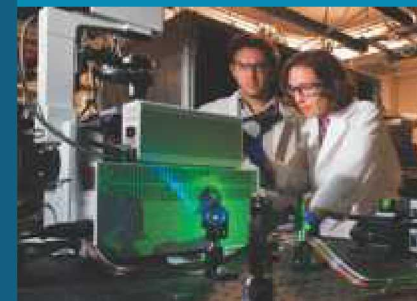
SAND2019-10302PE

Miscellaneous Topics Related to Rock Salt Constitutive Modeling



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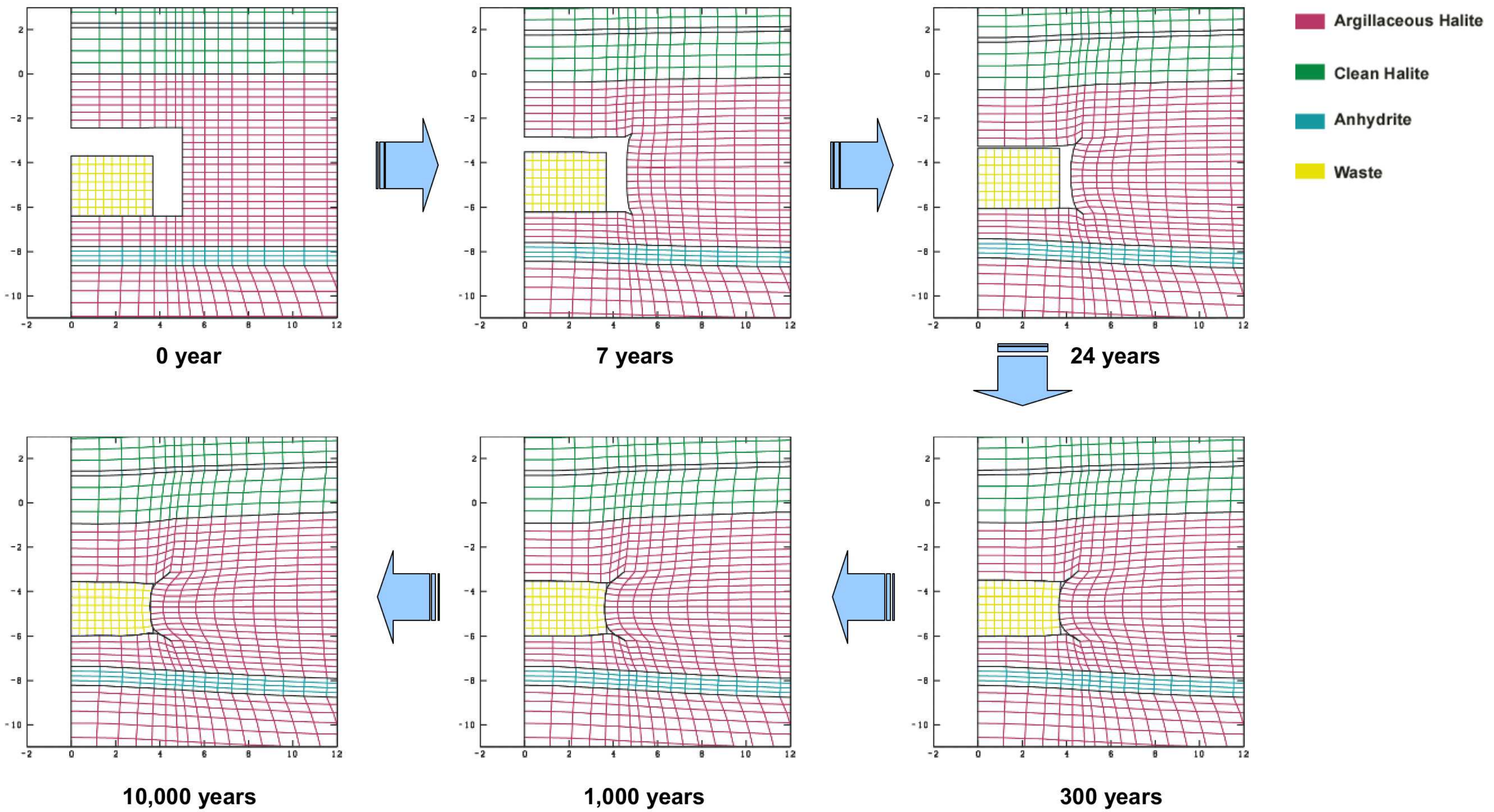
Topics

1. Container Compaction
2. Damage Modeling Questions
3. Meshless Simulation of Empty Room Closure
4. WIPP Core Status

Container Compaction

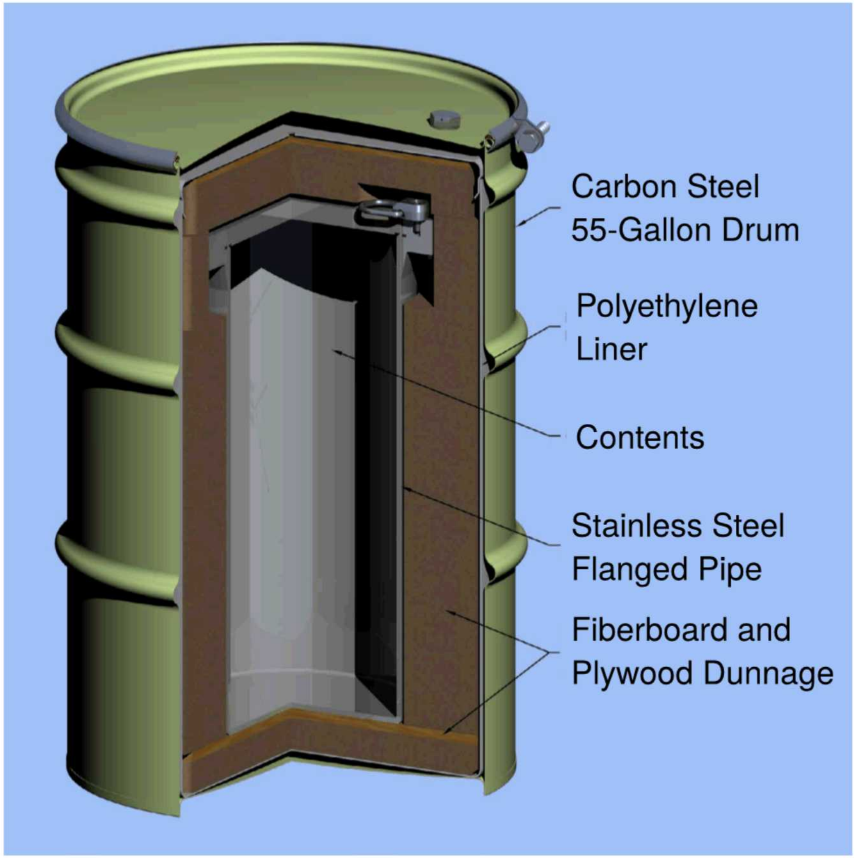
Homogenized Container Compaction Results



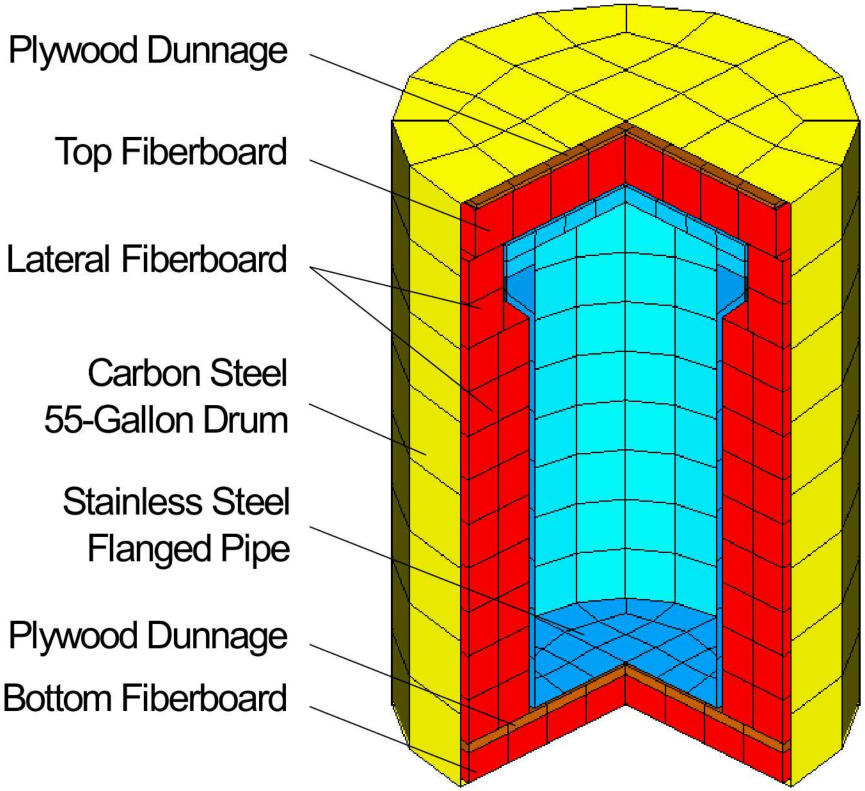
Park, B.Y. and Hansen, F. D., "Determination of the Porosity Surfaces of the Disposal Room Containing Various Waste Inventories for WIPP PA", 2005, SAND2005-4236

