Analysis and Measurement of Ground Control Stability in Set-Up Rooms and Gate Roads in an Illinois Longwall Operation

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In cooperation with

American Coal Galatia Mine

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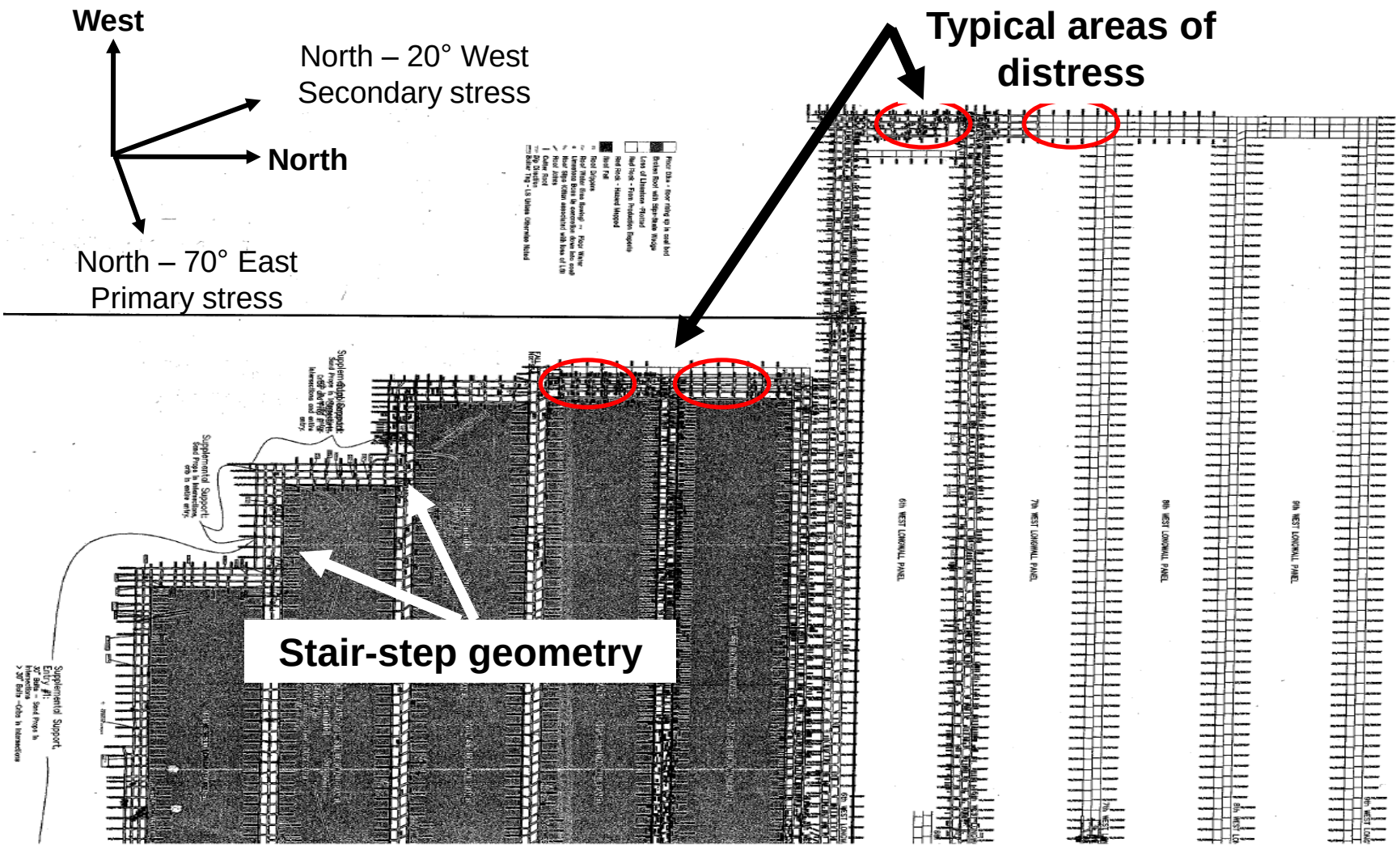
A Few Major Thanks….

- Engineering and operations professional staff at Galatia Mine for their continuous involvement, review of concepts and results and technical support in field implementation.
- Project team listed here and an unsung hero- John Pulliam - backbone of in-mine instrumentation and data gathering activities.
- Illinois Clean Coal Institute of the Department of Commerce and Economic Opportunity for financial support for this important project.
- NIOSH for providing continuous monitoring equipment.

Longwall panels horizontal stress field and typical areas of distress



Observations in set-up rooms areas

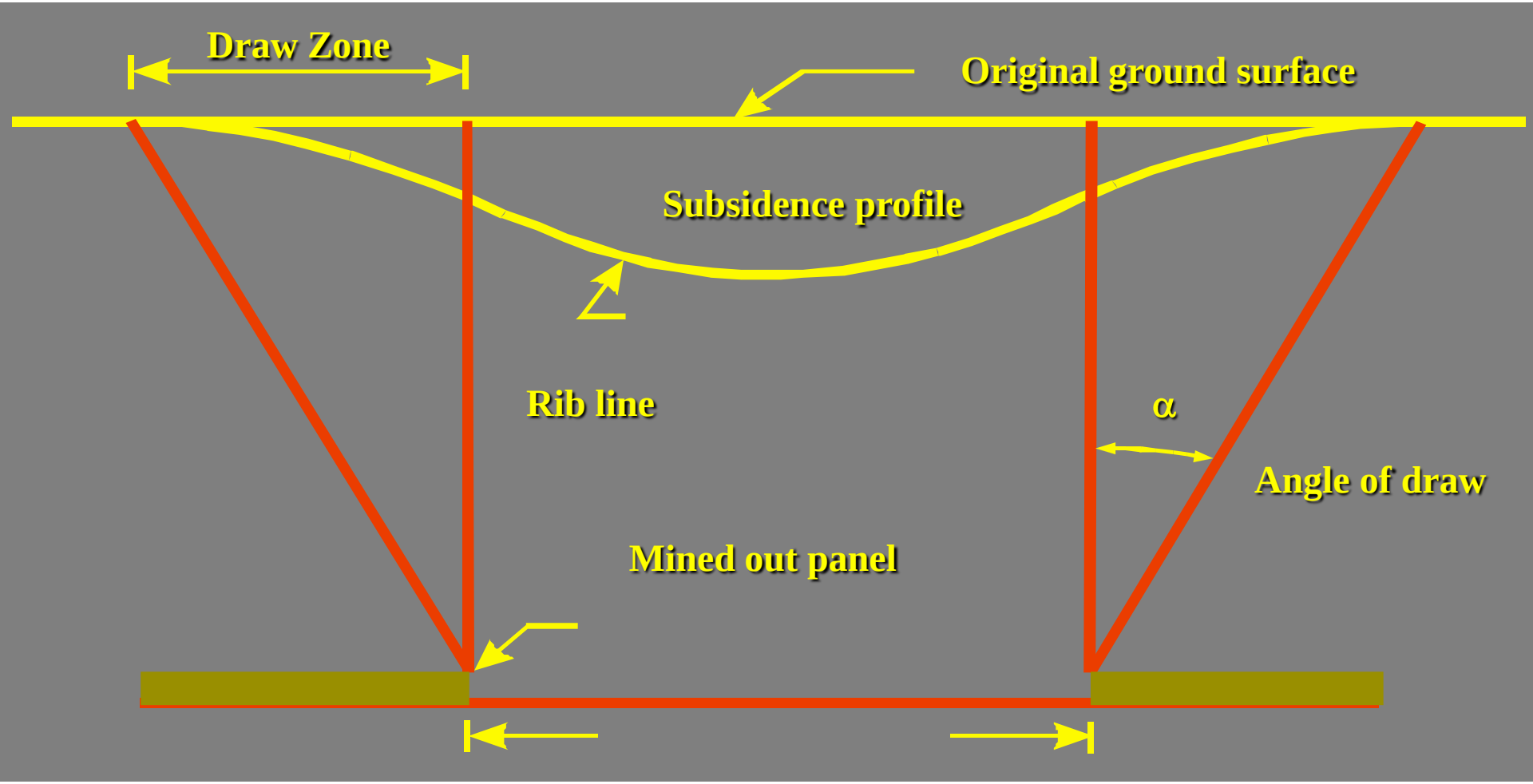
- Loosening of roof trusses
- Shearing of roof bolts along the head.
- Excessive roof to floor convergence.
- Cutter roof and roof failures
- Water “drippers” from roof
- Crib and supplementary supports movements
- Floor heave

Project Goals

- Identify mechanisms of stress and instability in set-up rooms and methods for improvement.
- Improve ground control in set-up rooms through alternate geometries and support systems.
- Improve ground control in development entries through alternate geometries and supports.

Identify and Test Mechanisms of Instability in Set Up Rooms

Instability mechanisms hypotheses: zones of movement around mined-out areas



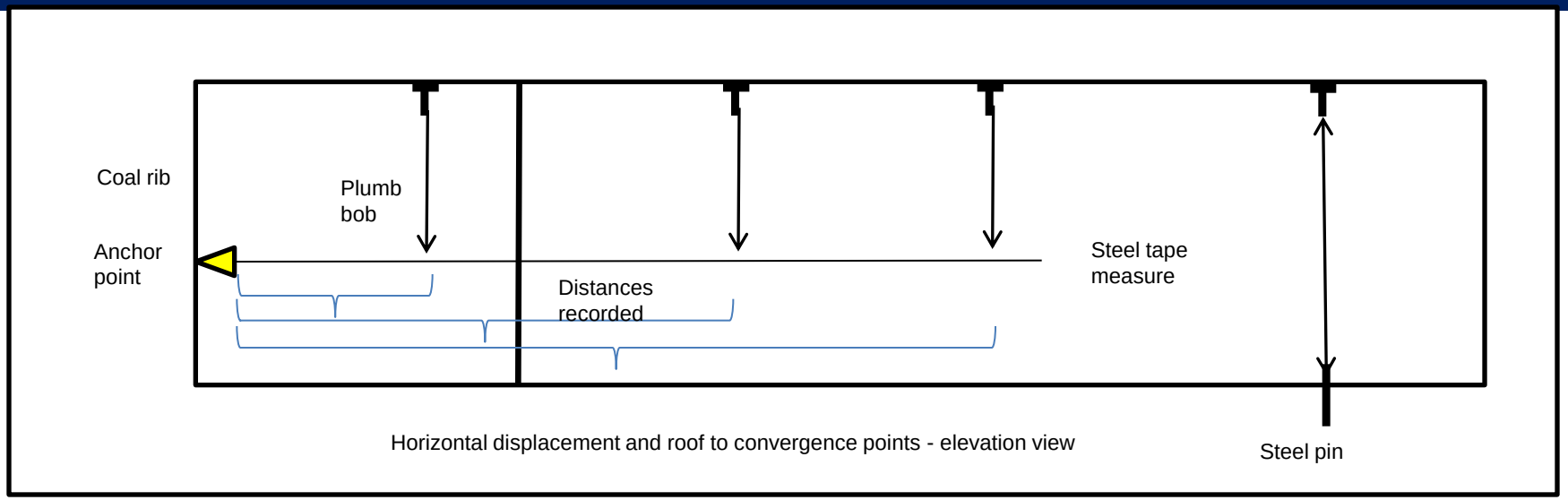
Tools Used

- Field measurements involving:
- Roof-floor convergence
- Differential displacement of different pillars
- Distortion of supports (cribs) and roof bolt rosettes.
- Visual observations of distress in roof, ribs, and pillars

