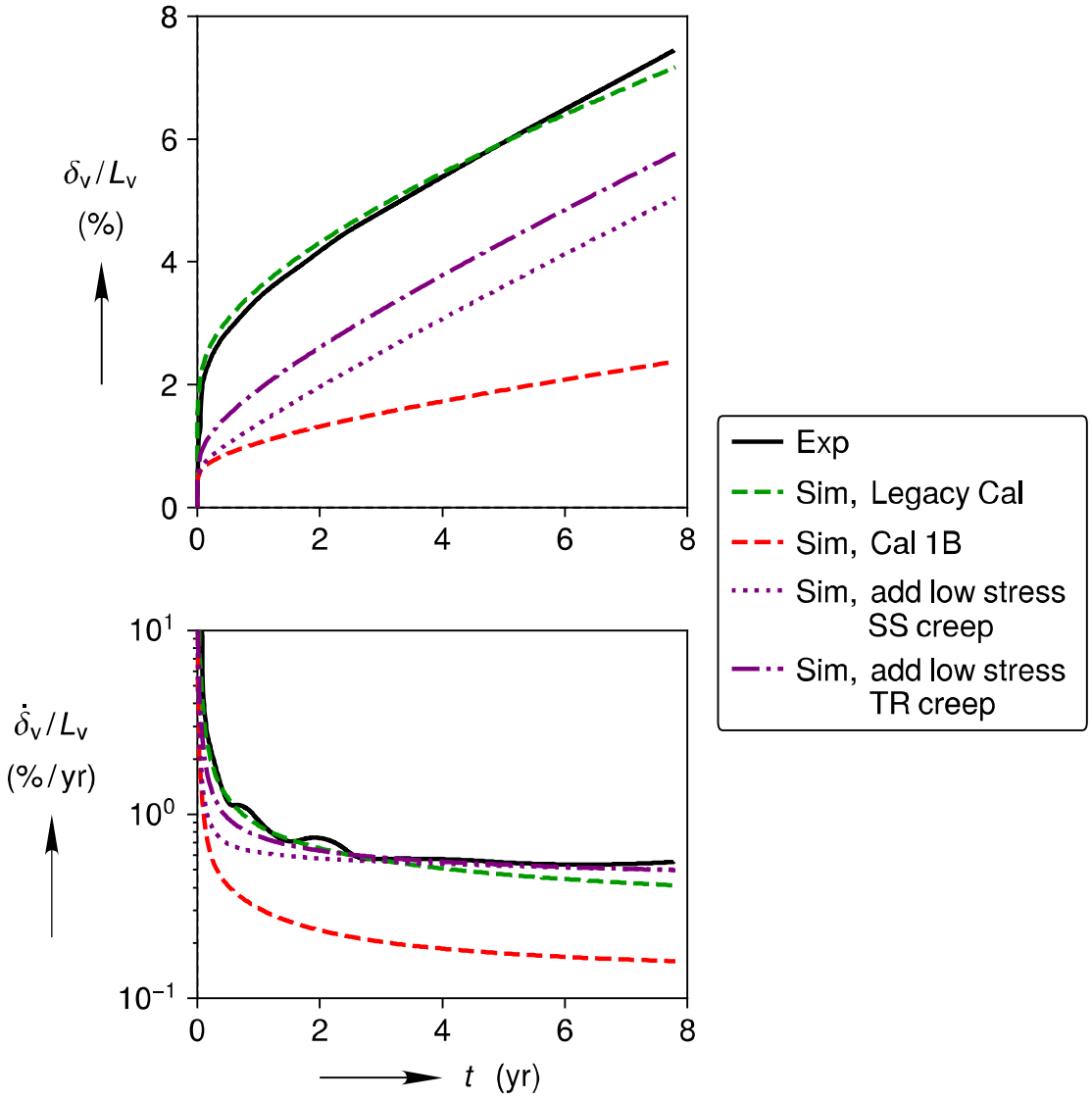
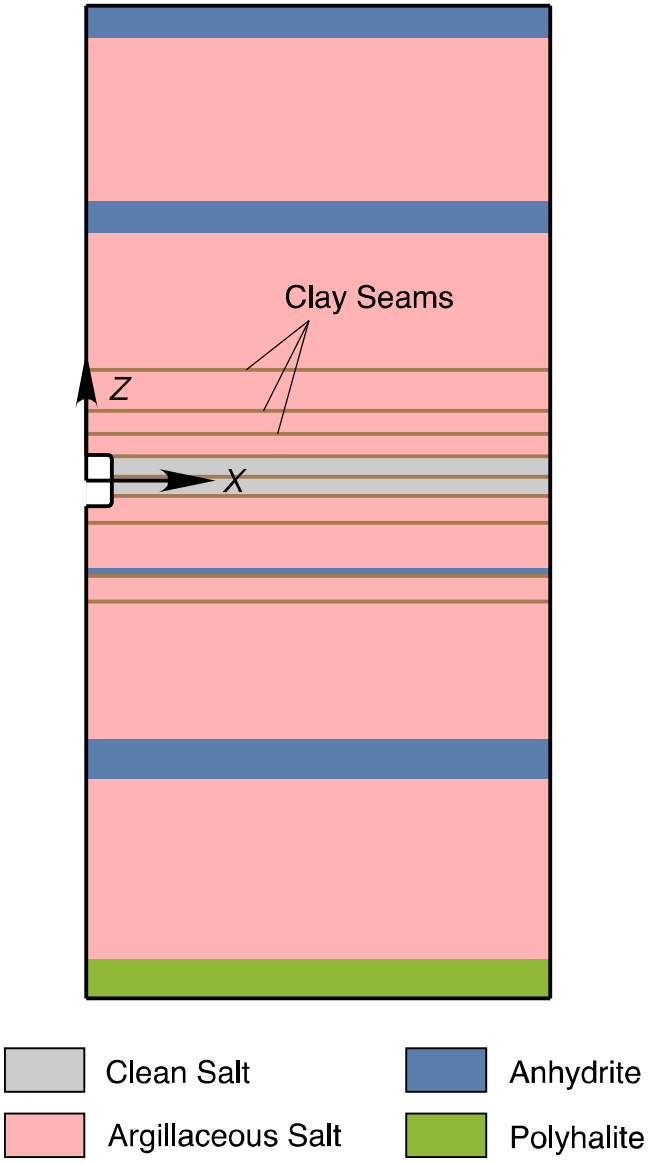
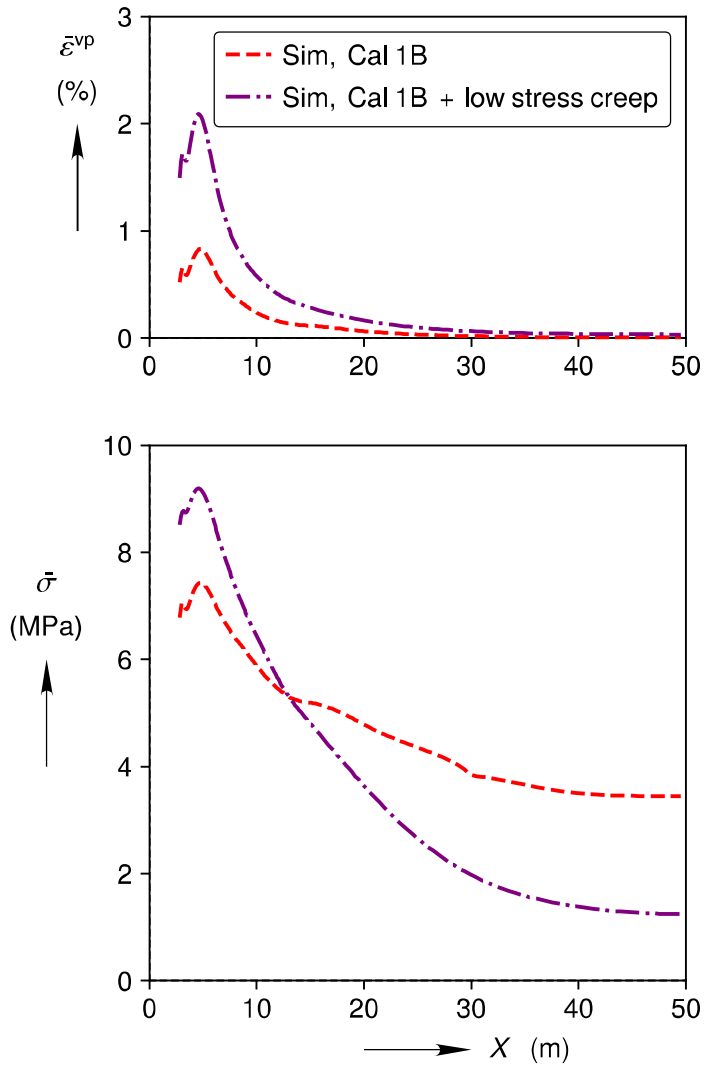




Why Does Low Stress Creep Change Closure?



Strain and stress into the rib at t = 7.9 yr.



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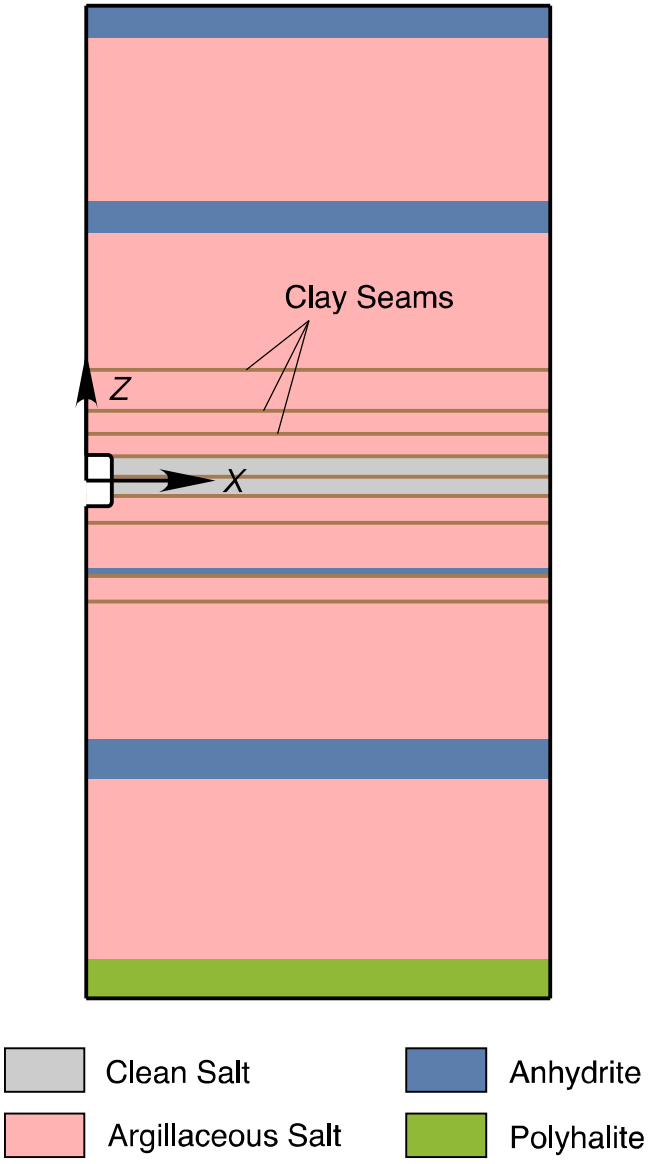

