Energy concepts in the analysis of unstable coal pillar failure

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Research Topic

- Study of unstable coal pillar failure
- Back analysis of 2007 Crandall Canyon accident

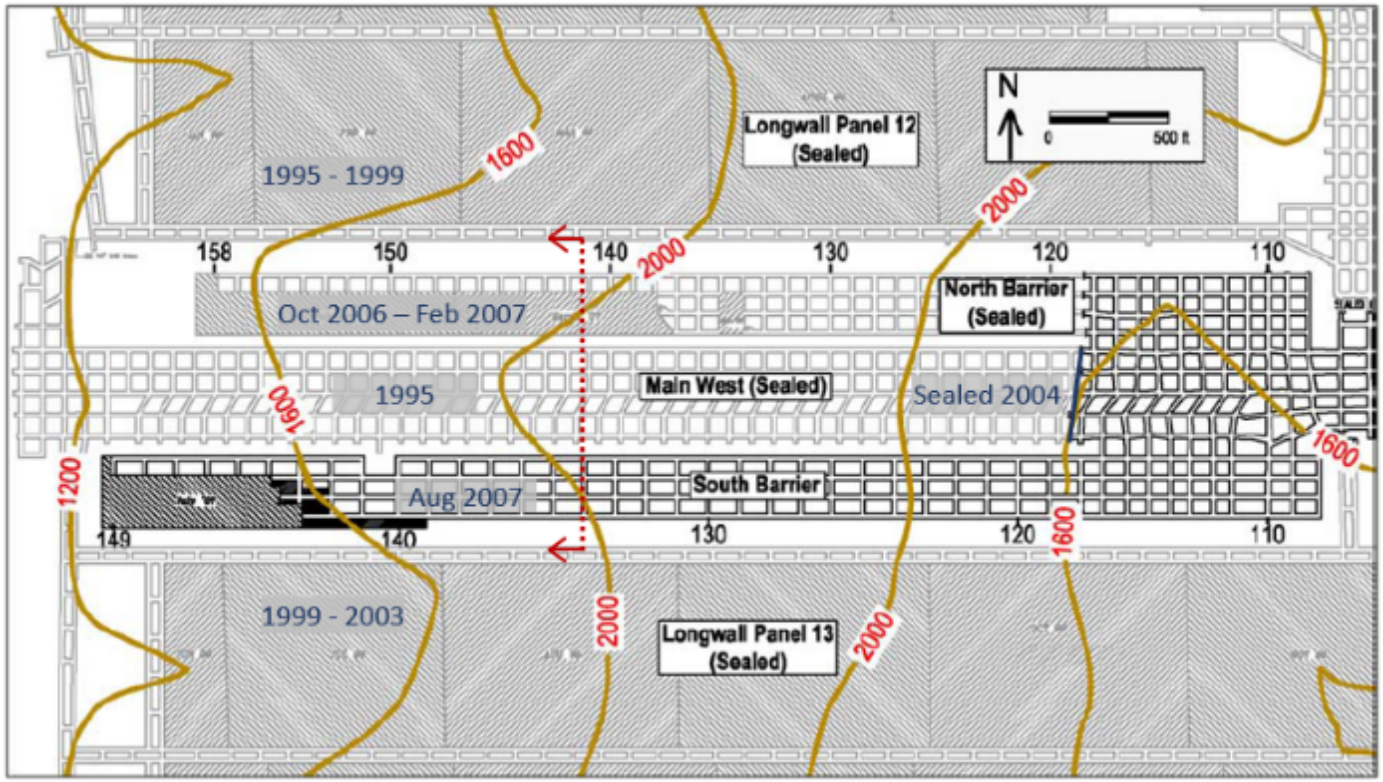
Objective of Study

- Evaluate unstable failure in pillar-scale analyses
  - Loading conditions
  - Coal material properties
  - Coal / rock interface properties
- Quantify unstable failure in mine-scale analyses
  - Calculation of released kinetic energy
  - Pillar stress / strain
  - Vertical closure along coal seam

Crandall Canyon Main West

Depth of overburden
Abutment loads

Excavation sequence
Geometry



(Gates, 2008)

Pillar-Scale Analysis

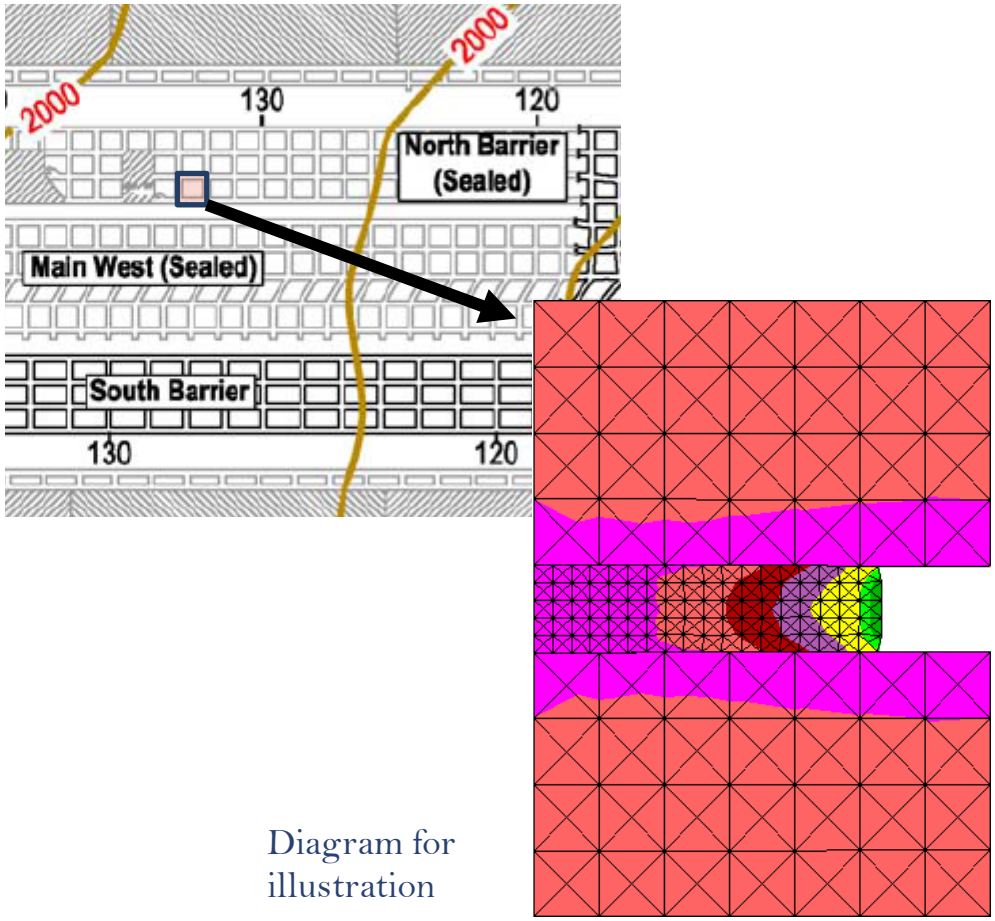
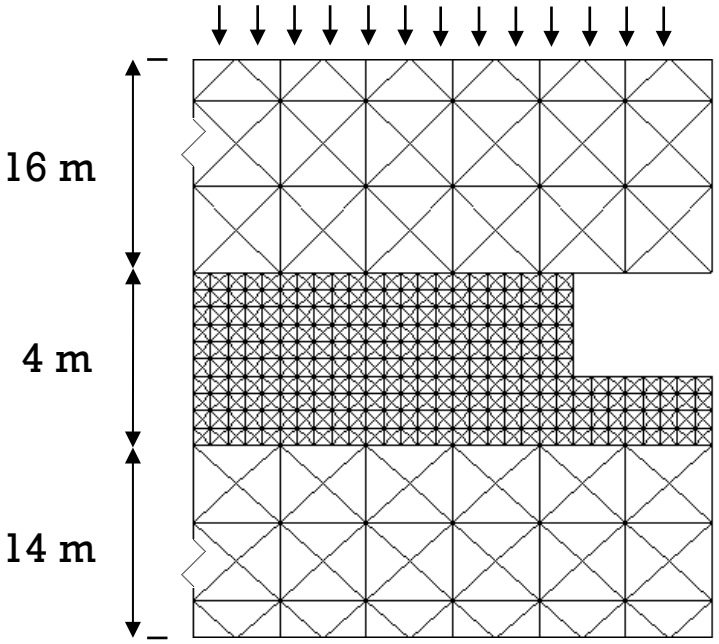


Diagram for illustration

- Assumption: collapse involved unstable failure of large number of squat pillars at once
- Can we reproduce unstable failure of a squat pillar?
- Will magnitude of released energy in a single pillar provide insight to collapse?

