SAND2020-5949PE

Status of the Sierra CRK Implementation

(CRK: Conforming Reproducing Kernel)

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Thanks to: Sierra Solid Mechanics Team

June 11, 2020

SAND20XX-XXXX PE

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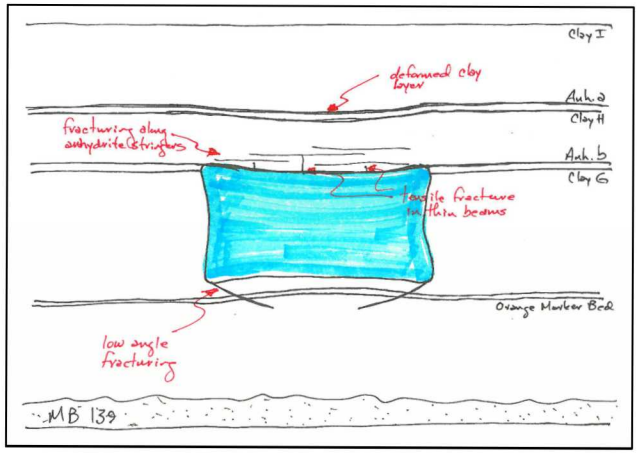
Outline

- Why use meshfree methods for WIPP analyses?
  - Empty room collapse
  - Review of related FY19 meshfree studies
- CRK overview
  - Motivation for CRK
  - Direction of meshfree / CRK research and development
- CRK implementation into Sierra
  - Development highlights
  - Room closure analyses

Why use meshfree methods for WIPP analyses?

Open room closure

1



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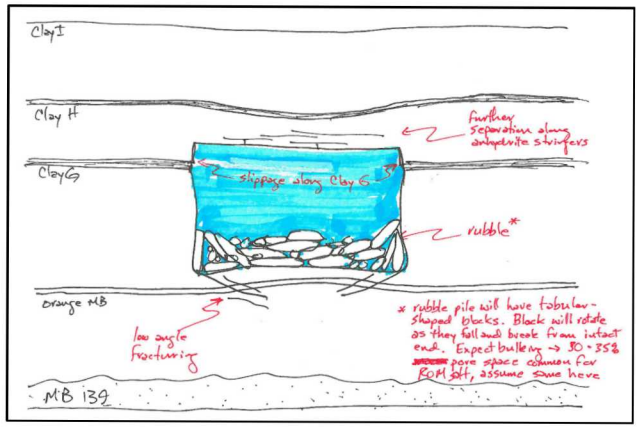

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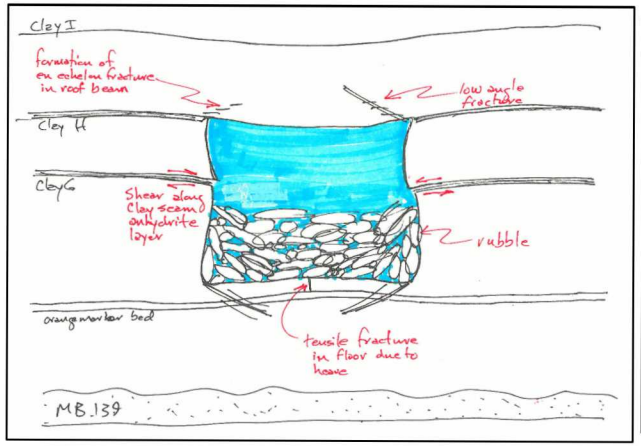

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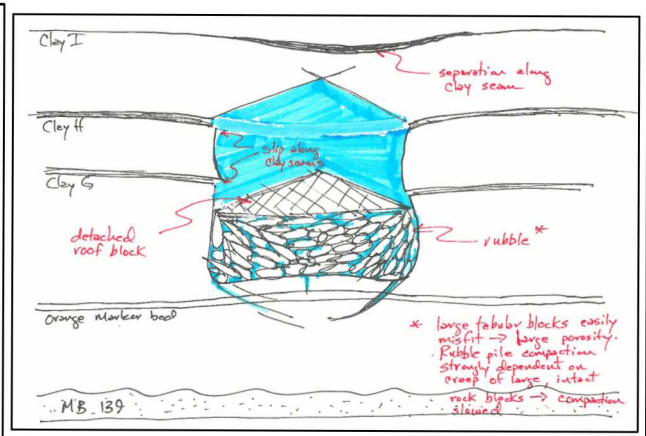

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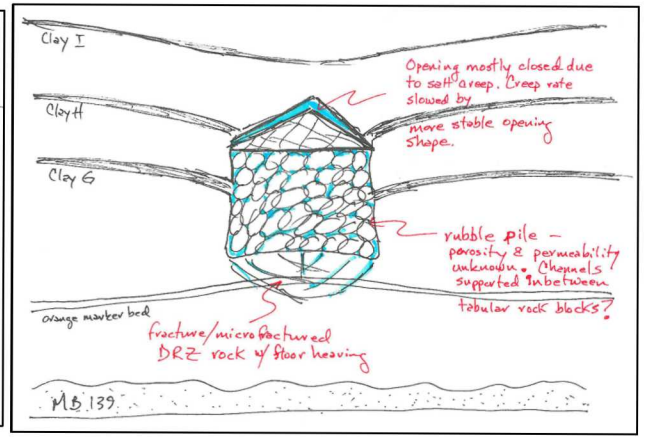

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Why use meshfree methods for WIPP analyses?

Upper Horizon Roof Fall at WIPP

Why use meshfree methods for WIPP analyses?

Simulating open room closure involves

- Pervasive fracture
- Impact / rubbilization
- Compaction of rubble piles

Extremely challenging for mesh-based methods like finite element analysis!

Meshfree methods provide a robust means of simulating roof collapse.

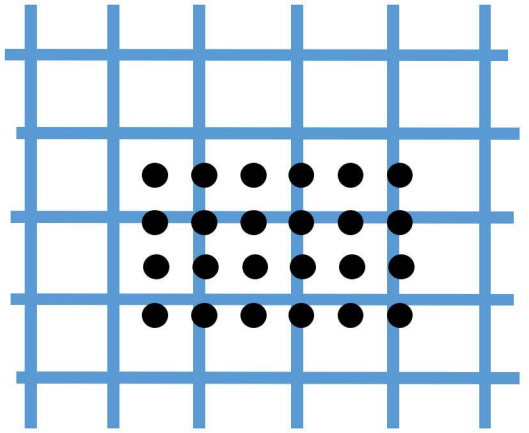
Options were explored in FY19:

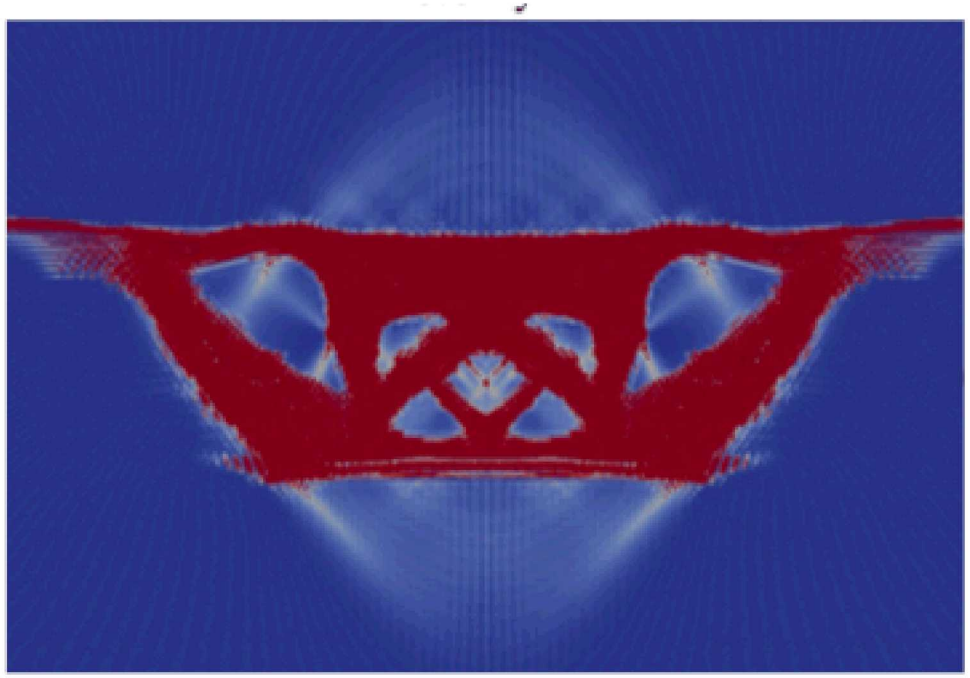
- A Material Point Method (MPM)-like approach.
  - Prof. Yuri Bazilevs, Brown University
- The Reproducing Kernel Particle Method (RKPM).
  - Prof. J.S. Chen, University of California, San Diego
- The Conforming Reproducing Kernel (CRK) method.
  - Jake Koester, Mike Tupek at SNL