Containers

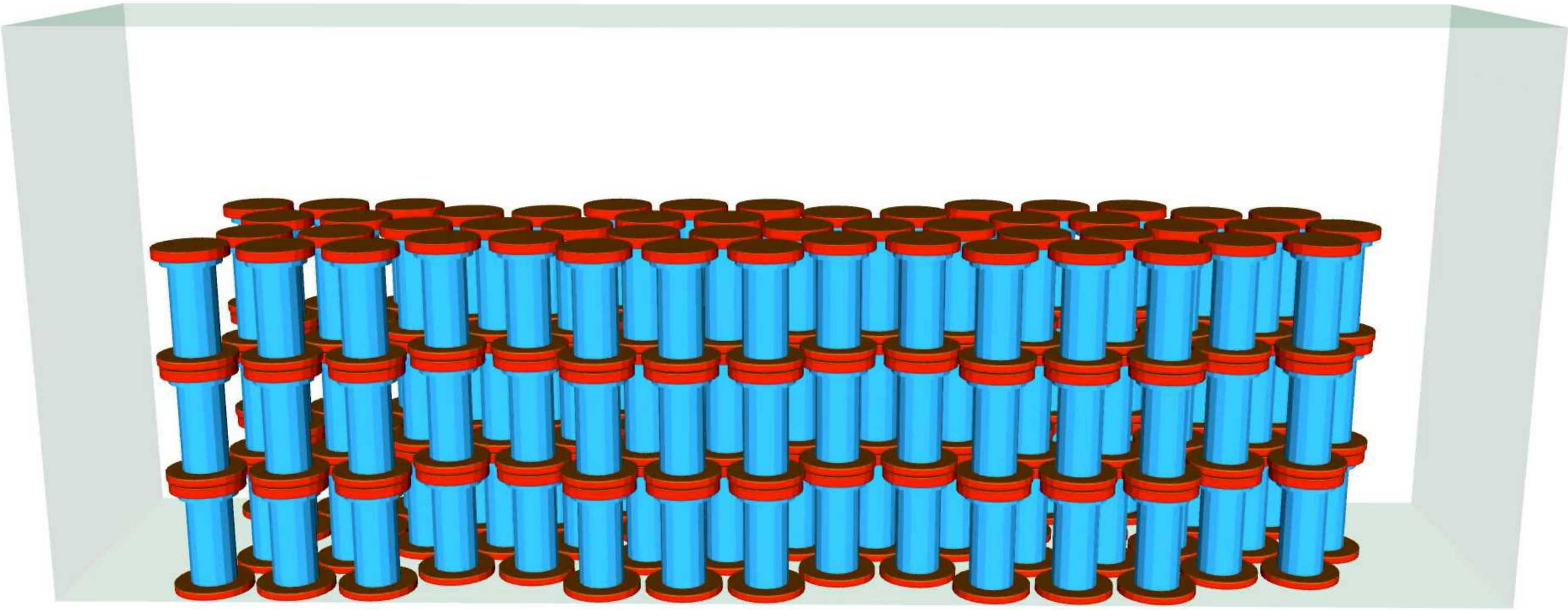
Schematic



Finite Element Mesh



Gradual Compaction Simulation

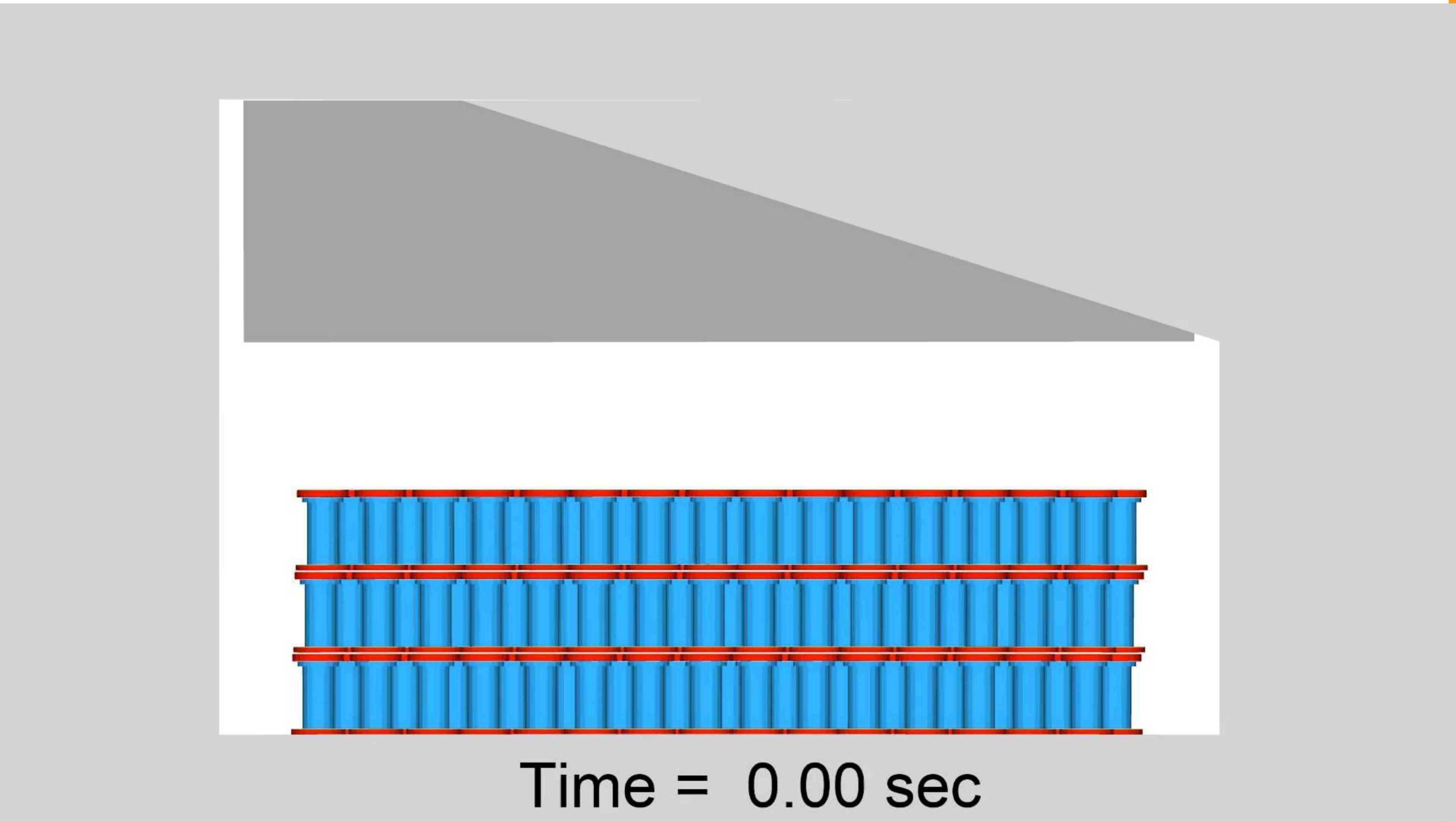


Time = 0 yrs

Severe Rock Fall Rationale

1. Biggest rock fall known to occur at WIPP
   a. Thin on right side, thick on left side
2. Each container stacked 25 mm to the right of the container beneath
3. Block dropped immediately after room excavation
4. MgO sacks ignored
5. Block was not allowed to break into smaller pieces
6. Conservative stainless steel, carbon steel, and plywood behavior
   a. Rate dependence ignored.
   b. Weak yield strengths

Rock Fall Simulation



Damage Modeling

Effective or Macro Stress?