Geometry and Input Variables



- Loading Conditions
  - Gradual pressure increase
  - Constant (slow) displacement
- Coal material properties
  - Mohr-Coulomb
  - MC Strain Softening
- Coal / rock interface
  - Fixed (no shear slip)
  - Coulomb slip
  - Continuously-Yielding
    - (displacement softening)

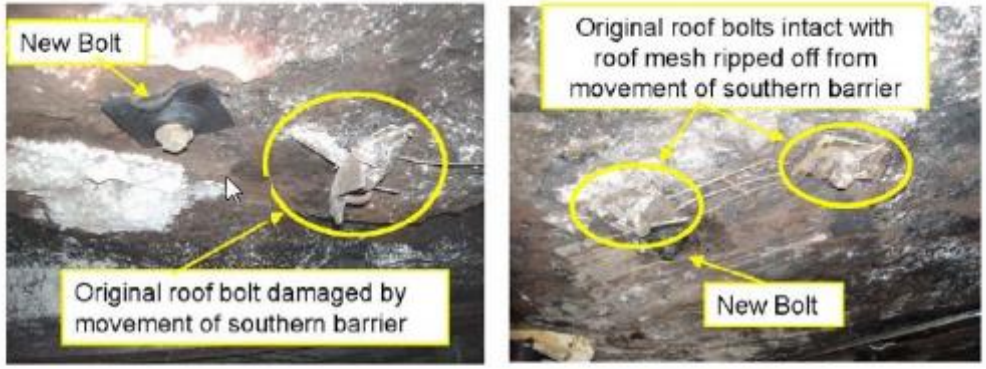


Figure 7- Damaged Roof Bolts and Torn Mesh after August 6 Accident Resulting from Northward Movement of Southern Barrier

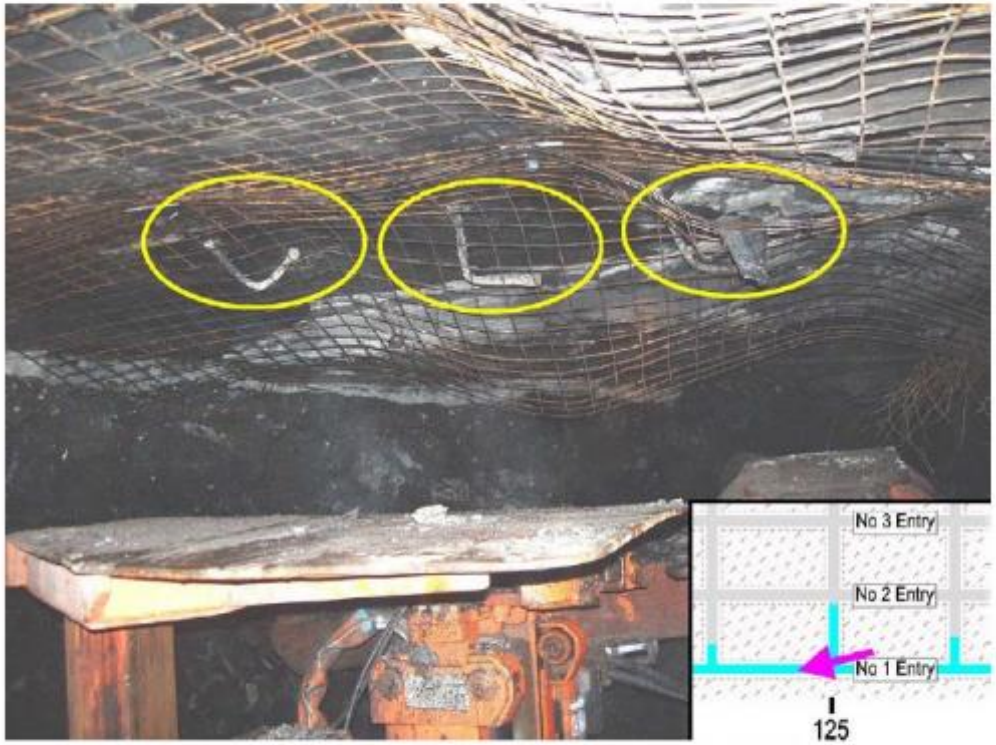
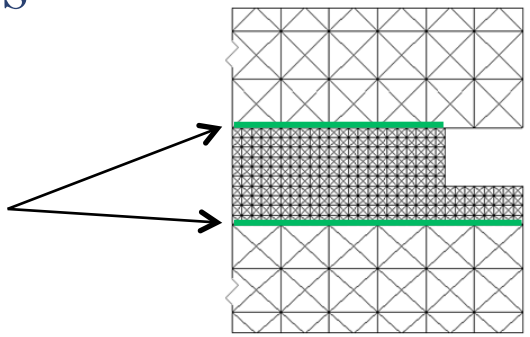
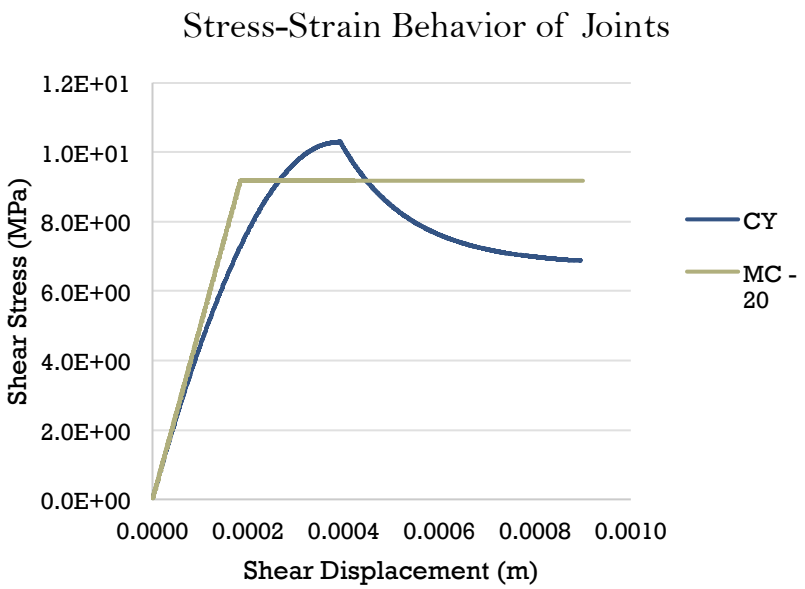


Figure 8 - Damaged Roof Bolts in No. 1 Entry after August 6 Accident Resulting from Northward Movement of Southern Barrier. Mesh shown was installed during rescue operations, over damaged original roof bolts. Camera view is indicated by arrow in index map insert.