FY19 study: MPM-like approach

Numerical Approach

- Approximation space comes from a background grid.
- "Material point" moves through the grid and carries state information



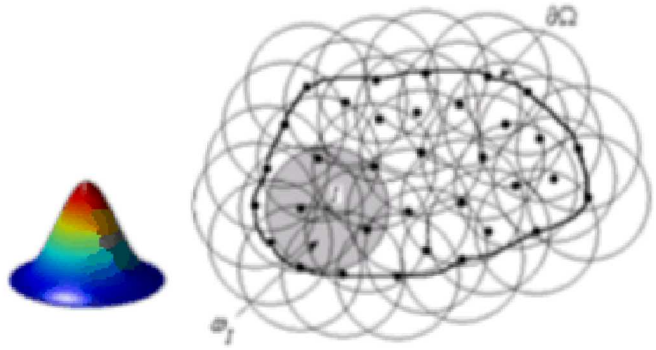


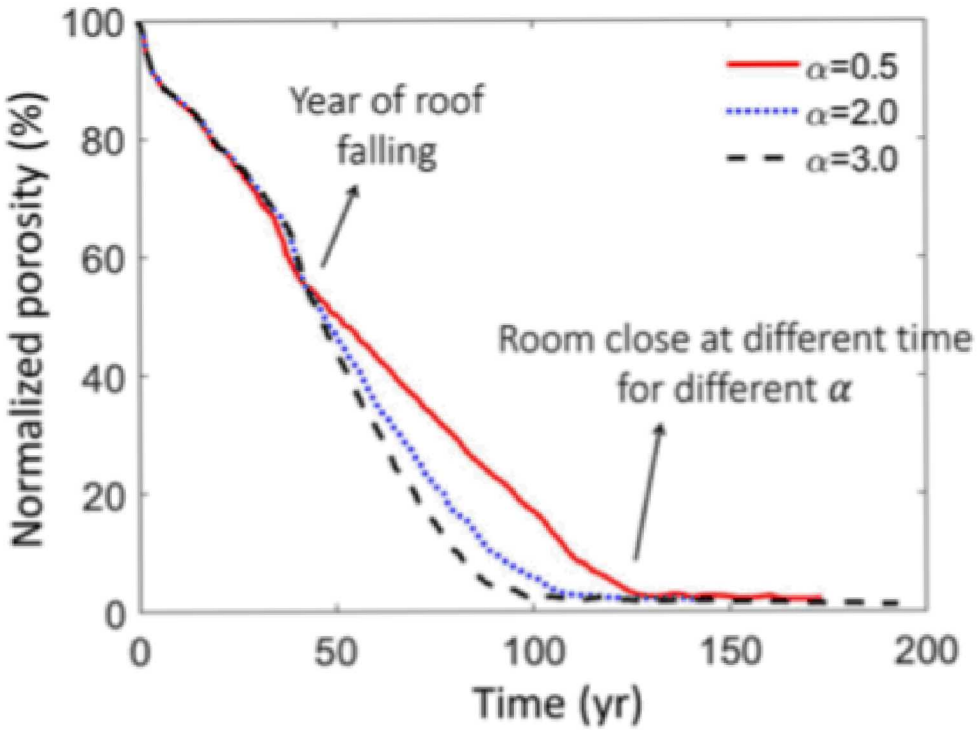
50 yr

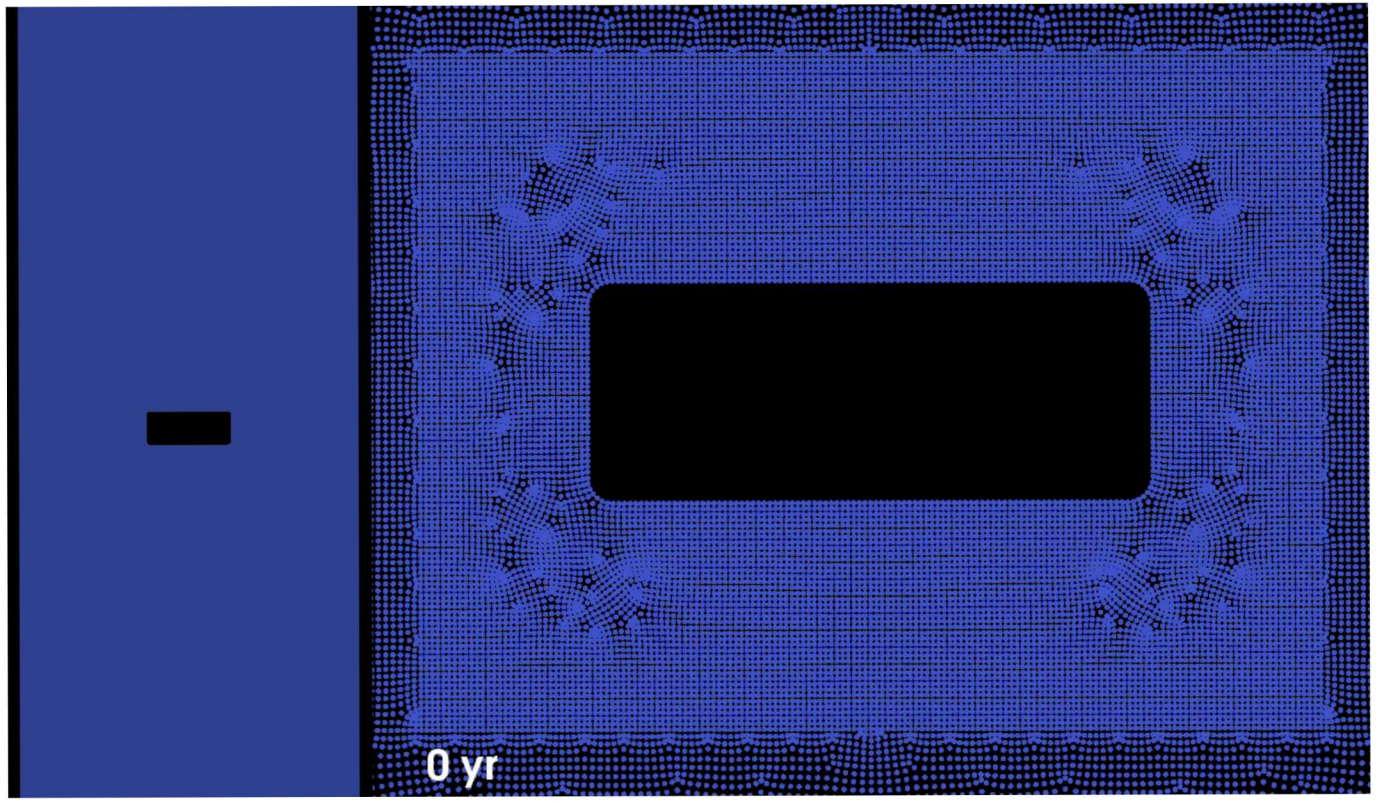
FY19 study: RKPM approach

Numerical Approach

- Approximation space associated with the particles
- Particles also carry state information