Dilatancy Boundary

$$\bar{\sigma}^{\mathrm{db}} = \bar{\sigma}^{\mathrm{db}}(\sigma_3)$$

or

$$\bar{\sigma}^{\mathrm{db}} = \bar{\sigma}^{\mathrm{db}}\left(\frac{\sigma_3}{1-d}\right)$$

Damage Evolution Equation

$$\dot{d} = D\left\langle \bar{\sigma} - \bar{\sigma}^{\mathrm{db}} \right\rangle \dot{\varepsilon}^{\mathrm{vp}}$$

or

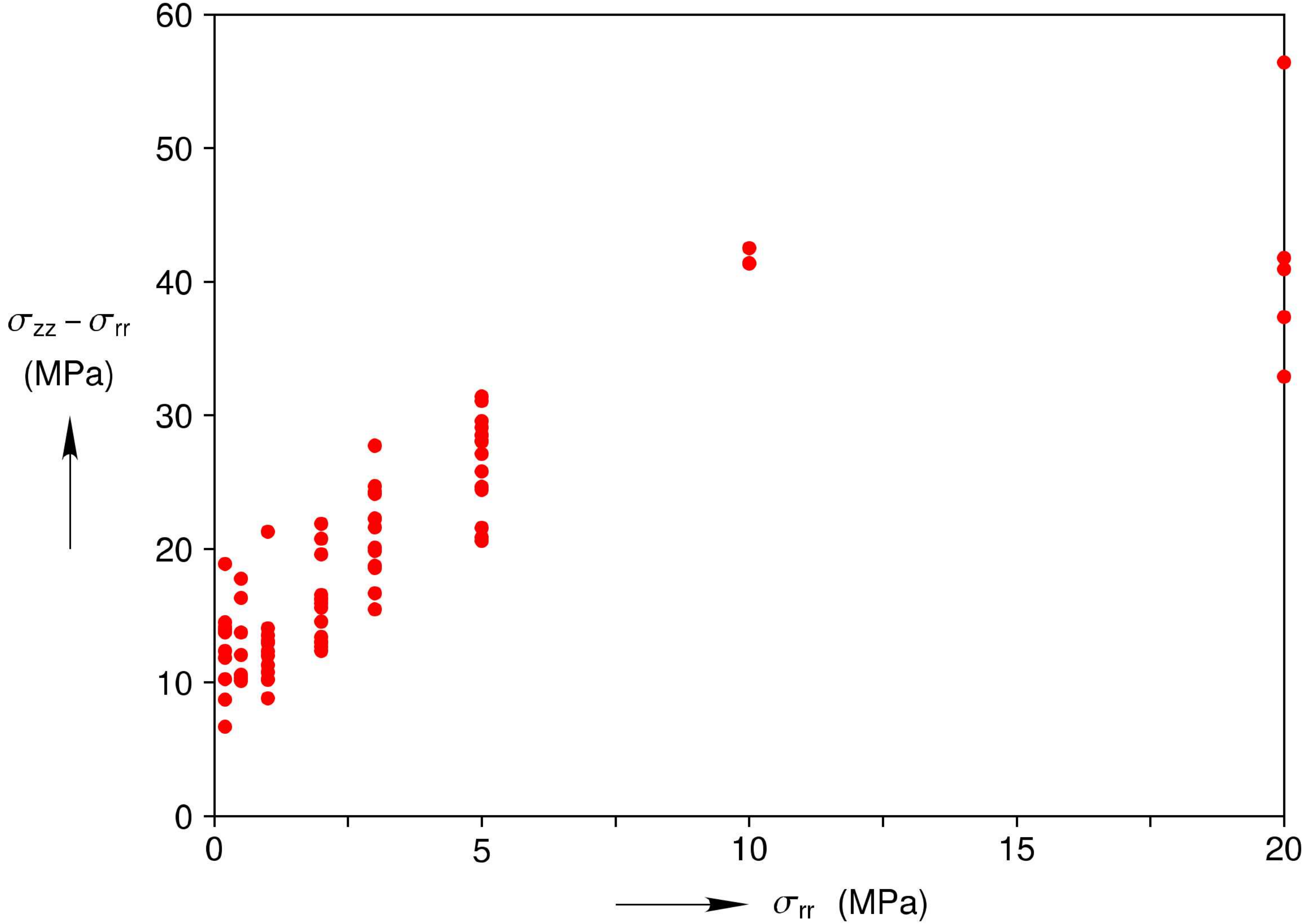
$$\dot{d} = D\left\langle \frac{\bar{\sigma}}{1-d} - \bar{\sigma}^{\mathrm{db}} \right\rangle \dot{\varepsilon}^{\mathrm{vp}}$$

or

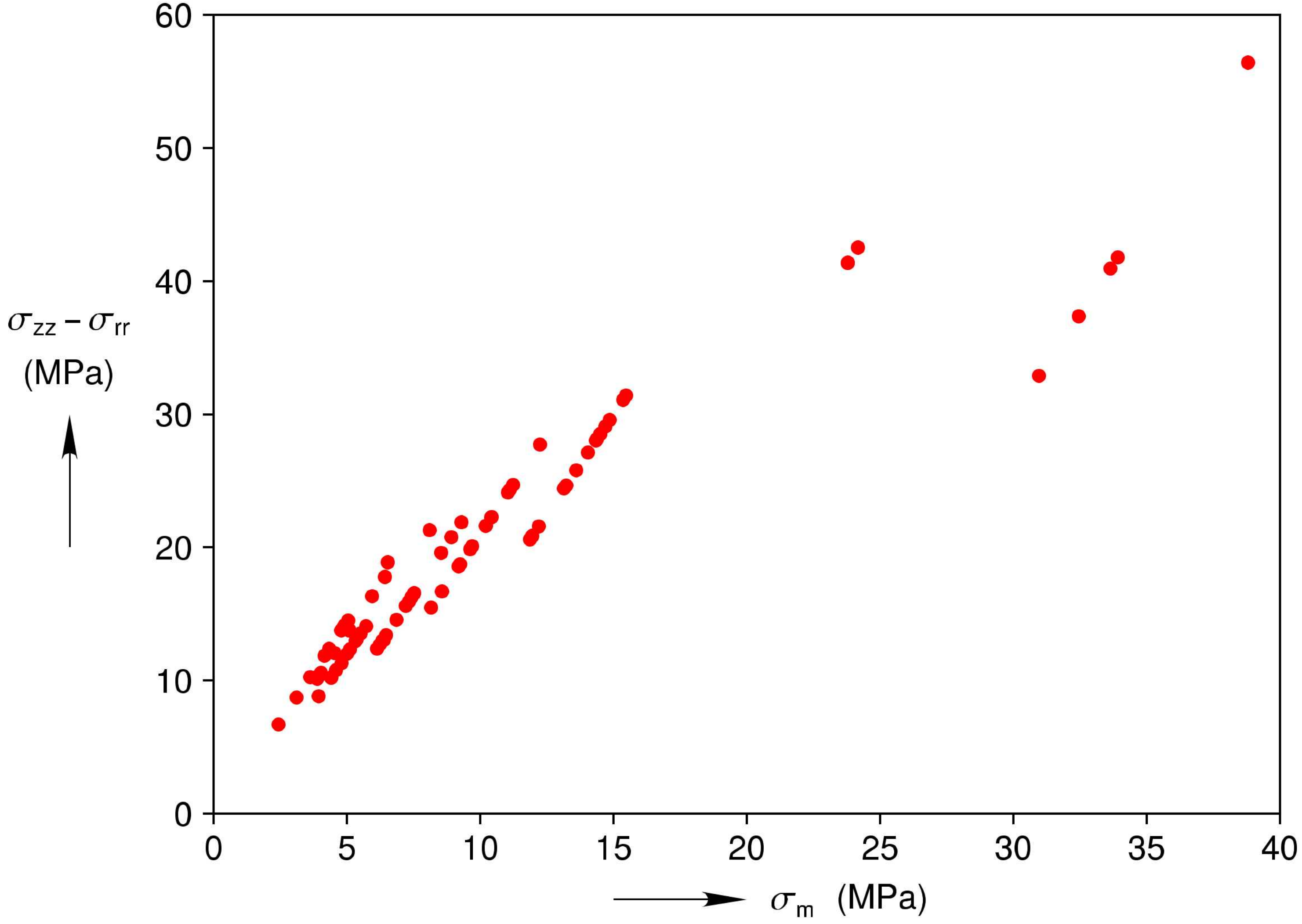
$$\dot{d} = D\,\frac{\left\langle \bar{\sigma} - \bar{\sigma}^{\mathrm{db}} \right\rangle}{1-d}\,\dot{\varepsilon}^{\mathrm{vp}}$$

Does the dilatancy boundary move as damage evolves?
Does the dilatancy boundary move differently if the stress is tensile or compressive?

