Evaluation of Coal Burst Potential Using Numerical Modeling

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Introduction

- Coal bursts – a form of rock bursts – are typically characterized by a rapid failure of coal and rock around an underground coal entry or crosscut.
- Coal bursts typically occur under a complex set of conditions:
  - Mining depth (>1,000 ft.)
  - Competent and massive strata in the roof and floor (sandstone or siltstone)
  - Multiple seam mining
  - Faults or fractured zones
  - Steep terrain and/or dipping seams

(Maleki and Lawson 2017; Mark 2018)

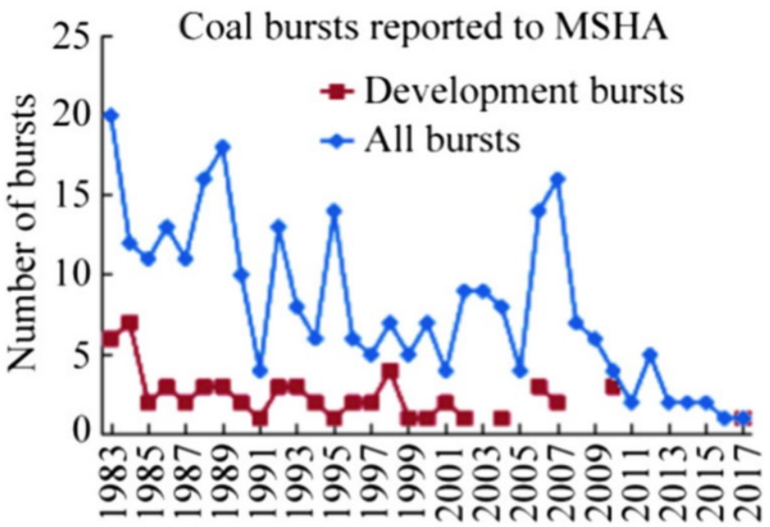
Coal Bursts vs Coal Bumps

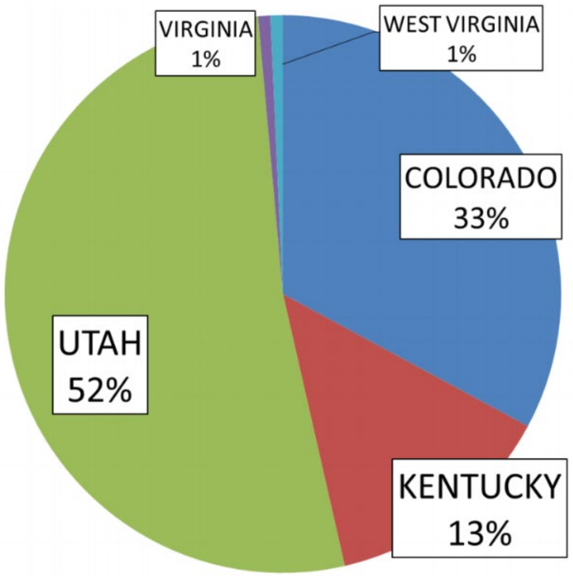
- Coal bumps are defined as a form of dynamic release of energy within the coal or rock mass, generating an audible signal or ground vibration due to the intact rock failure or displacement along a geological structure.
- Coal bursts usually involve sudden and violent failures of the coal and rock mass that eject large amounts of broken material into the face or entry area. Coal bursts typically occur during longwall or pillar extraction, but they can also occur during development.

(Seedsman, 2019)

Coal Bursts in the US (1/2)

- Between 1983 and 2017, 283 bursts were reported to MSHA. Seven of these resulted in a total of nine fatalities; two on longwalls, and seven during five pillar recovery events.
- The long-term declining trend is very pronounced. During the early 1980s, approximately 14 bursts were reported each year, but, in recent years, the number has averaged less than three.