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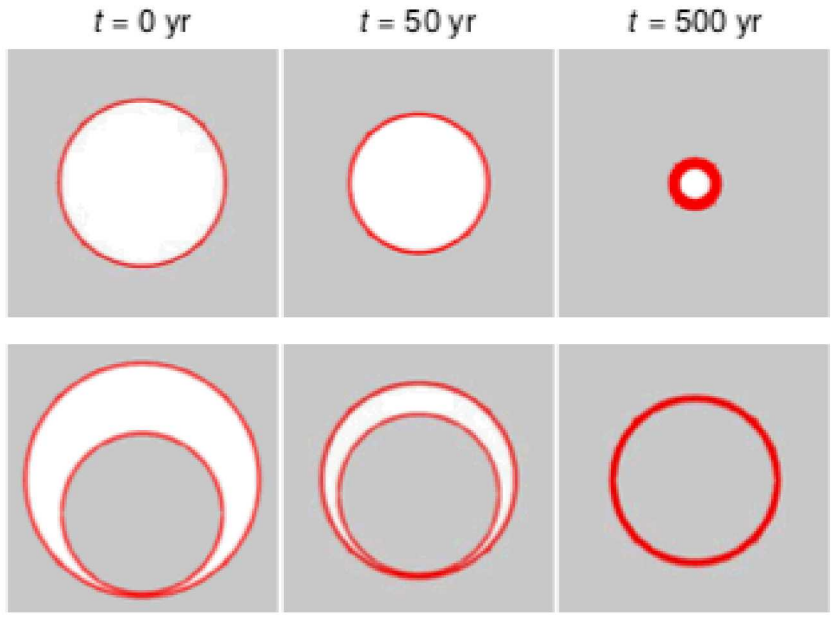
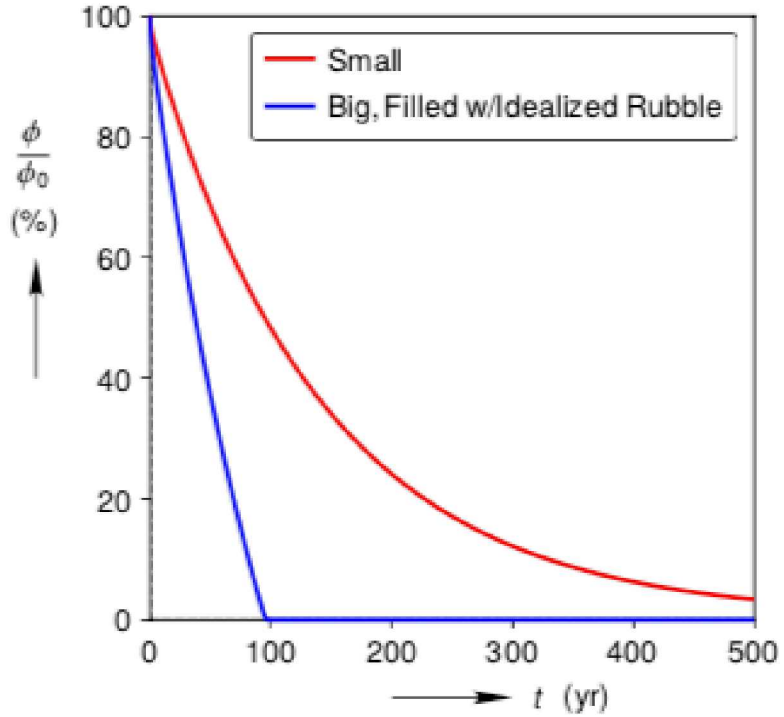
FY19 studies summary

- Many configurations, numerical method variations, material property sets explored
- Methods provided insight into the roof collapse process
- Helped guide understanding, make adjustments to simplified analyses



Deformed room shapes at selected times



Relative porosity histories

Outline

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  - Review of related FY19 meshfree studies

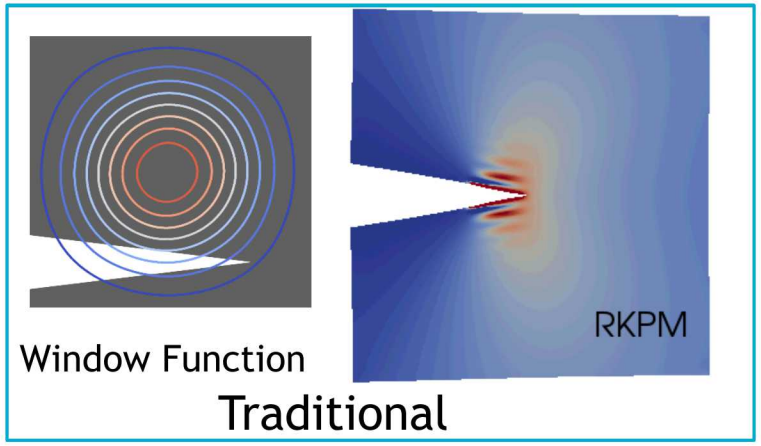
- **CRK overview**
  - **Motivation for CRK**
  - **Direction of meshfree / CRK research and development**

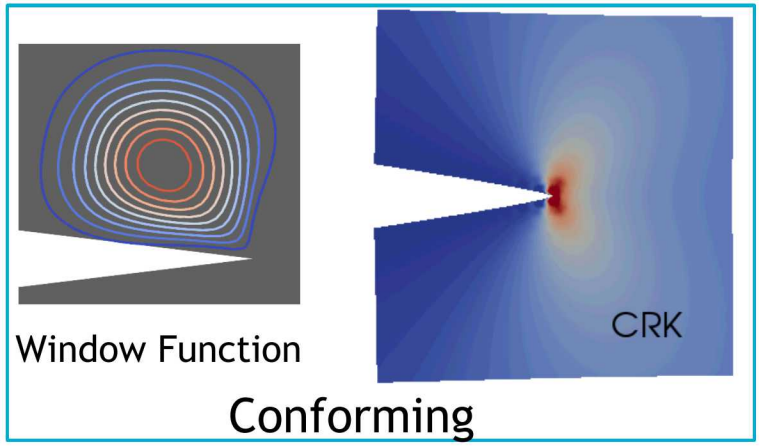
- CRK implementation into Sierra
  - Development highlights
  - Room closure analyses

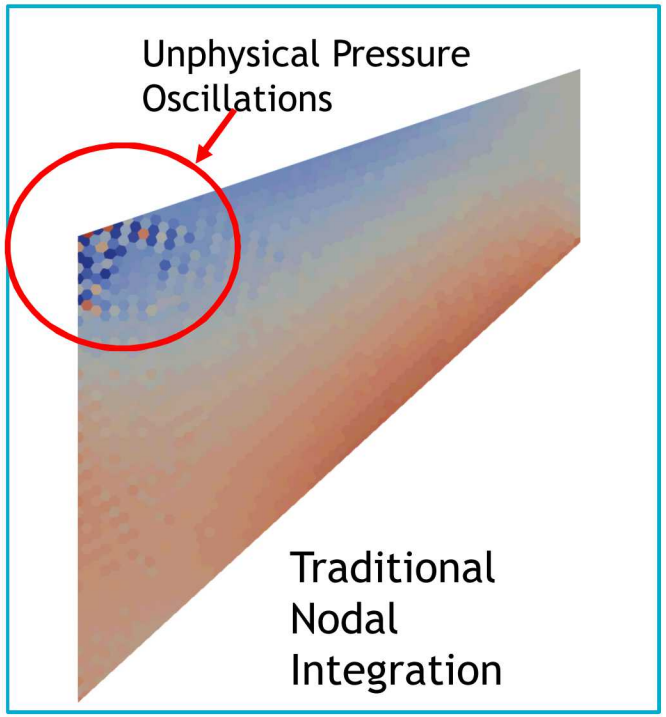
Overview of CRK

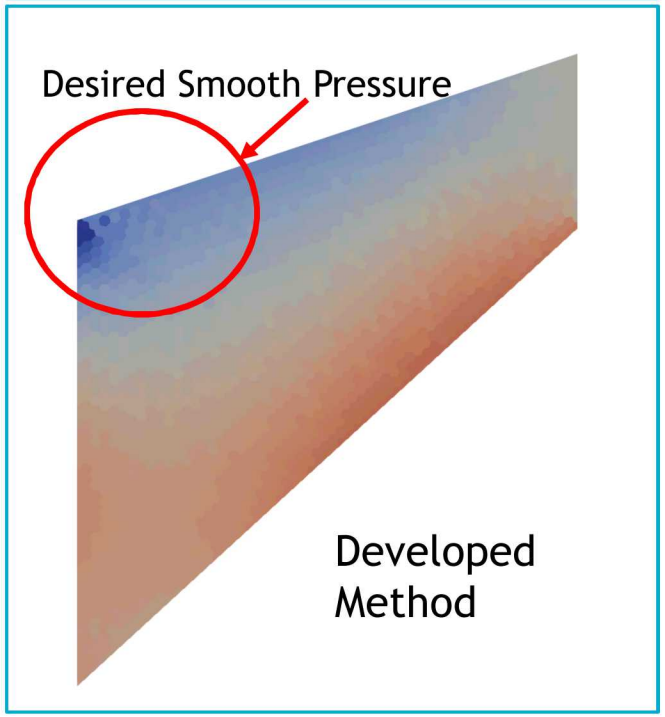
Fix short-comings of RKPM for part and system analyses

- Prototype implementation developed in a LDRD in FY18-19
- Leverage work on large deformation and integration[1,2]
- Addresses:
  - Analysis on complicated geometries, low quality discretizations
  - Nearly incompressible material[3]
  - Material failure in a total Lagrangian setting
- Efficient implementation a goal







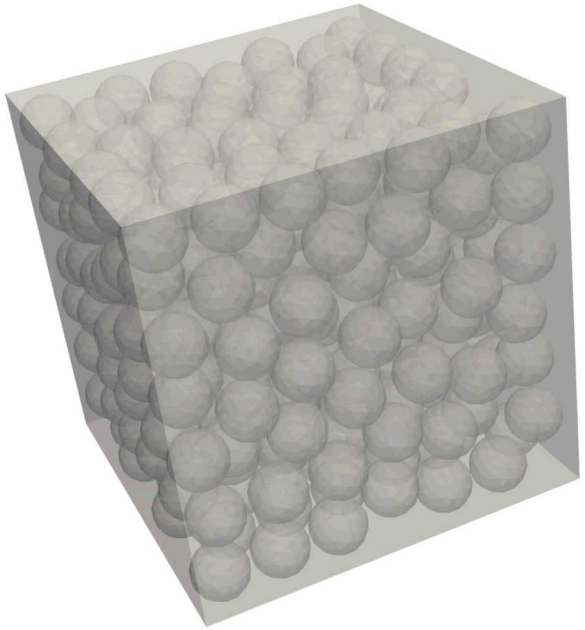


[1] J.-S. Chen, C. Pan, C.-T. Wu, and W. K. Liu. Reproducing kernel particle methods for large deformation analysis of non-linear structures. Computer Methods in Applied Mechanics and Engineering, 1996.
[2] J.-S. Chen, C.-T. Wu, S. Yoon, and Y. You. A stabilized conforming nodal integration for Galerkin mesh-free methods. International Journal for Numerical Methods in Engineering, 2001.
[3] G. Moutsanidis, J. Koester, M. Tupek, Y. Bazilevs, and J.-S. Chen. Treatment of near-incompressibility in meshfree and immersed-particle methods. Computational Particle Mechanics, 2019.