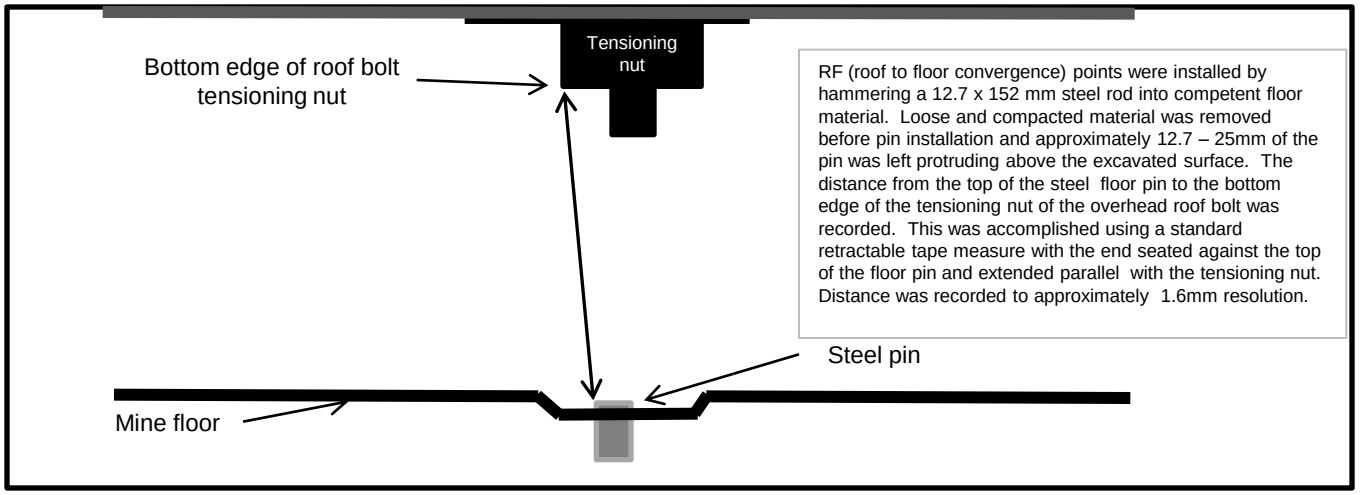
- Numerical modeling to:
- Develop a structural model of the current mining system.
- Determine stress and displacement fields and stability for alternate mining geometries with longwall face advance.

- Utilize Alternate Pillar Geometry Concepts
- Vary pillar sizes within mining areas based on expected stresses.
- Demonstrated the concepts at two room and pillar mines in Illinois.

Horizontal displacement and roof-to-floor convergence point installation

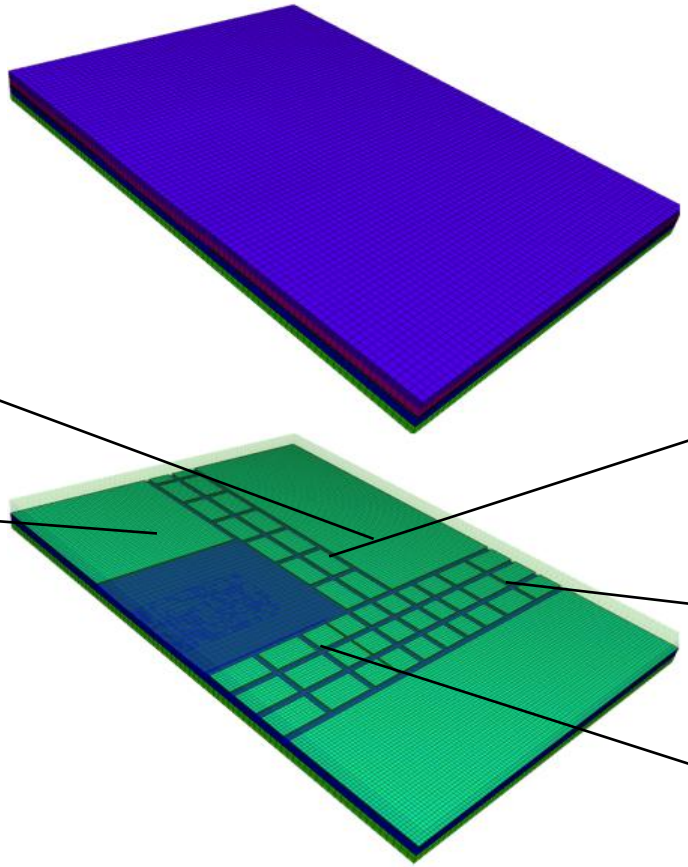


Horizontal displacement and roof to convergence points - elevation view



RF (roof to floor convergence) points were installed by hammering a 12.7 x 152 mm steel rod into competent floor material. Loose and compacted material was removed before pin installation and approximately 12.7 – 25mm of the pin was left protruding above the excavated surface. The distance from the top of the steel floor pin to the bottom edge of the tensioning nut of the overhead roof bolt was recorded. This was accomplished using a standard retractable tape measure with the end seated against the top of the floor pin and extended parallel with the tensioning nut. Distance was recorded to approximately 1.6mm resolution.

Developed 3-D numerical model for set-up entries stability analysis



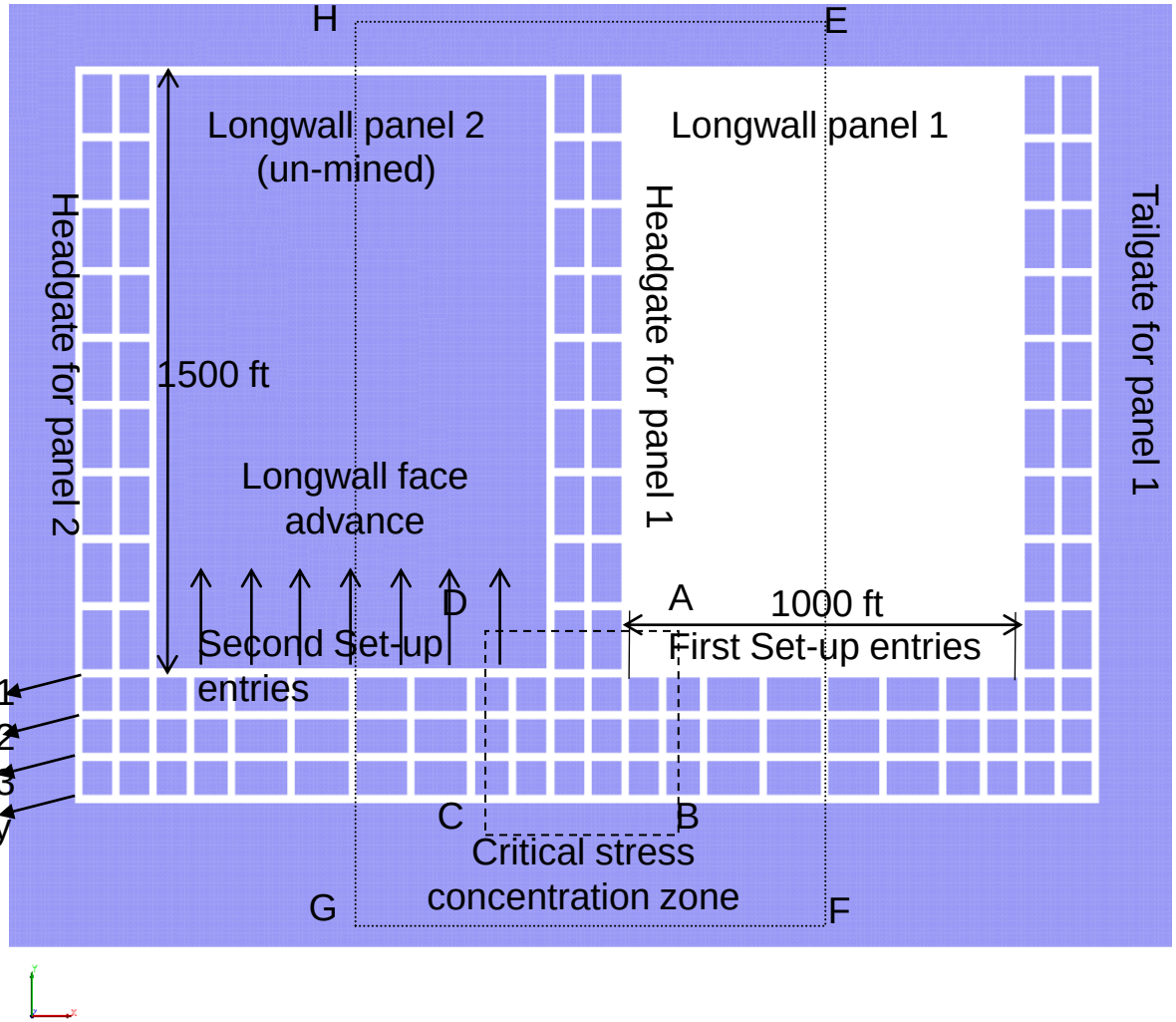
Simulation of expected areas of instability when mining two adjacent longwall panels

1) Develop set-up room, headgate and tailgate for panel one.

2) Advance Longwall face in panel one in 100-ft increment to 500-ft.

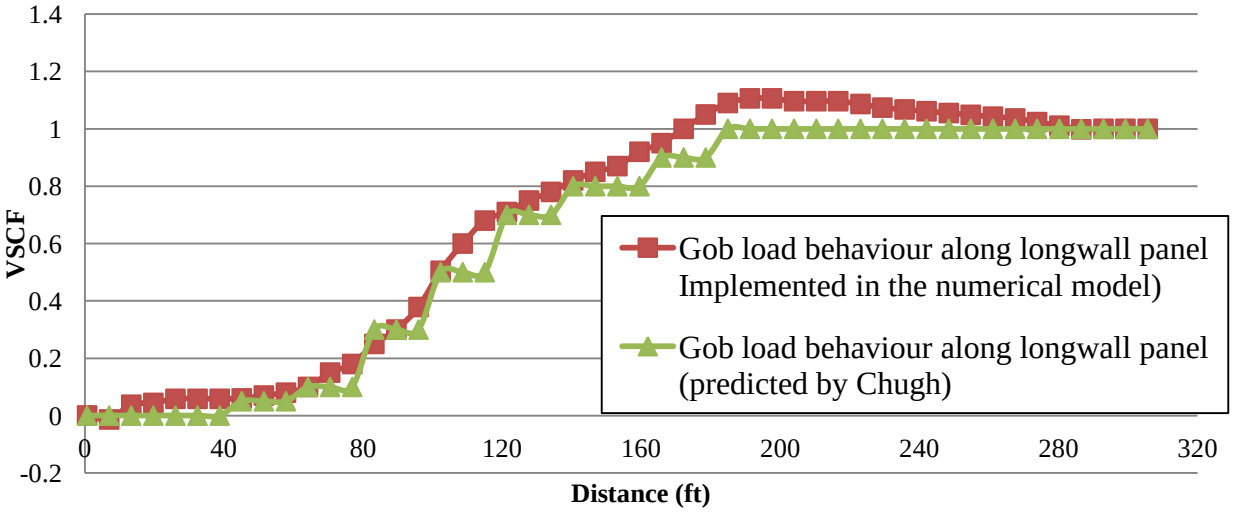
3) Develop the set-up room and headgate for panel two.

4) Advance longwall face in panel two in 100-ft increment to 500-ft.