Dilatancy Boundary: Confining vs. Mean Pressure



Dilatancy Boundary: Confining vs. Mean Pressure



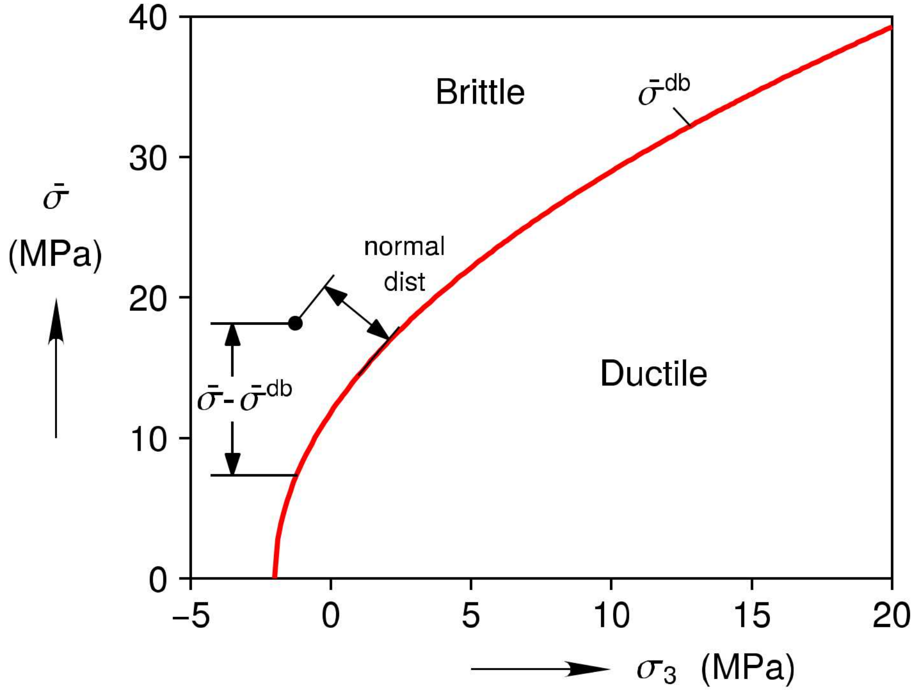
Miscellaneous Questions

1. Is it worth decreasing the elastic moduli?

$$\boldsymbol{\sigma} = (1 - d)\,\boldsymbol{C} : \boldsymbol{\varepsilon}$$

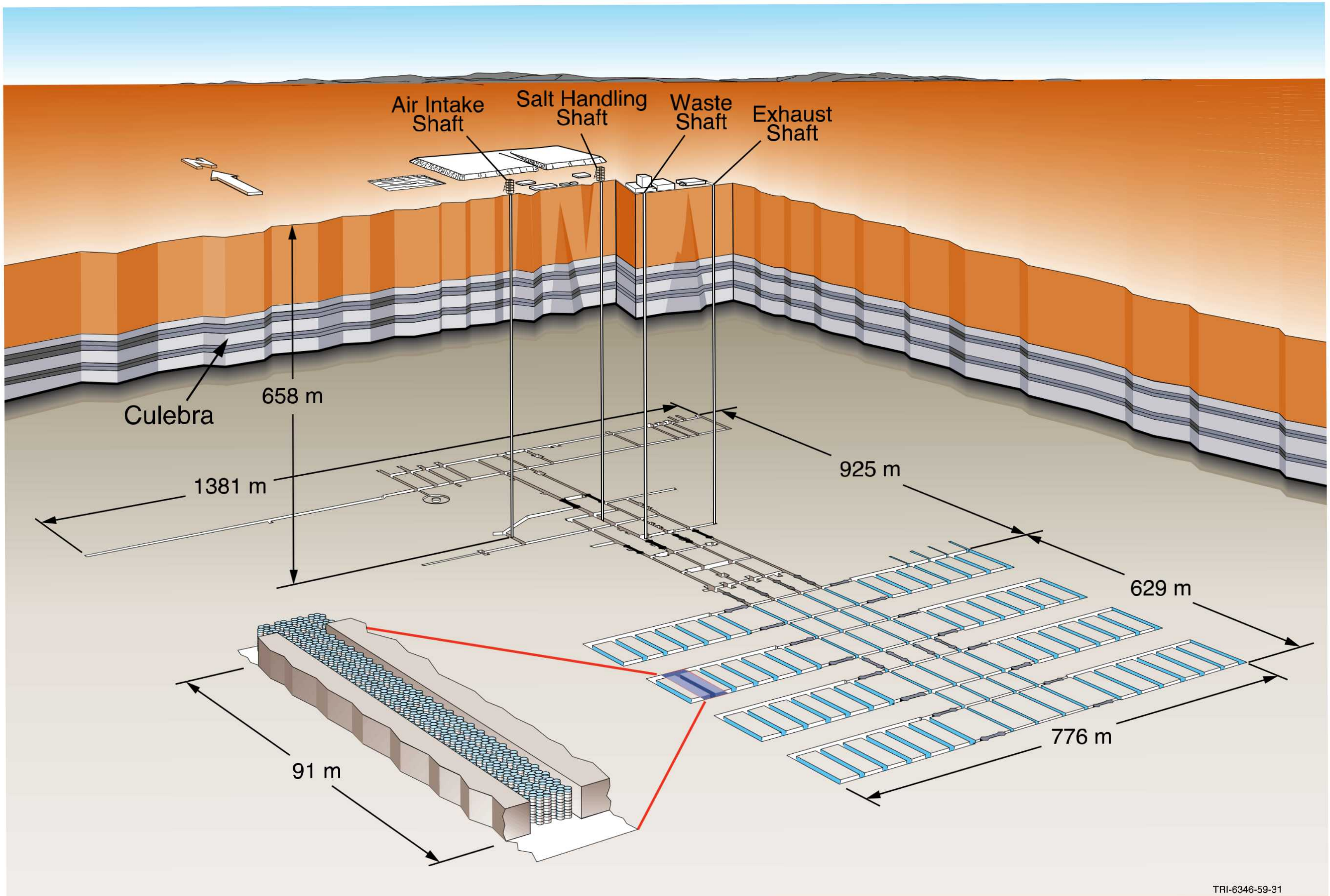
$$\dot{\boldsymbol{\sigma}} = (1 - d)\,\boldsymbol{C} : \dot{\boldsymbol{\varepsilon}} - \dot{d}\,\boldsymbol{C} : \boldsymbol{\varepsilon}$$

2. Constant strain rate tests with 30 or 40 MPa radial pressure?
3. Distance Metric?



Meshless Simulation of Empty Room Closure

WIPP Layout


Air Intake
Shaft
Salt Handling
Shaft
Waste
Shaft
Exhaust
Shaft
Culebra
658 m
1381 m
925 m
629 m
776 m
91 m
TRI-6346-59-31