Direction of meshfree / CRK research

CRK encompasses RKPM

- LDRD-developed CRK "miniapp" will be the platform for meshfree research
- CRK is being developed / productionized in Sierra/SolidMechanics

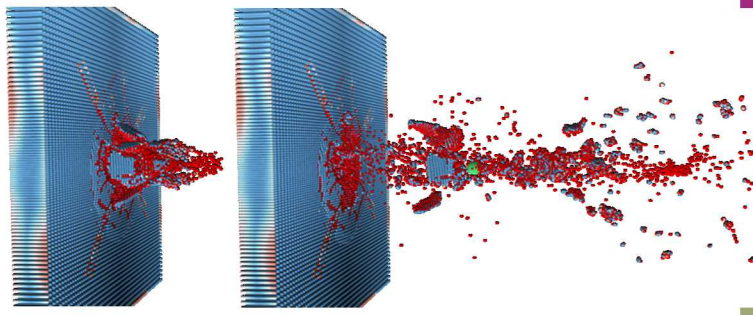


Current Funding

- ASC PEM: General research and Sierra implementation
- WIPP: Sierra implementation and associated analyses
- Next Generation Simulation: Sierra implementation, interested in rapid design-to-analysis
- Goodyear: Evaluating robustness for large deformation rubber analysis
- LDRD: For robust, large deformation analysis of CT scanned foam mesostructures

Potential Funding:

- Lagrangian-Eulerian coupling for blast-structure interaction
- LDRD proposed: Large deformation / rubbilization of energetic materials
- LDRD proposed: Simulating hypervelocity impact scenarios



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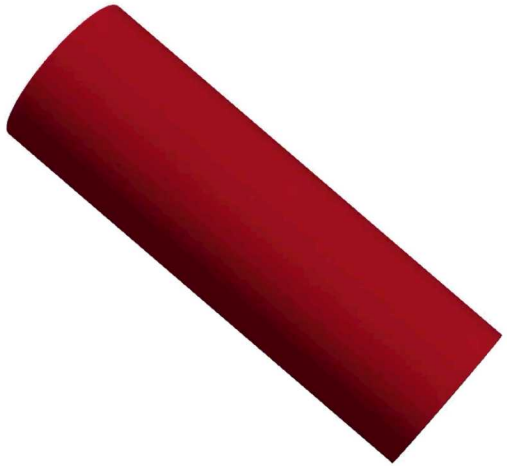
CRK implementation into Sierra

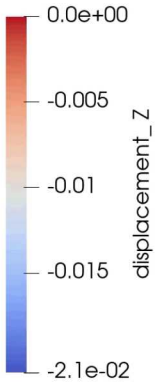
Summary of development stories:

- Create CRK interface. Call CRK internal force calculation from Sierra
- Connect CRK to Dash contact (primary Sierra contact method)
- Implement a local stable time increment estimate and hook CRK into global estimates
- Implement / connect other features needed for WIPP room closure analyses
  - Gravity loading
  - Pressure loading
  - Lithostatic prestress

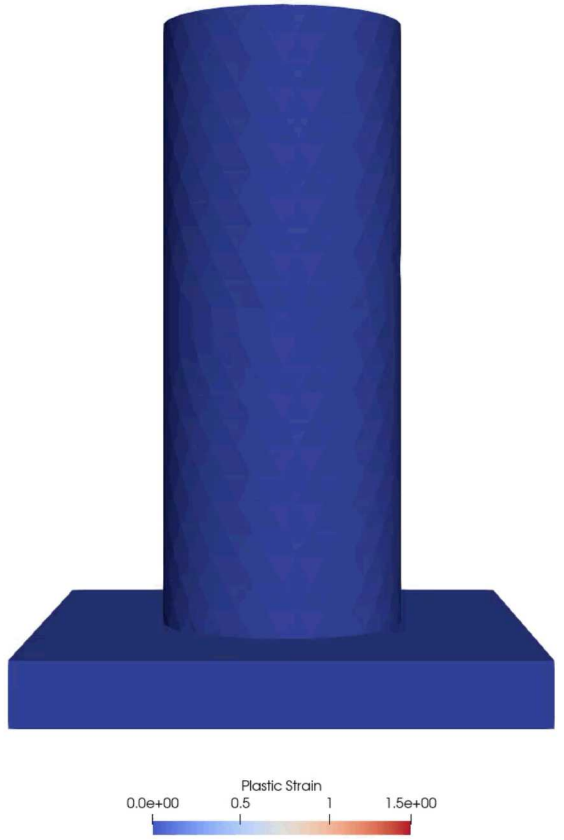
CRK implementation into Sierra

- Create CRK interface. Call CRK internal force calculation from Sierra
- Connect CRK to Dash contact (primary Sierra contact)