Coal/Rock Interface Parameters

Modeled above and below coal seam





	Coulomb Slip	Continuously Yielding
Shear Stiffness (Pa)	50.0e9	50.0e9
Normal Stiffness (Pa)	50.0e9	50.0e9
Initial Friction angle (deg)	20.0	40.0
Intrinsic Friction angle (deg)	-	15.0
Joint roughness (m)	-	0.00015
Cohesion (Pa)	0.0	-
Dilation angle (deg)	0.0	-
Tensile Strength (Pa)	0.0	-

Released Kinetic Energy, W_r

Calculated and recorded by UDEC

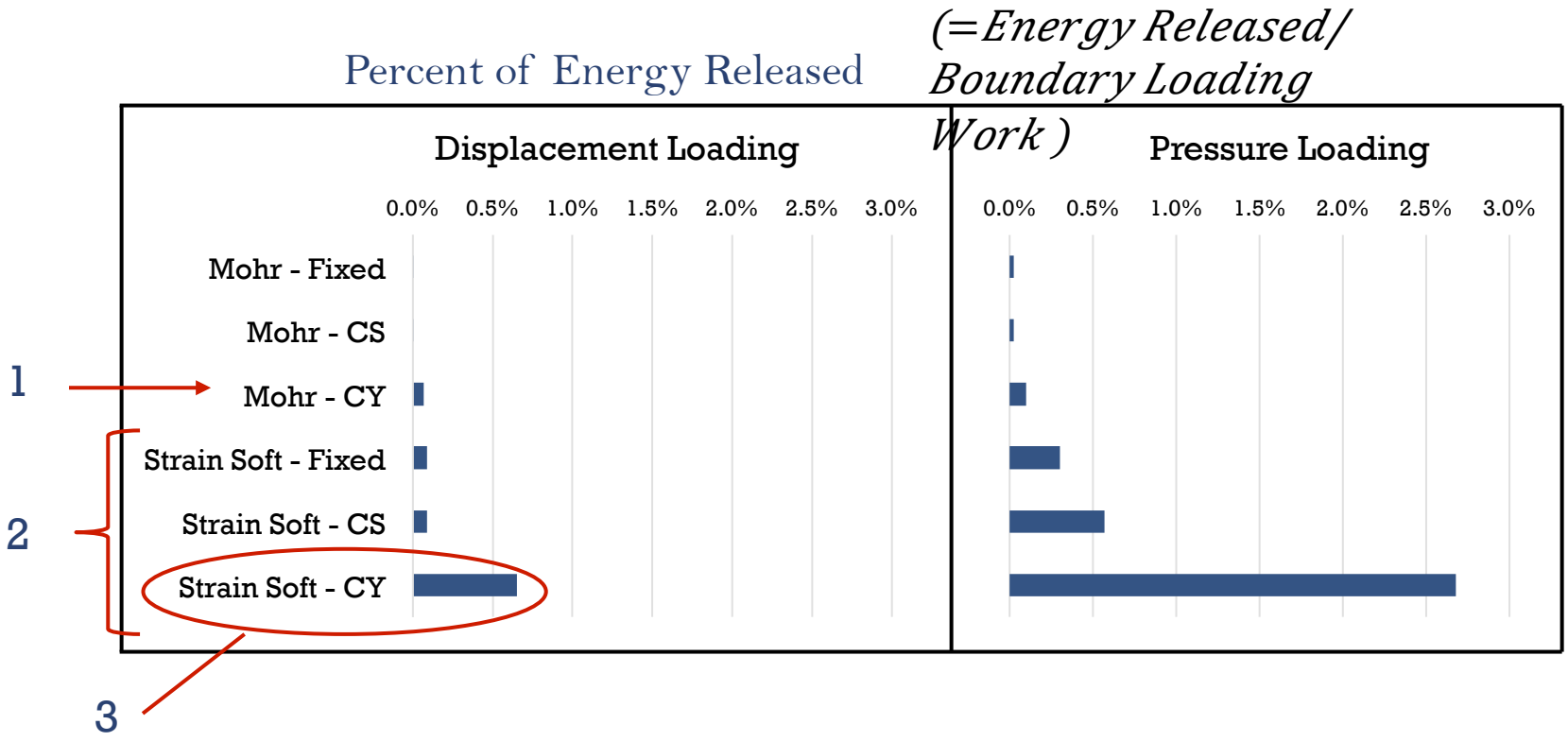
$$W\downarrow r = U\downarrow k + W\downarrow k$$

Current value of kinetic energy in system

Work dissipated by damping

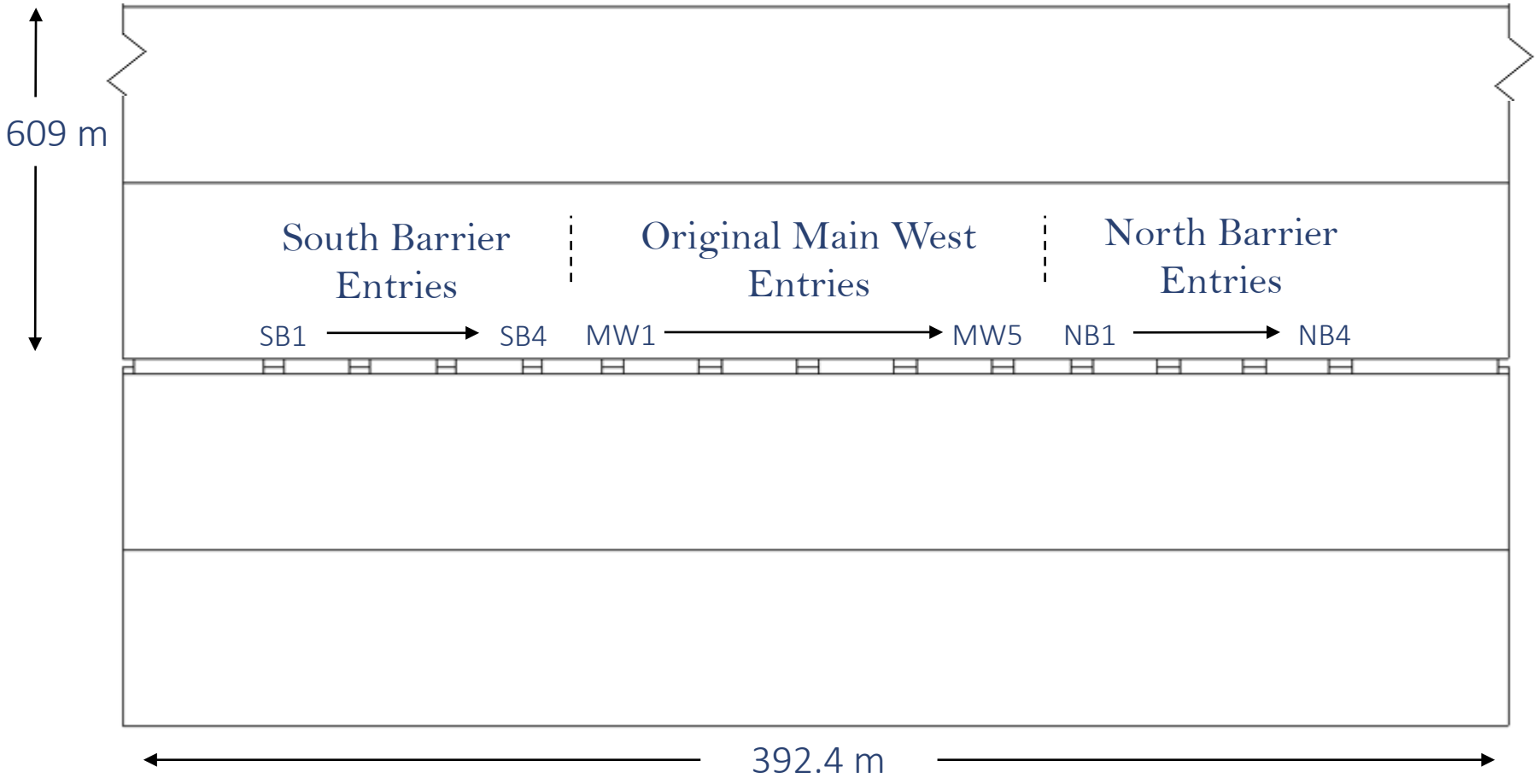
Pillar-Scale Results

1. Softening interface promotes instability (energy release)
2. Strain-softening coal promotes instability
3. Combination of these facilitates unstable failure of pillars