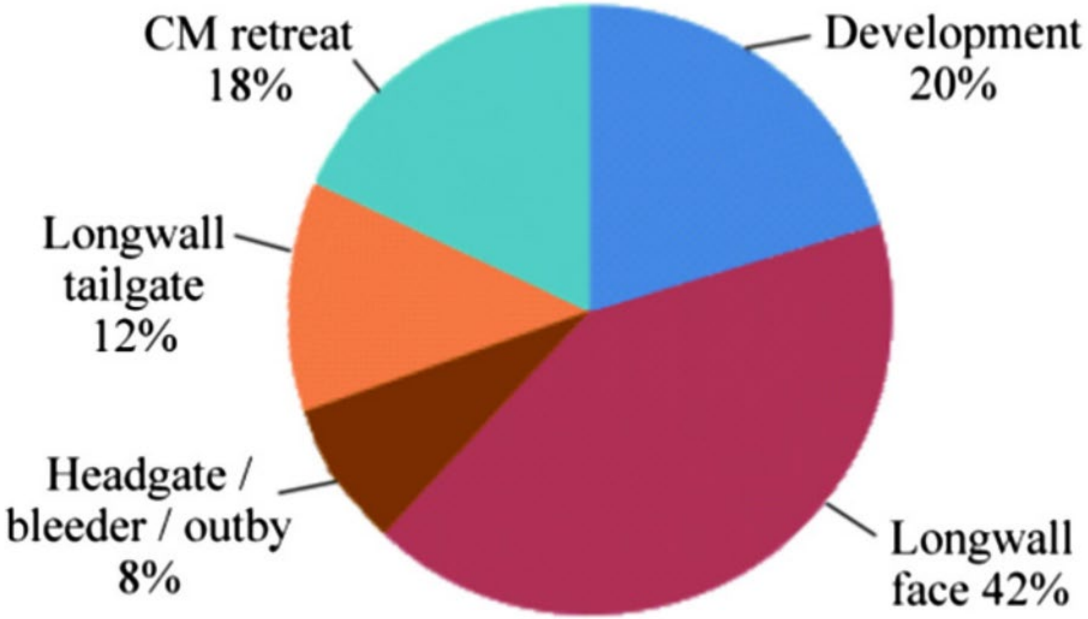




(Mark, 2018)

Coal Bursts in the US (2/2)

- All of these locations are subject to very high stresses, and they are directly affected by mining activity and might be considered likely locations for bursts.



Bursts reported to MSHA, 1983-2015 (Mark, 2018)

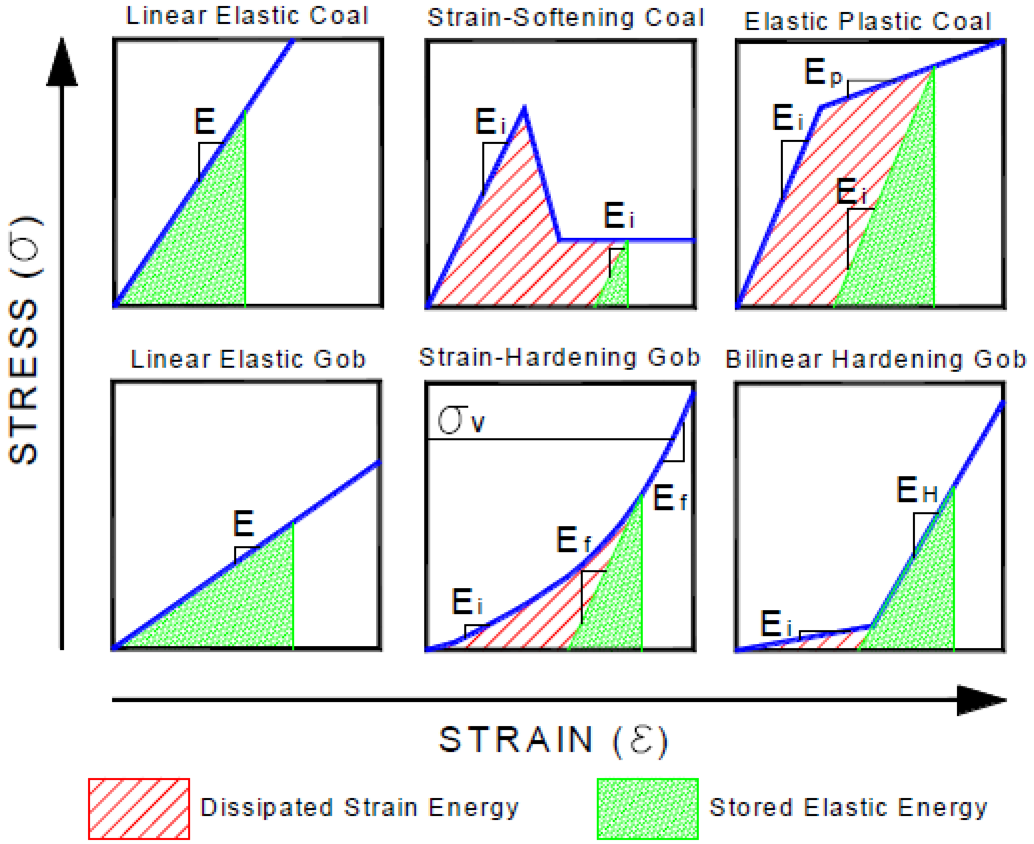
Mechanisms of failure

- For a burst to occur, four conditions must be satisfied:
  - The stress level must be adequate to cause failure for the rock or coal.
  - A state of unstable equilibrium must be present (low friction bedding plane where the potential exists for the coefficient of friction to drop rapidly from its static to dynamic value)
  - A change in the loading system must occur (reduction in confining stresses due to mining activity, or a change in system strength)
  - Sufficient energy must be available in the system for a violent failure (depth of cover)

(Vardar, Zhang, Canbulat, & Hebblewhite, 2018)

Dissipated and Elastic Energy

- Static energy (input): stored strain energy at a given strain level.
  - Total input energy: entire area under the stress strain curve
  - Stored elastic energy: energy stored in the material as elastic energy (recoverable)
  - Dissipated strain energy: dissipated to the environment by the element through rock failure, cracking, friction, and heat.