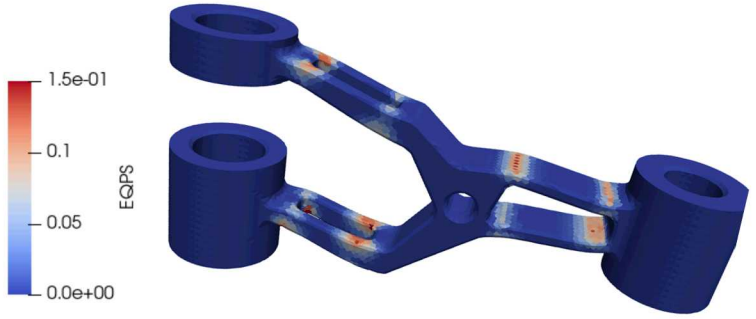
Fixed on End



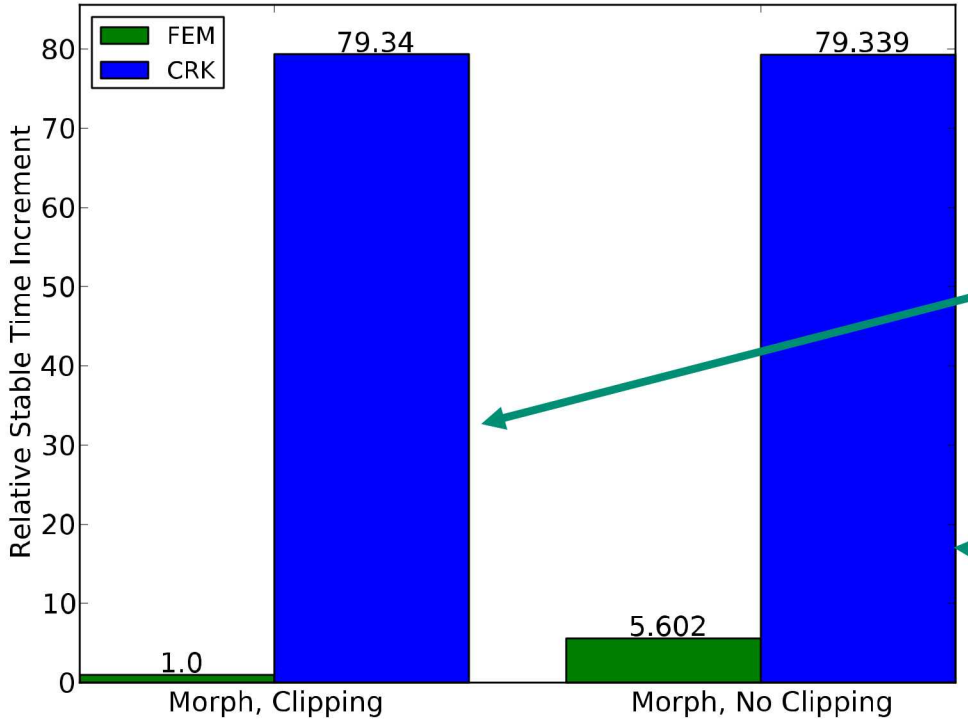
With Dash Contact

CRK implementation into Sierra

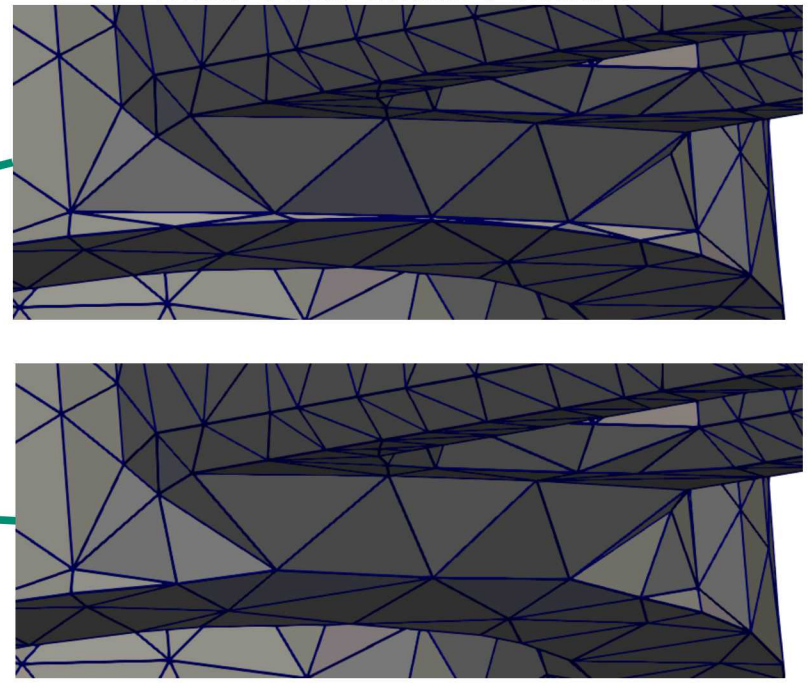
- Implement a local stable time increment estimate and hook CRK into global estimates
- Compared to FEA



Example: Control Arm



Mesh Near Small Feature



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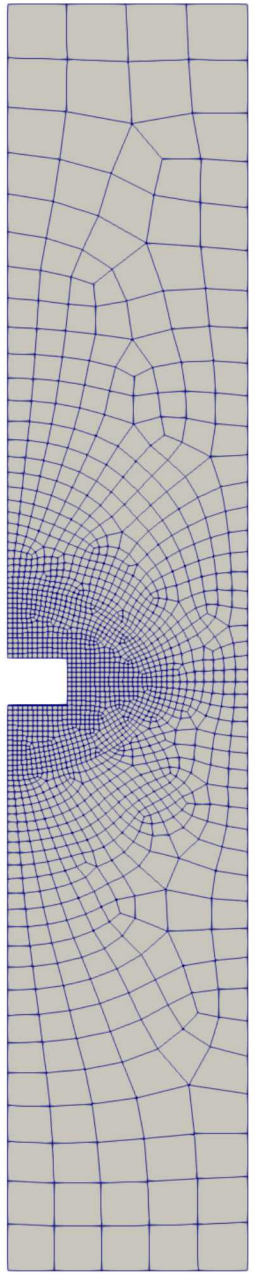
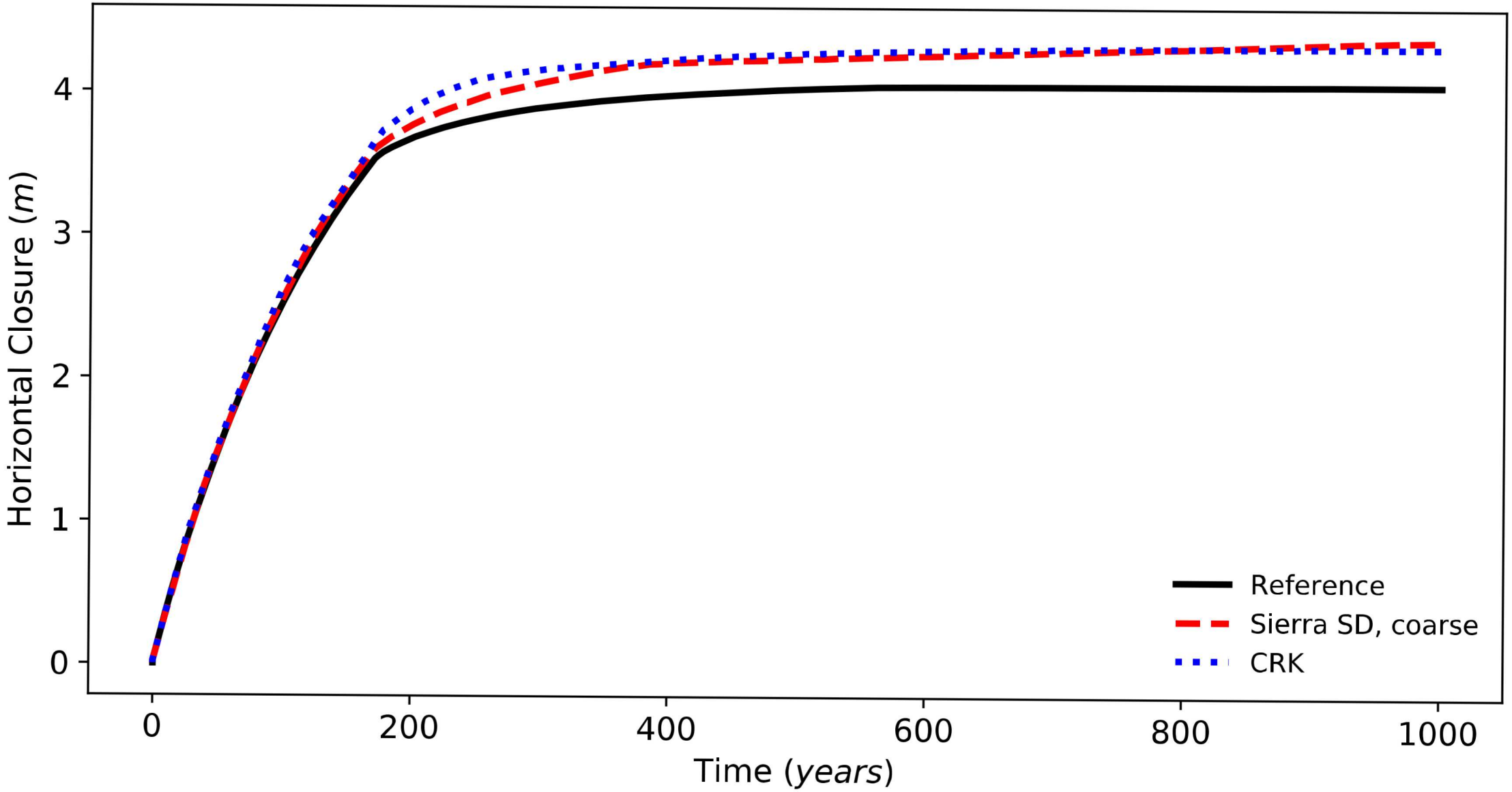
Room Closure Analyses

- Room closure without damage / failure
- Viscoplastic rate factor = 2.e9
- Mesh
  - Edge length: 0.42 m
  - Number of nodes: 3520