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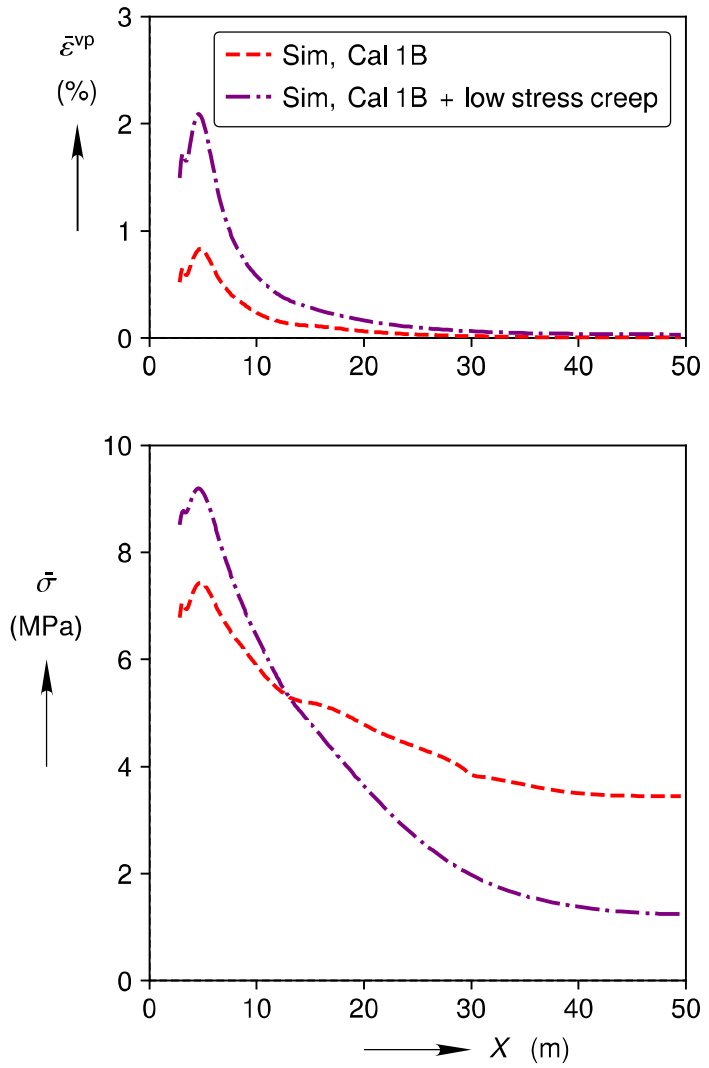
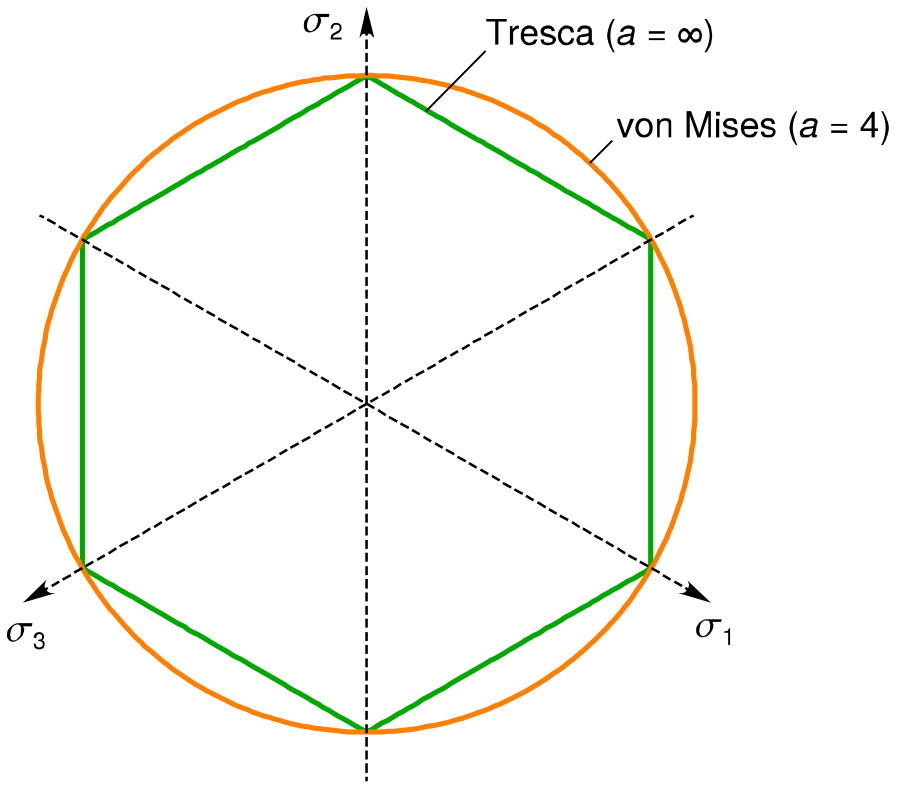


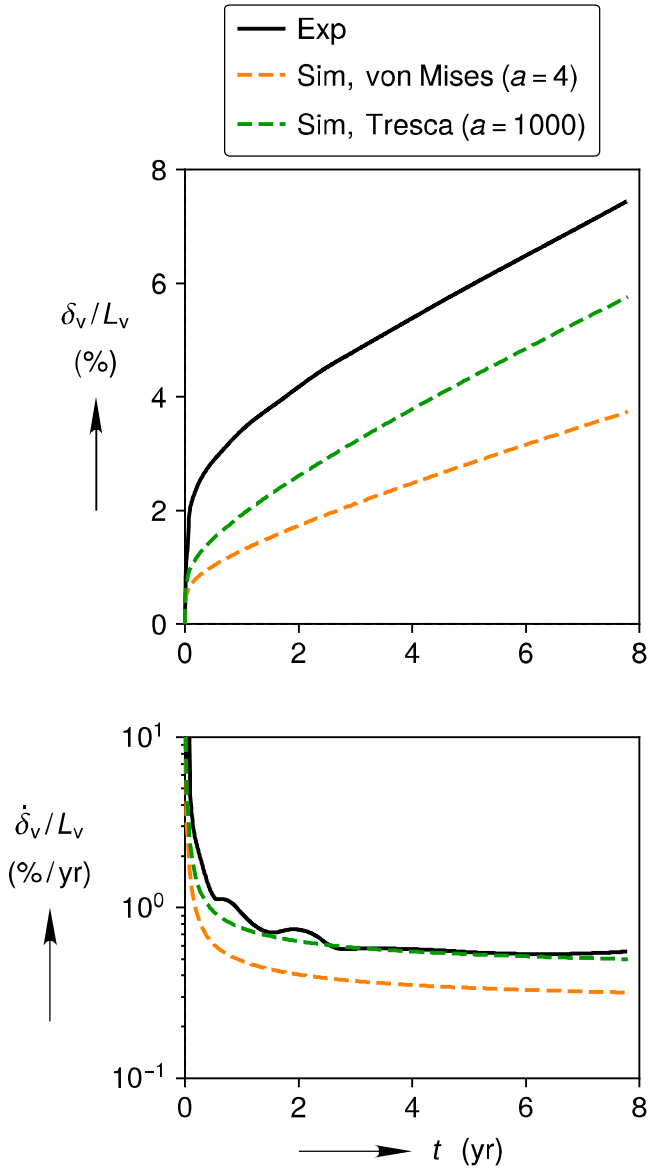
Hosford Equivalent Stress

von Mises vs. Tresca

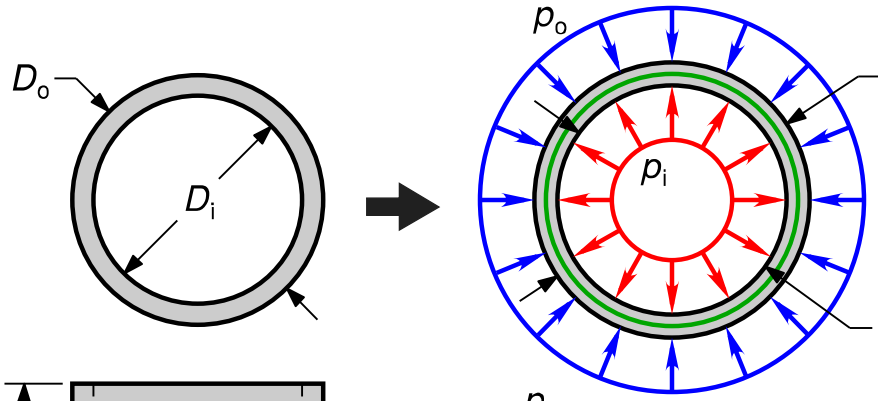


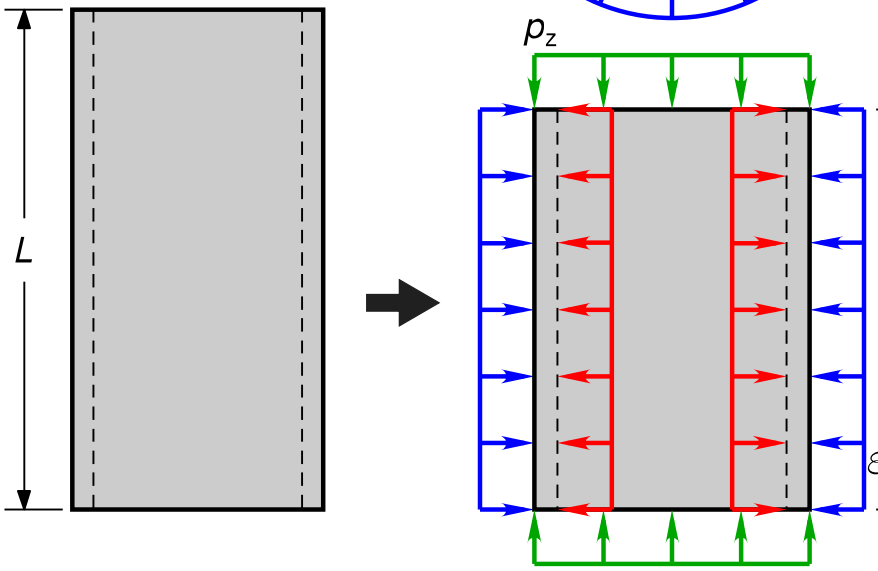
Hosford:

$$\bar{\sigma} = \left\{ \frac{1}{2} \left[|\sigma_1 - \sigma_2|^a + |\sigma_2 - \sigma_3|^a + |\sigma_1 - \sigma_3|^a \right] \right\}^{1/a}$$



Hollow Cylinder Experiments





Cauchy Stresses

$$\sigma_{rr} = \frac{p_i d_i + p_o d_o}{d_i + d_o}$$

$$\sigma_{\theta\theta} = \frac{p_i d_i - p_o d_o}{d_i - d_o}$$

$$\sigma_{zz} = p_z$$

Log Strains

$$\varepsilon_{rr}^{l} = \ln\left(\frac{d_o - d_i}{D_o - D_i}\right)$$

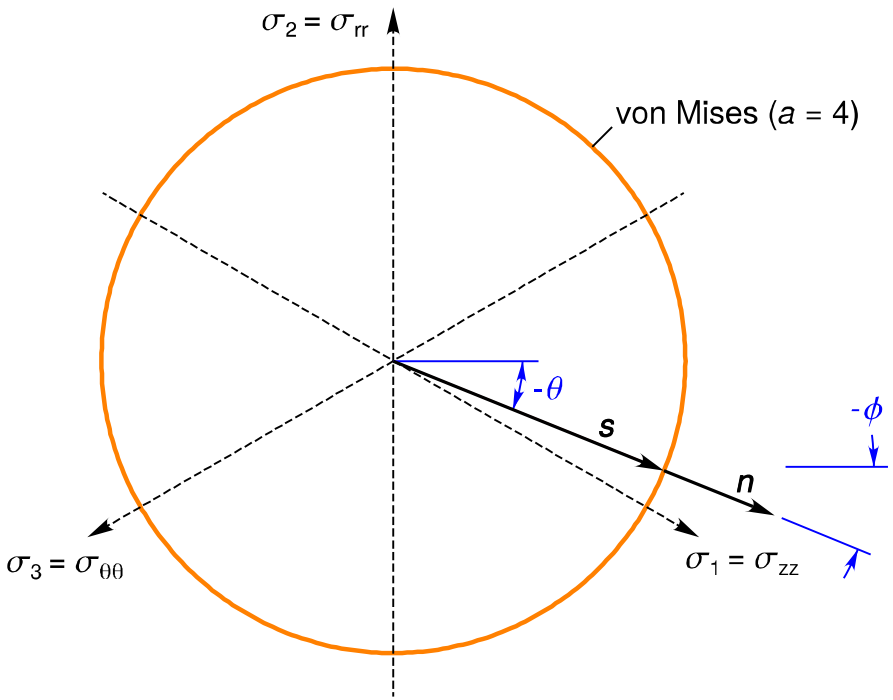
$$\varepsilon_{\theta\theta} = \ln\left(\frac{d_o + d_i}{D_o + D_i}\right)$$