Mine-Scale Analysis

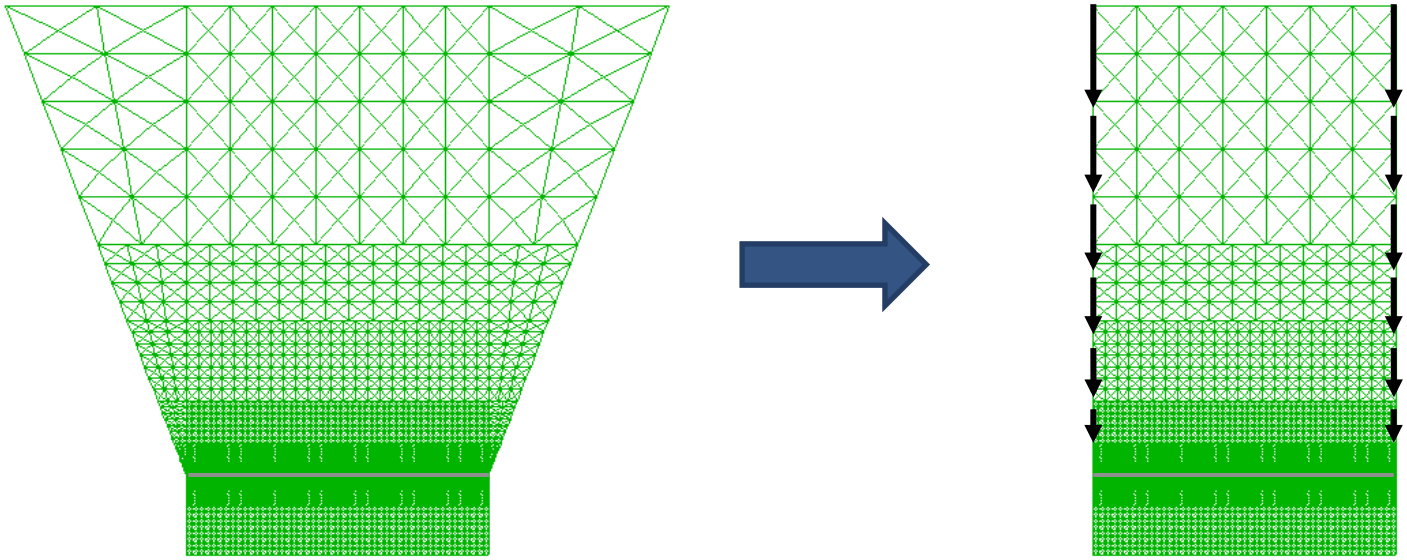
Mine-Scale Geometry



Simulation of Abutment Loads

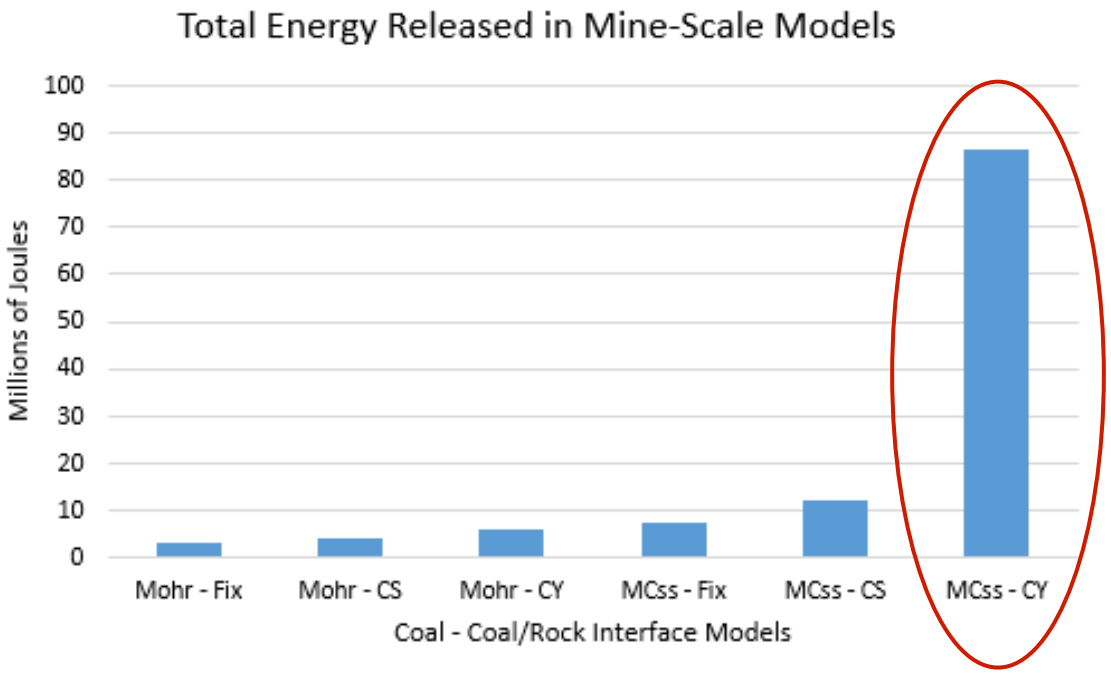
Physical abutment wedge at static equilibrium