Room Closure Analyses



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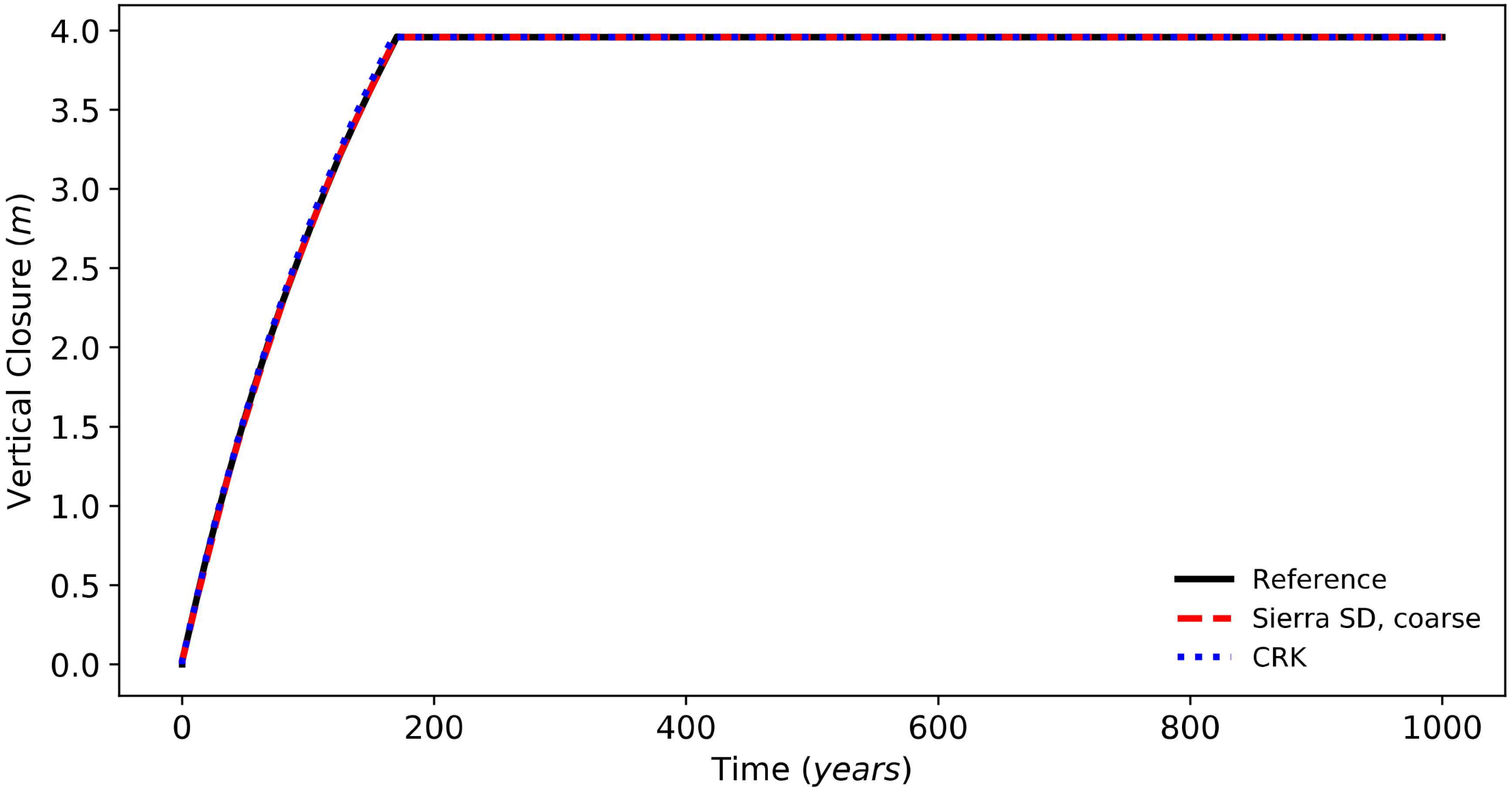
Room Closure Analyses



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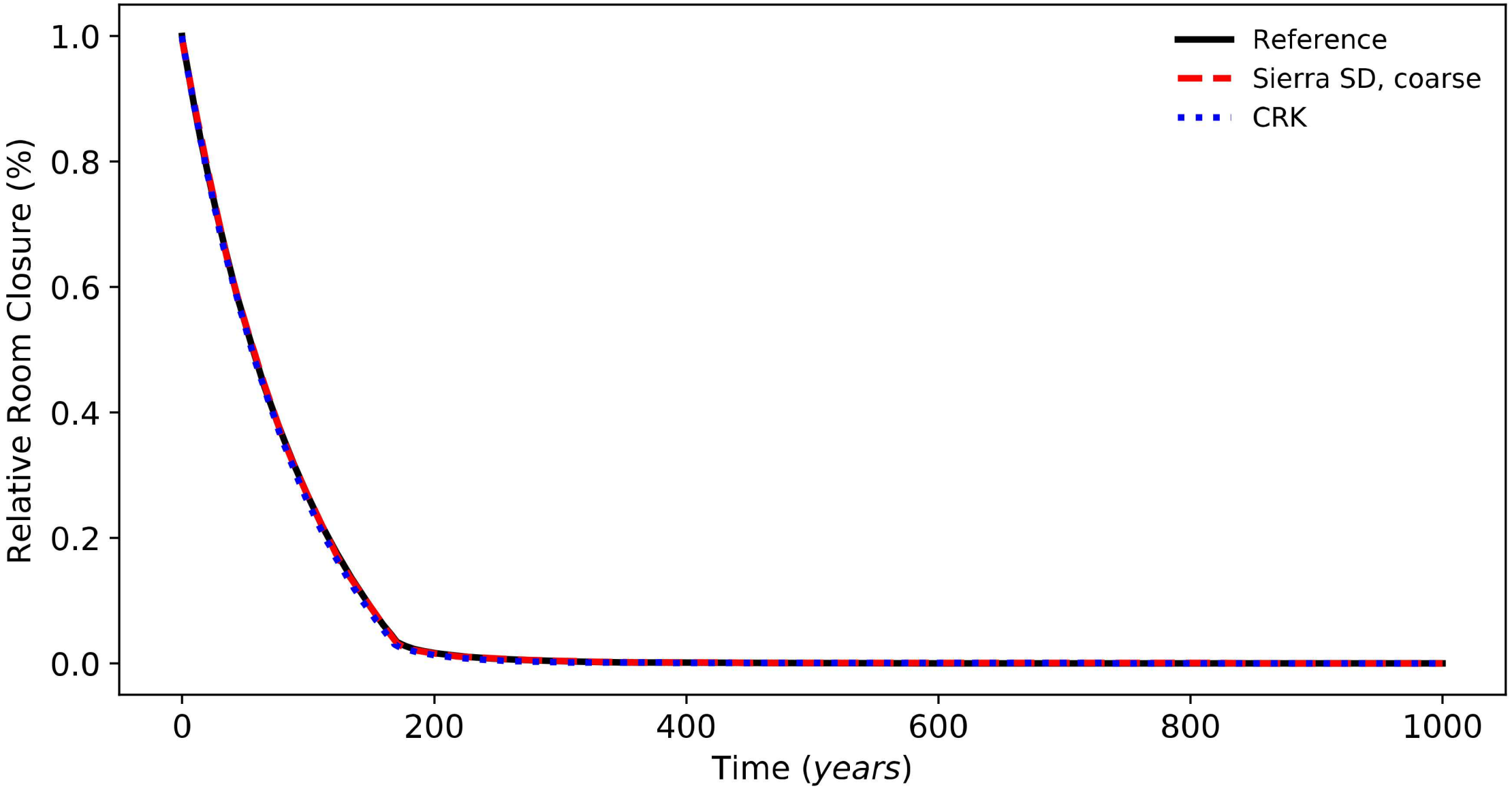
Room Closure Analyses



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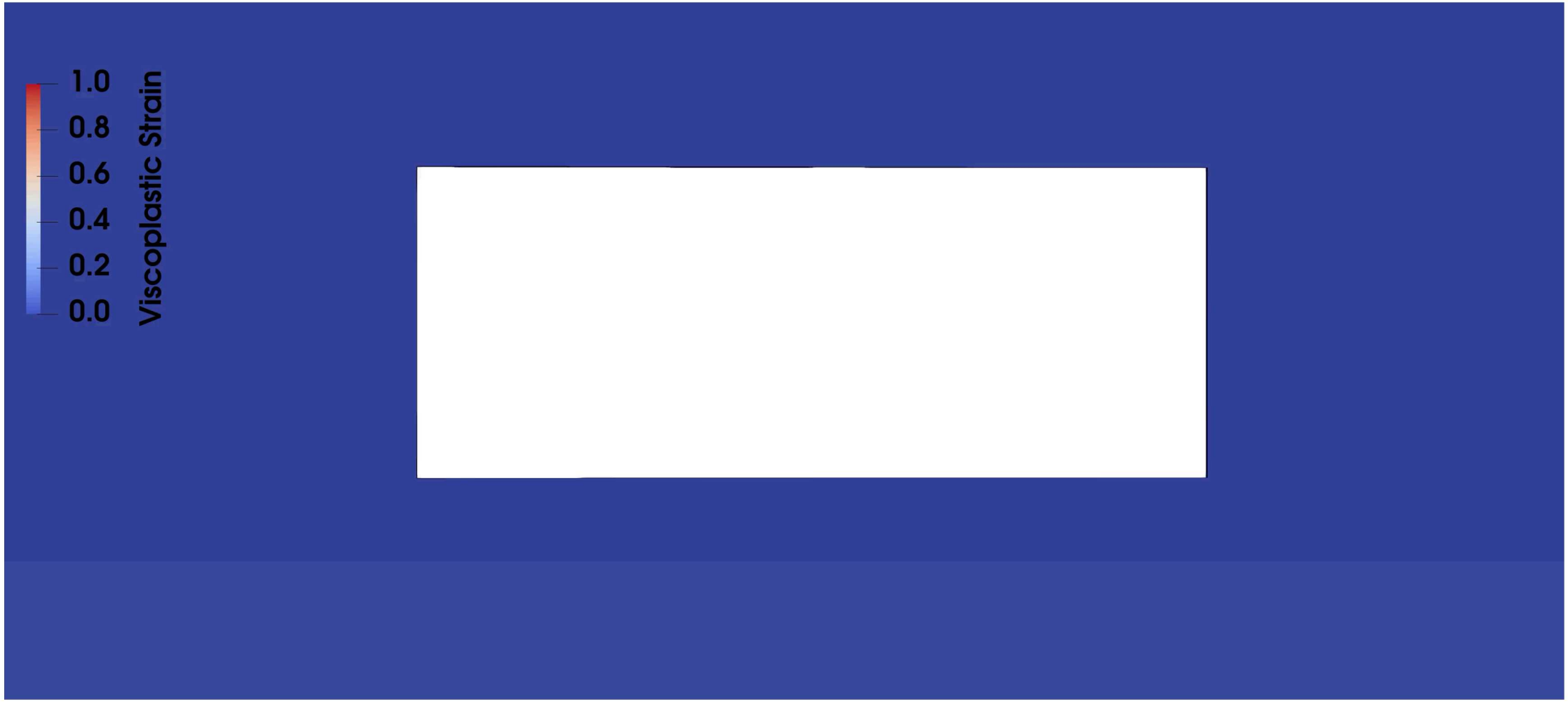
Room Closure Analyses