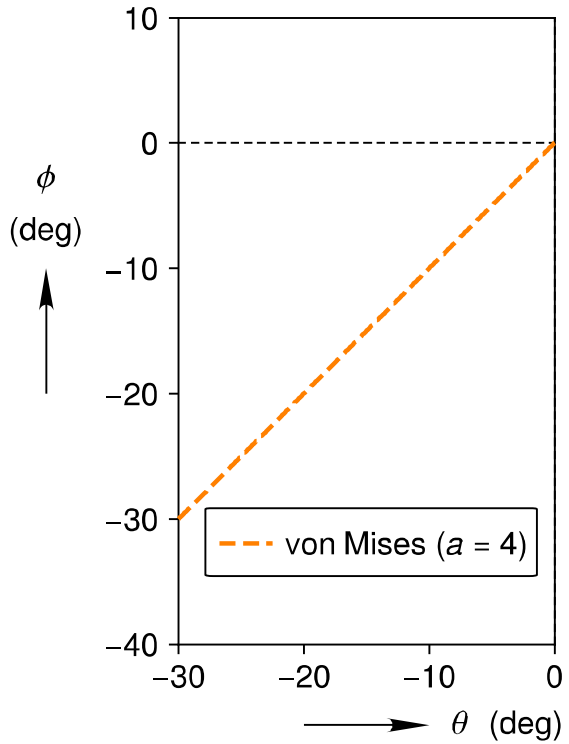
$$\varepsilon_{zz} = \ln\left(\frac{l}{L}\right)$$

$$\frac{D_o + D_i}{D_o - D_i} = 5.5$$

$$D_o - D_i \approx 3.5\, D_g$$

Distinguishing Between von Mises and Tresca





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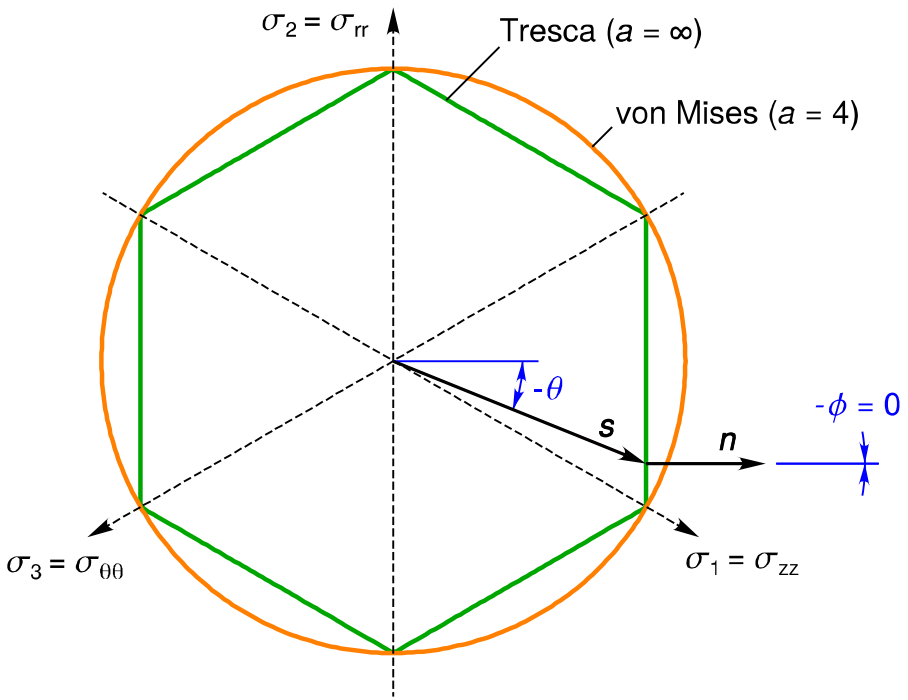

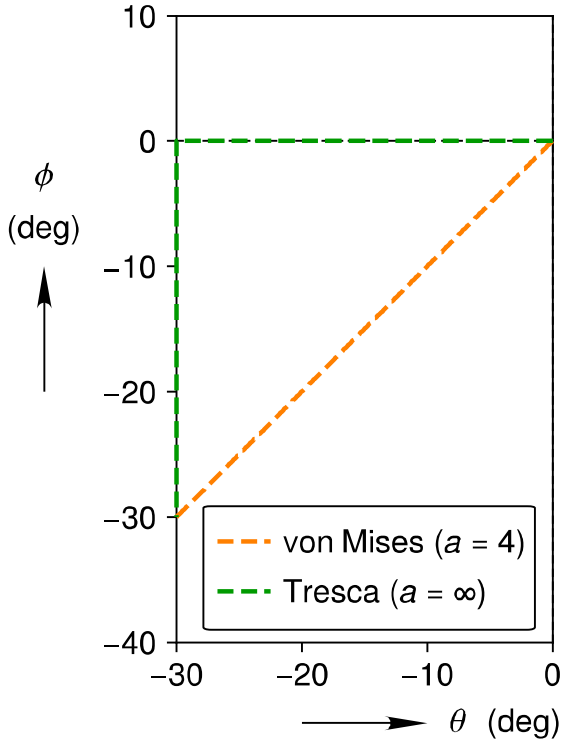

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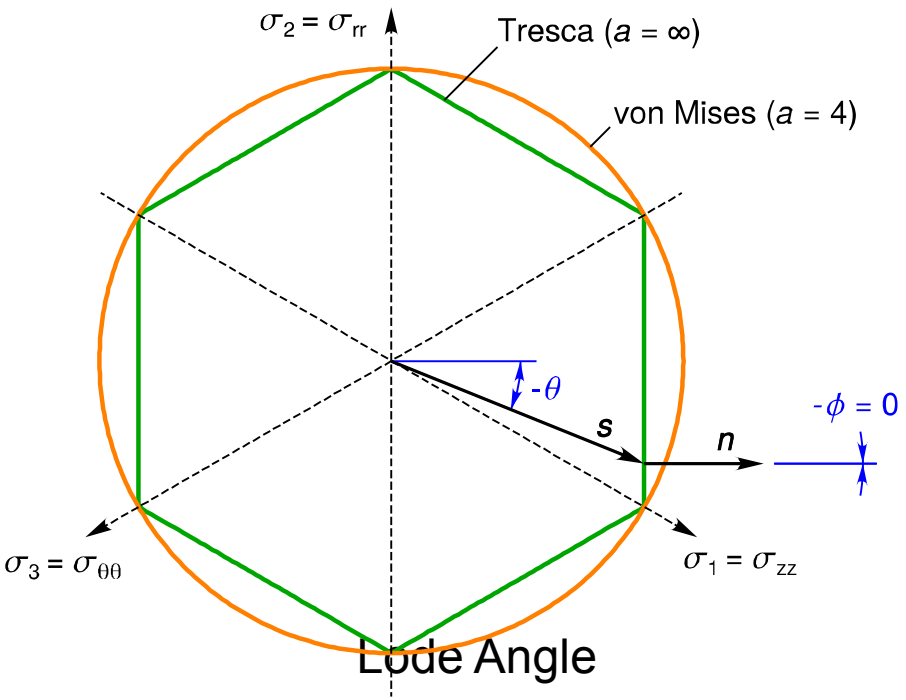
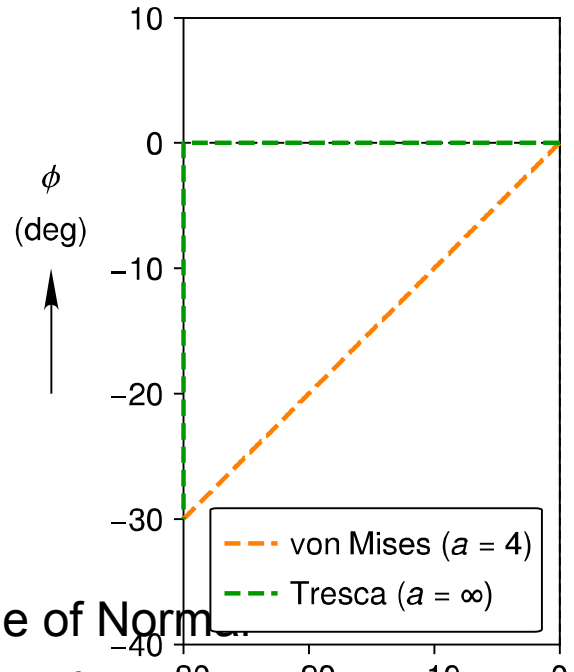


Lode Angle

$$\sin\theta = \frac{\sqrt{3/2}\, s_2}{\|\boldsymbol{s}\|}$$



Angle of Norm...

$$\dot{\bar{\varepsilon}}^{vp} = \dot{\bar{\varepsilon}}^{vp} \frac{\partial \bar{\sigma}}{\partial \boldsymbol{\sigma}} = \dot{\bar{\varepsilon}}^{vp} \boldsymbol{n}$$

$$\sin\phi = \frac{\sqrt{3/2}\, \dot{\varepsilon}_2^{vp}}{\|\dot{\boldsymbol{\varepsilon}}^{vp}\|}$$

Hollow Cylinder Experiment Analysis

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Lode Angle

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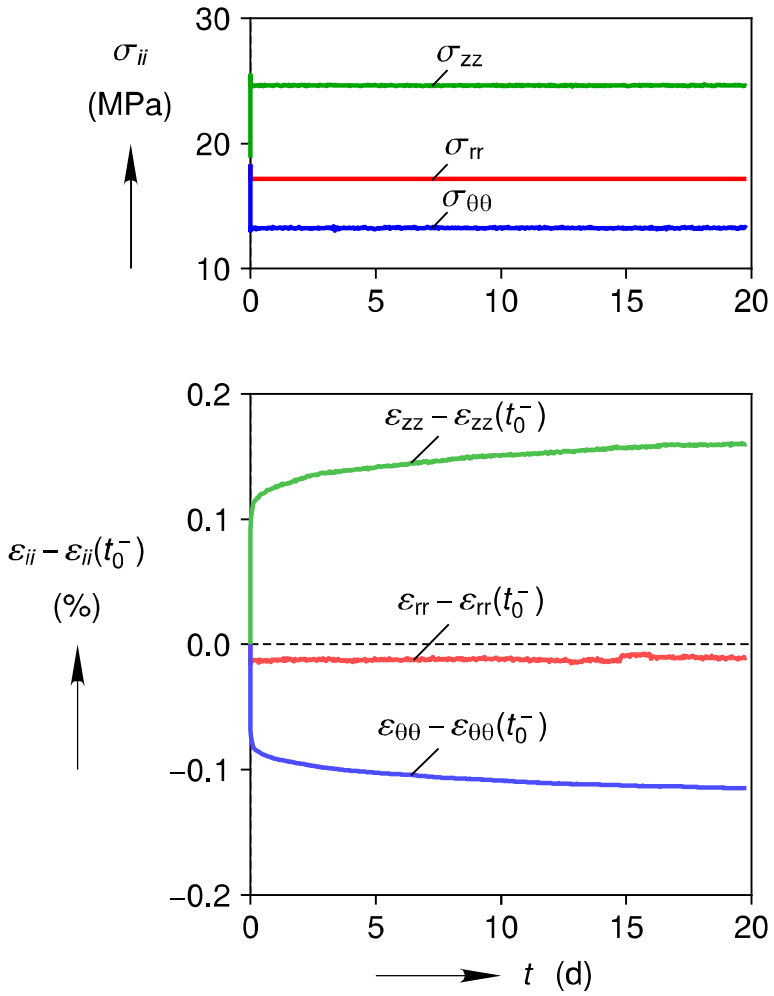

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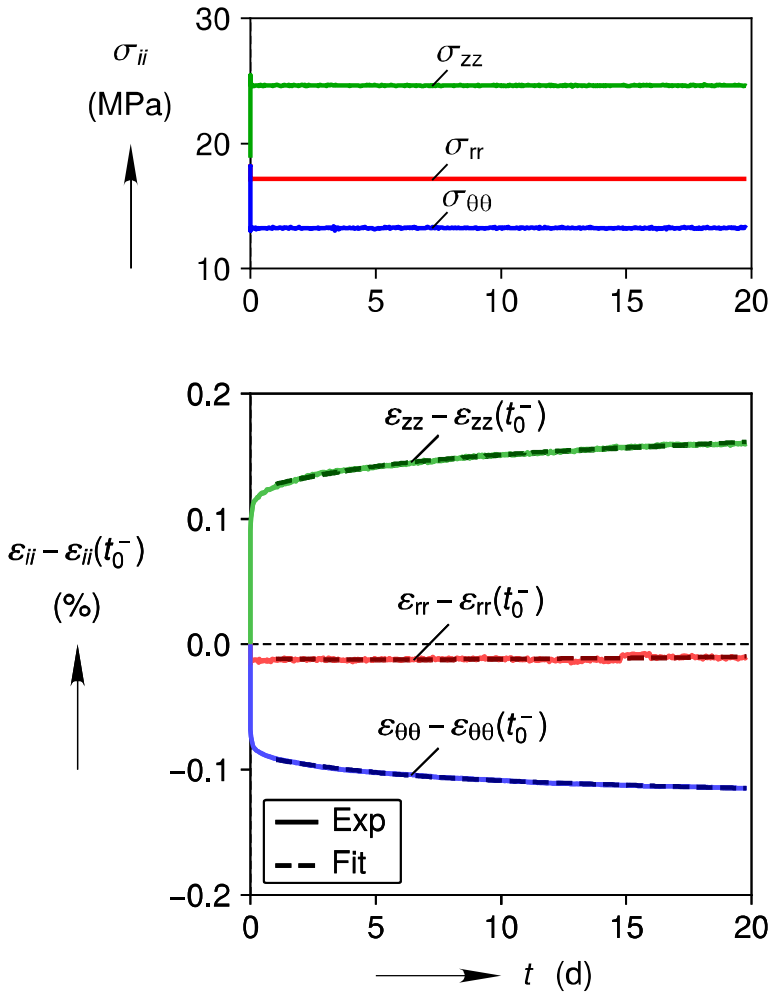