Equivalent grid point forces



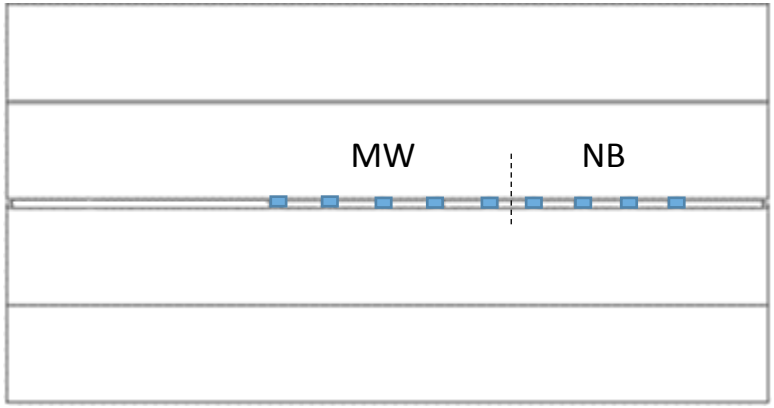
Mine-Scale Results

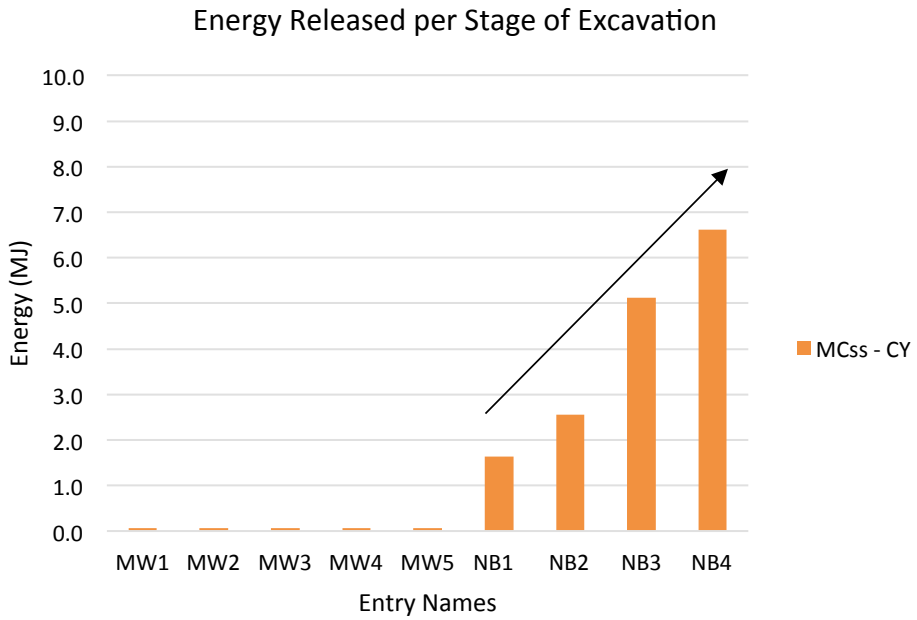
- Same combination of material properties used in pillar-scale analysis
- Same energy calculation procedure as pillar-scale models
  - For a 2D model - energy released per meter in 3rd direction



Model to be discussed further

Energy Released Through Development of North Barrier





- In virgin ground conditions, very little released energy
- After abutment loading, increasing instability
- Energy values in range of megajoules may relate to March 2007 bump

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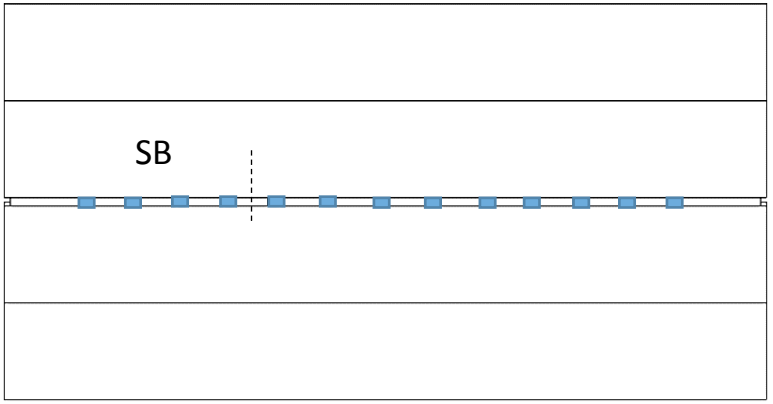
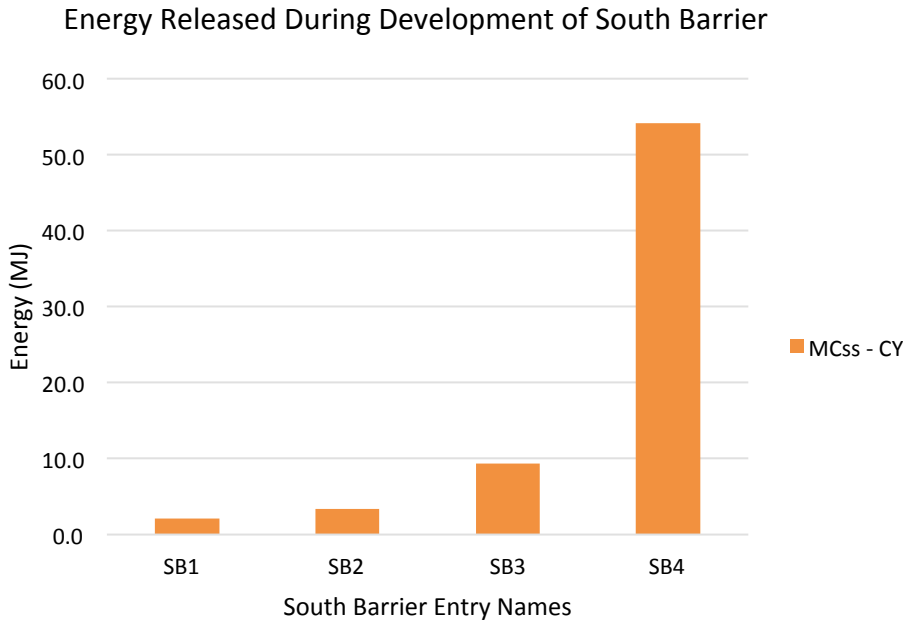
Energy Released During Development of South Barrier





- More energy values in the range of megajoules
- Collapse during excavation of final entry
  - Verified through stress/ strain behavior

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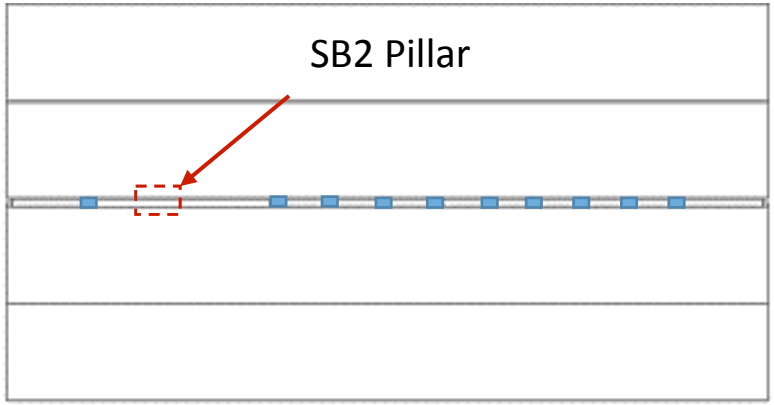
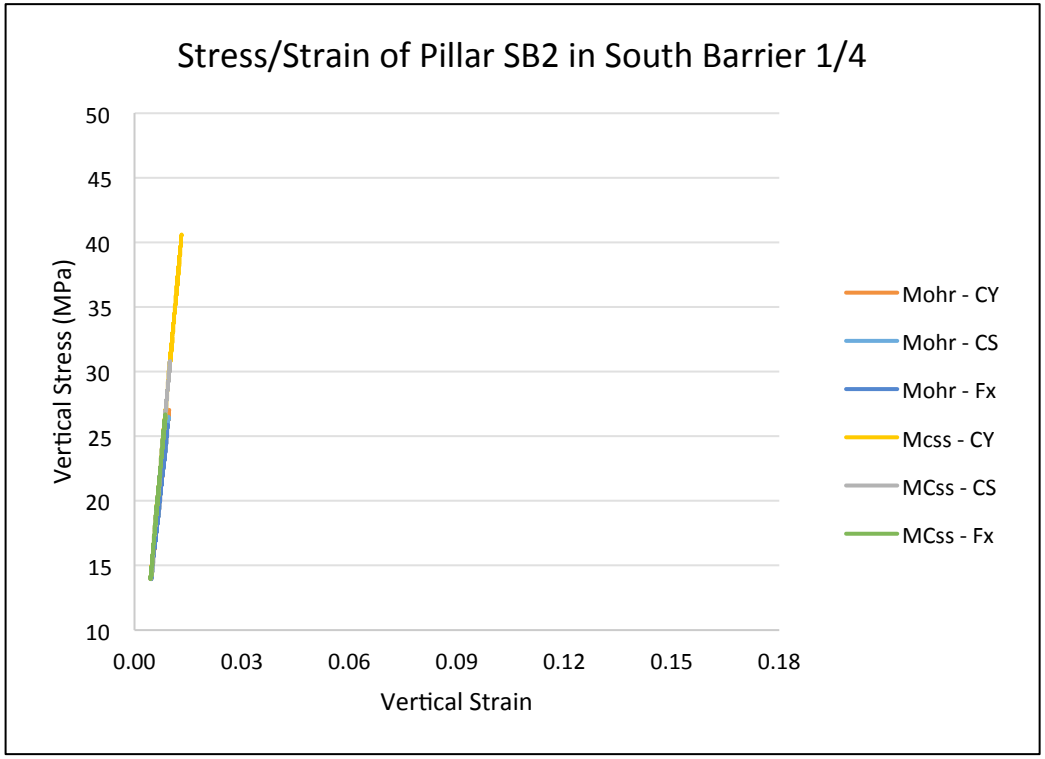
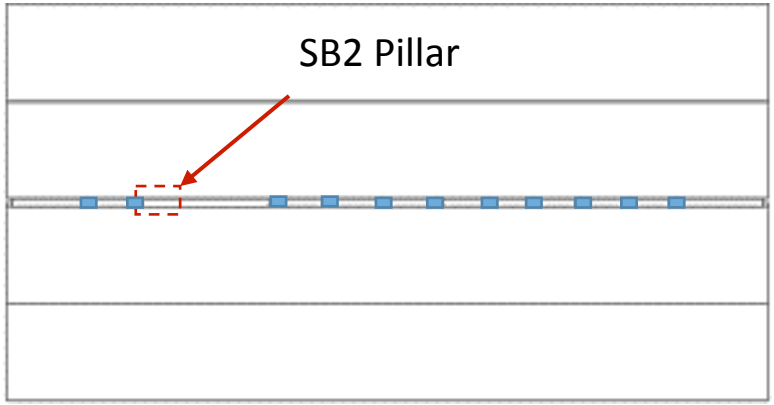
Stress/Strain Behavior in Parametric Simulations