(Heasley and Tulu, 2018)

Rock Burst Potential Indices (1/2)

- **Strain energy density (SED):** is defined as the maximum elastic strain energy per unit volume that a rock specimen can withstand before it fails under compression.
- If the specimen is assumed to behave in a linear-elastic mode before failure, the strain energy density can be calculated.

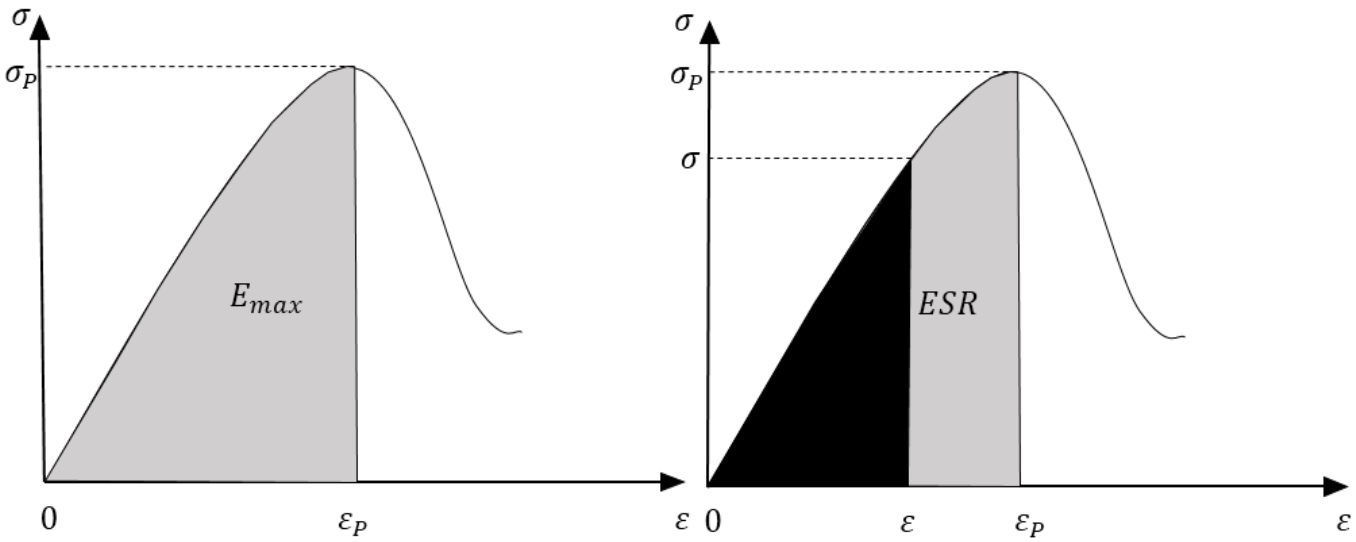
$$SED = \frac{{\sigma_c}^2}{2E}$$

Strain Energy Density (kJ/m^3)	Rock burst hazard potential classification
$\mathrm{SED} \leq 50$	Very low
$50 < \mathrm{SED} \leq 100$	Low
$100 < \mathrm{SED} \leq 150$	Moderate
$150 < \mathrm{SED} \leq 200$	High
$\mathrm{SED} > 200$	Very high

(Wattimena et al. 2012)

Rock Burst Potential Indices (2/2)

- **Burst Potential Index (BPI):** considers the energy storage rate (ESR) and the maximum strain energy (E_{max}). It is defined as the ratio between the effective strain energy stored in the rock mass and the maximum strain energy that the rock can sustain before failure.