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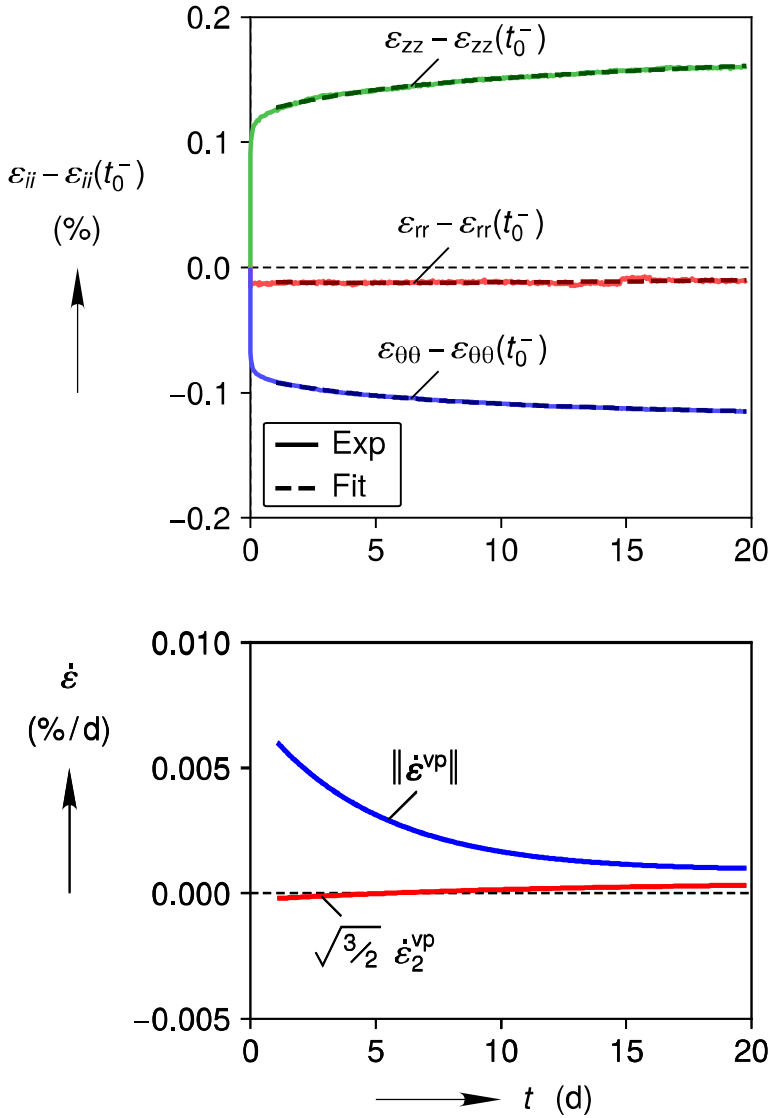

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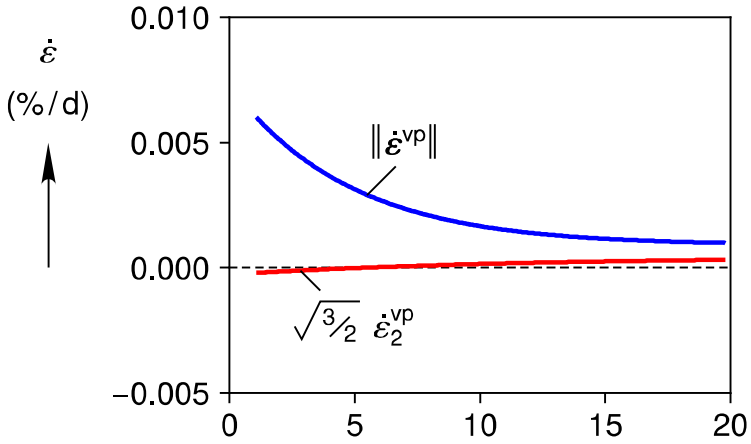

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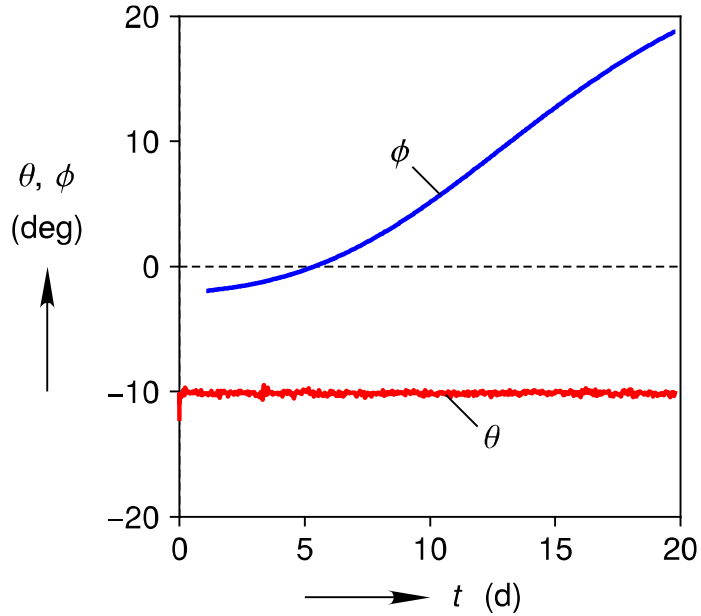
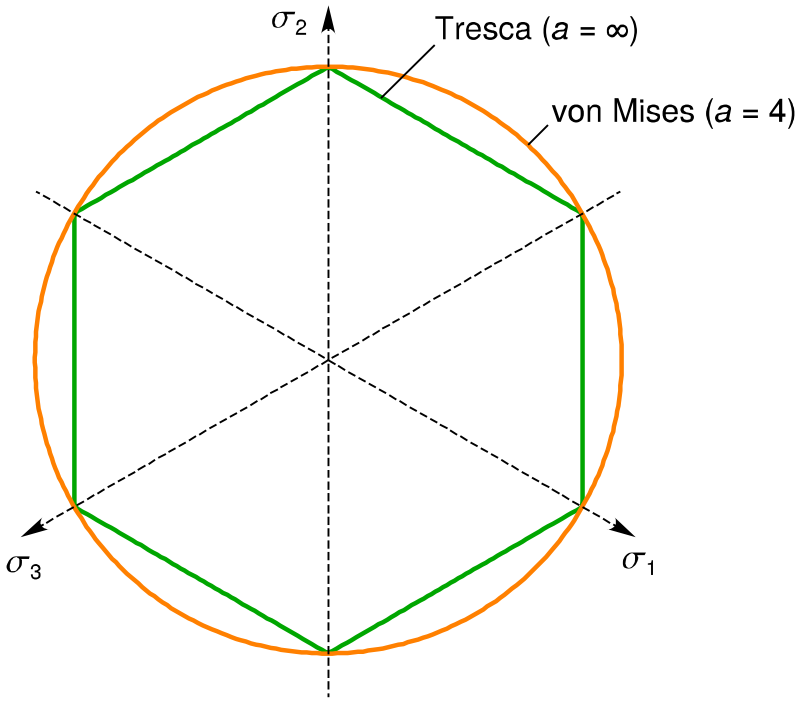
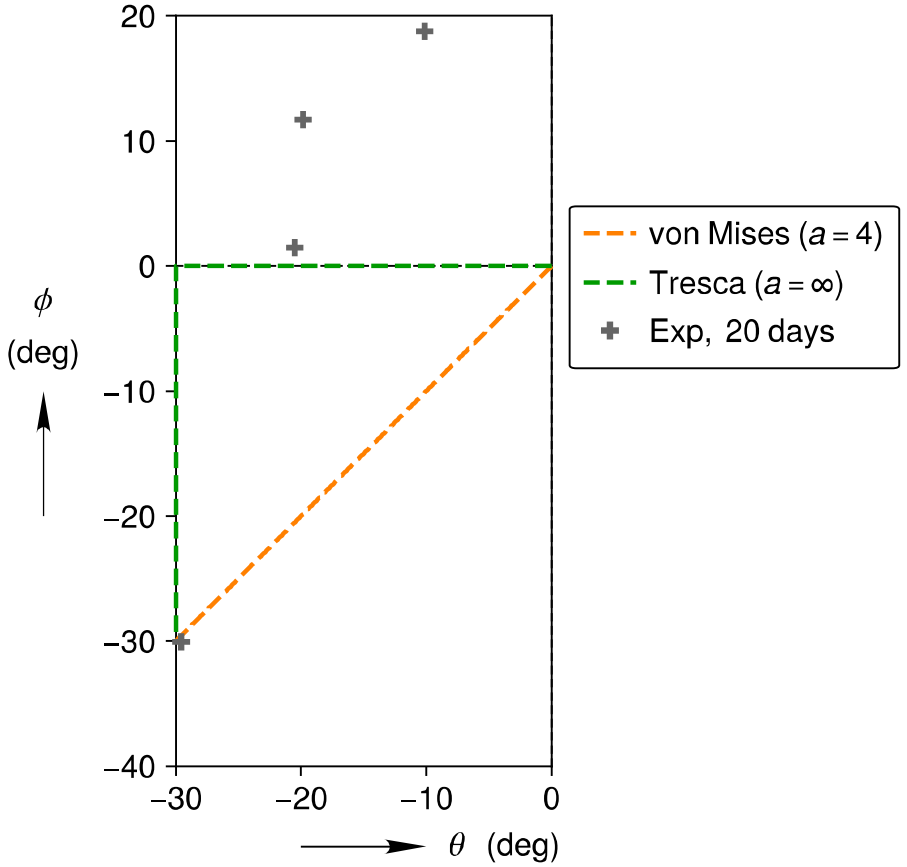


Selection of Hosford Exponent





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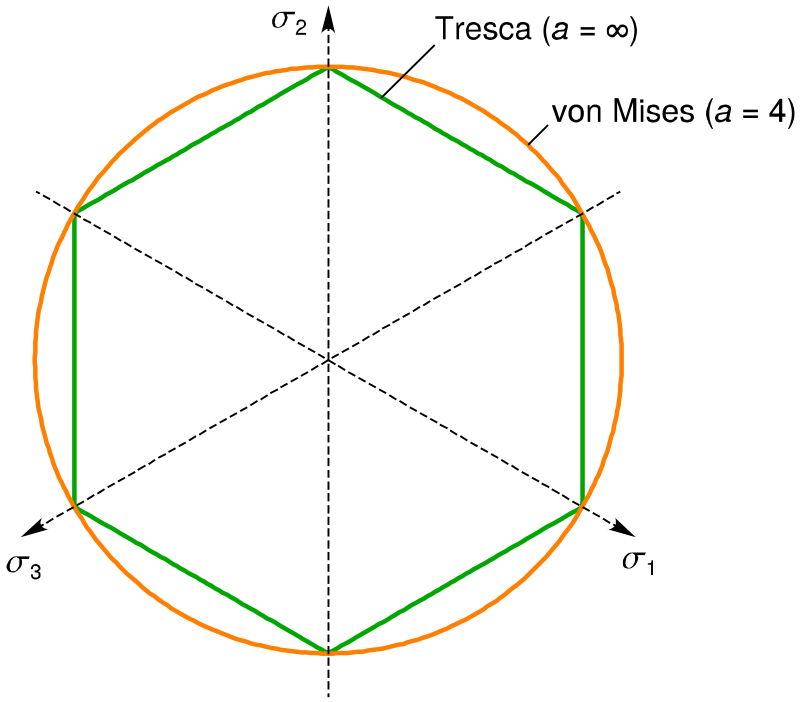