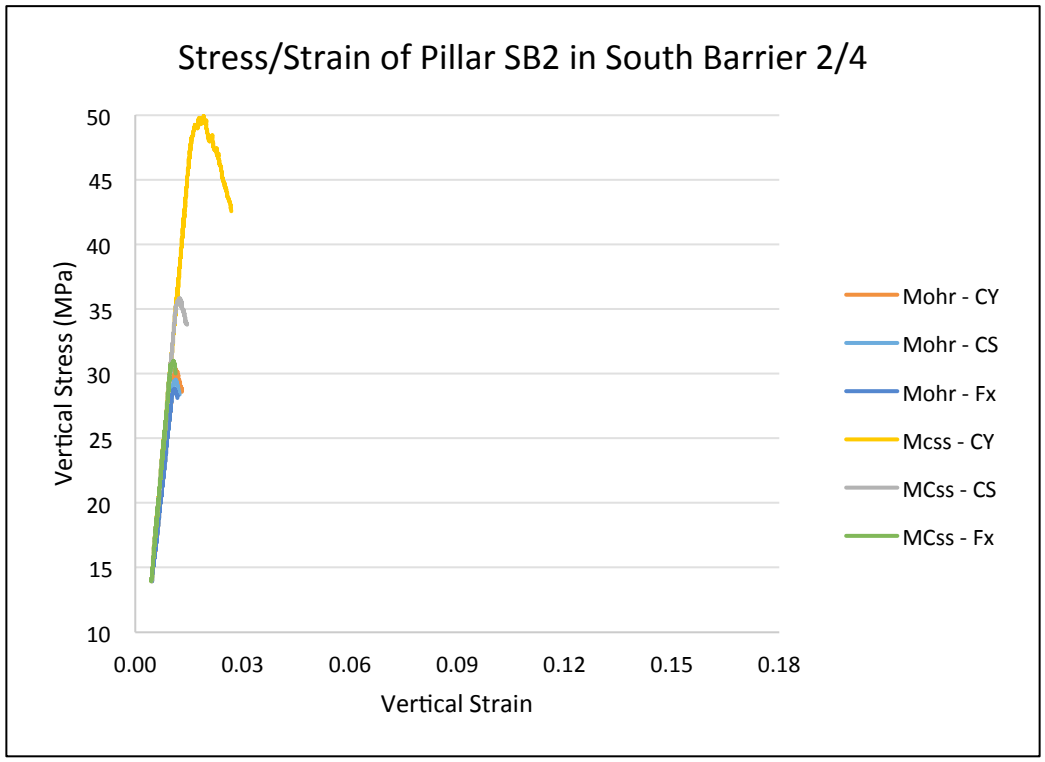




- Vertical stress through intact coal depends upon strength of pillars elsewhere

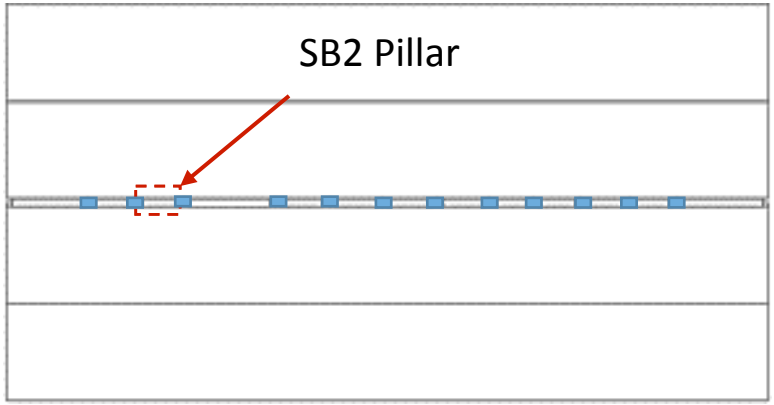
Stress/Strain Behavior in Parametric Simulations

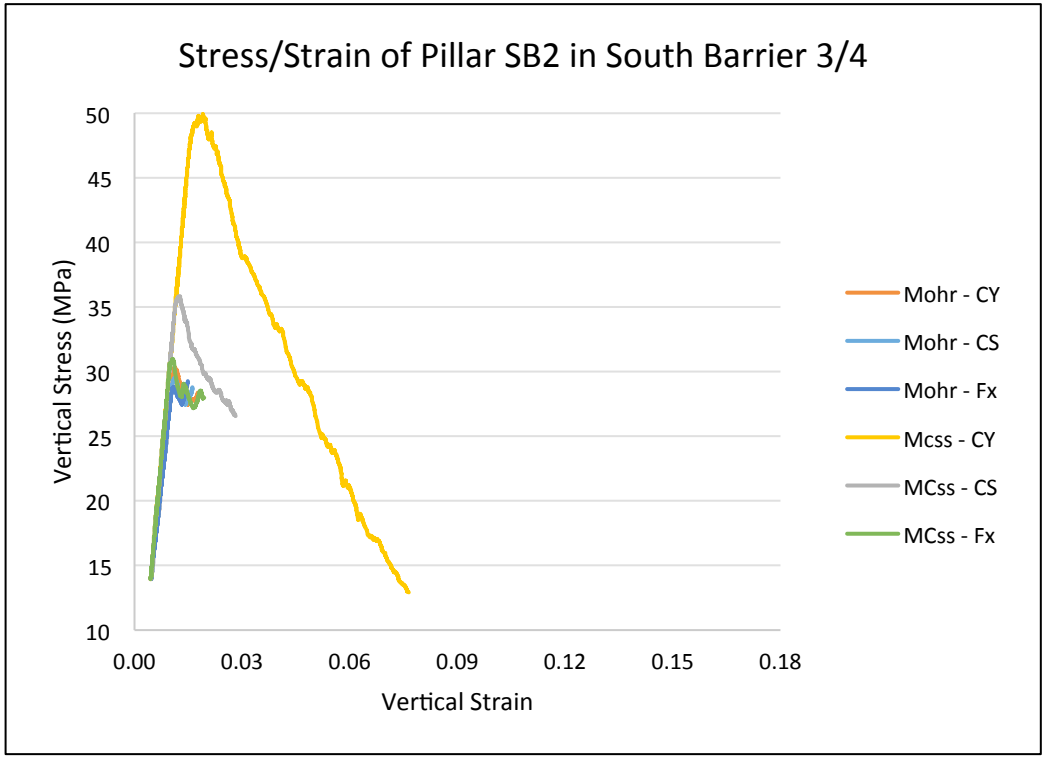




- Stress drop in all models due to deconfinement (excavation)