CRK

Finite Element
(Selective Deviatoric Hex)

Future Work

Sierra Implementation

- Implement fracture capabilities
  - "element" death
  - Bond-based fracture methods
- More work on improving Dash contact implementation
- Updated / Semi Lagrangian (like Prof. J.S. Chen's work)

Research

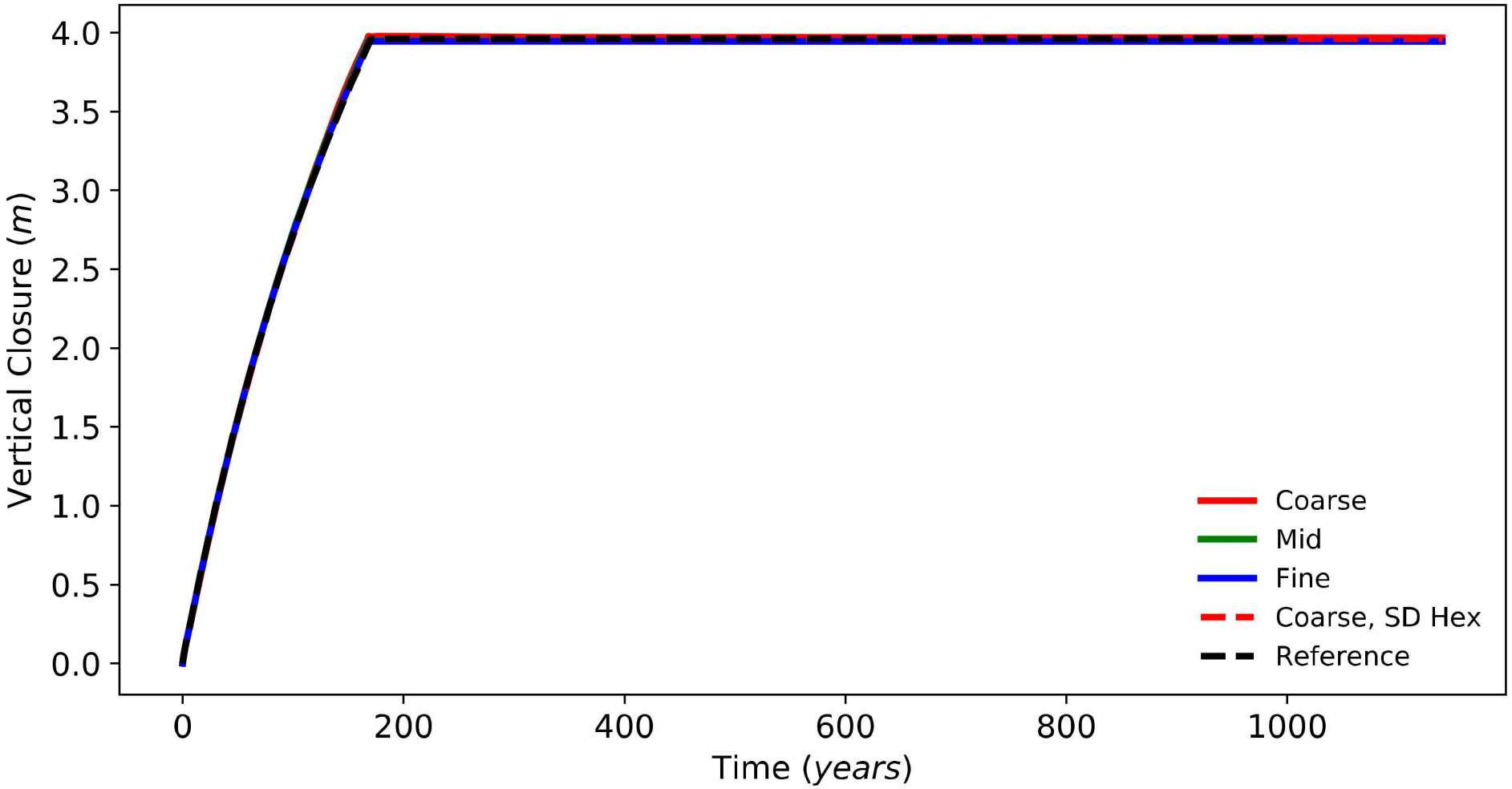
- Improvements to fracture methodologies
- Alternative, robust, efficient, contact algorithms to improve rubble pile compaction predictions

Thank You

Questions?

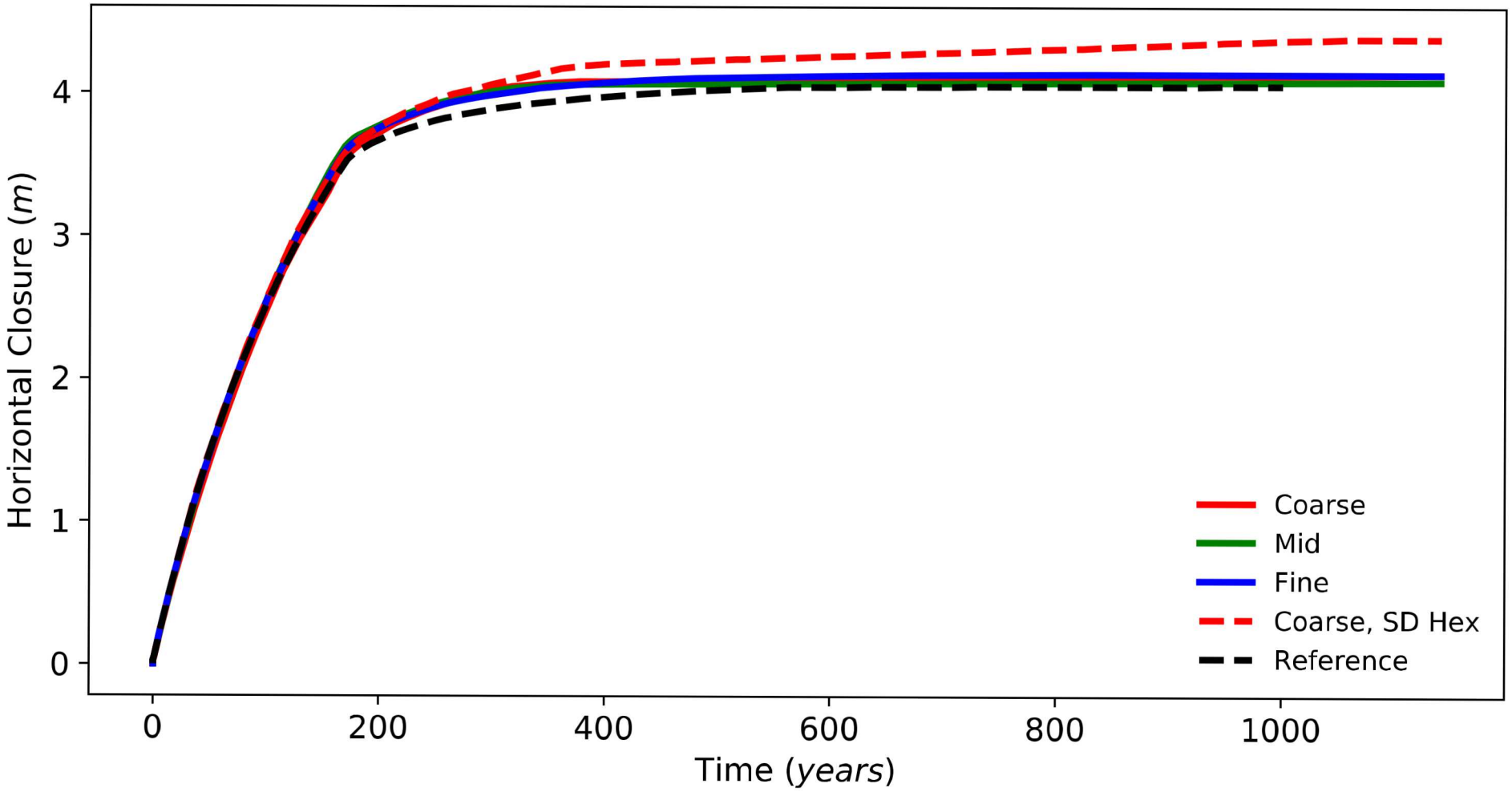
Backup Slides

Preliminary WIPP Results Using CRK "Miniapp", Vertical Closure



- Matches FEM solution

Preliminary WIPP Results Using CRK "Miniapp", Horizontal Closure



- Converging to reference solution
- Different contact method (vs reference), causing some discrepancy