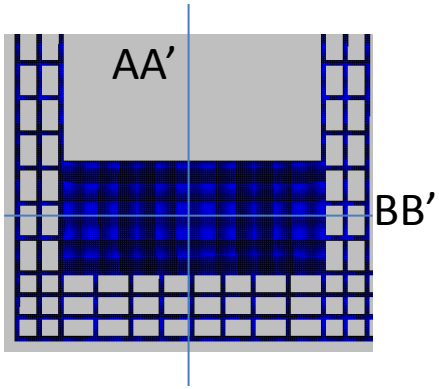


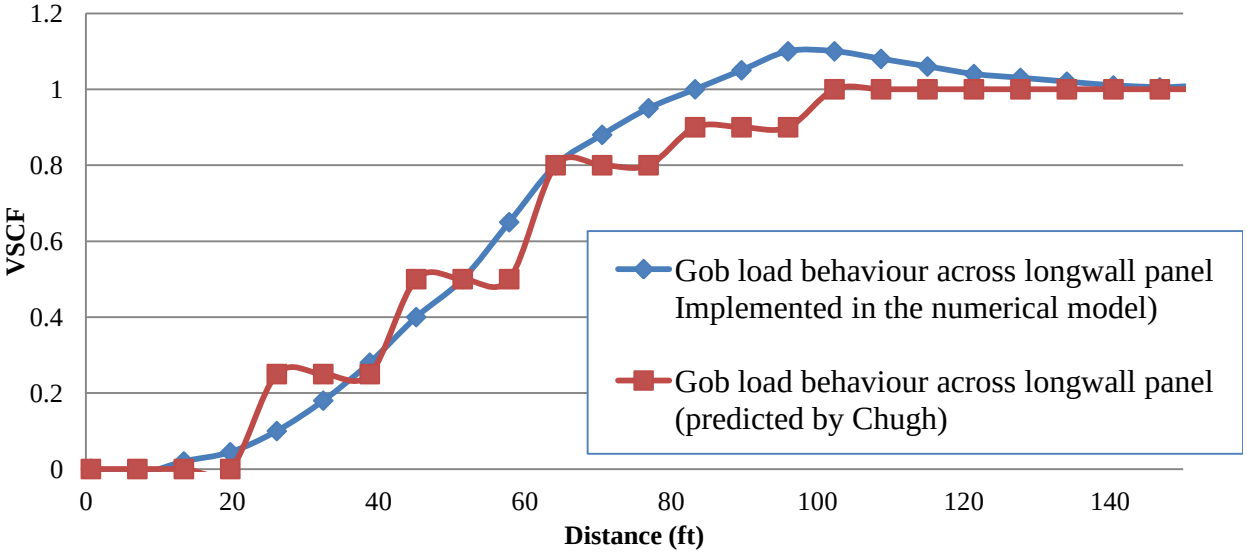
Modeling of gob behavior

VSCF vs. cross section AA' after 500ft face advance

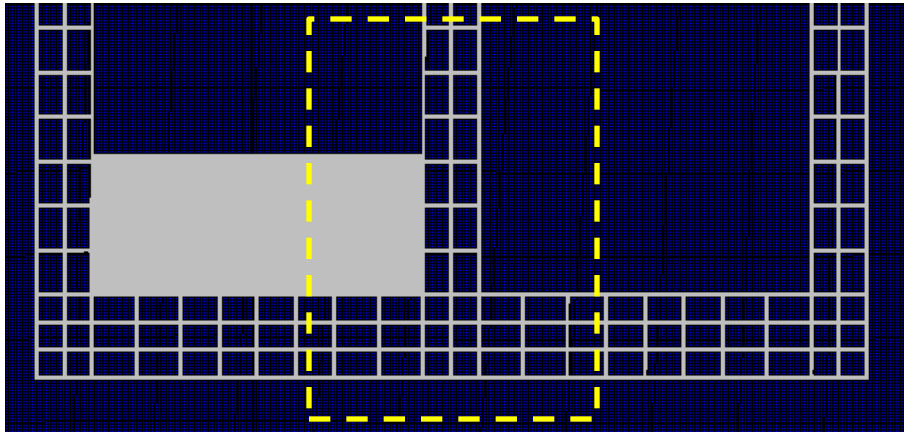


VSCF vs. cross section BB' after 500ft face advance

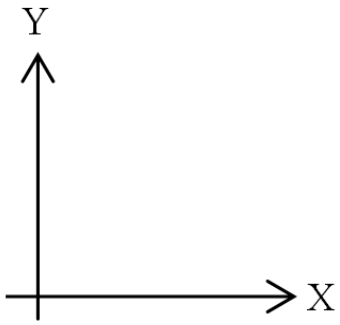


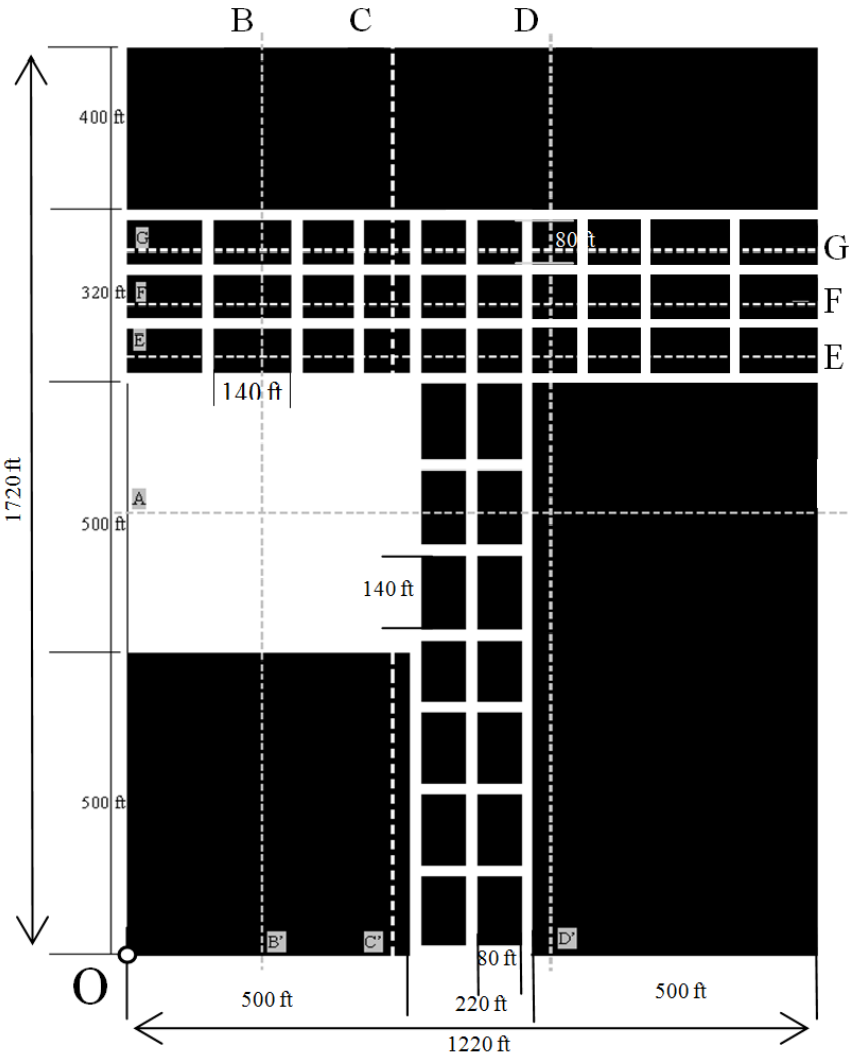


Plan view of the area modeled for the typical 4-entry set-up room longwall panel geometry - Geometry 0



Area modeled





Definition of different stress concentration factors in stress analysis

- Stress Concentration Factor

  Vertical Stress Concentration Factor (VSCF) = $\frac{\sigma_v}{S_v}$

  Horizontal Stress Concentration Factor (HSCF) = $\frac{\sigma_h}{S_v}$

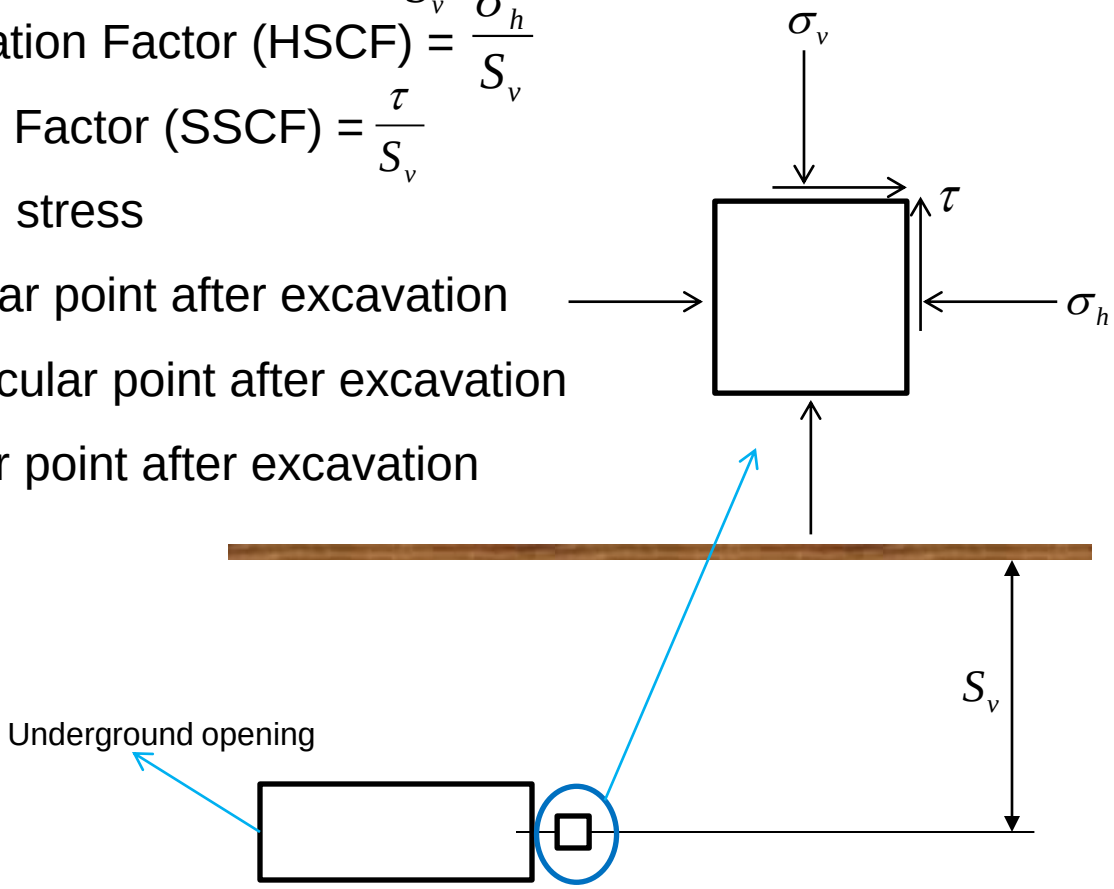
  Shear Stress Concentration Factor (SSCF) = $\frac{\tau}{S_v}$

S_v : Pre-mining applied vertical stress

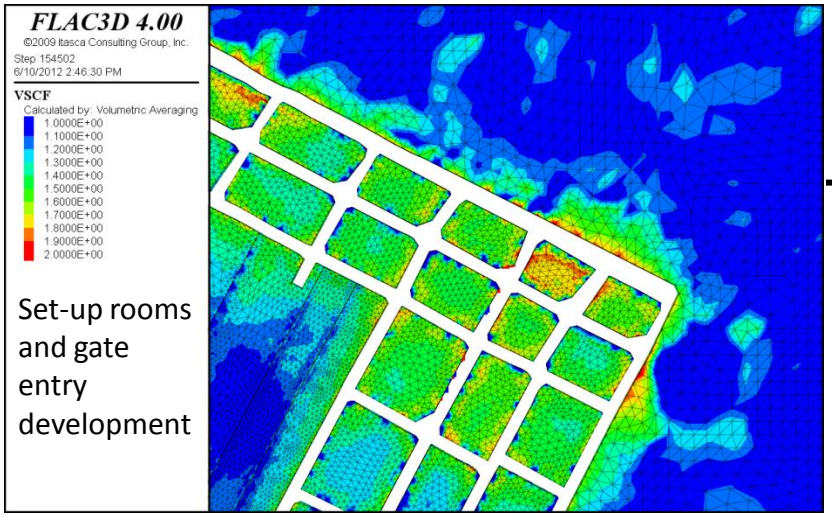
σ_v : Vertical stress at a particular point after excavation