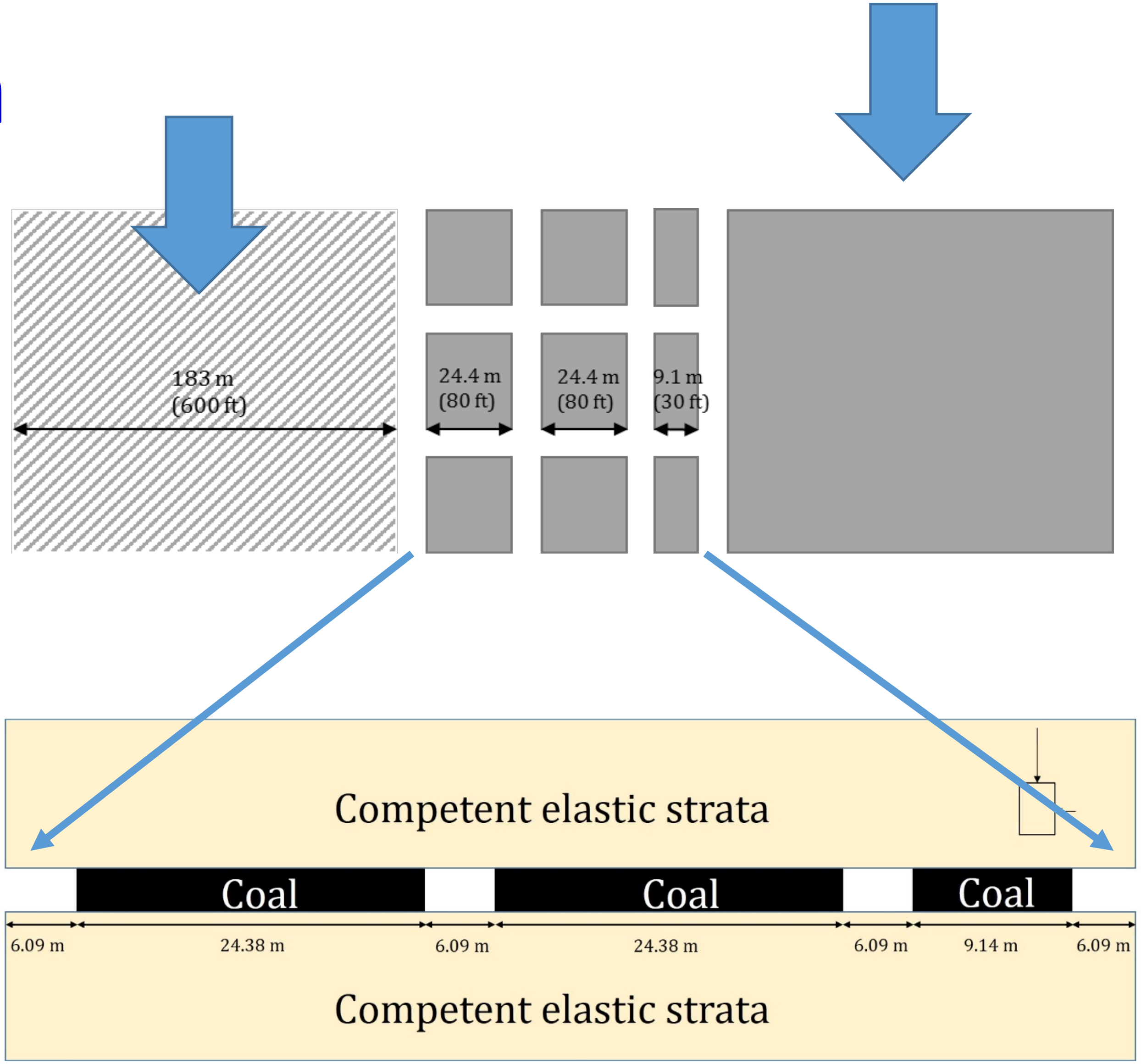


$$BPI = \frac{ESR}{E_{max}} * 100\%$$

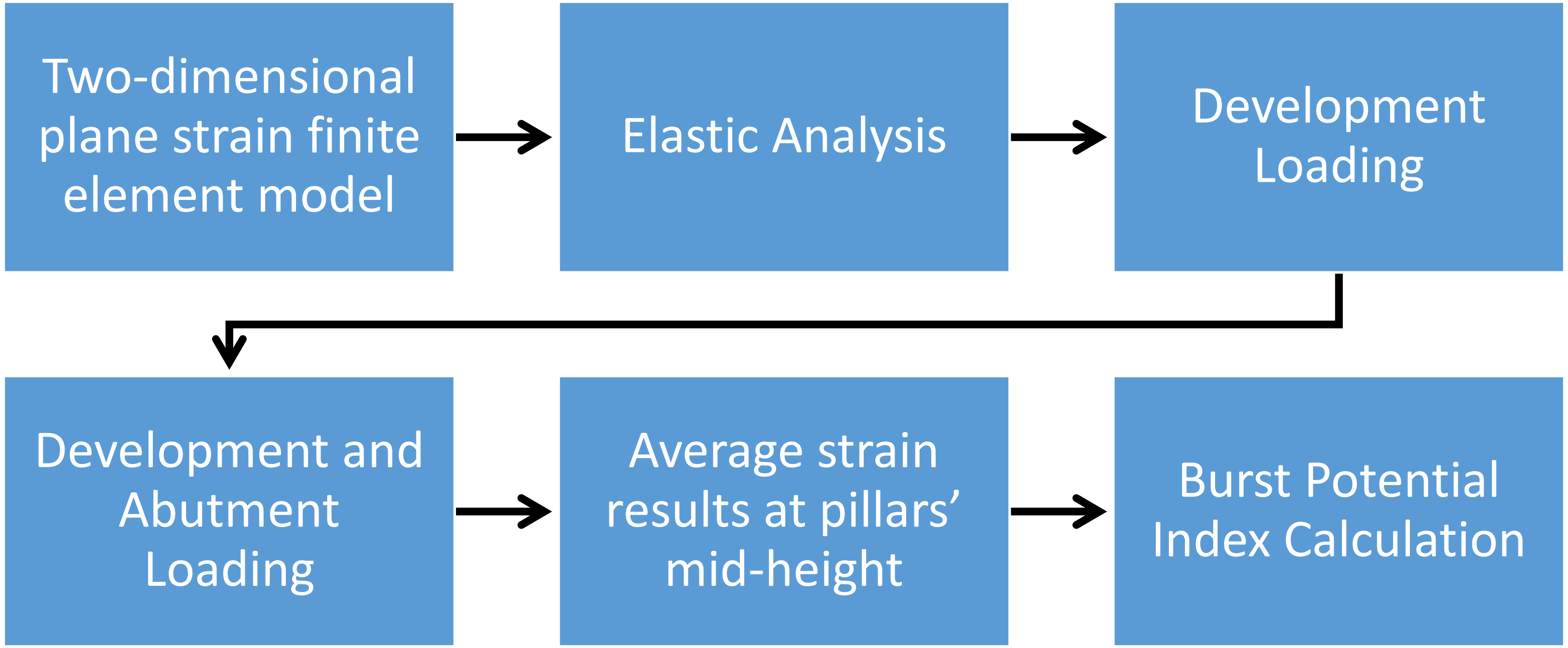
(Mitri et al. 1999)