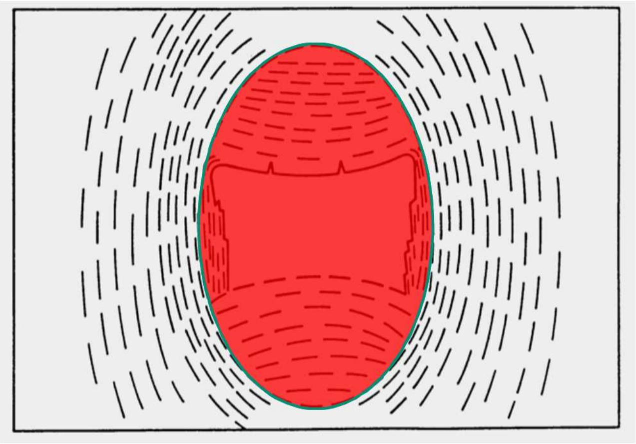
Fracturing Around Empty Rooms

1. Controls the size and character of the rubble pile.

Lower Horizon

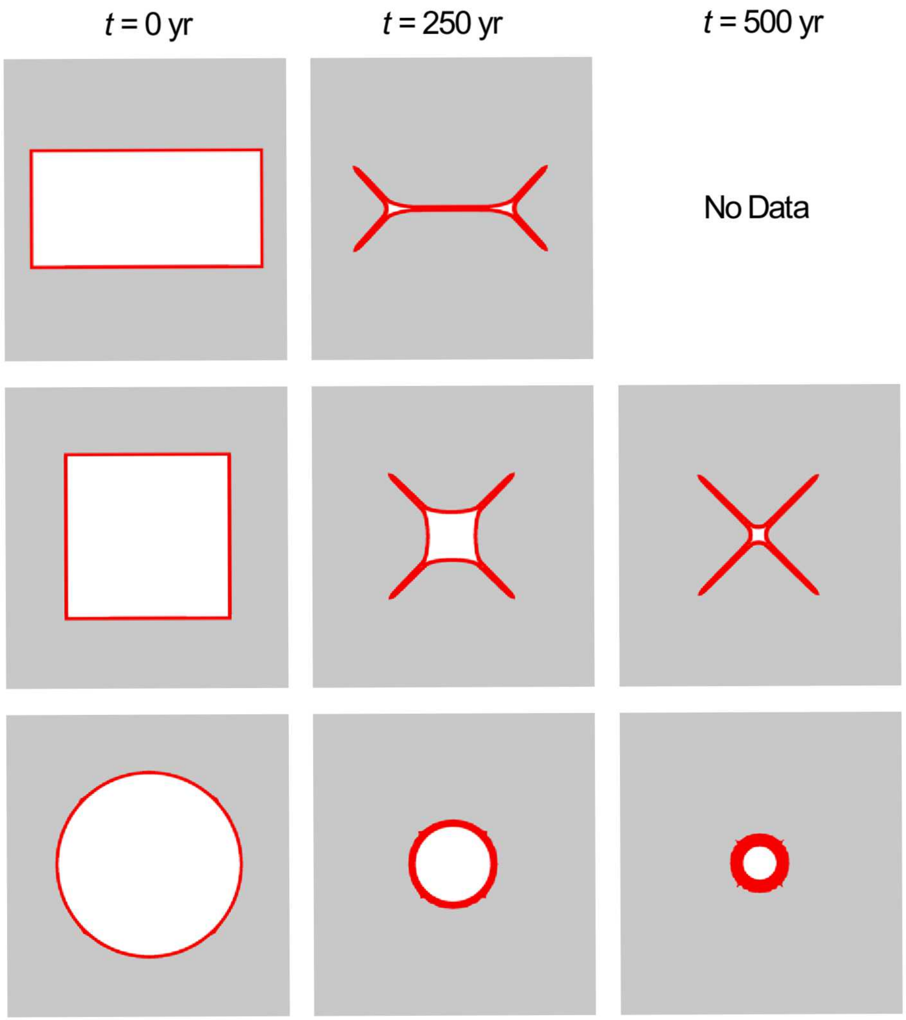
Upper Horizon

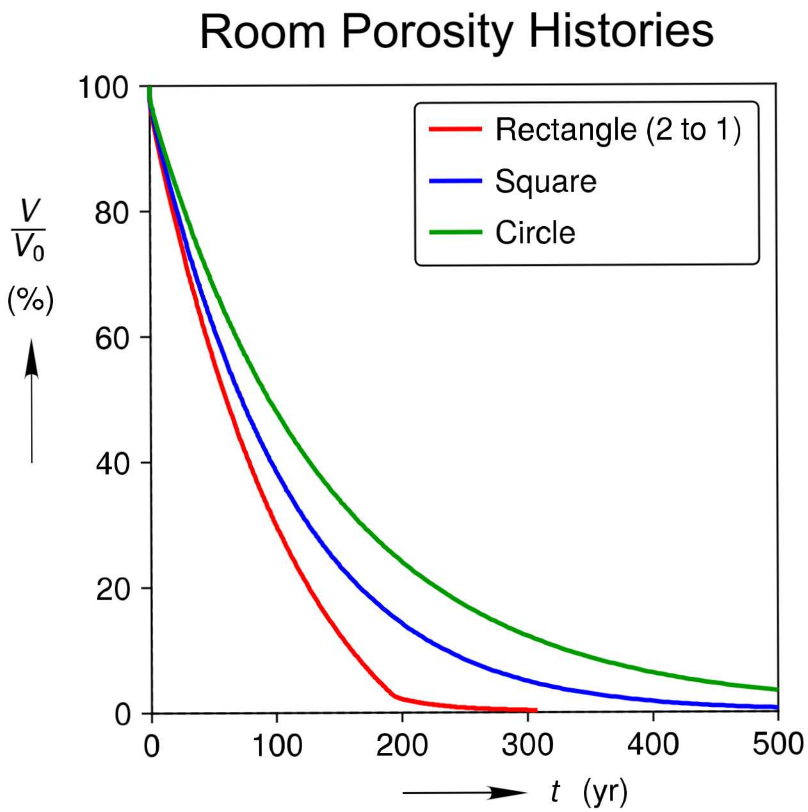
2. Changes room cross-section to a more stable, enduring, shape.



Borns, D.J. and J.C. Stormont. (1989) (Modified)

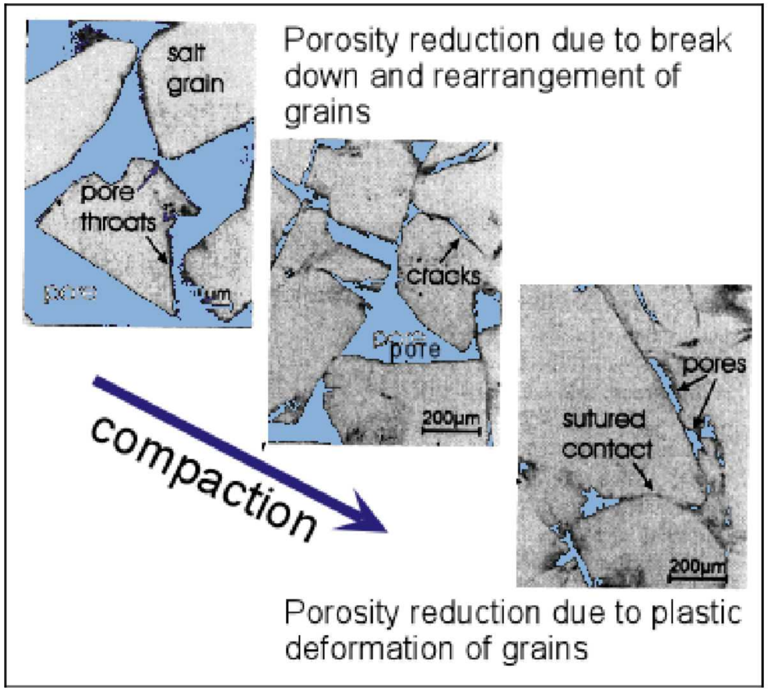
Room Shape affects Creep Closure





Rubble Pile Compaction

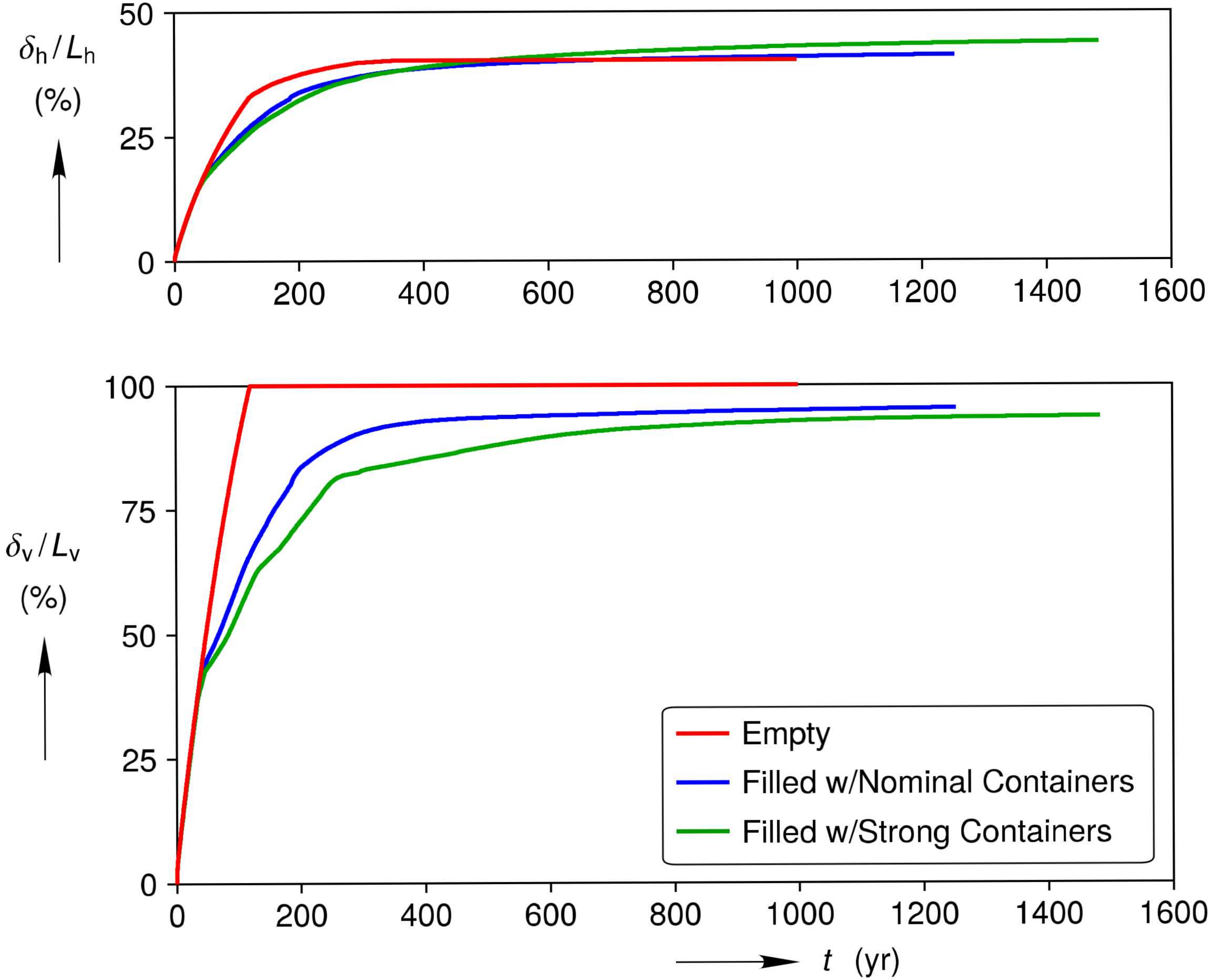
1. Important Processes
   a. Rubble reorganization
   b. Rubble fracture
   c. Creep
      i. Dislocation
      ii. Pressure solution



Spangenberg (1998) (Modified)