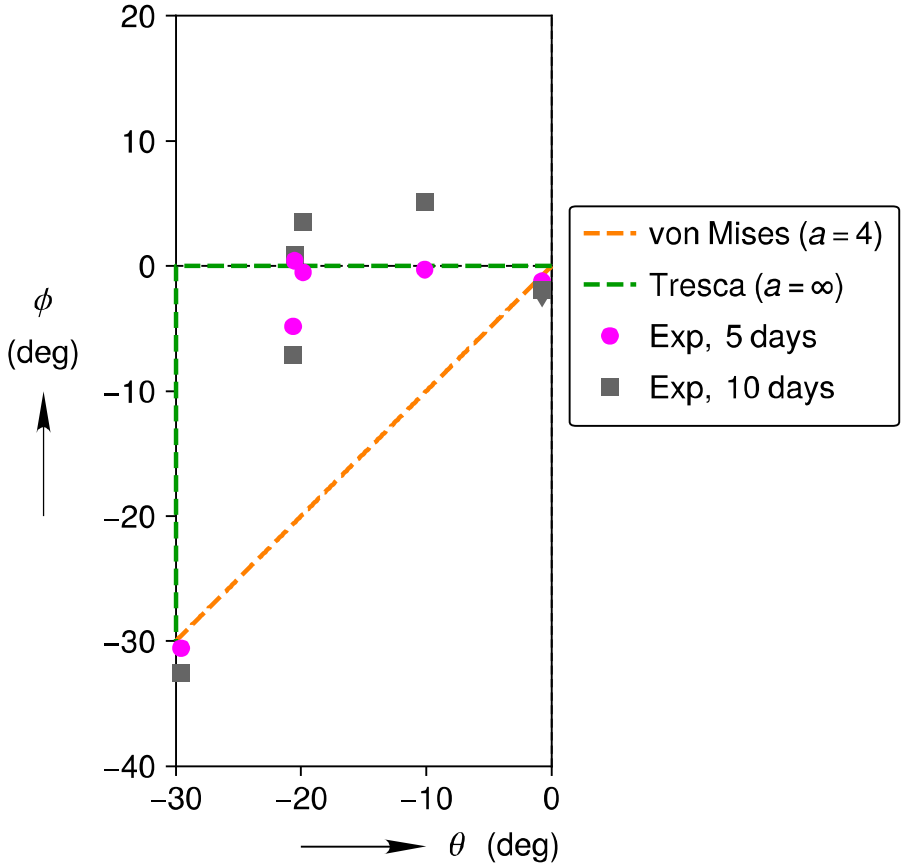

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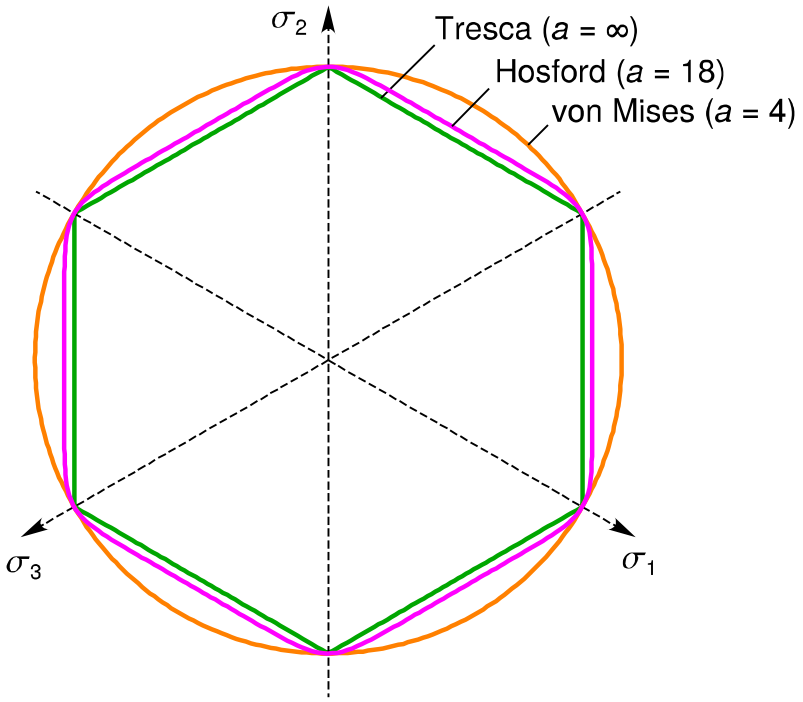

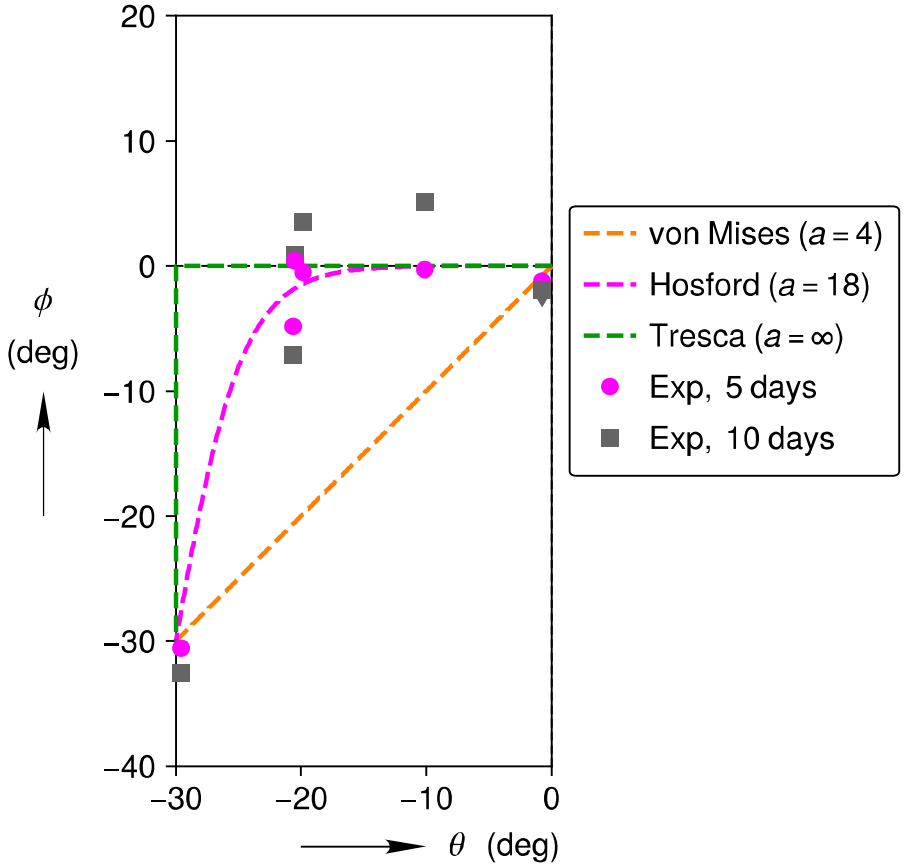

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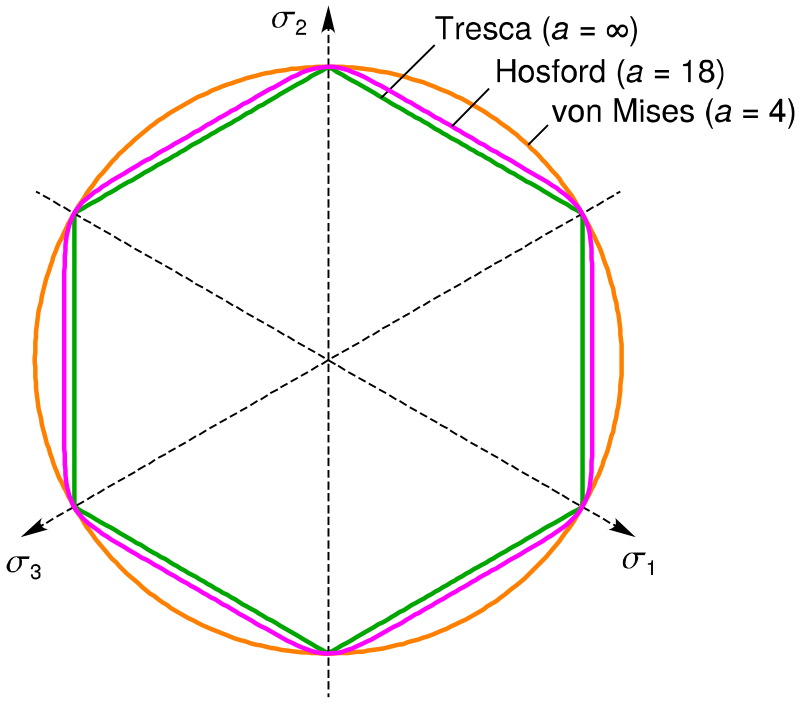
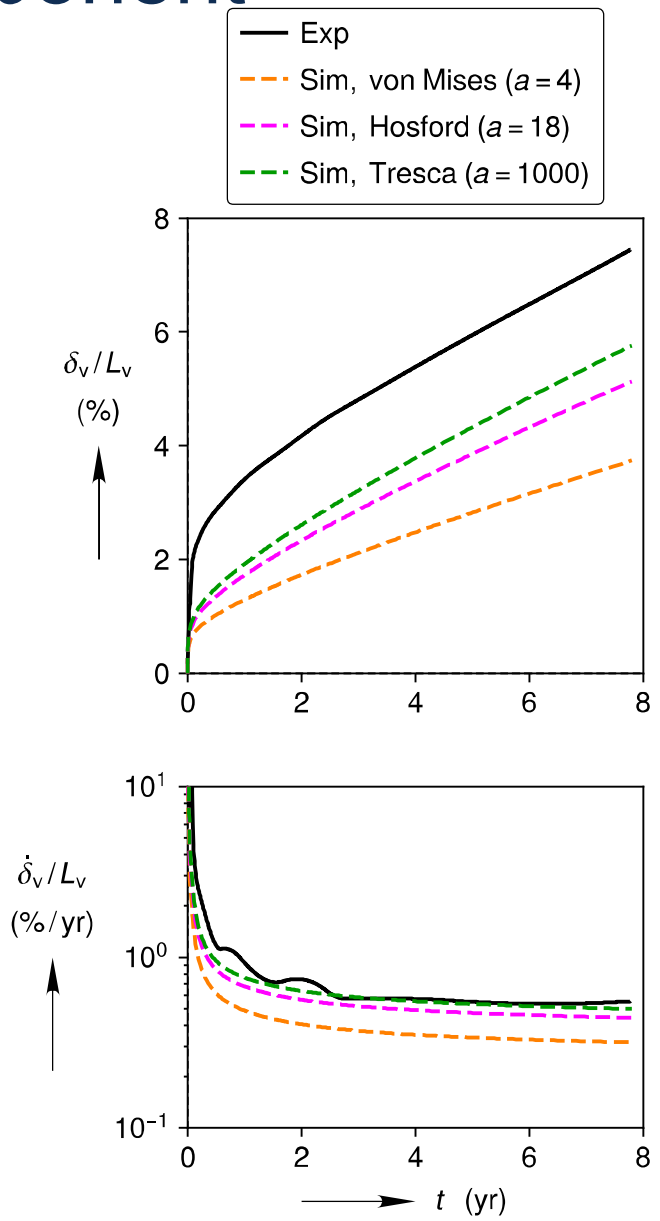
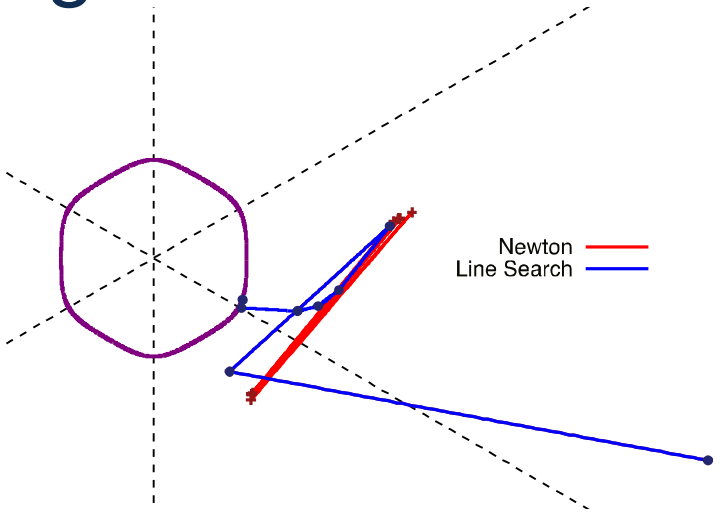
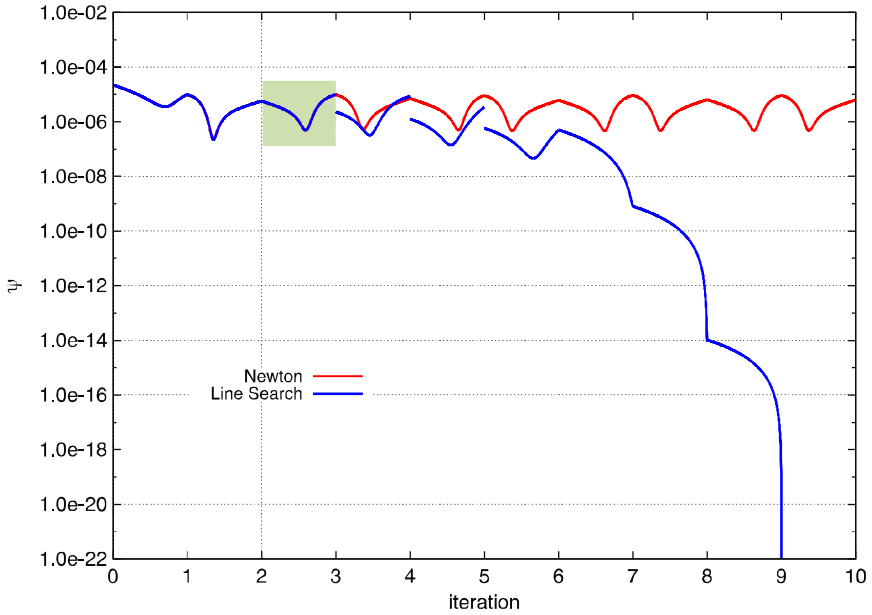
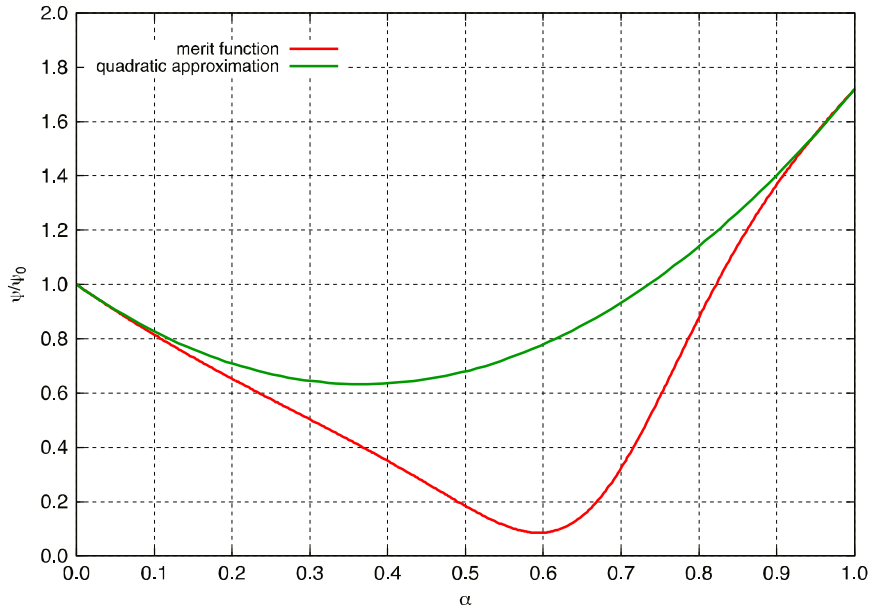