Case Study Description

- Documented coal burst at an underground longwall coal mining operation in Virginia. (Depth 1900 ft.)
- The coal burst occurred in the center pillar after the left panel was mined and in front of the face of second panel.
- Longwall panel width: 600 ft.
- Gate road system: stable-stable-yield configuration.
  - Entry width: 20 ft.
  - Rib-to-rib stable pillar width: 80 ft.
  - Rib-to-rib yield pillar width: 30 ft.
  - Pillar height: 6 ft.



Methodology



Numerical Modeling and Material Models

- Numerical modeling is used together with burst potential indicators to identify burst-prone pillar geometries at an underground coal mining operation.
- Assumptions:
  - No dissipation of energy during loading (“worst-case scenario”)
  - Roof and floor are competent strata
  - Elastic constitutive model for coal and surrounding rock.

Coal	
Parameter	Value
Unit Weight	0.0196 MN/m³
Young's Modulus	3 GPa (435,000 psi)
Poisson's Ratio	0.25

(Esterhuizen et al. 2010)

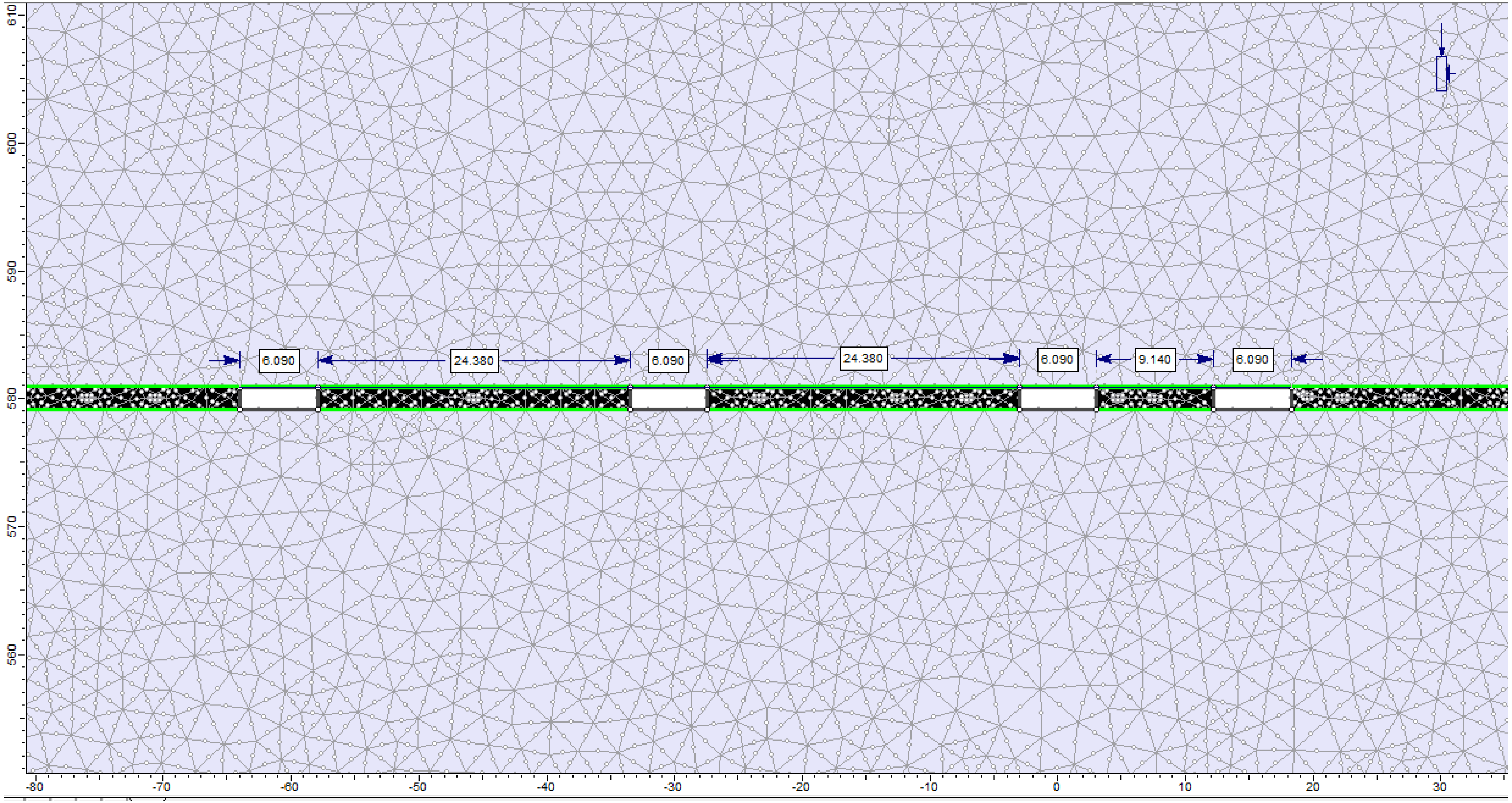
Competent Strata (e.g. Sandstone)	
Parameter	Value
Unit Weight	0.024 MN/m³
Young's Modulus	20.46 GPa (2.96 million psi)
Poisson's Ratio	0.1