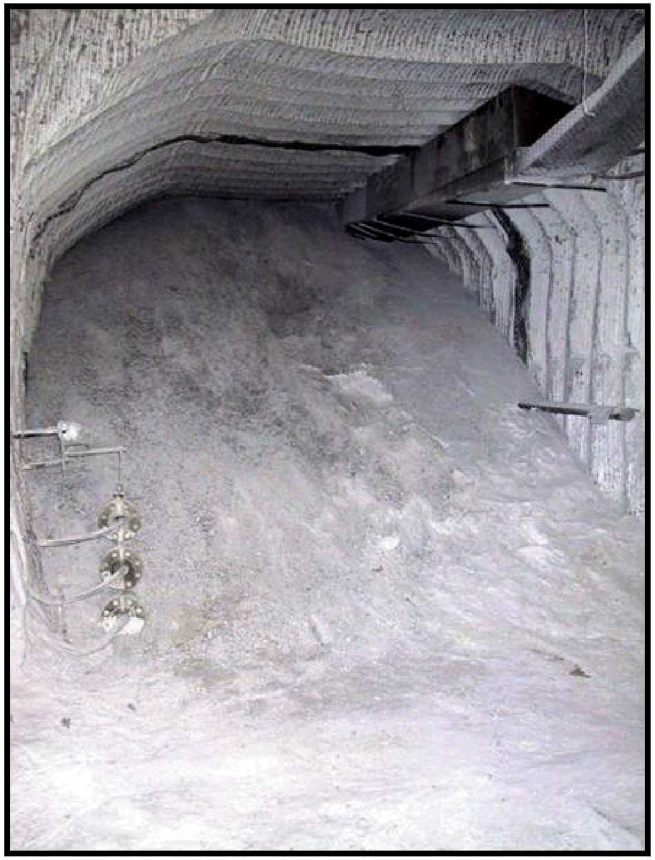
2. Impact
   a. Compaction processes control flow pathways
      i. Two samples with same porosity can have different permeability
   b. Rubble pile supplies back pressure to surrounding rock formation
      i. Larger rubble likely compacts slower than smaller rubble

Filled Rooms Creep Closed More Slowly



Crushed Salt vs. Rubble Pile

Crushed Salt



Bechthold, W., et. al. (2004). Backfilling and Sealing of Underground Repositories for Radioactive Waste in Salt (BAMBUS II Project), Final Report. European Commission, EUR 20621 EN

Rubble Piles

Plan

1. Creep closure
   a. Already partially validated by room D, G, and Q data

2. Roof falls
   a. Attempt to simulate size and shape of roof falls
      i. Stochastic distribution of defect sites?
   b. Calibrate/validate against lab-scale room collapse experiments and observations at WIPP

3. Rubble pile compaction
   a. Flow channels
      i. Explicitly represent macroflow channels
      ii. Implicitly represent microflow channels
   b. Ignore healing for now
   c. Validate against crushed salt experiments
      i. Vary grain size distribution
      ii. Vary temperature and compaction pressure

Potential Numerical Methods

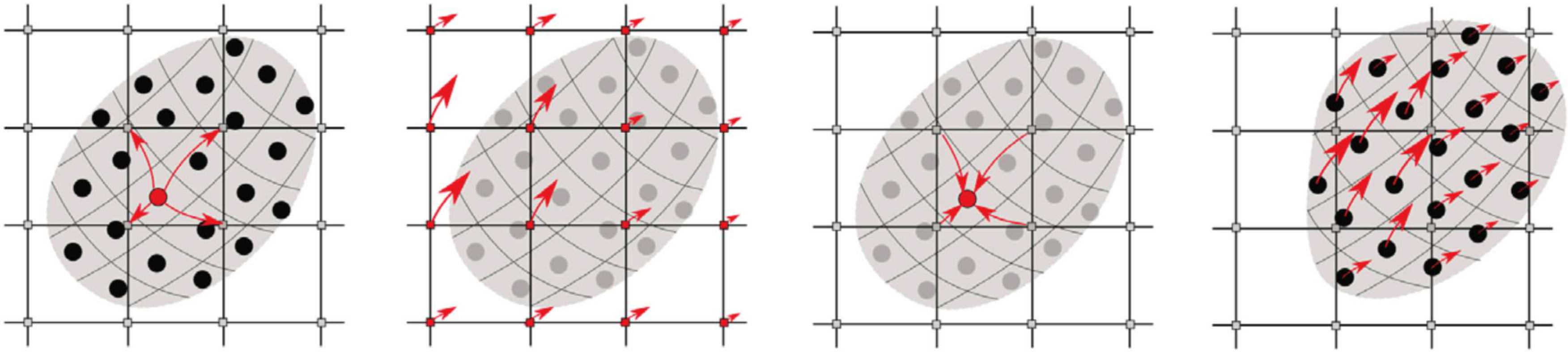
1. Fundamental issue: we are trying to capture a discrete crack with a continuum level model
2. Potential numerical issues
   a. Mass loss
   b. Mesh structure dependence
   c. Mesh size dependence
3. Candidate numerical methods
   a. Finite elements with element death
   b. Finite elements with interelement cracks
   c. Particle methods
   d. Meshless methods

Meshless Methods

1. Primary advantages
   a. Designed to handle severe deformation (>100 % strain)
   b. Inherently captures normal contact without expensive interface tracking
   c. Regularization techniques are relatively easy to implement
   d. Adaptive particle insertion and deletion is relatively easy
   e. Can utilize classical continuum material models
   f. Healing just needs to be added to the material model
2. Primary drawbacks
   a. Potential longer run times
   b. Sliding contact is challenging
   c. Surfaces must sufficiently separate to stop interacting
3. Sandia's nuclear weapon program will likely continue to invest in meshless methods

Material Point Method (MPM)

Evaluate material model and map info to nodes | Solve equations of motion | Map accelerations to material points | Update positions of material points

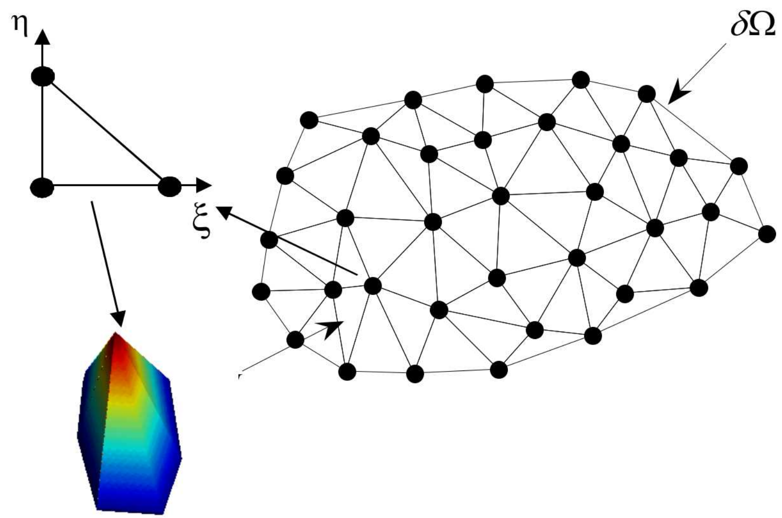


Rohe, A., Pinyol, N., Ceccato, F., Yerro, A., Fern, J., and Chmelnizkij, A., Modelling large deformation and soil–water–structure interaction with Anura3D, GiD Convention Workshop, UPC Barcelona, 2018 (Modified)

Reproducing Kernel Particle Method (RKPM)

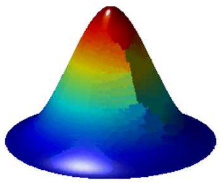
Finite Element Method

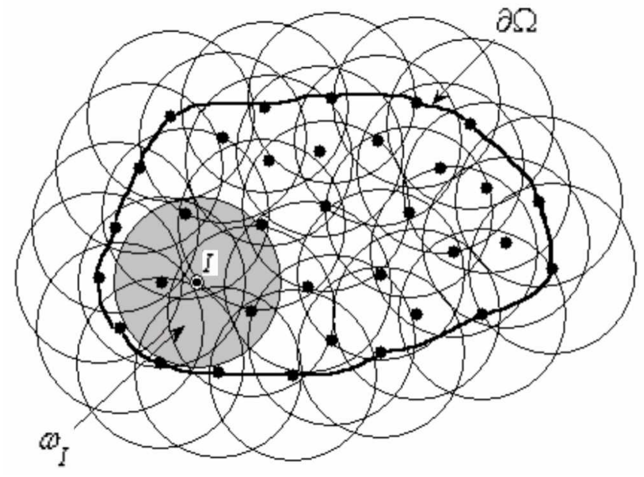
Shape functions and integration are both defined on the element domain.