Line Search Algorithm







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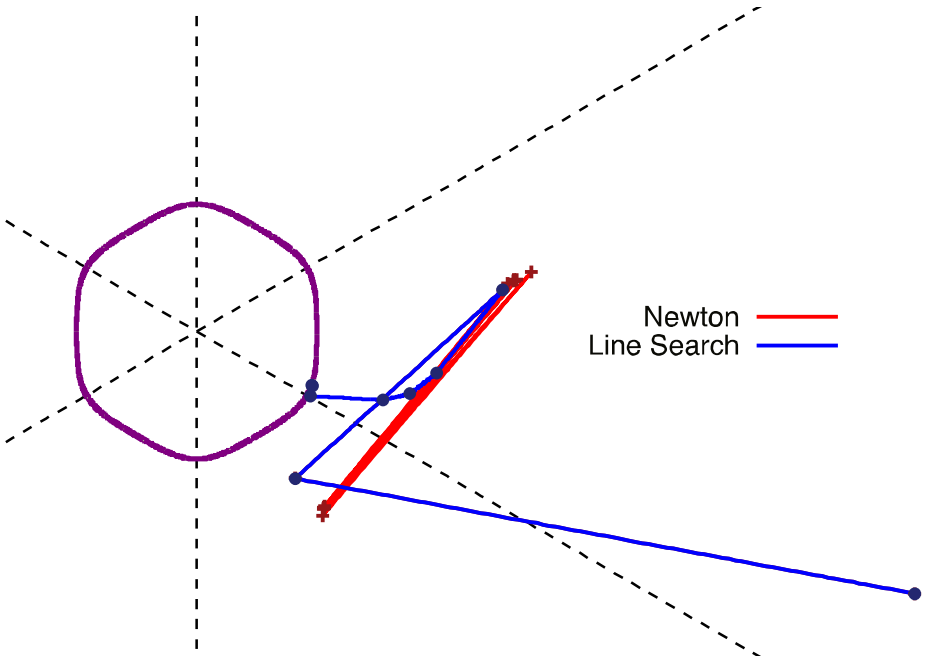
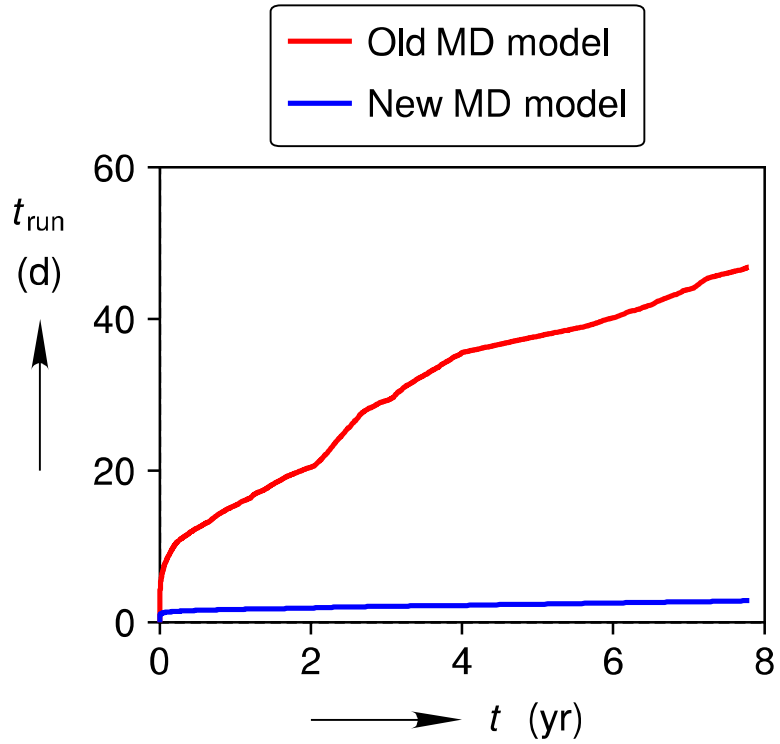
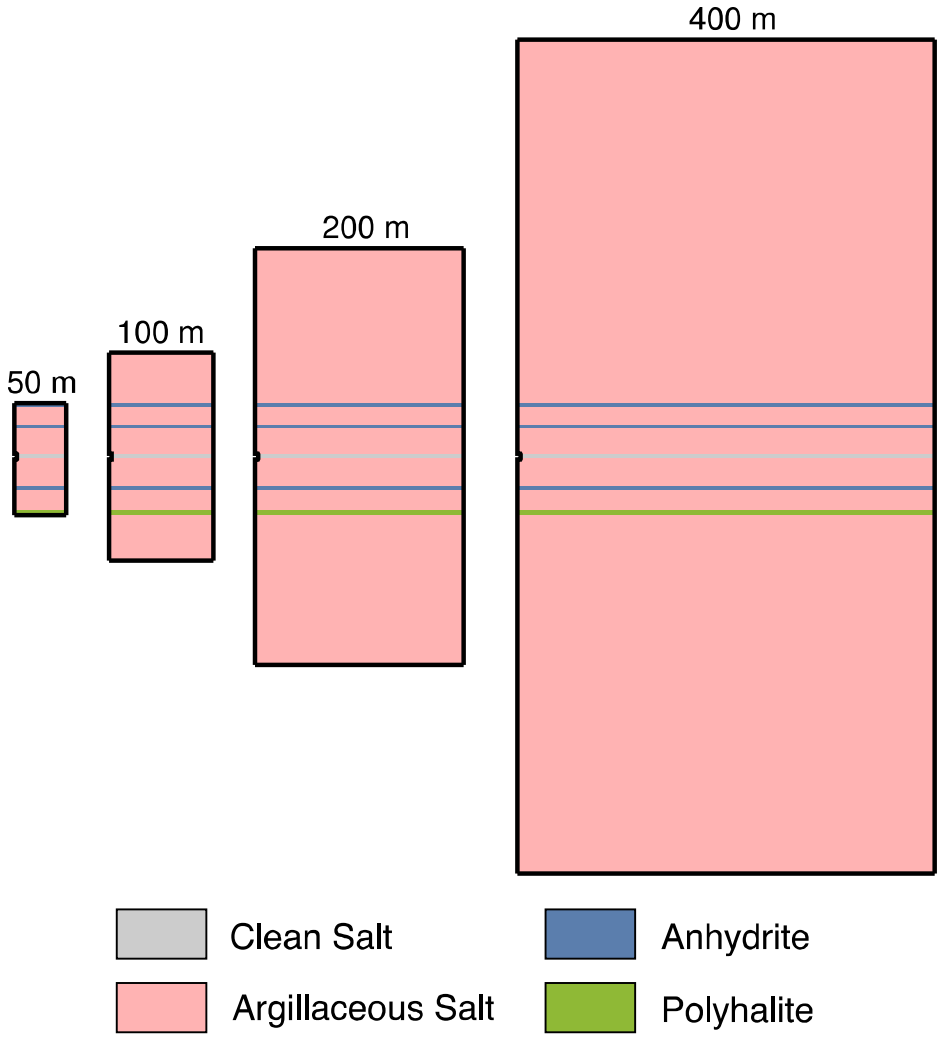