σ_h : Horizontal stress at a particular point after excavation

τ : Shear stress at a particular point after excavation



VSCF distribution for field longwall geometry with face advance



Set-up rooms and gate entry development

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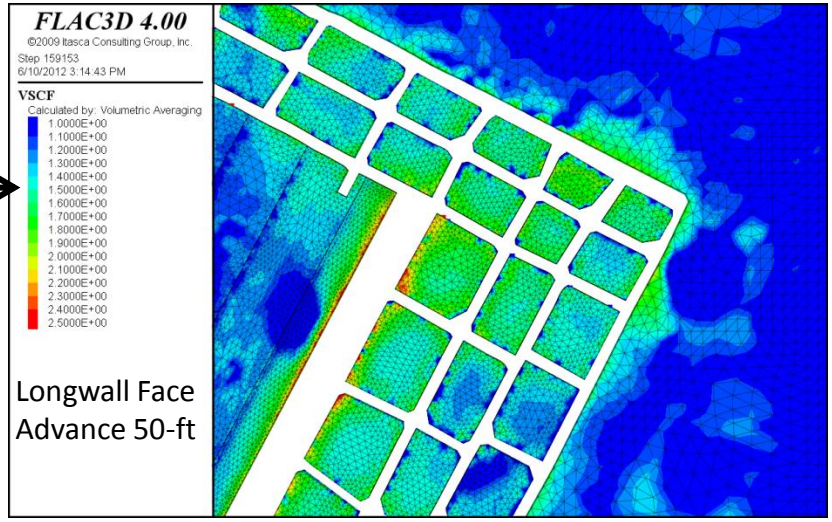
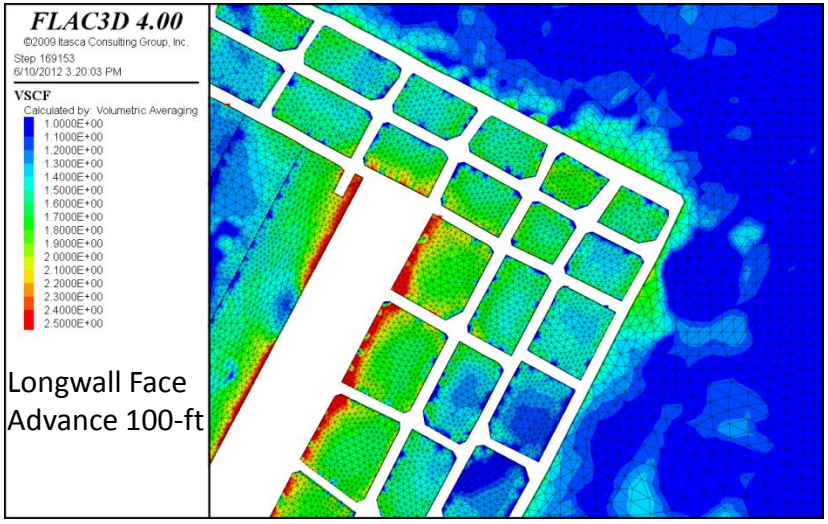
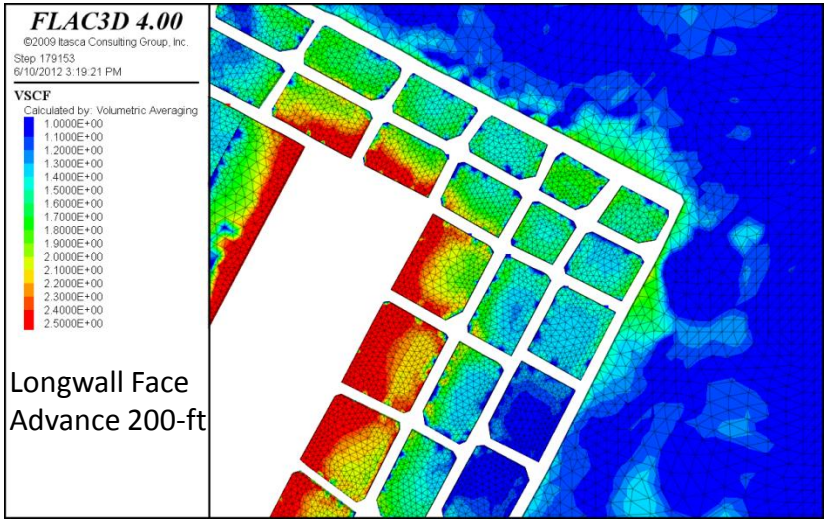


Longwall Face Advance 50-ft

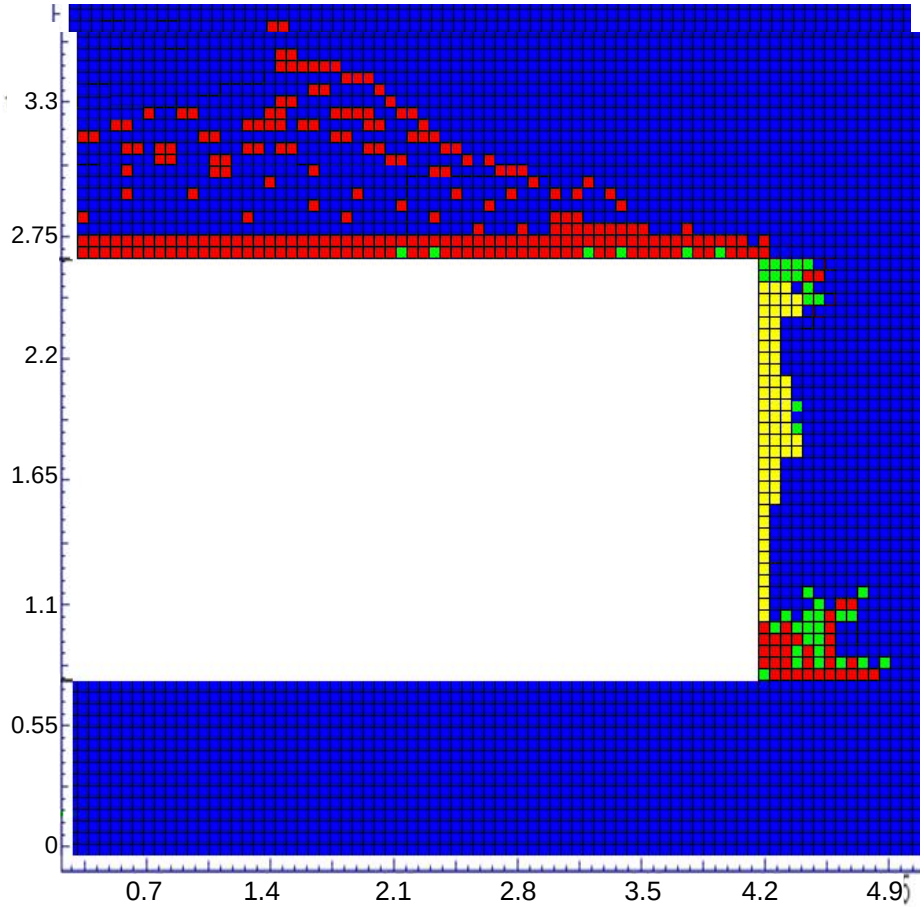


Longwall Face Advance 100-ft

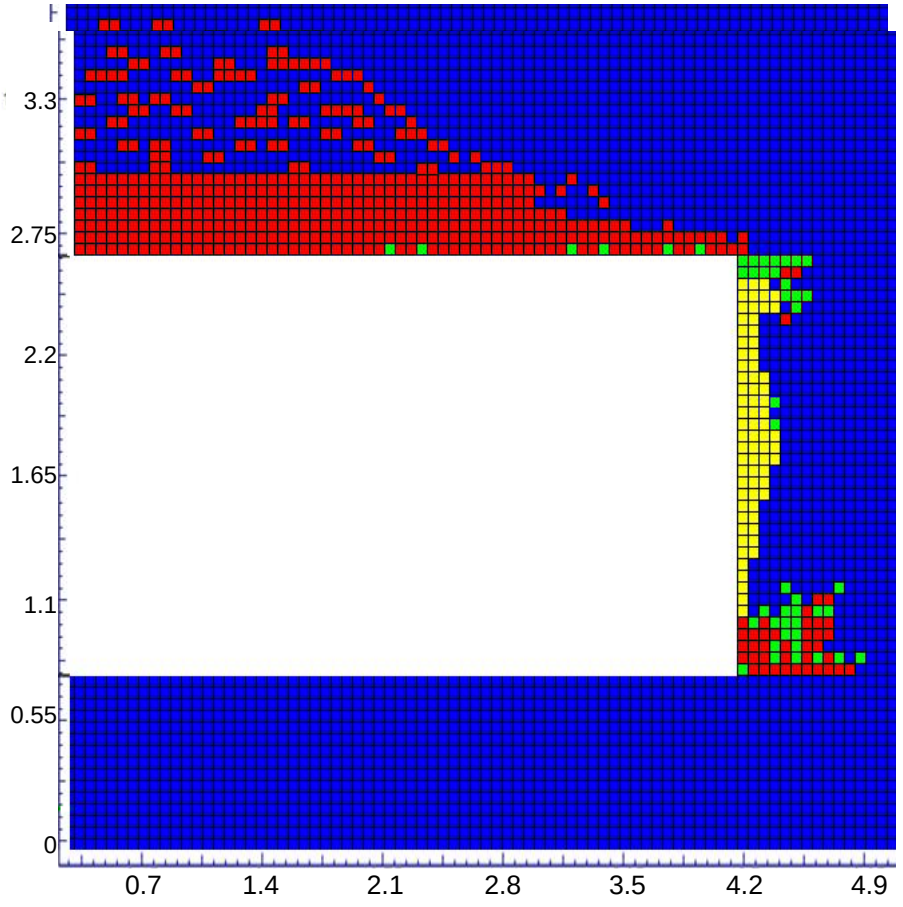


Longwall Face Advance 200-ft

Progressive yielded elements for different vertical stresses around an intersection