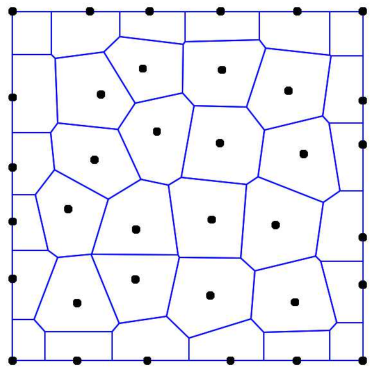
RKPM

Shape Functions





Domain Integration



Littlewood, D., Hillman, M., Yruex, E., Bishop, J., Beckwidth, F., Chen, J.S., Implementation and Verification of RKPM in the Sierra/Solid Mechanics Code. ASME IMECE Conference. 2015. (Modified)

Material Model

Strain Decomposition

$$\dot{\boldsymbol{\varepsilon}} = \dot{\boldsymbol{\varepsilon}}^{\mathrm{el}} + \dot{\boldsymbol{\varepsilon}}^{\mathrm{vp}}$$

Isotropic, Linear, Hypoelasticity

$$\dot{\boldsymbol{\sigma}} = \boldsymbol{\mathcal{C}} : \dot{\boldsymbol{\varepsilon}}^{\mathrm{el}}$$

$$\boldsymbol{\mathcal{C}} = (K - 2\,G/3)\,\boldsymbol{I} \otimes \boldsymbol{I} + 2\,G\,\boldsymbol{\mathcal{I}}$$

Associated Flow Rule

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

von Mises Equivalent Stress

$$\bar{\sigma} = \sqrt{3\,J_2}$$

Equivalent Viscoplastic Strain Rate

$$\dot{\bar{\varepsilon}}^{\mathrm{vp}} = \sum_{i=1}^{2} A_i \left[\frac{\bar{\sigma}}{G\,(1-d)} \right]^{n_i}$$

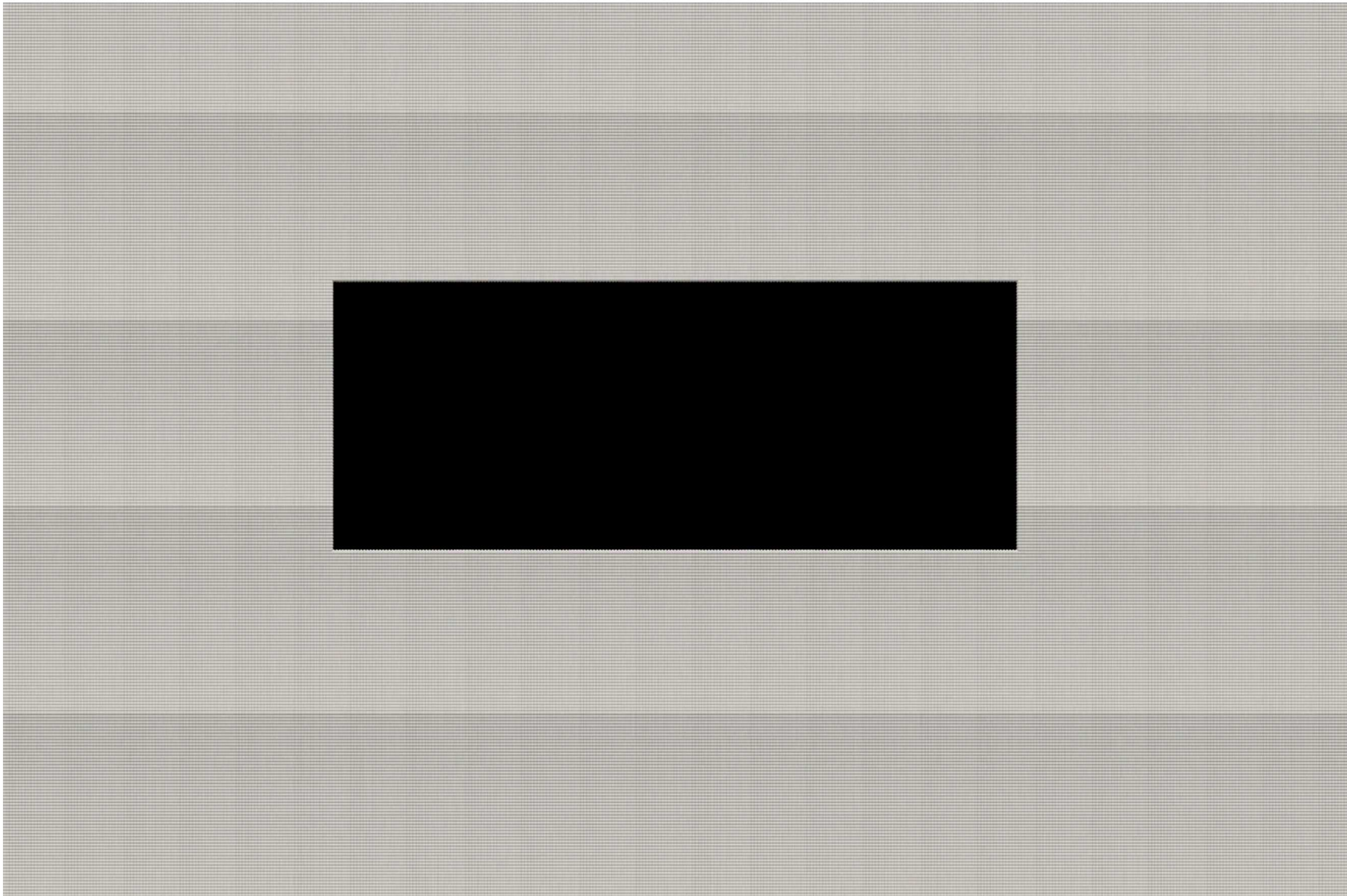
Damage Evolution

$$\dot{d} = D \frac{\left\langle \bar{\sigma} - \bar{\sigma}^{\mathrm{db}} \right\rangle}{1-d} \dot{\bar{\varepsilon}}^{\mathrm{vp}}$$

Damage Boundary

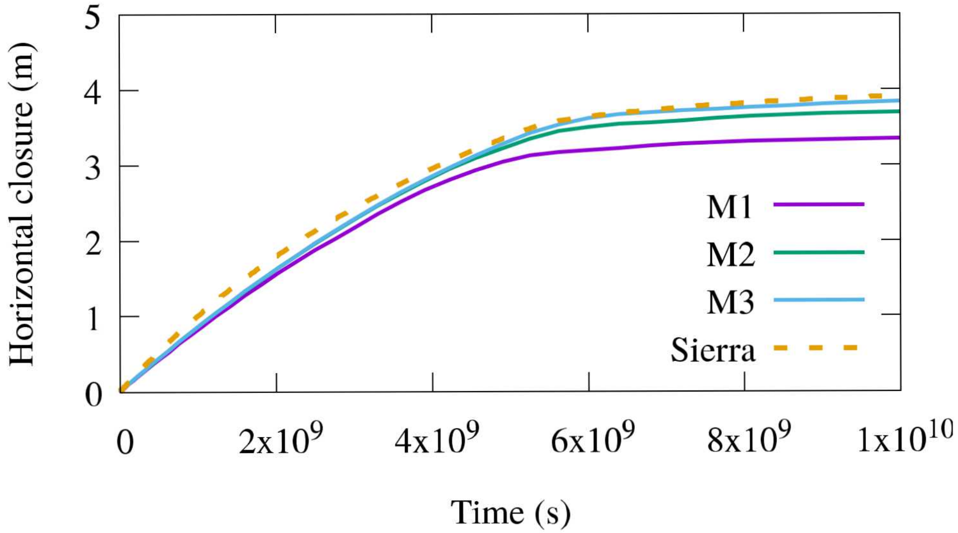
$$\bar{\sigma}^{\mathrm{db}} = B_2\,(p - B_1)$$