Stress/Strain Behavior in Parametric Simulations





- Stress drop in all models due to deconfinement (excavation)
- Lower residual strength with softening coal/rock interface

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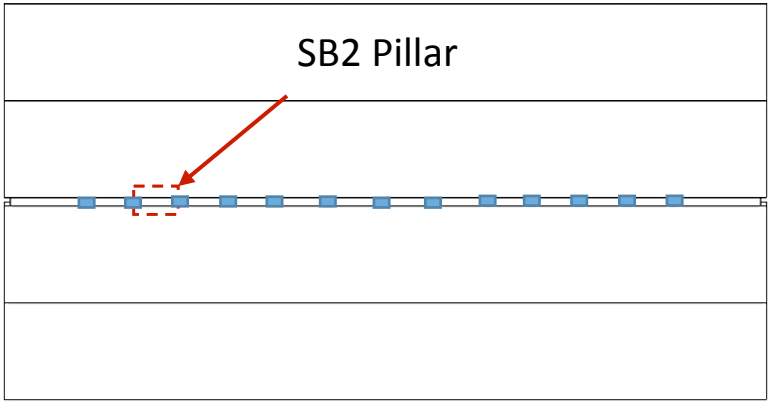
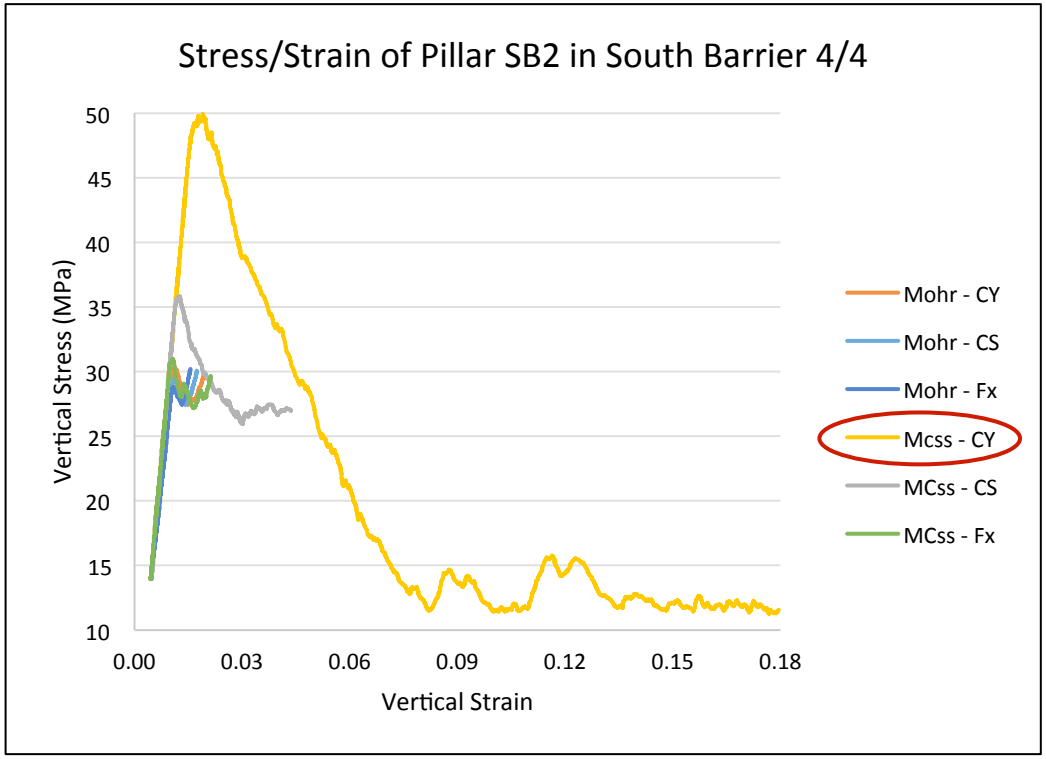
Stress/Strain Behavior in Parametric Simulations





- Combination of softening parameters facilitates collapse of MCss-CY model
- Failure mode of squat pillars dependent upon shear slip

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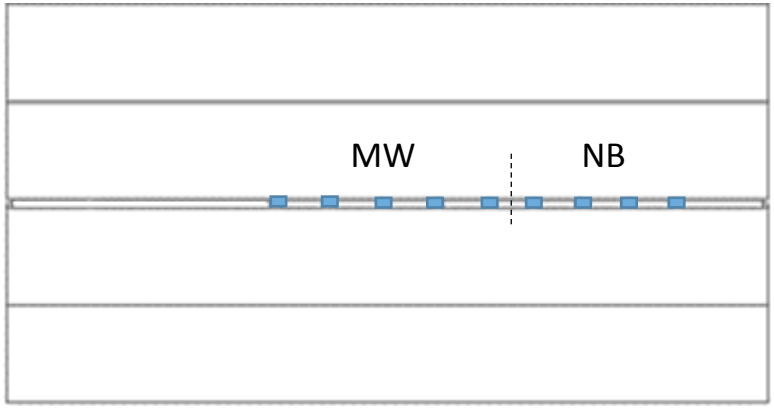
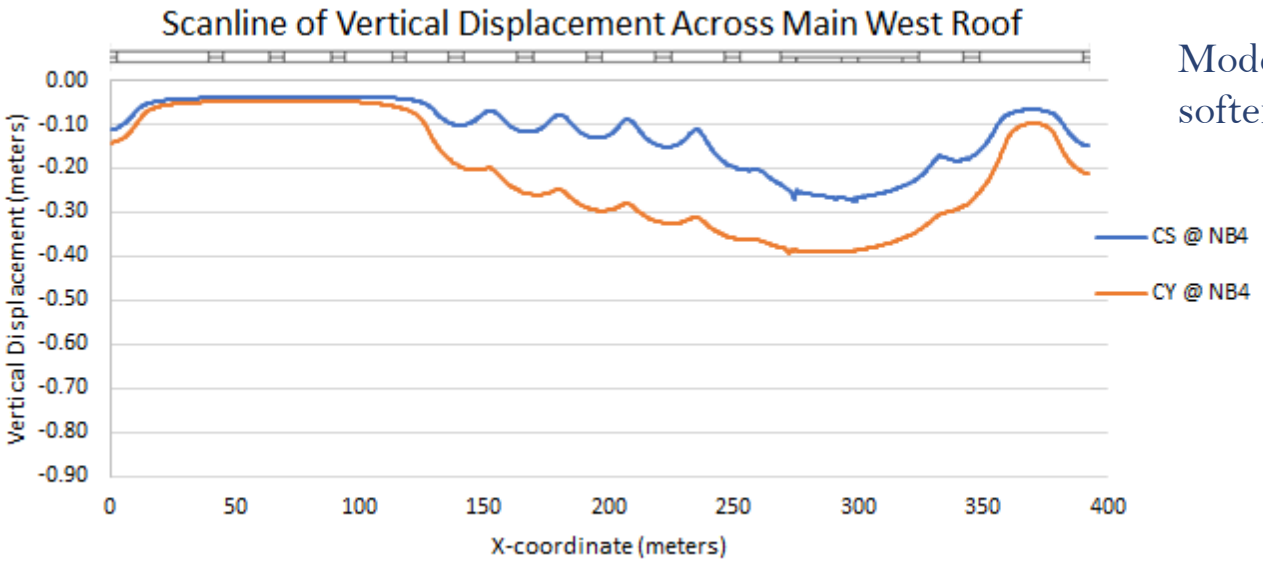
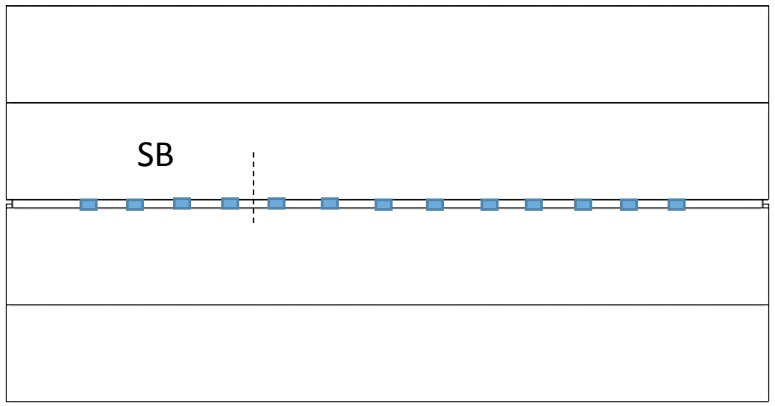
Closure After North Barrier Development