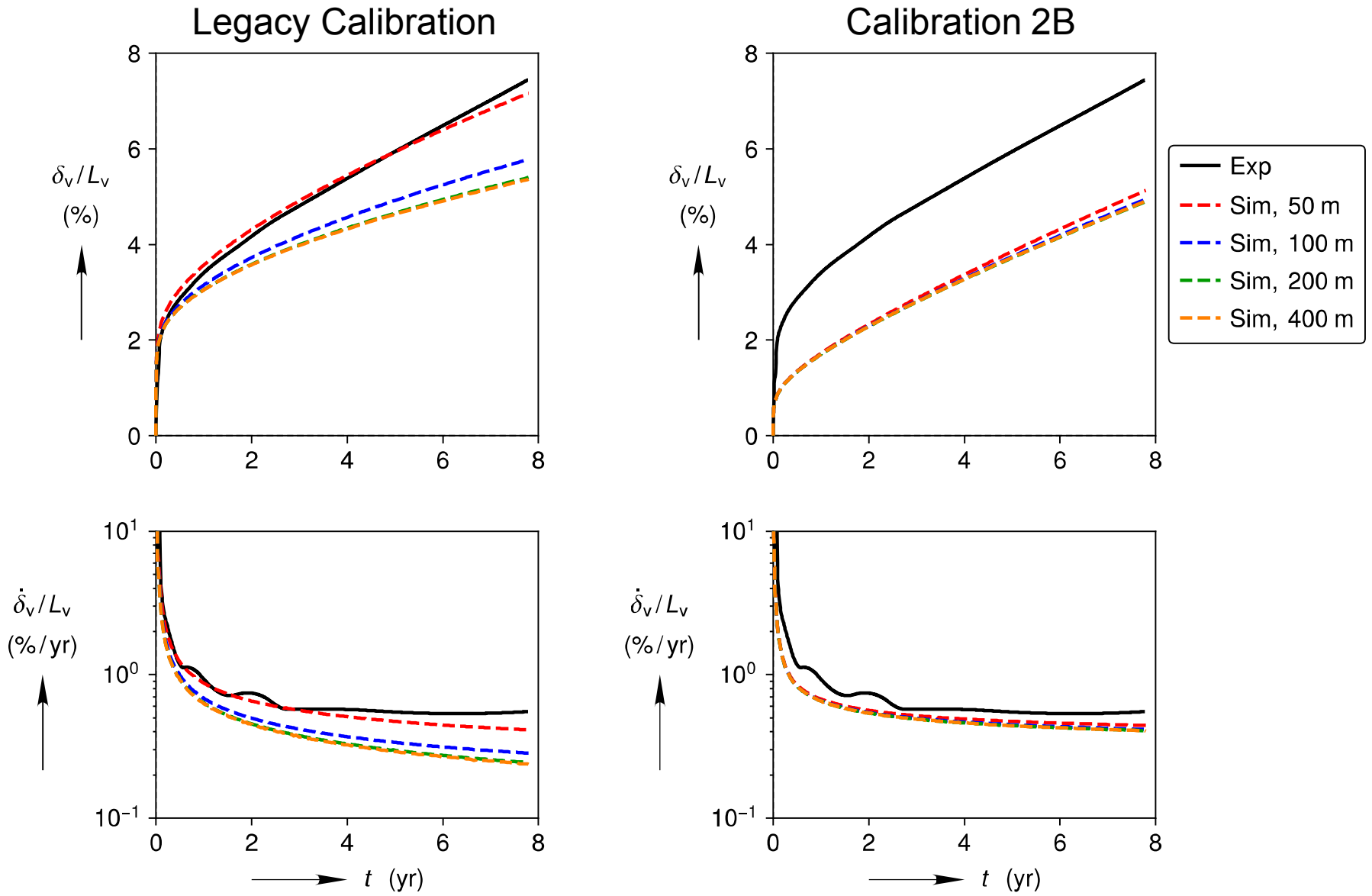
Scherzinger, W. M. 2017. A return mapping algorithm for isotropic and anisotropic plasticity models using a line search method. Computer Methods in Applied Mechanics and Engineering, 317, 526–553. (Modified)

Domain Size Study

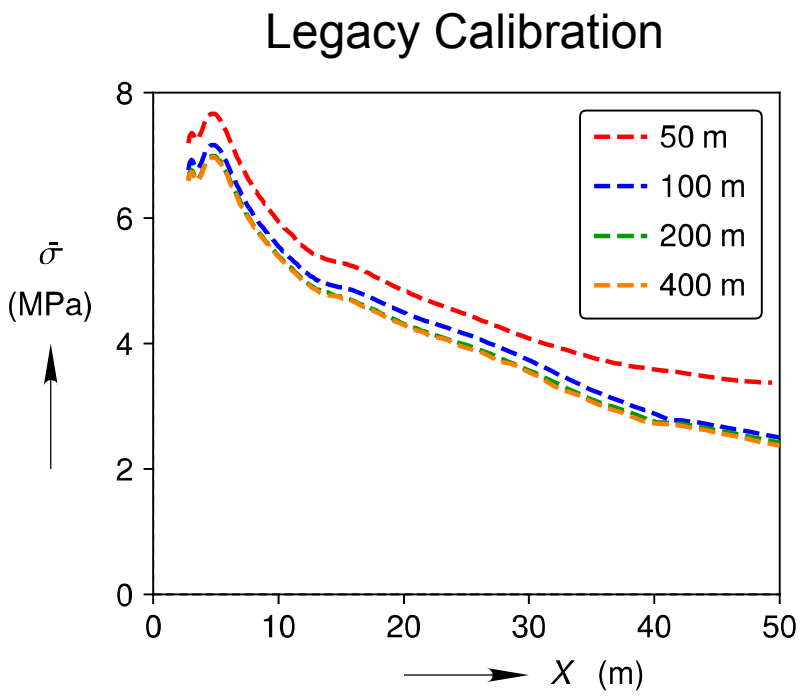
Domains Simulated

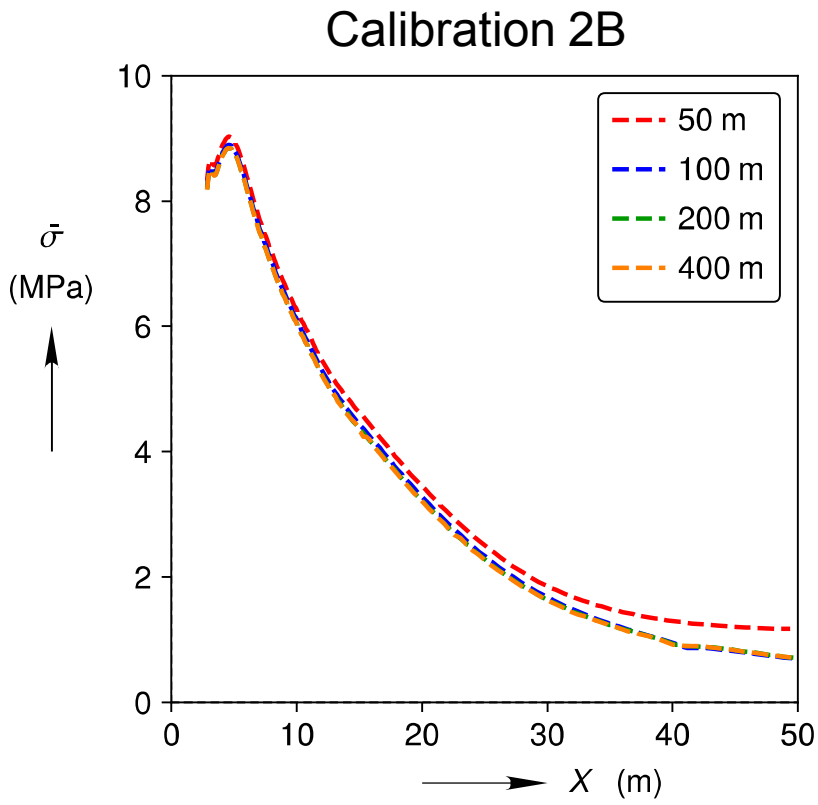


Vertical Closure



Stress Traces into Rib





Summary

Summary

- Creep at low equivalent stress
  - Substantially improves the closure predictions
  - Relaxes far-field so that near-field can attain higher stresses
  - Reduces sensitivity to domain size

- Hosford equivalent stress
  - Allows one to select something between Tresca and von Mises
  - Hollow cylinder data is imperfect, but indicates something close to Tresca
  - Numerical implementation of Hosford dramatically reduced simulation run time from 46 days to 3 days.

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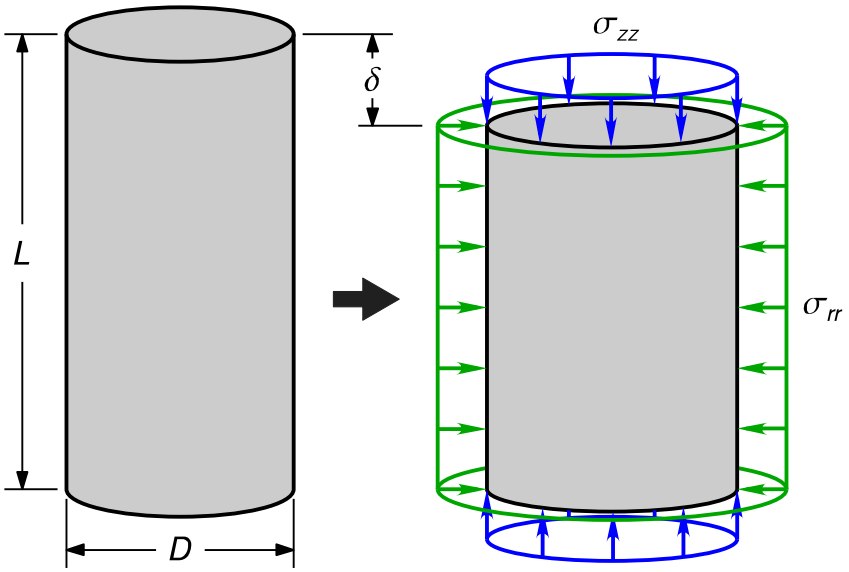
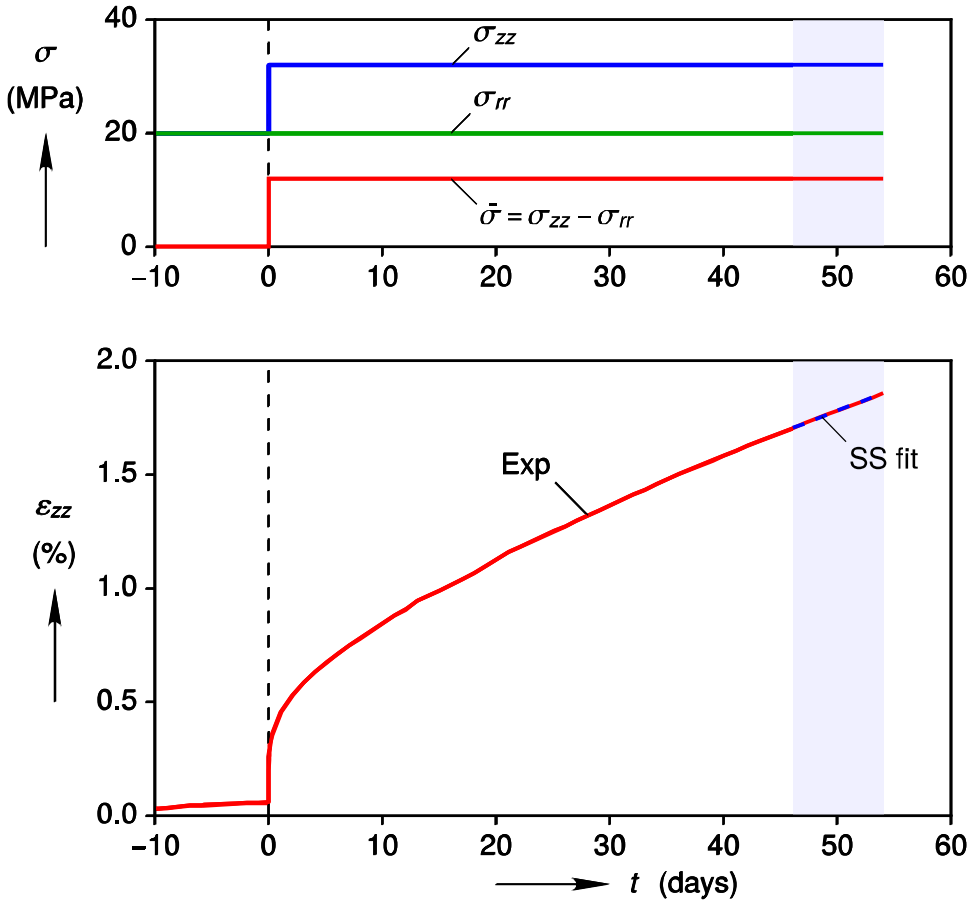
Extra Slides