Vertical stress= 2.2 MPa

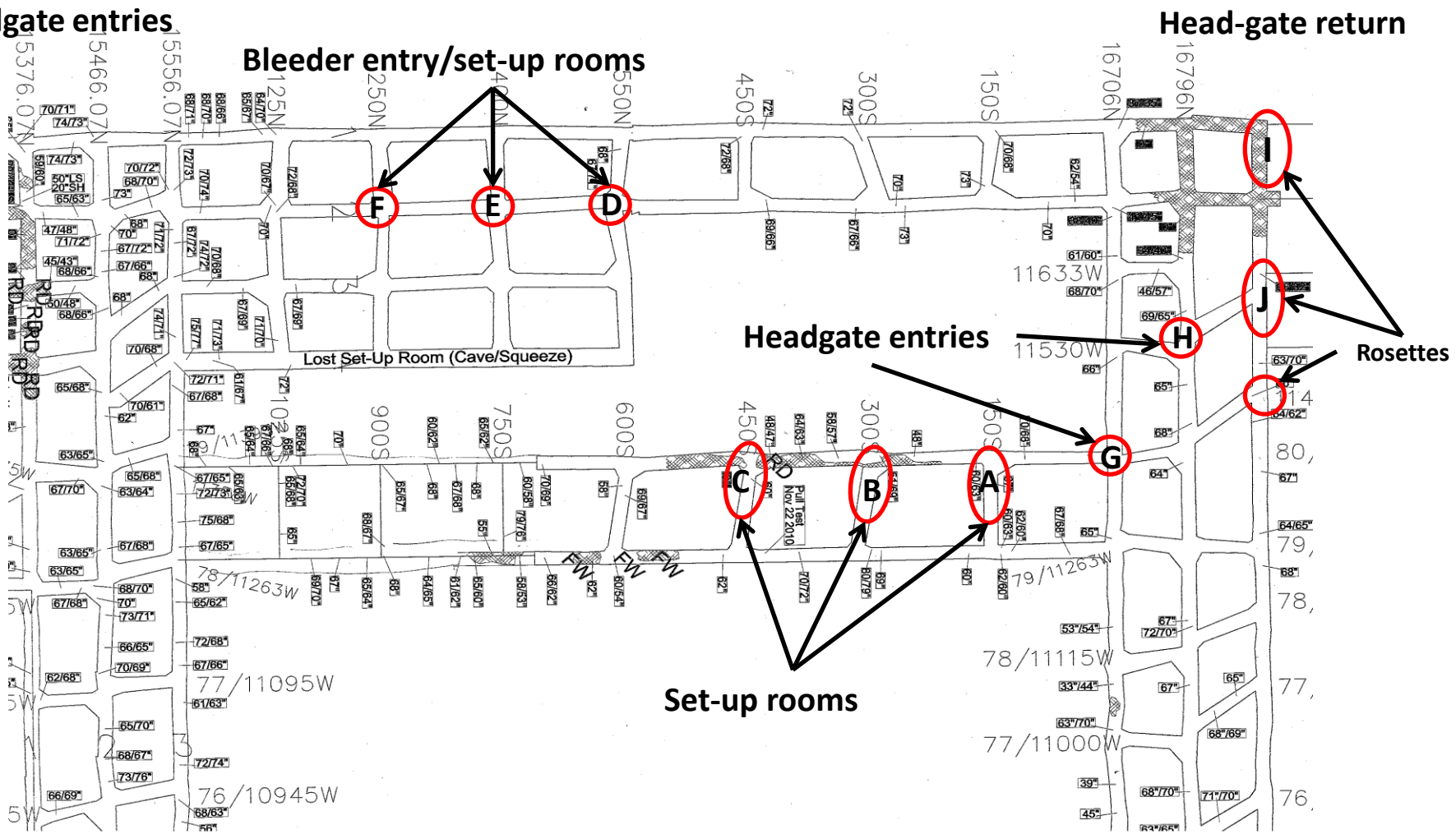


Vertical stress = 2.5 MPa

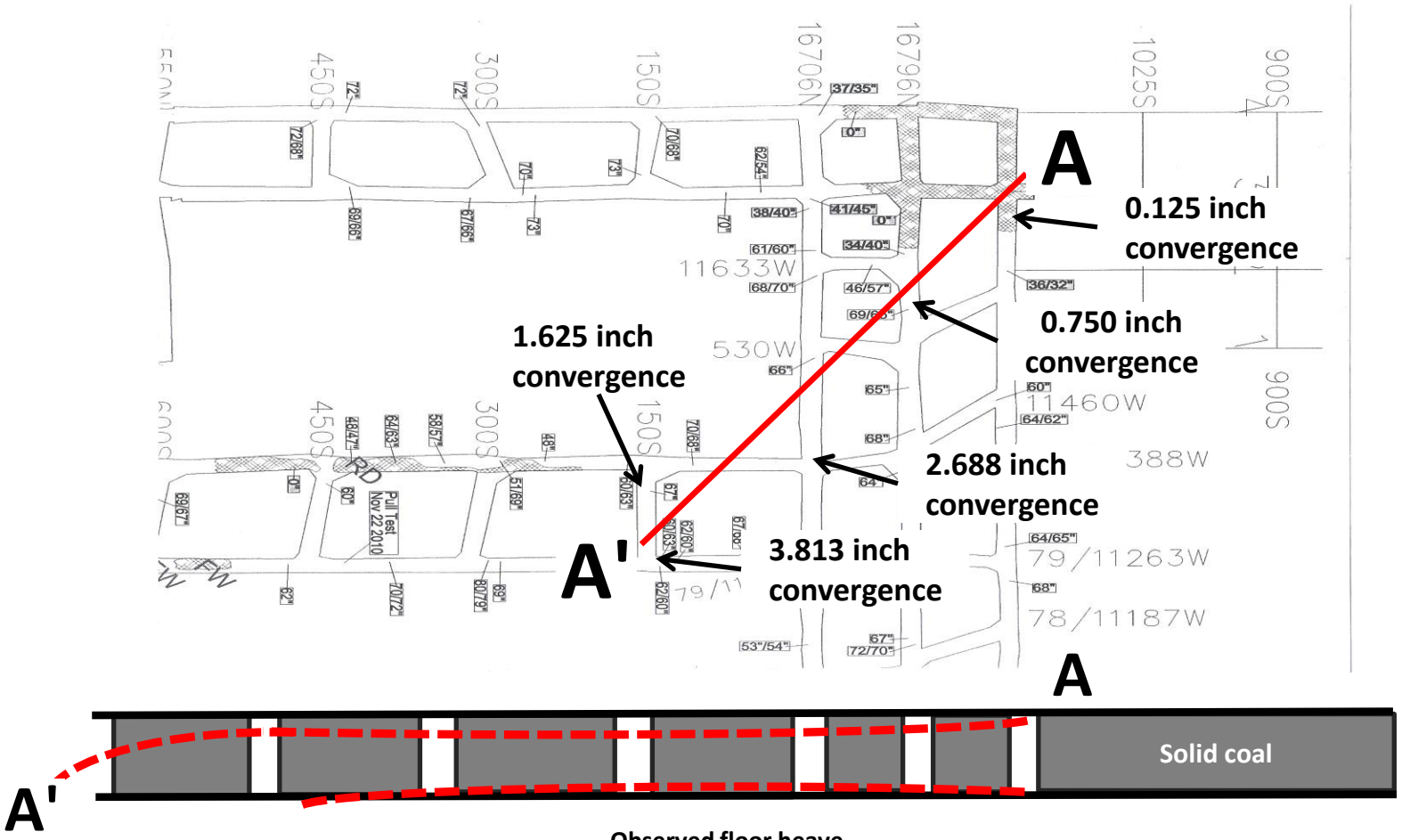
- Shear failure
- Tension failure
- Combination of Shear and Tension failure

Studies at Mine 1

Set-up room monitoring locations



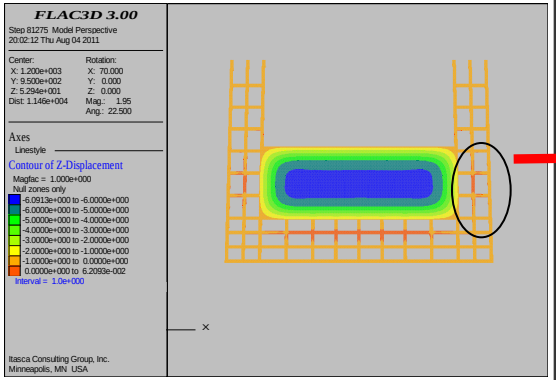
Roof-to-floor convergence across cross-section A-A’ 16 days after longwall start-up

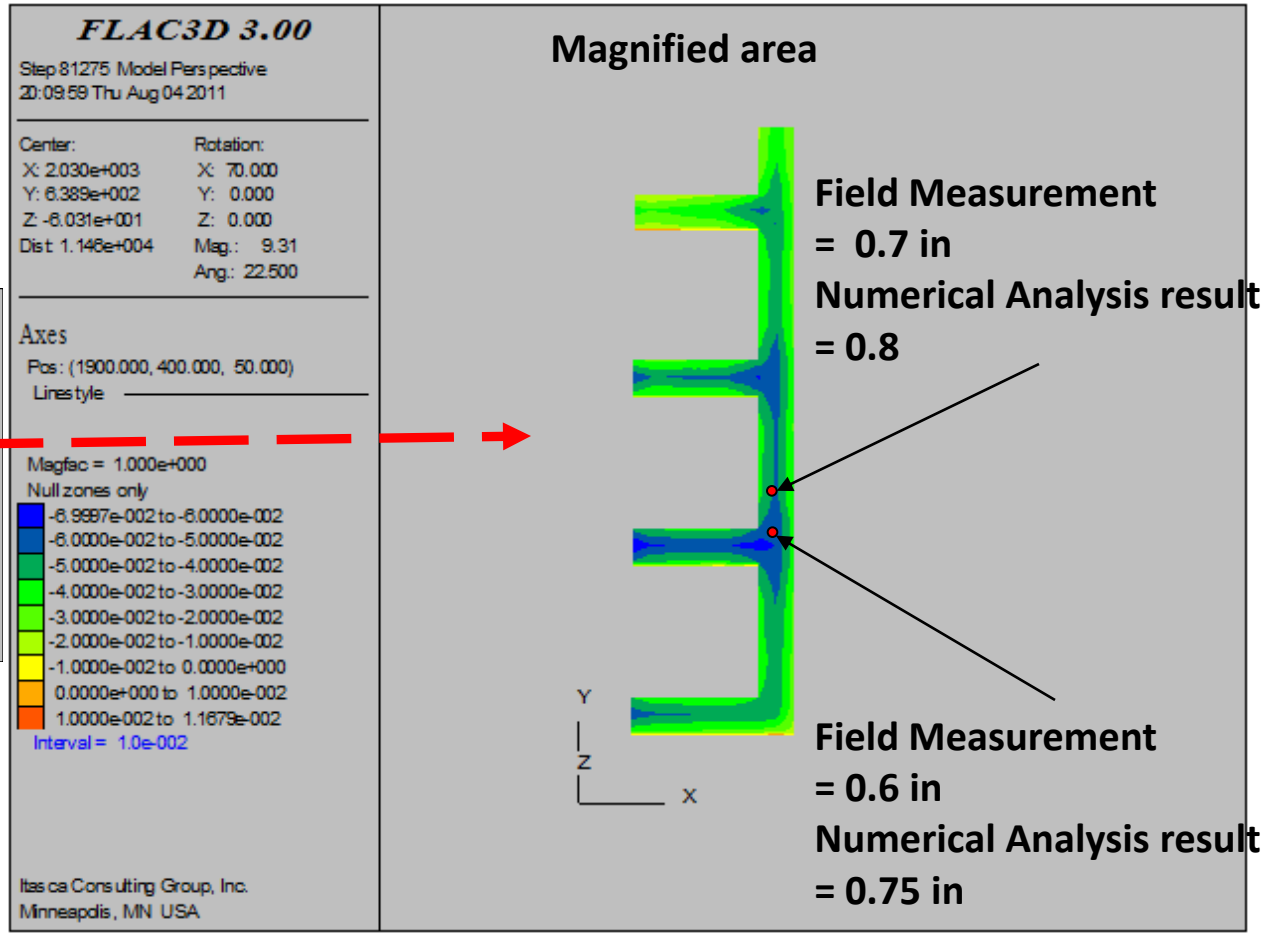


Horizontal movement in set-up rooms 16 days after longwall start-up – black outline represents day 0, red indicates day 16 position