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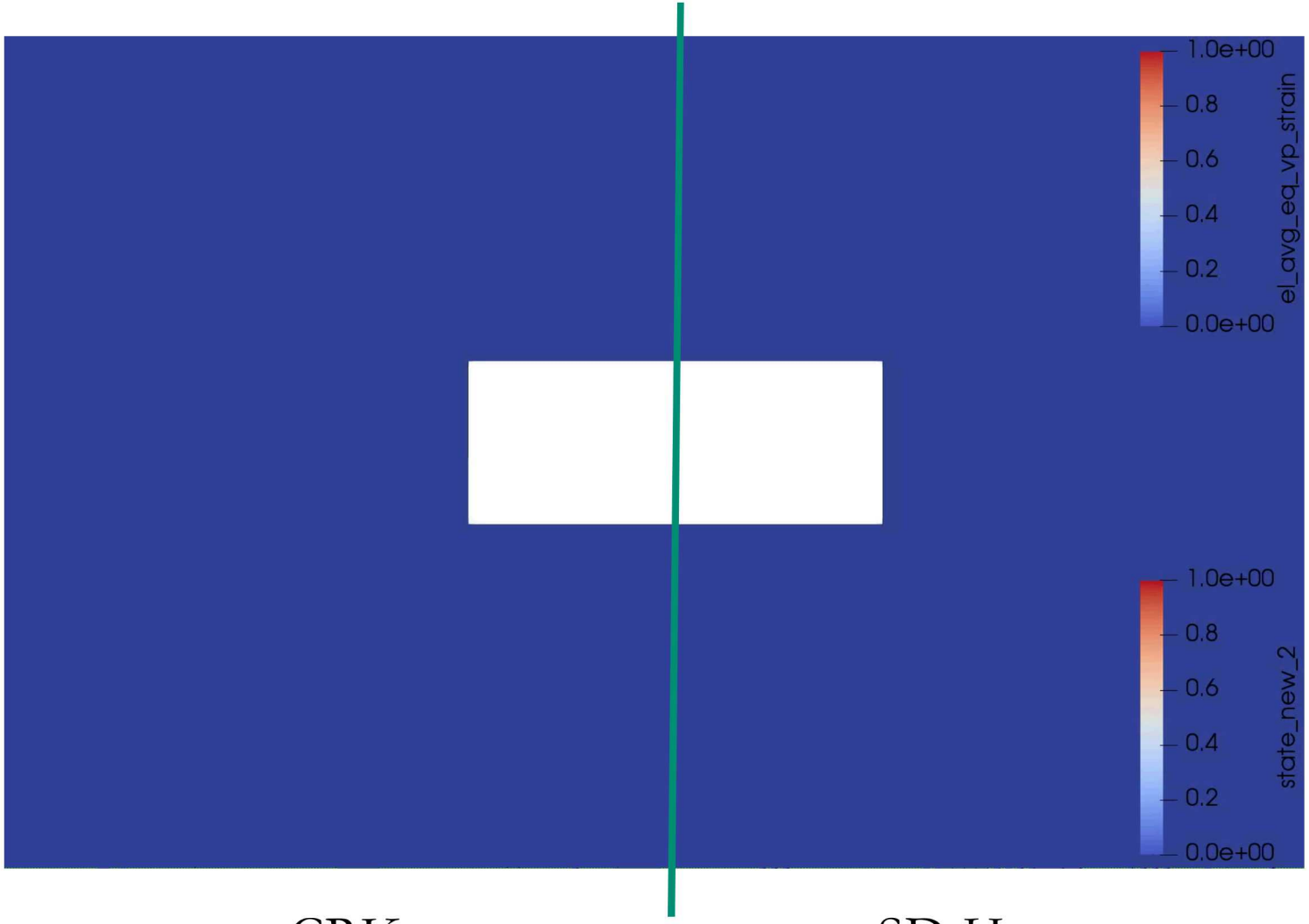
Preliminary WIPP Results Using CRK "Miniapp", Viscoplastic Strain



CRK SD Hex

- CRK using the developed nodal-based $\overline{\boldsymbol{F}}$ method

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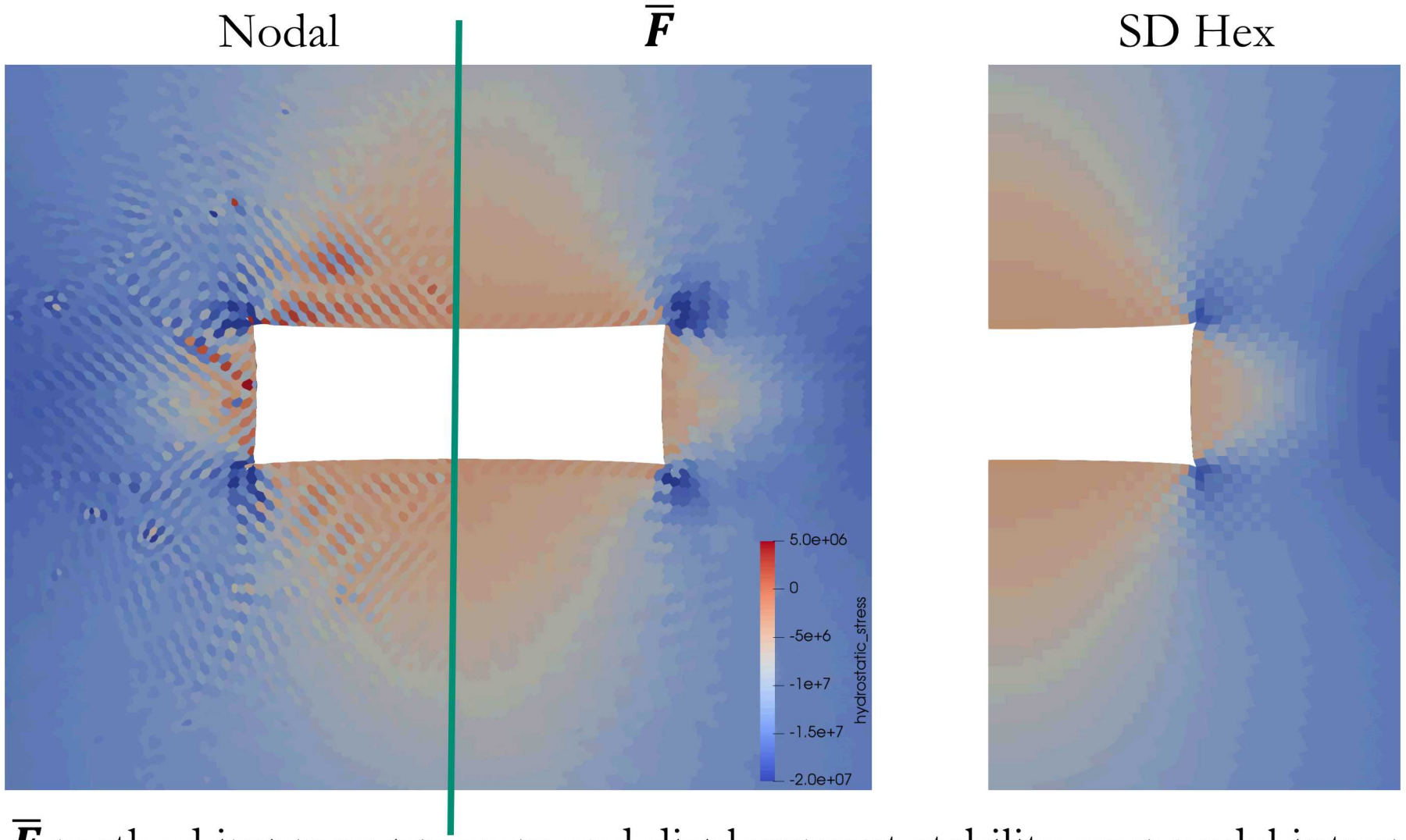
Preliminary WIPP Results Using CRK "Miniapp", Hydrostatic Stress



- $\overline{F}$ method improve pressure and displacement stability over nodal integration

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