(Tulu et al. 2017)

Meshing and Boundary Conditions

- Symmetry through lateral boundary conditions
- Uniform mesh with 107,343 nodes and 53,336 six-nodded triangular elements
- Lateral boundaries restrained in the X direction
- Bottom boundary restrained in the X and Y-direction
- Loaded by the effect of the overburden loading as a gravitational force
- Horizontal stress was set as one-third of the vertical

Mesh Geometry



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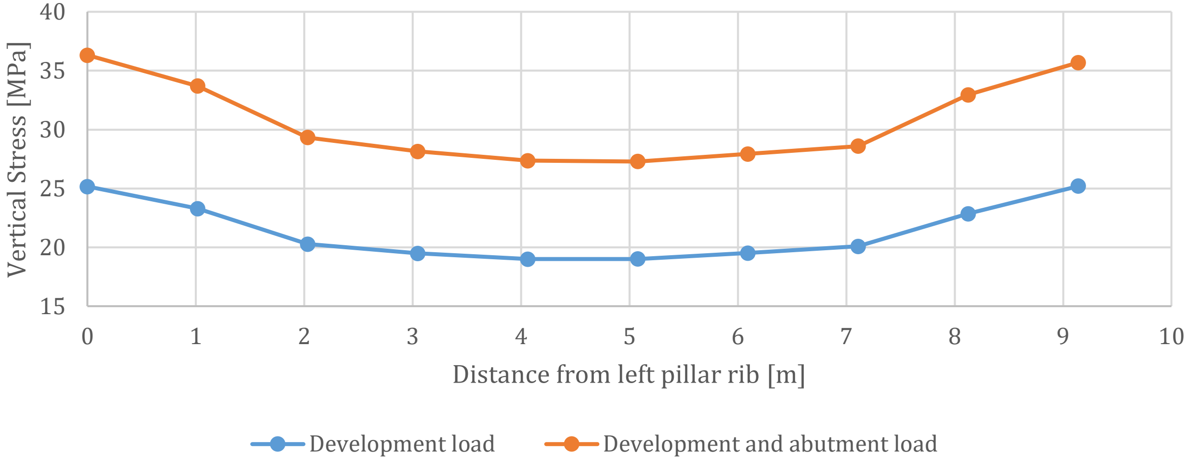
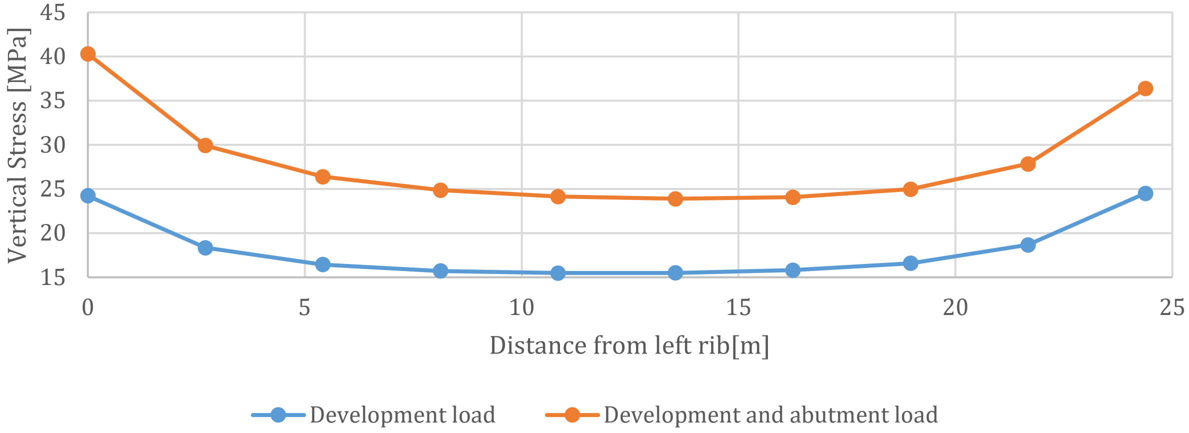
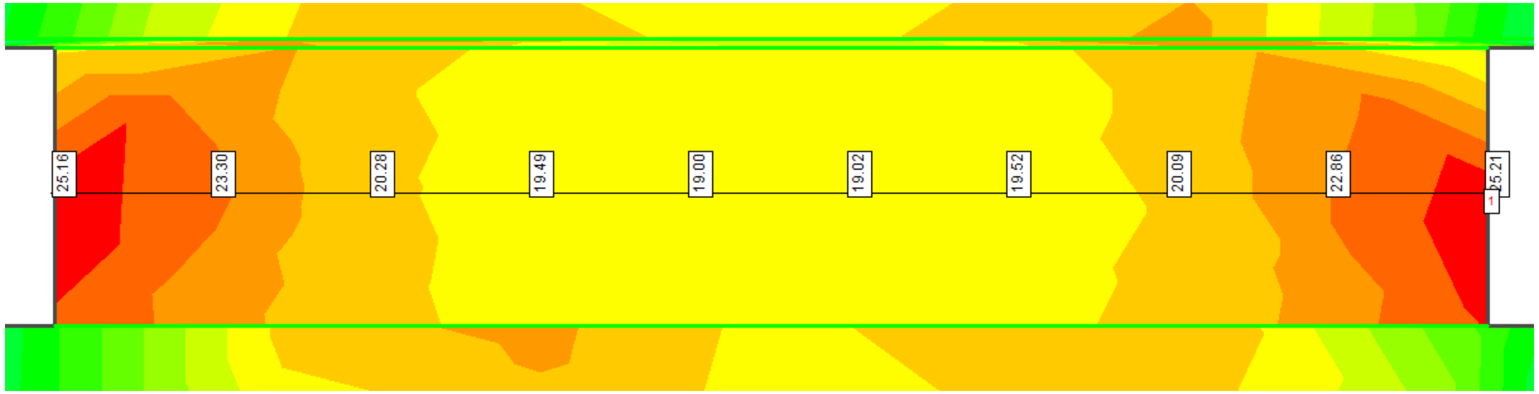
Stress Analysis