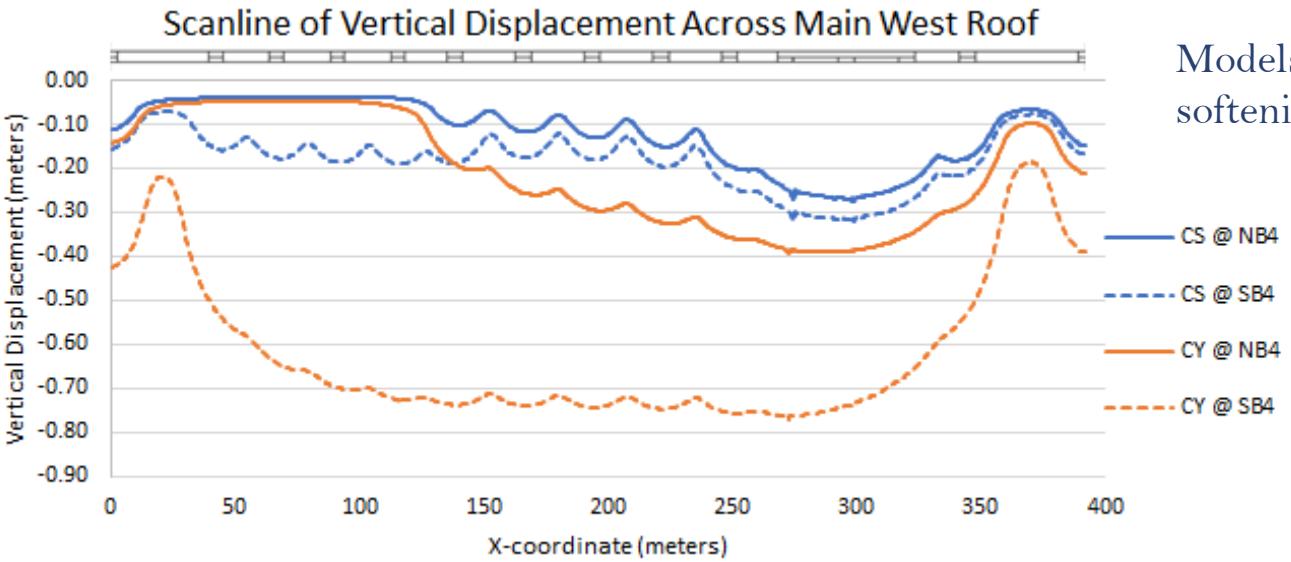




Models with strain-softening coal

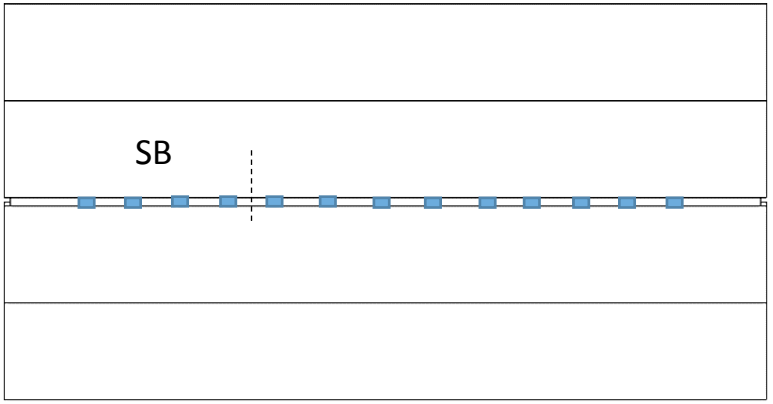
Closure After South Barrier Development

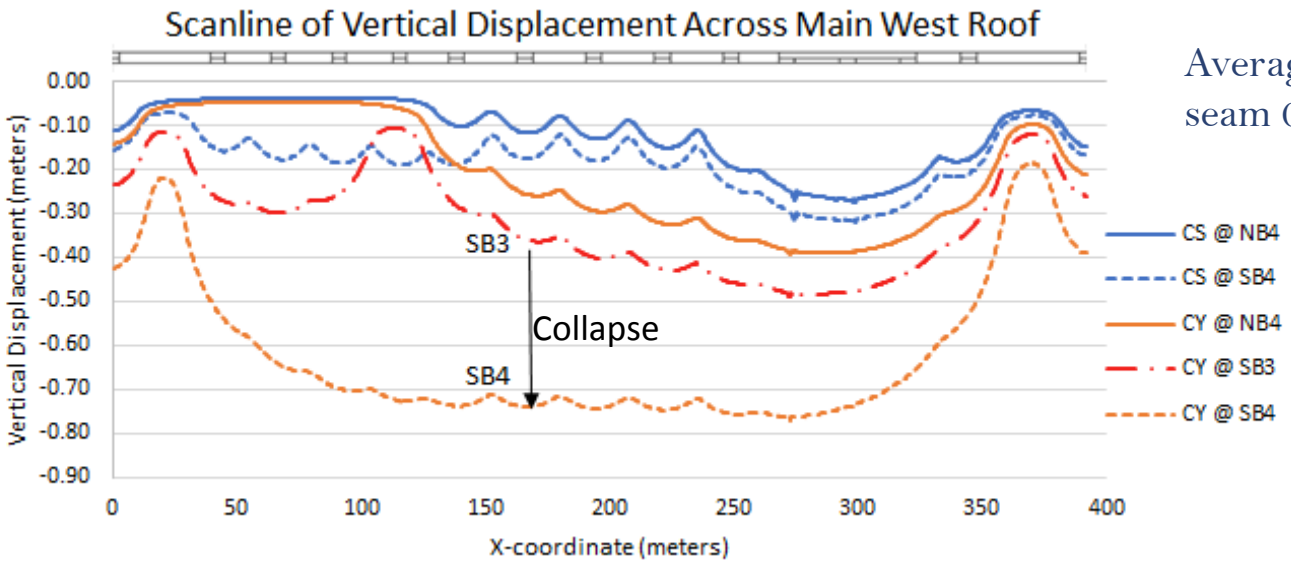




Models with strain-softening coal

Closure After South Barrier Development





Average closure across coal seam 0.3 meters (1ft)

Conclusions

- Calculation of released kinetic energy used to quantify degree of instability in study of pillar failure
- Strain softening coal + displacement softening interface = greatest instability
  - True for all loading conditions and pillar geometries
  - Reveals mode of pillar failure dependent upon shear slip
- Energy results from mine-scale simulation illustrate a trend of increasing energy release during North Barrier excavation and significant failure event during excavation of the South Barrier
- Further research required to correlate energy of simulated collapse with seismic magnitudes observed during accident