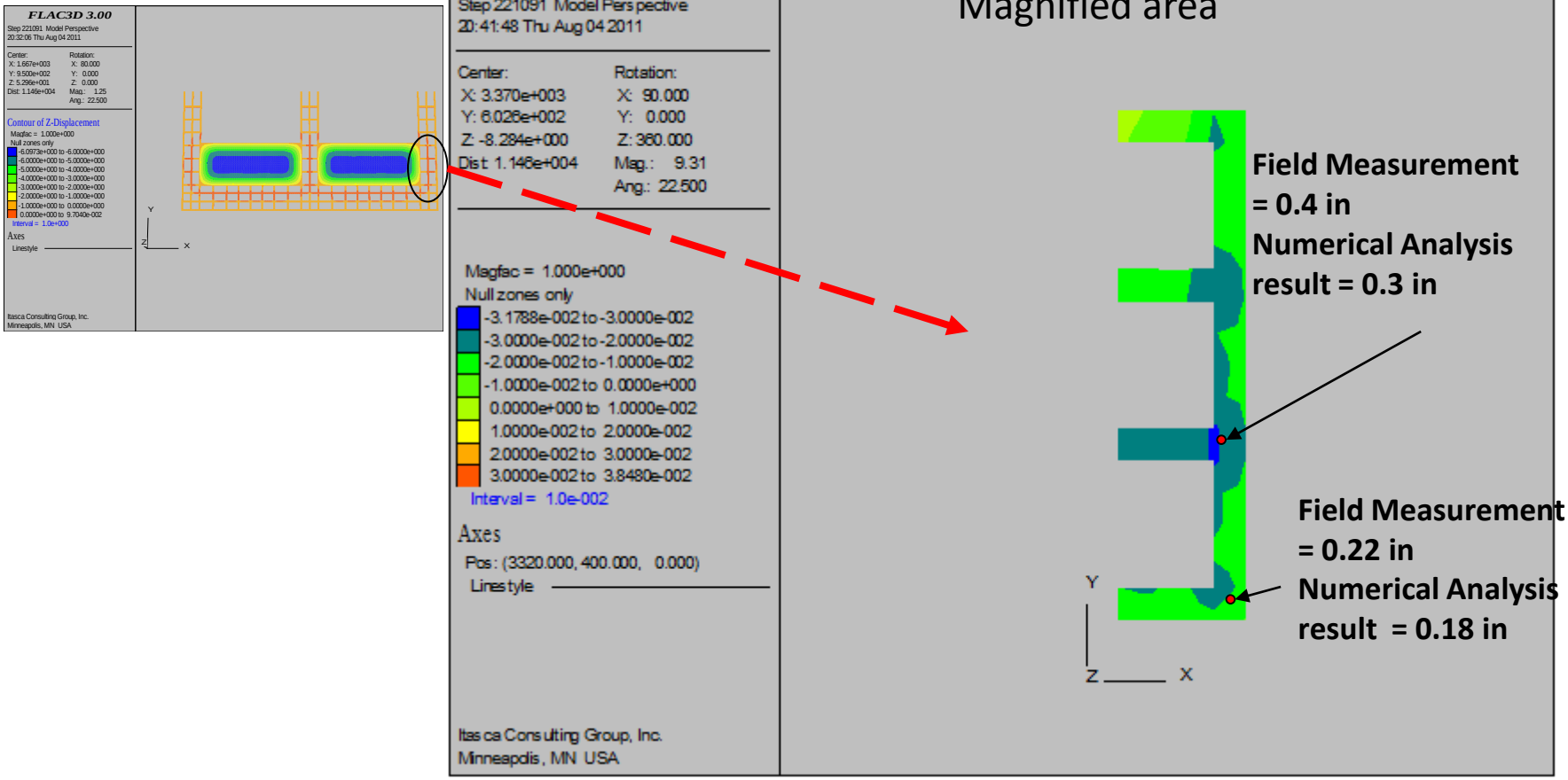
Hypothesized movements that occurred in set-up rooms and development entries after longwall panel advance

Field data for convergence in set-up entries vs. numerical analysis results (Geometry 0)

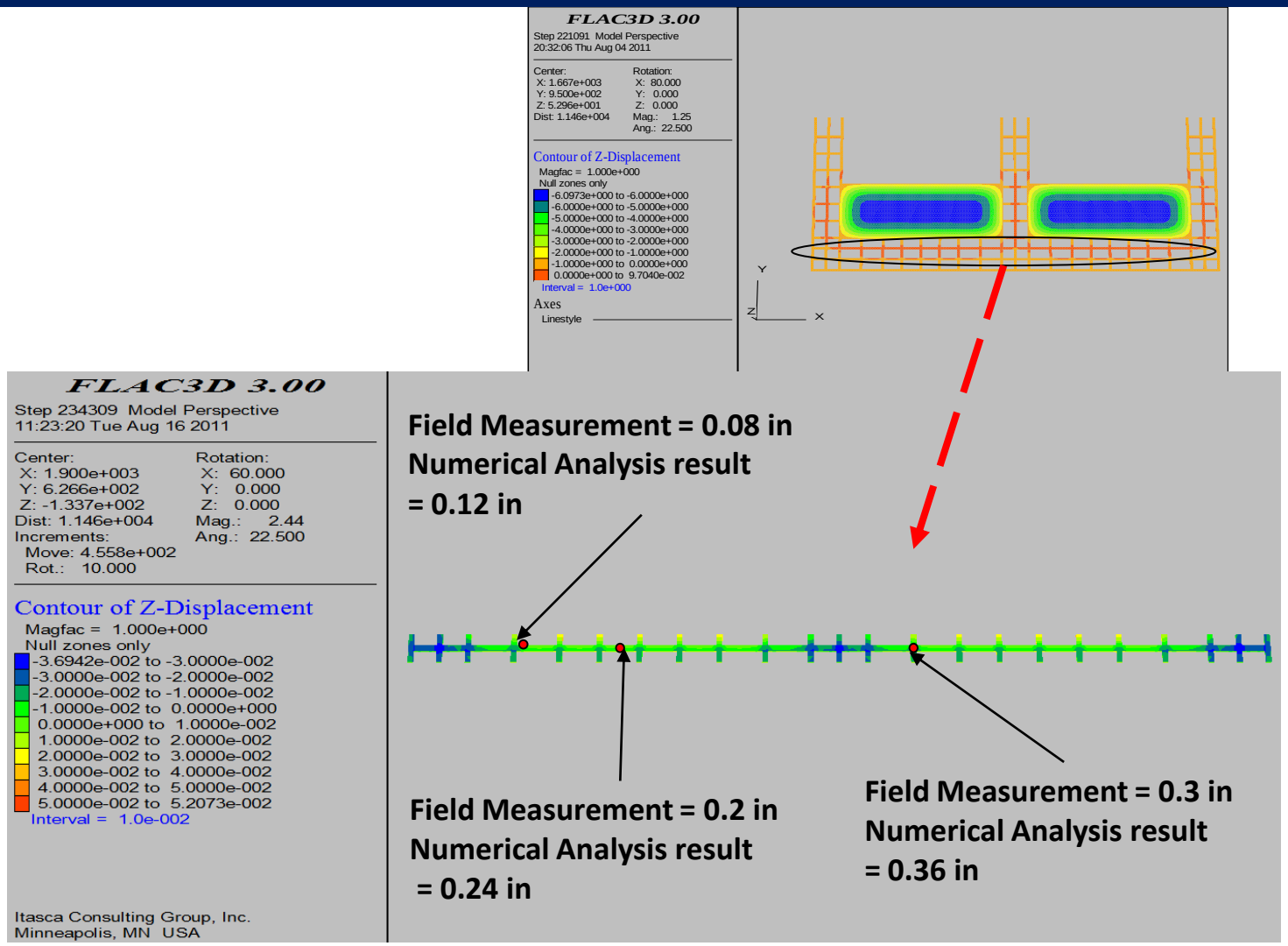




Field data for convergence in set-up entries vs. numerical analysis results (Geometry 0)



Field data for convergence in set-up entries vs. numerical analysis results (Geometry 0)



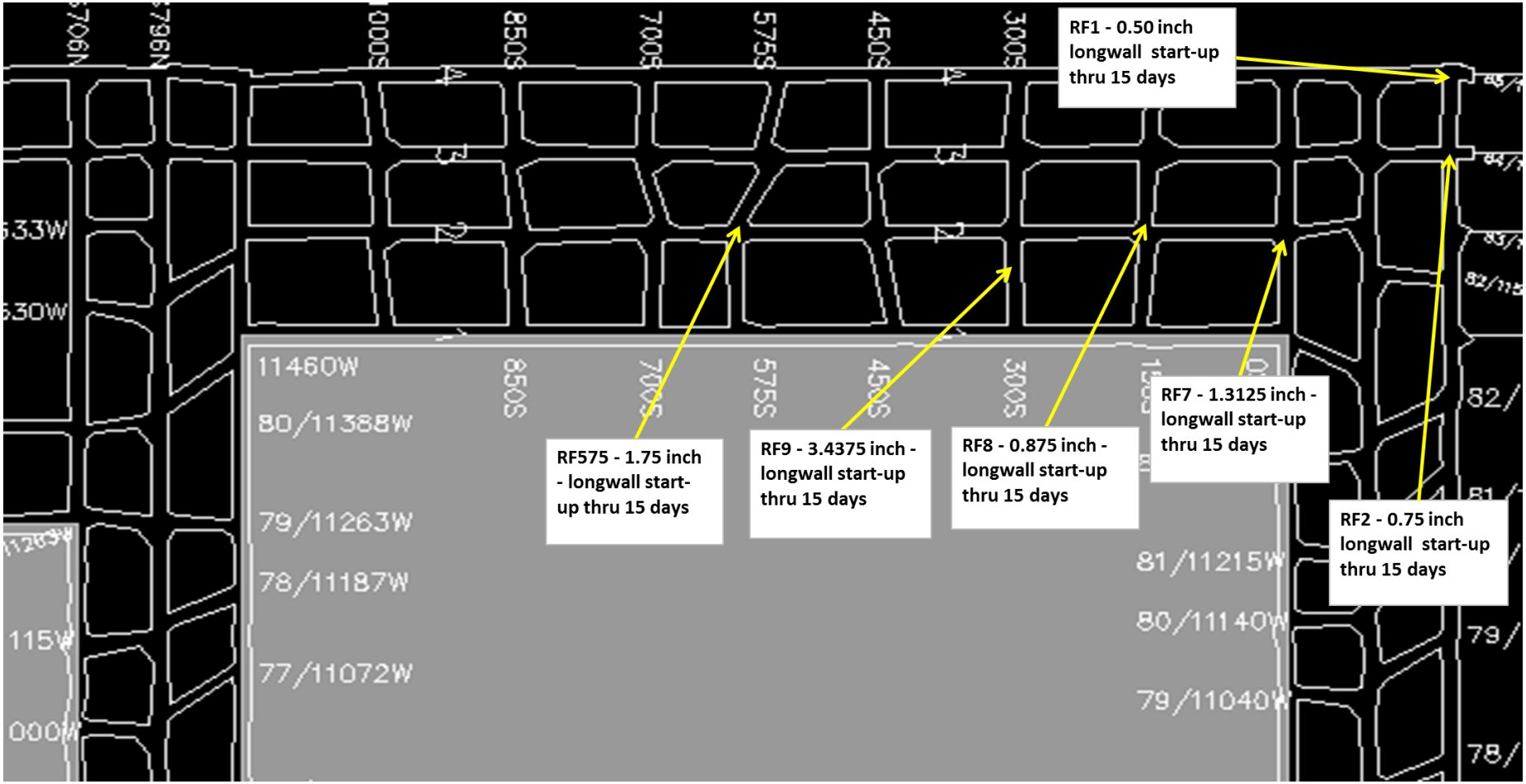
What did we learn from Panel 1 longwall panel studies?

- Stress build up in adjacent set-up rooms and head-gate entries due to horizontal displacement of rock mass behind the longwall face toward the mined-out area.
- Magnitude of horizontal movements quite large.
- Distortional movement of pillars in set-up rooms.
- Distortional movement of pillars also occurs in gate entries and was more than we expected.
- Stress build up results in roof falls, cutter roof, shearing of bolts, and floor heave.

Field Studies in Adjacent Longwall Panel

- Increased size of set room pillars
- Perform Field Studies from May 17 through July 7, 2011
- Roof to floor convergence points
- Horizontal displacement measurement points
- Crib-rosettes installation
- Roof bolt rosettes installation

Panel 2 roof-to-floor convergence manually collected data in bleeder entry



What did we learn from longwall panel 2 studies?