Stress distribution along the yield pillar



Stress distribution along the center pillar



Vertical stress distribution along the yield pillar

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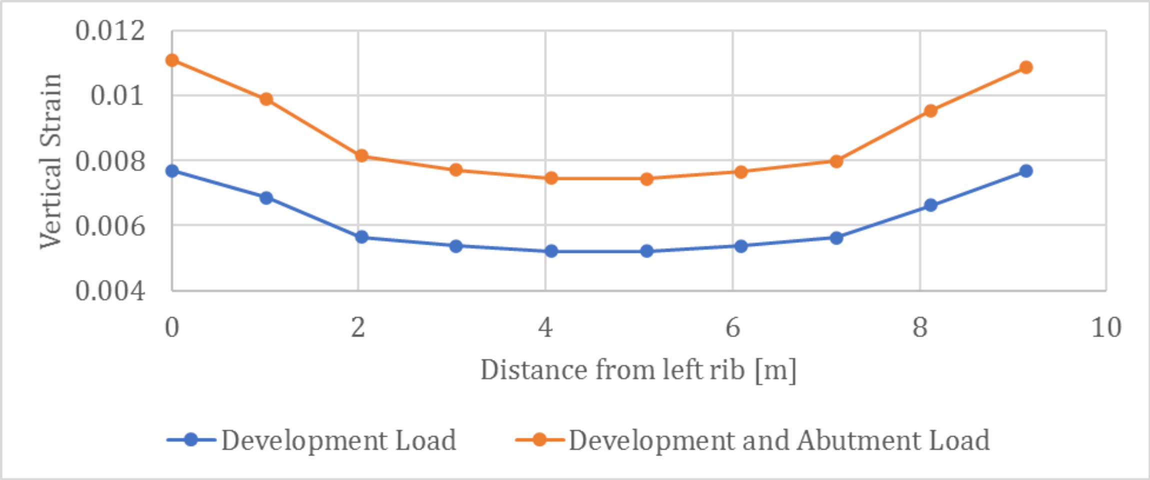
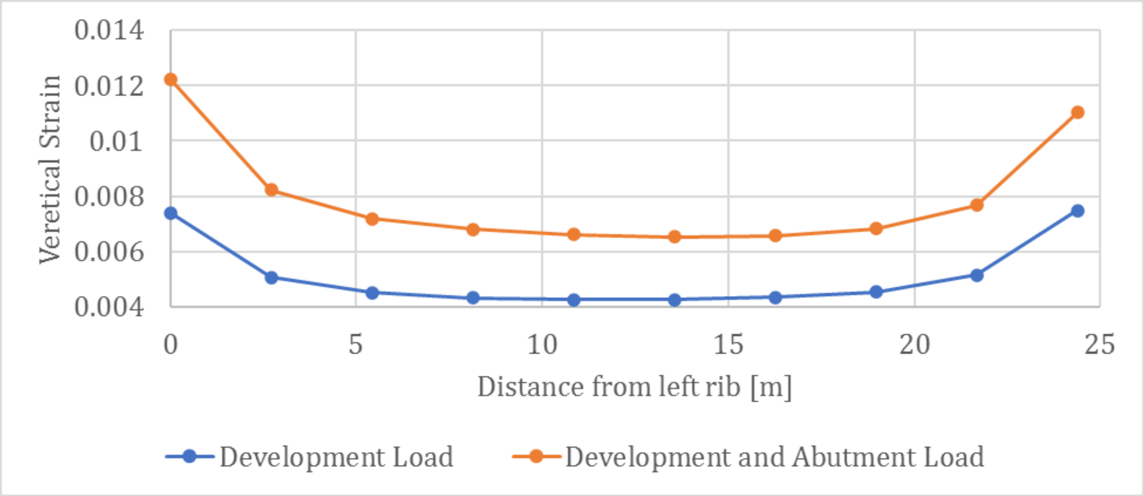
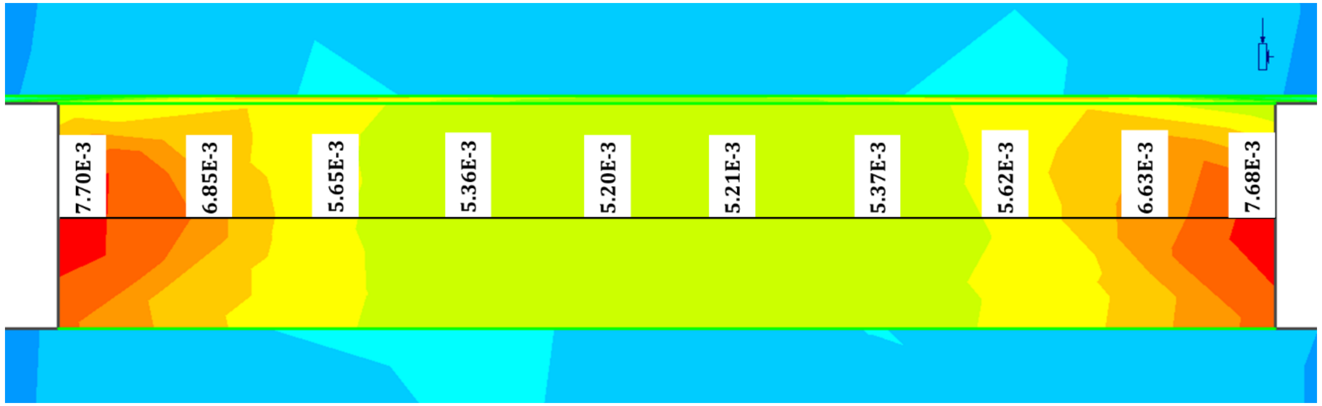
Strain Analysis