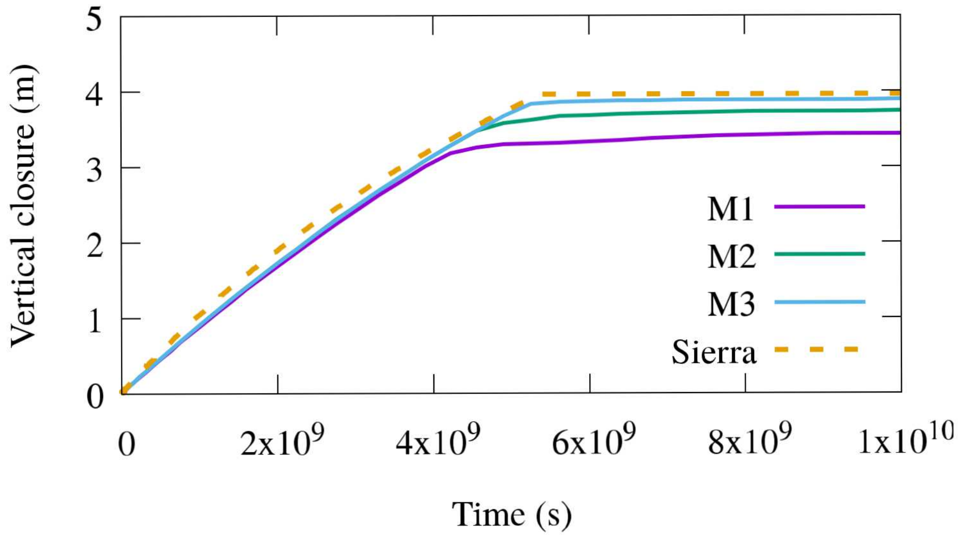
Closure Without Damage



Data courtesy of Prof. Yuri Bazilevs

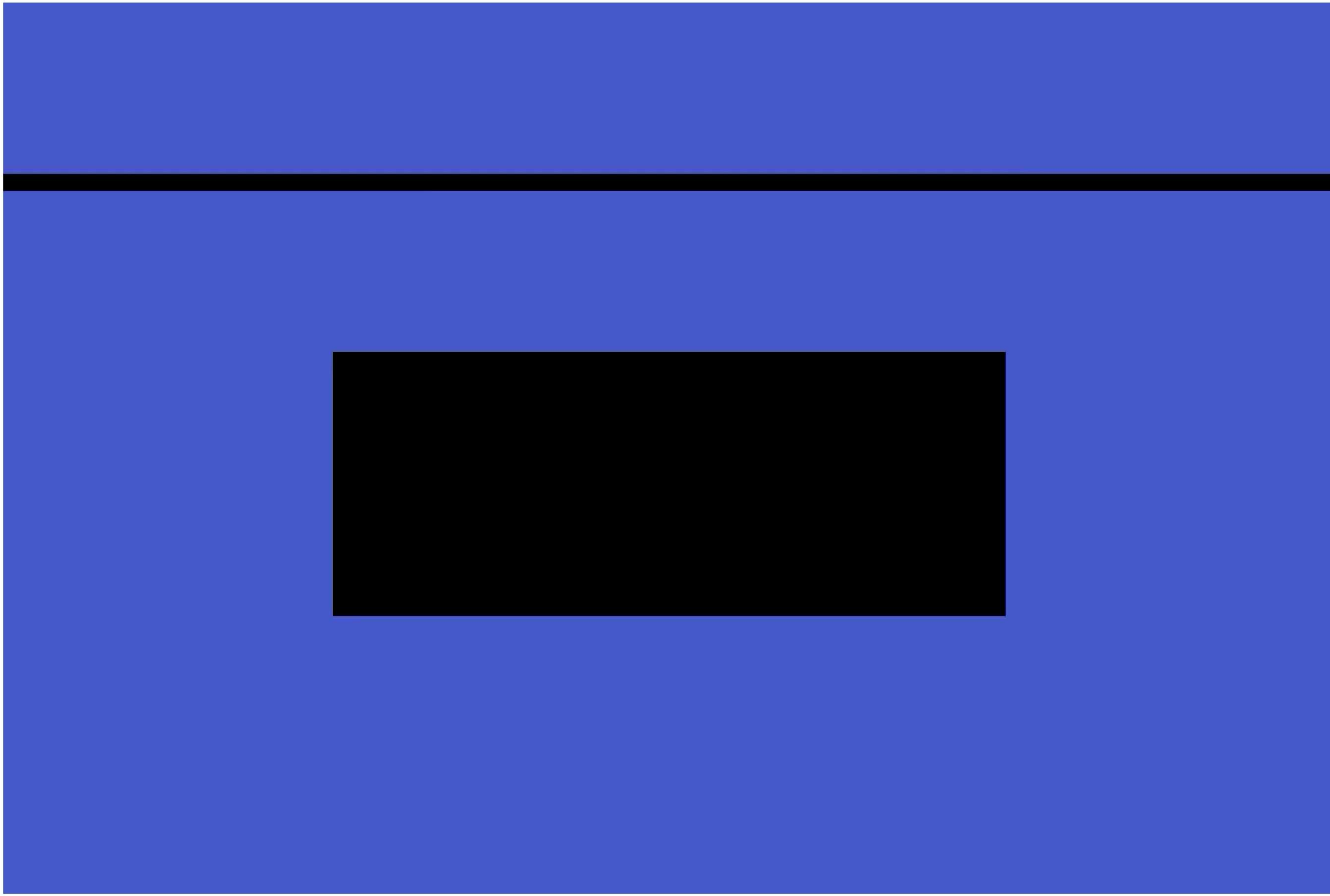
Closure Without Damage: Quantitative Comparisons





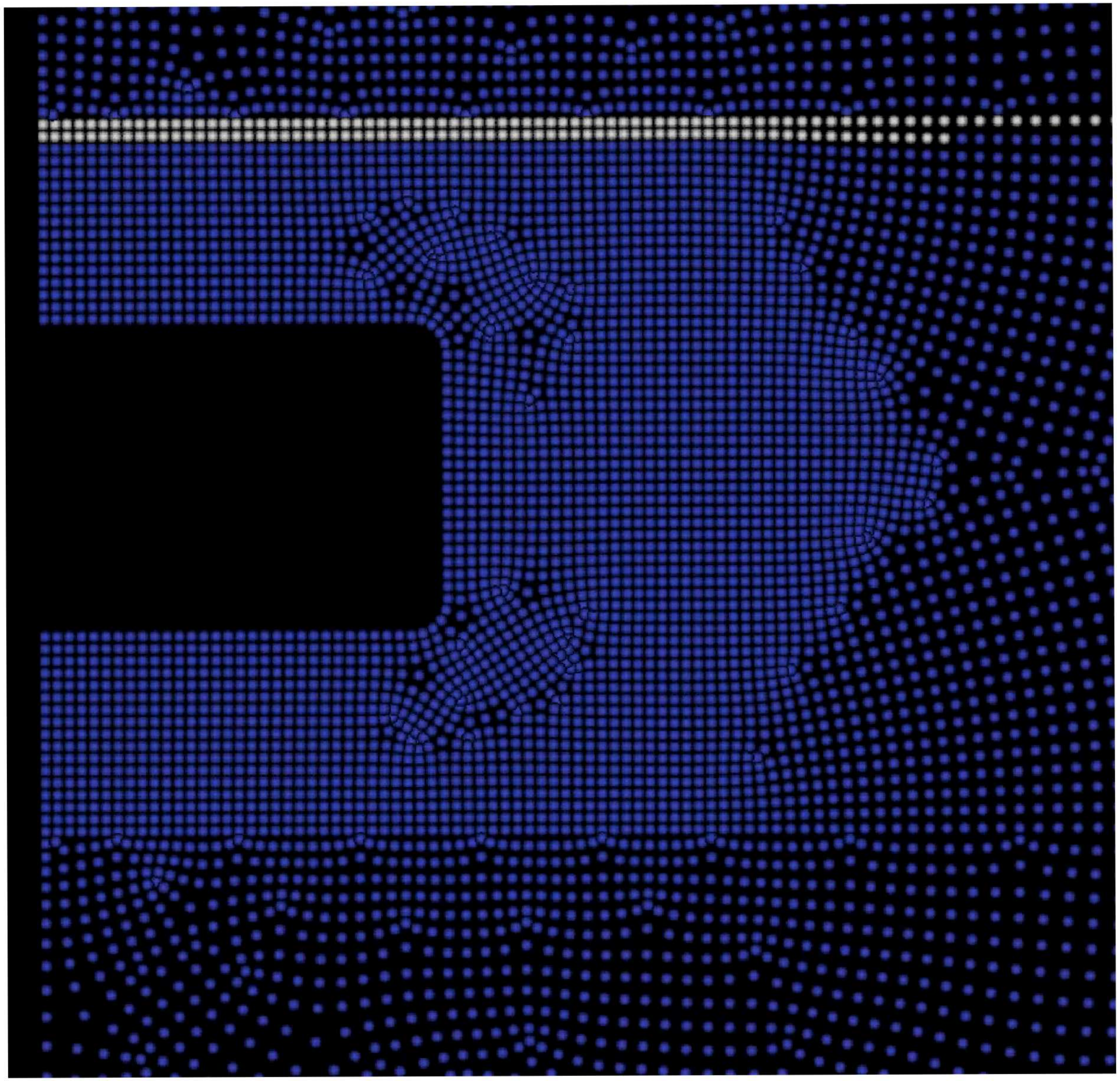
Data courtesy of Prof. Yuri Bazilevs

Closure with Damage: MPM Simulation



Data courtesy of Prof. Yuri Bazilevs

Closure with Damage: RKPM Simulation



Data courtesy of Prof. JS Chen

WIPP Core Status

WIPP Core Request Status

1. We've been pushing hard since Spring.
   a. Sandia Carlsbad is on its fifth WIPP rock mechanics manager.
   b. Sean Dunagan was on board, but he is going to become the president of Nuclear Waste Partnership (Operator of WIPP).
   c. Carlsbad Field Office wanted to know why this core was so important. How does it affect the WIPP performance assessment?

2. Latest update from Doug Weaver (Los Alamos National Labs)
   a. "The request for new core/samples has the support of Carlsbad Field Office senior management if it can be accomplished without impact to WIPP waste operations and adequate funding can be provided to the contractor. A resource loaded schedule will be developed by Nuclear Waste Partnership (Operator of WIPP) to determine the best timeframe for this work in addition to the resources required. This schedule is expected in the next couple weeks." --
   b. Once coring begins, it is expected to take 10 weeks.

WIPP Core Request Details

1. Core for Tensile Strength, Healing, and Low Stress Creep
   a. Drill into the walls of relatively new drifts. (Salt Disposal Investigations (SDI) Area, N-940 Drift.)
      i. "Clean Salt" (Mapping Unit 3)
   b. Six holes.
      i. Each hole will be 6.1 m deep and 300 mm in diameter.
      ii. The first 3.05 m will be discarded as damaged rock.
      iii. The retained 3.05 m will be protected from dry out.

2. Clay Seam Core
   a. Targeting specific clay seams
      i. Clay F (E-140 / N-1000)
      ii. Glay G (E-140 / N-1300)
      iii. Clay H (E-140 / N-1400)
   b. Drill into the walls of drifts
      i. Will attempt to make holes 6.1 m deep, but seam may wander.
      ii. 300 mm diameter
      iii. Any reasonably intact seam will be retained.
      iv. All retained core will be protected from dry out.