- No ground control problems seen in 8th west set-up rooms
- Instabilities occurred at expected locations
- Decreased roof-to-floor convergence in the set-up room by about 12-15%.
- Decreased roof-to-floor convergence in the head-gate entry area by about 40%.
- Bleeder entry system remained stable

Mine 2 Studies

(December 15, 2011 through February 14, 2012)

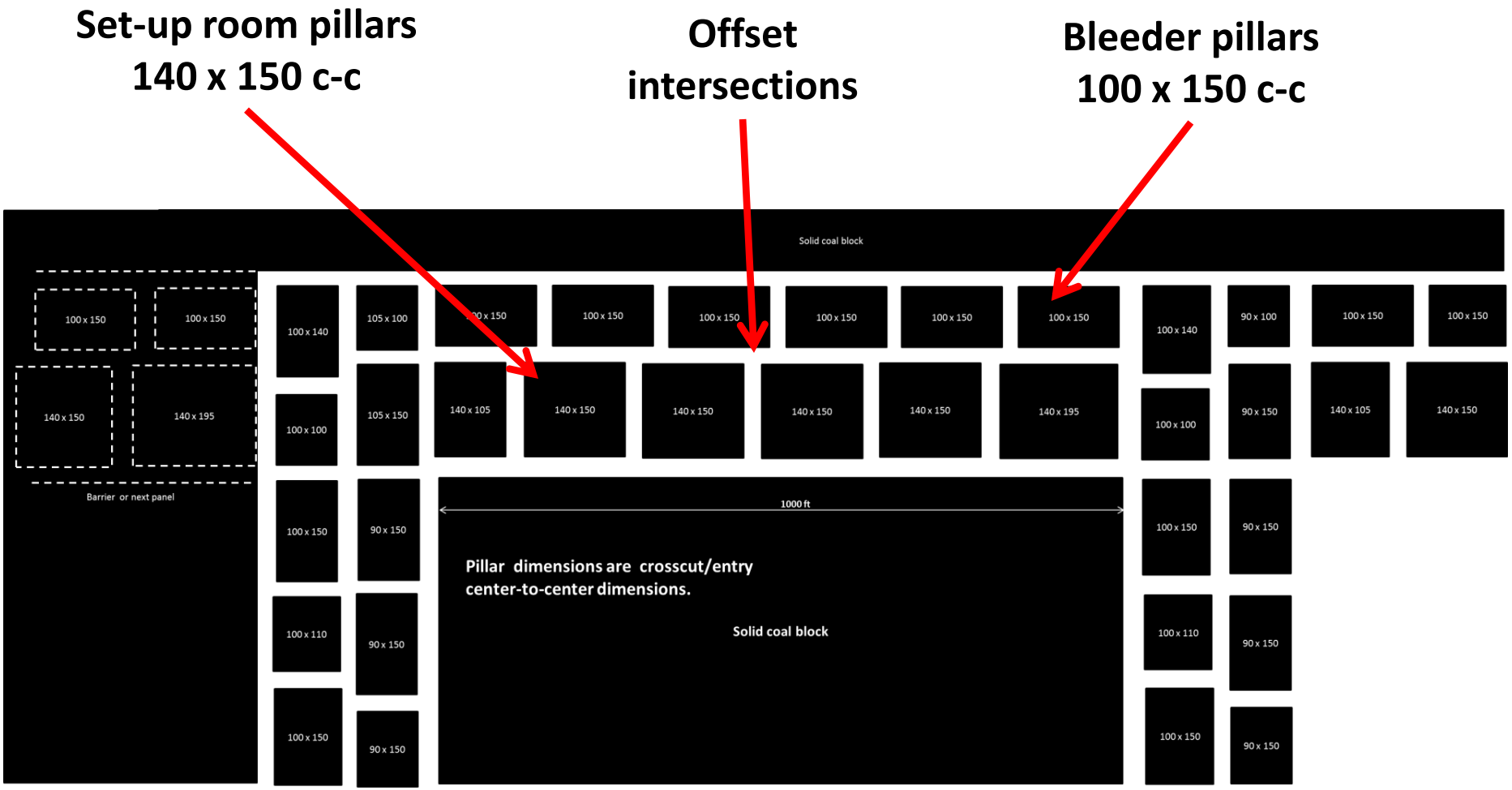
Development of 3-entry set-up rooms for Mine 2 panel oriented E-W and longwall panels oriented N28E

- Advantages of 3 entry set-up room system
  - Approximately 25% less drivage
    - 6340 feet of drivage for 4-entry system
    - 4790 feet of drivage for 3-entry system
  - Reduced primary support costs
  - Fewer intersections
  - Reduced supplemental support costs

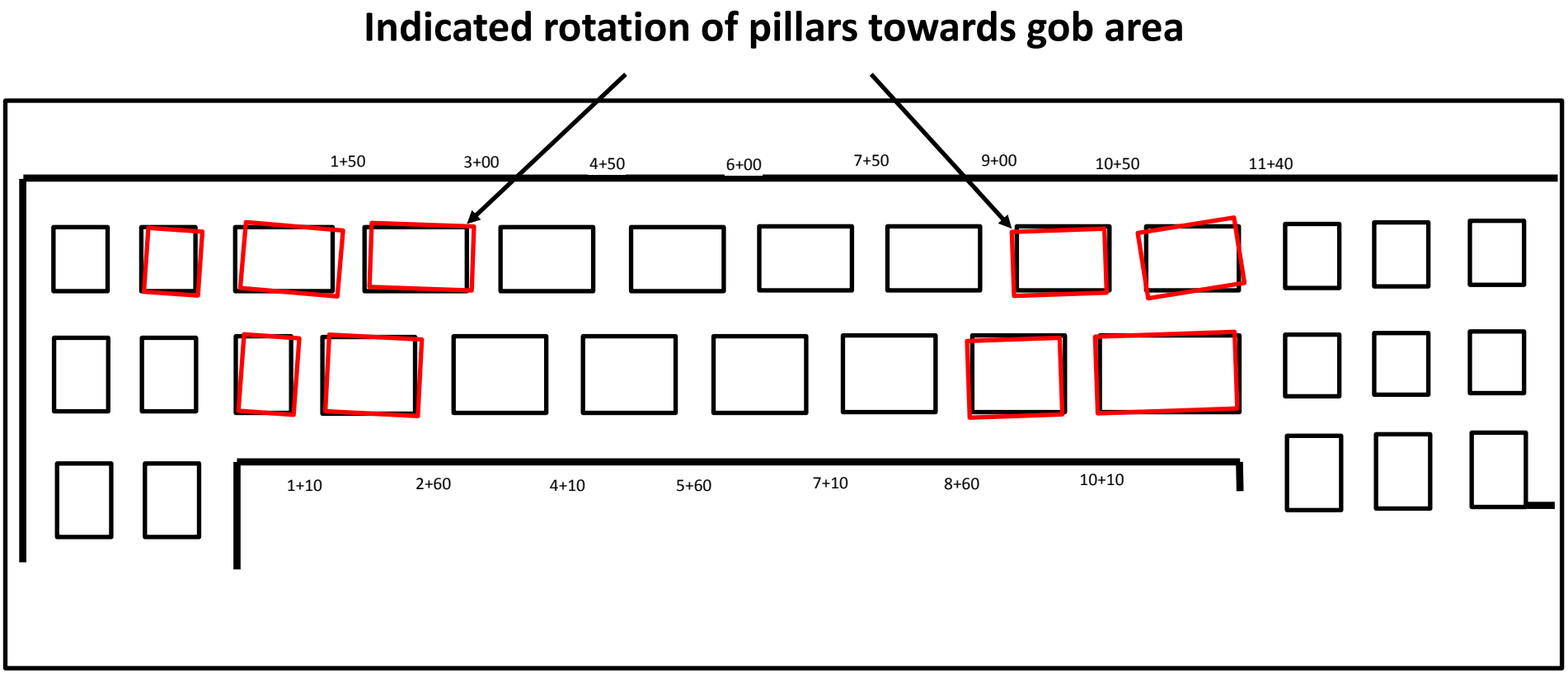
Some Modifications in Mining Geometry

- Increased first set-up room pillar length and width.
- Reduced the number of x-cuts in set-up rooms
- Increased the size of headgate and tailgate entry pillars around the mouth of set-up rooms
- To the extent possible, offset headgate and bleeder entry intersections to create 3-way intersections instead of 4-way intersections
- Installed supplemental supports in bleeder entries as quickly as possible.
- Successfully implemented the alternate geometry.

Proposed 3-entry layout in Mine 2 based on analytical studies

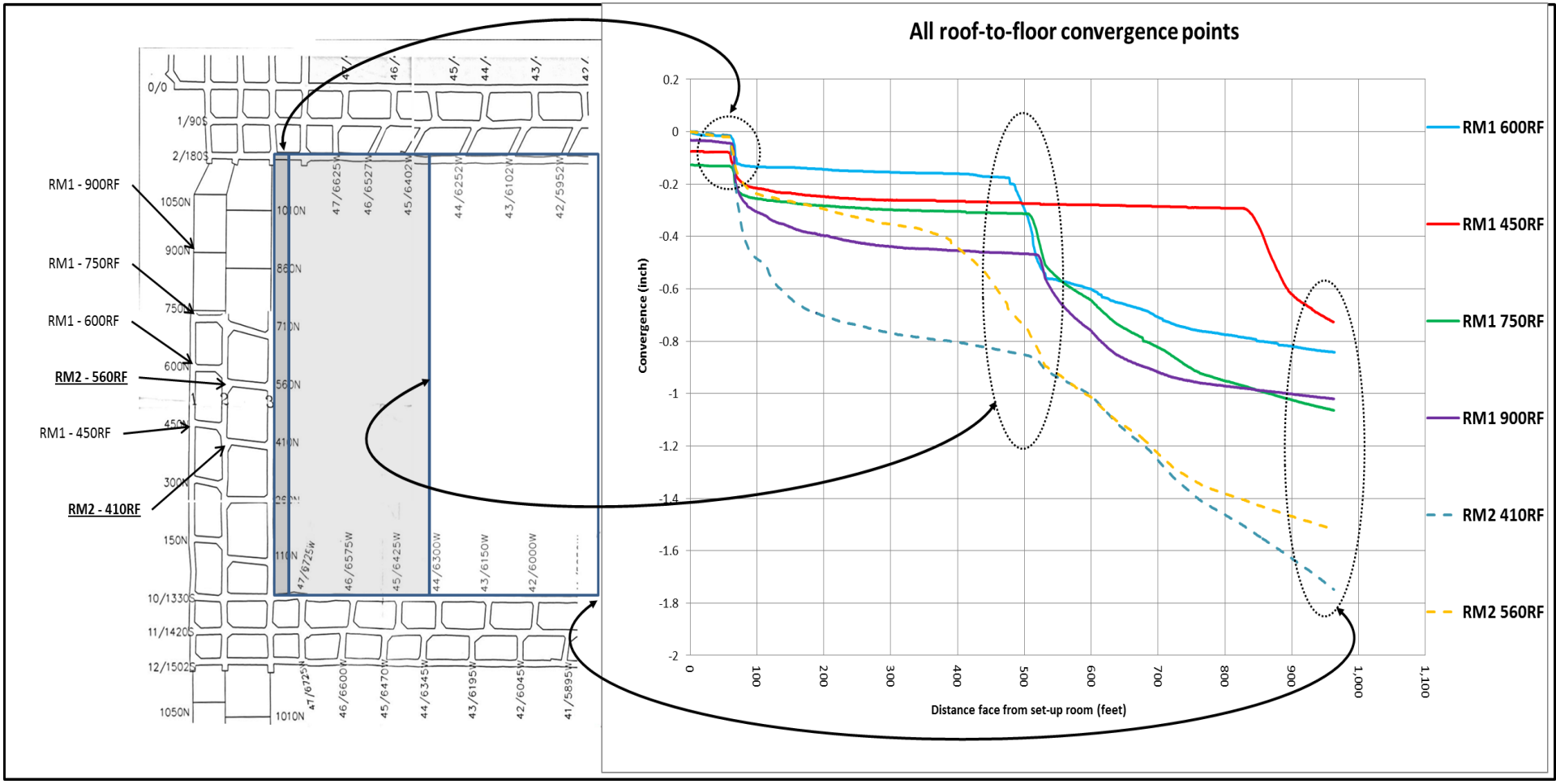


Movement of pillars indicated by field roof bolt and crib rosettes



Three Entry Set Up Rooms convergence

(solid line – Room #1, dotted line – Room#2)