Strain distribution along the yield pillar



Strain distribution along the center pillar



Vertical strain distribution along the yield pillar

Results and Discussion

- For each loading condition the modulus of elasticity was varied.
- The average vertical strain was calculated for both the center and yield pillar.

Pillar	Pillar Elastic Modulus (GPa)	Strain due to Development Load ($x10^{-3}$)	Strain due to Development & Abutment Load ($x 10^{-3}$)
Yield Pillar	2	8.89	12.87
	3	6.13	8.78
	4	4.69	6.70
Center Pillar	2	7.58	11.83
	3	5.14	7.99
	4	3.92	6.05

Strain Energy Density

- Index calculated based on the mechanical properties of coal.
- Calculation does not consider pillar dimensions.

Pillar Elastic Modulus (GPa)	Strain Energy Density (kJ/m^3)	Rockburst potential based on Wang and Park (2001)
2	100.0	Low
3	66.7	Low
4	50.0	Very low

Burst Potential Index

- The energy storage rate was calculated using the average vertical strain values
- BPI was estimated during post-processing using the ESR and SED.

Pillar	Pillar Elastic Modulus (GPa)	BPI for Development Load (%)	BPI for Development and Abutment Load (%)
Yield Pillar	2	80	168
	3	86	178
	4	91	186
Center Pillar	2	59	145
	3	63	152
	4	66	158

Discussion

- Yield pillars have a “higher” burst potential; however they are designed to dissipate energy and yield.
- Center pillar exhibits a high BPI and suggests that they may fail; however, the process does not explain why other center pillars did not burst.
- A number of factors have not been considered in this analysis such as the rate of panel advance, dissipation of energy, presence of discontinuities, etc.

BPI for Development Load

- Yield Pillar: 80-91%
- Center Pillar: 59-66%

BPI for Development & Abutment Load

- Yield Pillar: 168-186%
- Center Pillar: 145-158%

Conclusions

- Results indicate that the center pillar in the gate road system developed a burst potential index above 100% for all values of elastic modulus considered.
- The BPI can be used as an indicator of the amount of elastic strain energy the coal (or rock) mass has retained with respect to the maximum energy the rock mass can store before failing. As this does not consider any energy dissipation it may overestimate the burst potential.
- This work presents a first order approximation that demonstrates that if strain is allowed to build up in a pillar of a specific geometry, then the burst potential increases unless steps are taken to mitigate the strain build-up.

This work has been published in the Proceedings of the 40th International Conference on Ground Control in Mining.