Laboratory Creep Tests

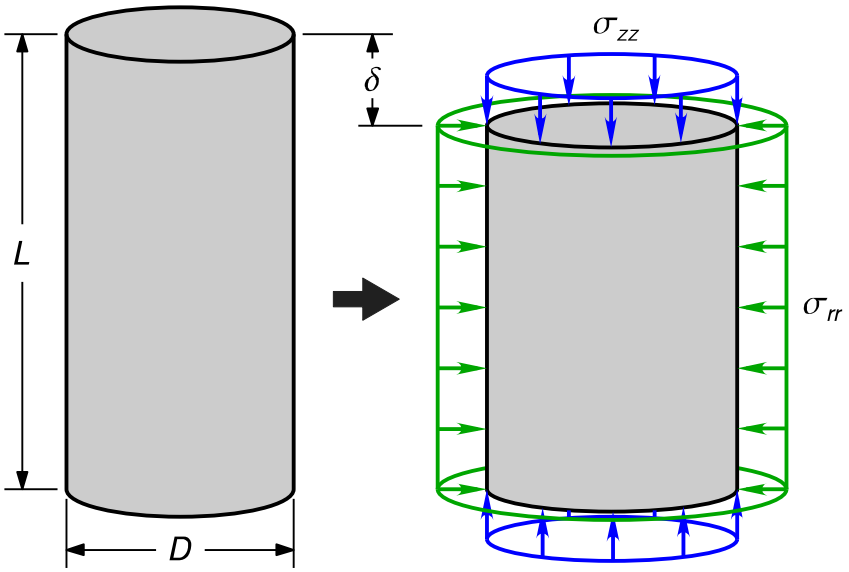


$$\frac{L}{D} = 2$$

$$\varepsilon_{zz} = \ln\left(1 + \frac{\delta}{L}\right)$$



Laboratory Creep Tests



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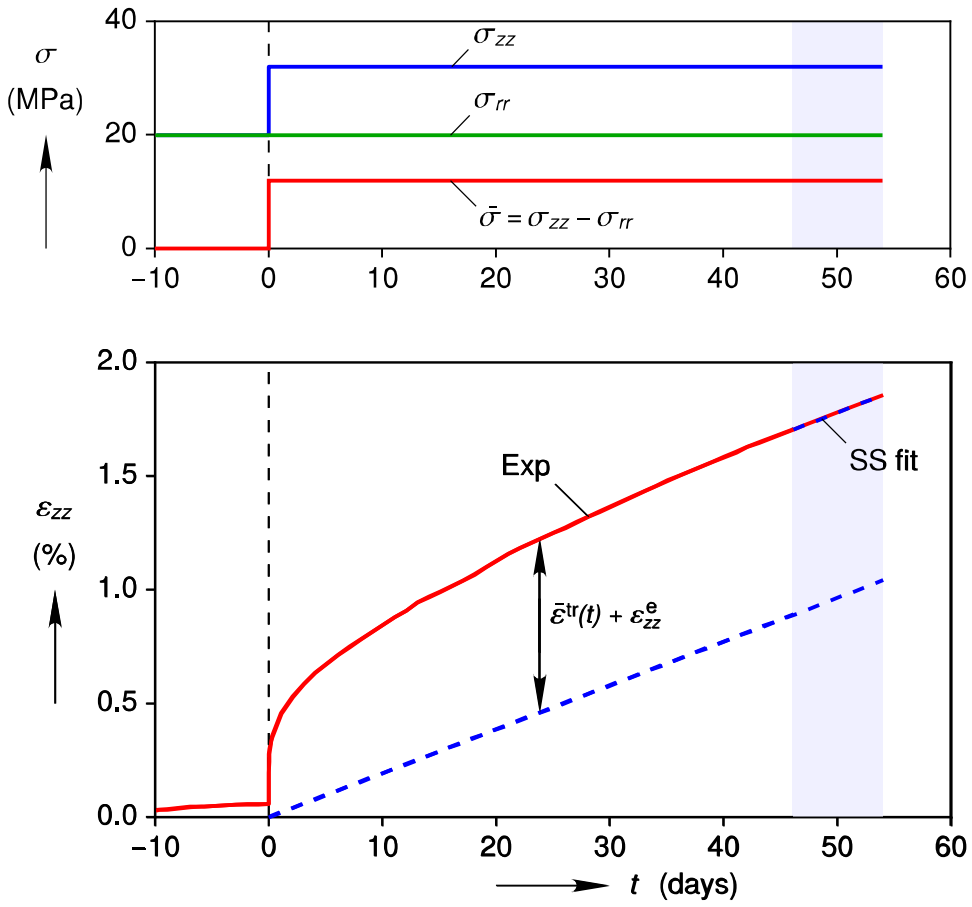
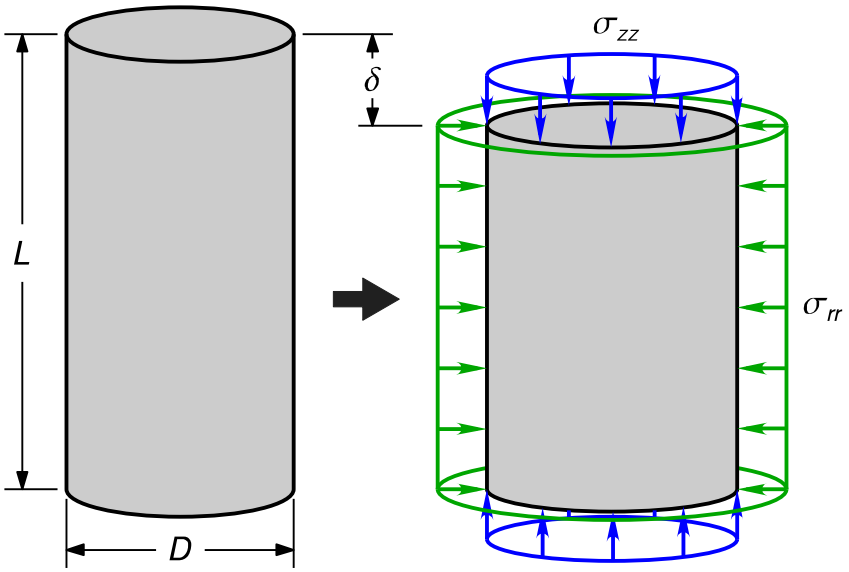


Laboratory Creep Tests



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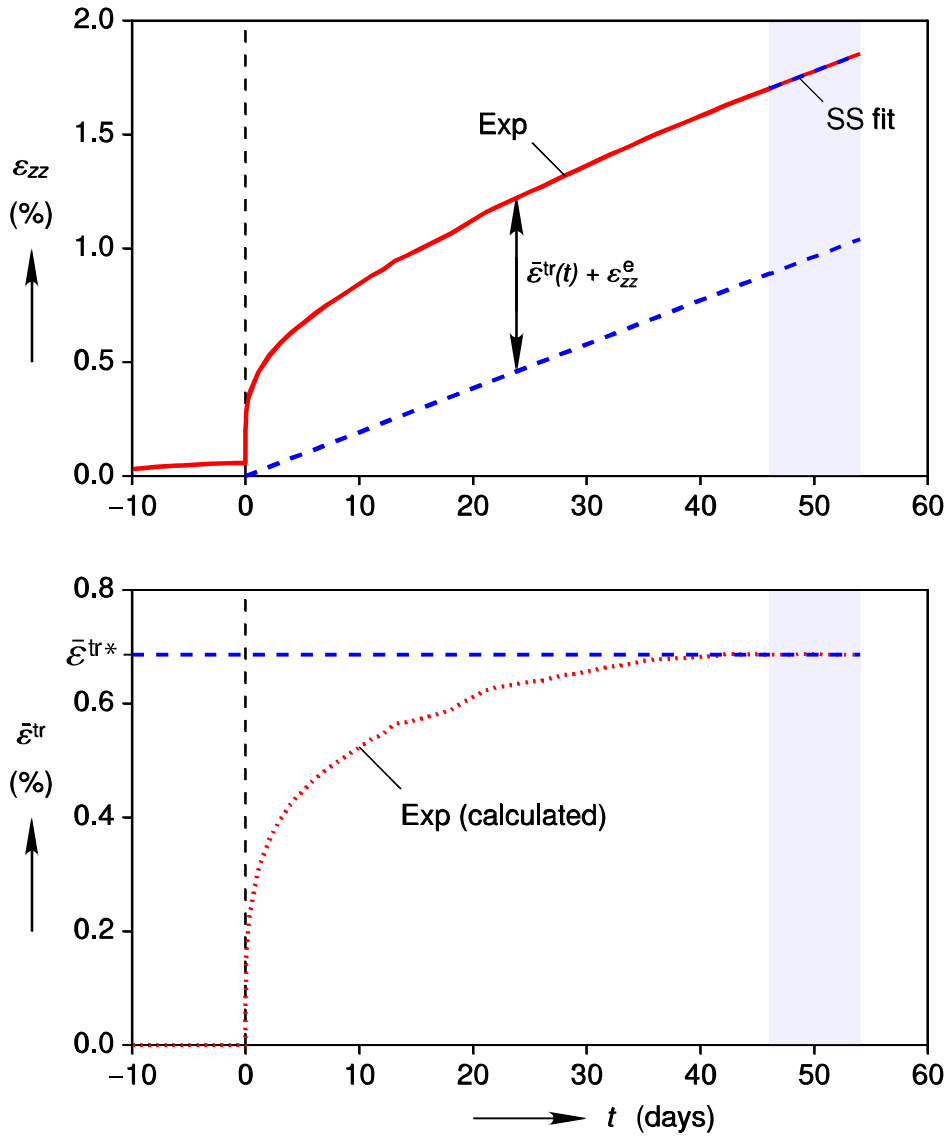
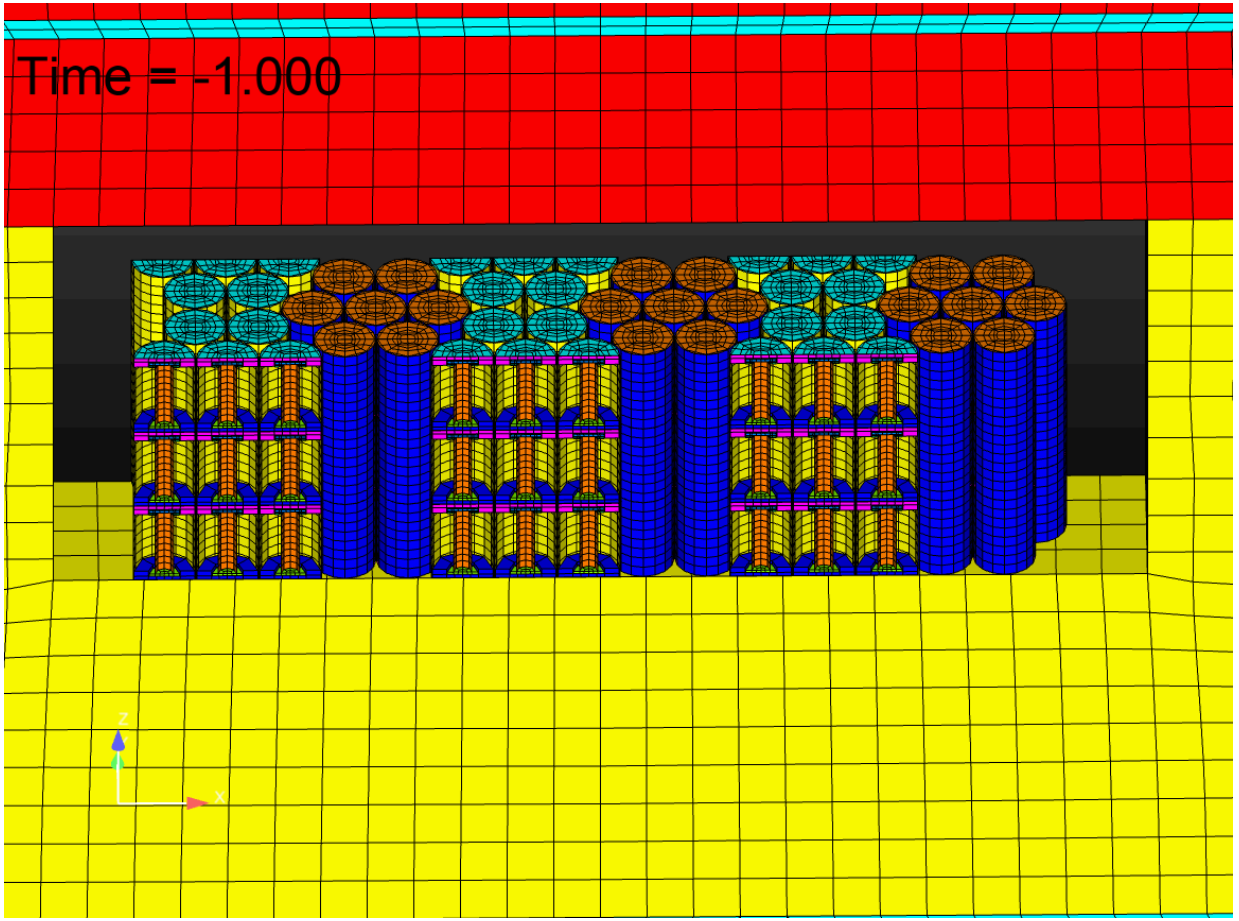


Canister Crushing, Initial Configuration



Video of Canister Crushing