Electronic continuous monitoring data - collected at 30 minute intervals

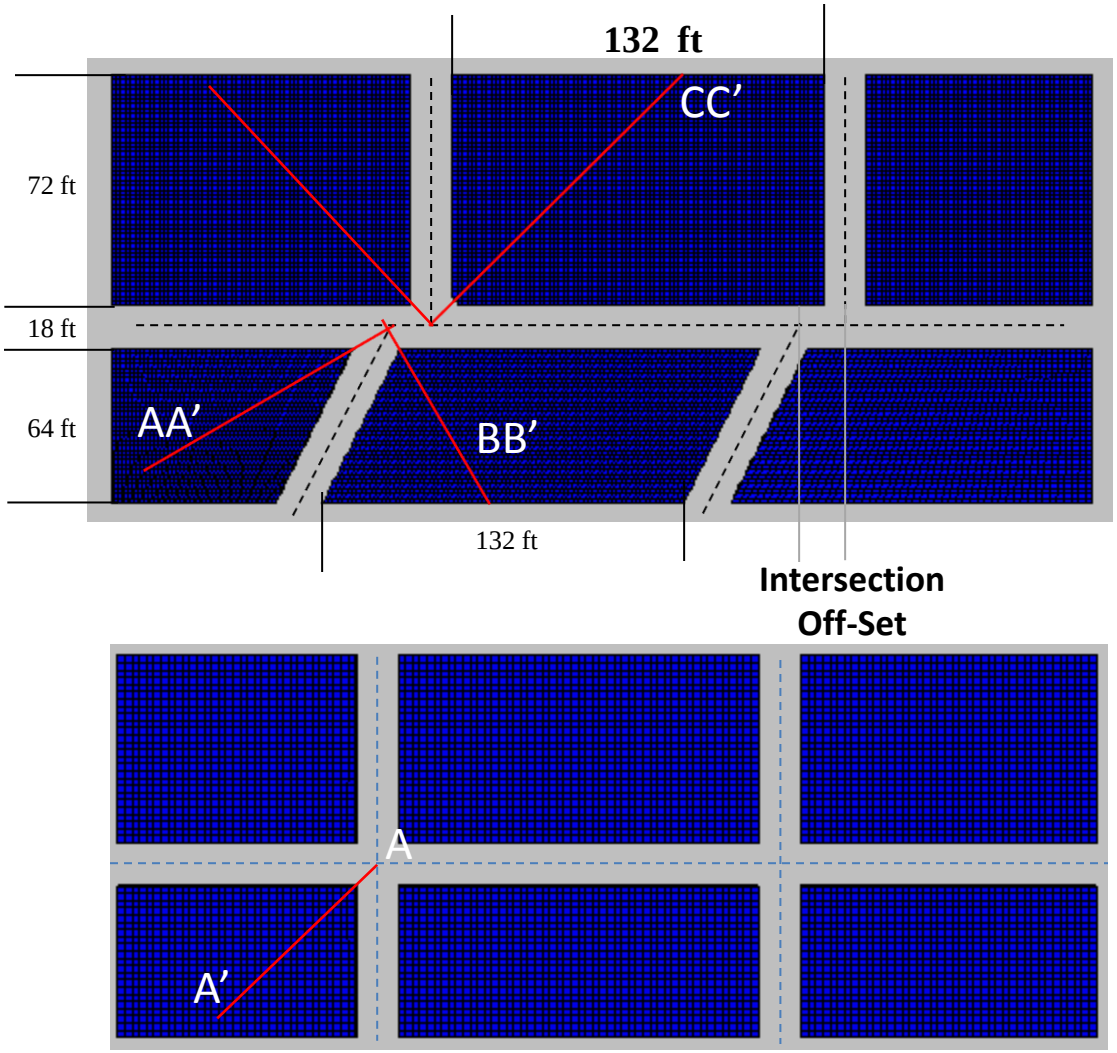
What have we learnt from Mine 2 studies in the field)

- 3-entry system is viable with increased pillar sizes
- No ground control problems in set-up rooms.
- Rotation of pillars still occurs to a small degree
- Convergence in the bleeder entry increases after about 40 feet of longwall advance then stabilizes, then increases again at about 500 feet of advance

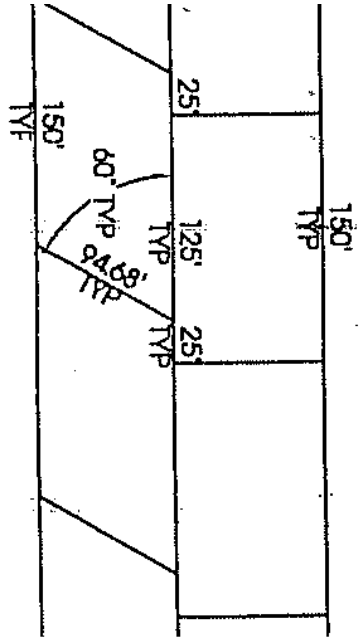
Ground Control Studies for Development Entries and Intersections

(60 ° vs. 90° staggered and non-staggered crosscuts intersections)

About 80% of roof falls at the mine occurred at intersections
Layout of 3-way and 4-way intersections

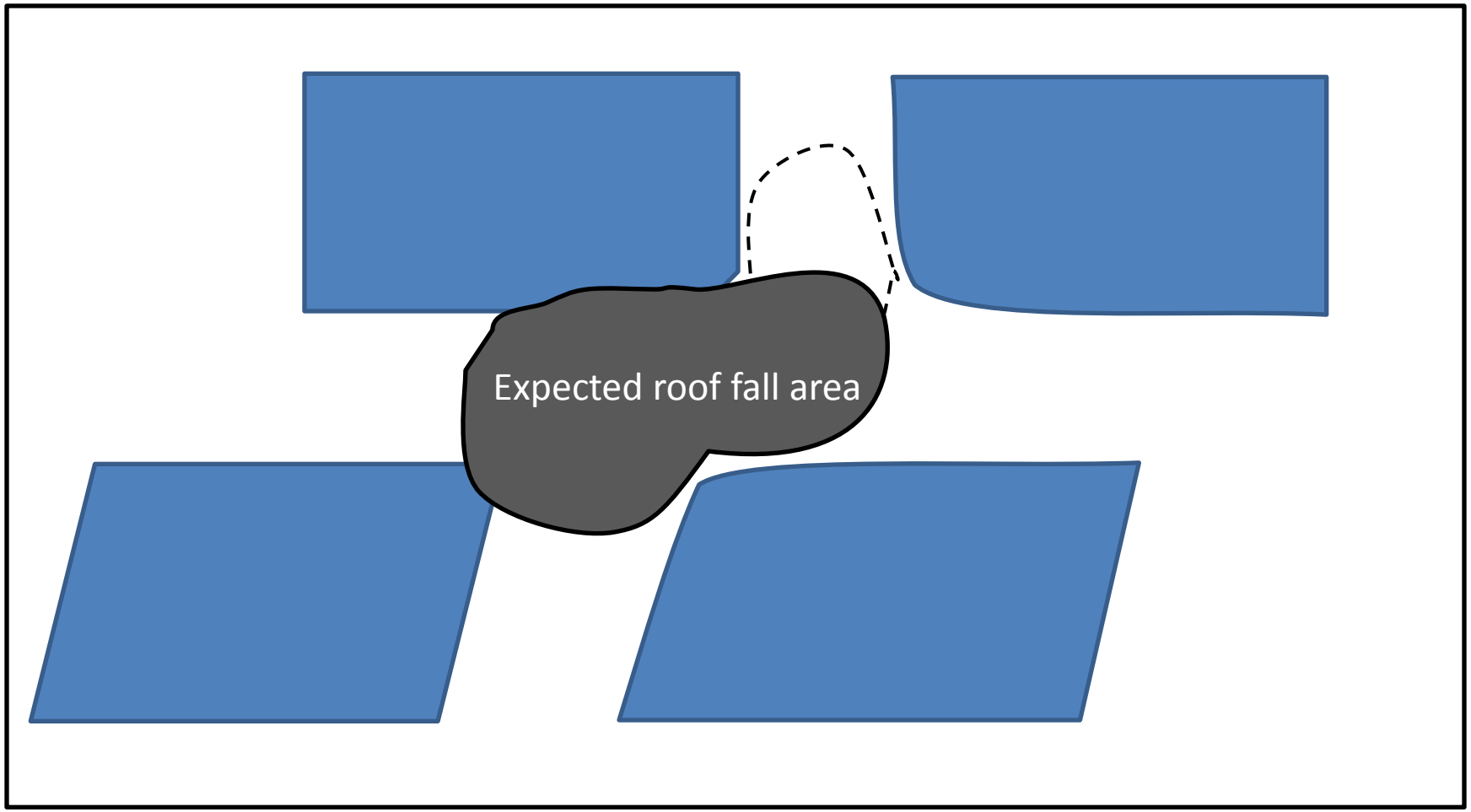


3-way Intersection



4-way Intersection

Predicted initial roof fall geometry
(Company agreed with it)

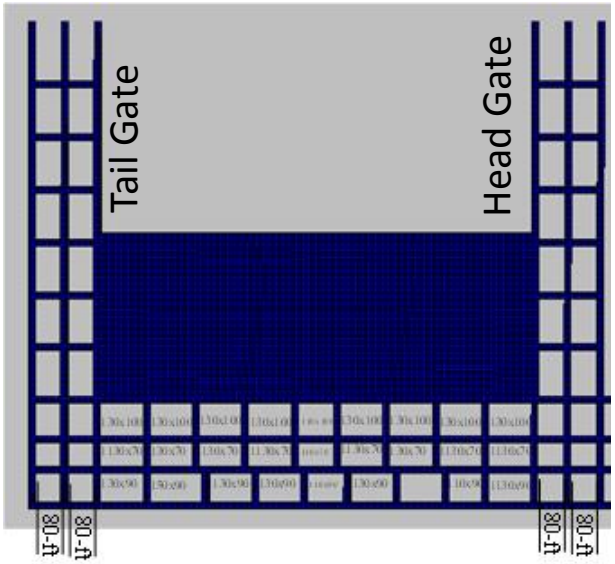


Gate entries development

- Minimize angled cross-cuts.
- For staggered cross-cuts, require minimum 40 feet and preferably 45 feet offset.
- Have successfully implemented these concepts in the field.
- Uneven size pillars in development entries – make belt entry pillar larger.

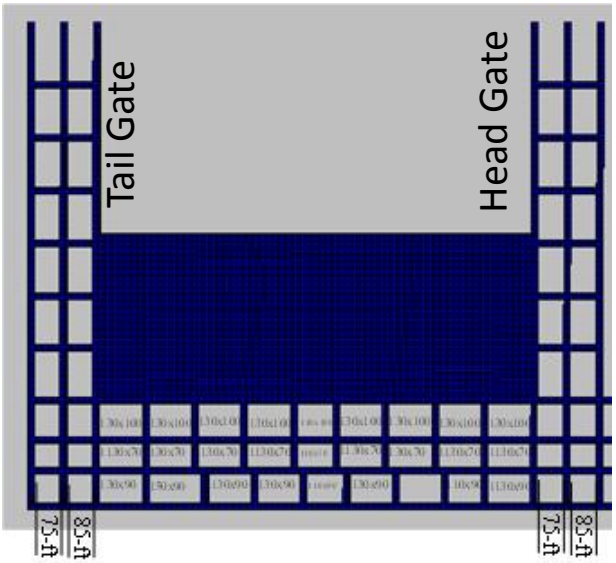
Pillars geometry in head-gate and tailgate entries (Which is better??)

Geometry 1



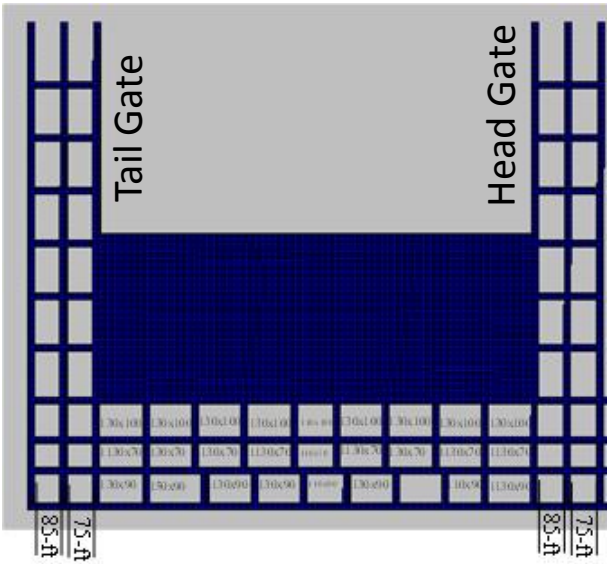
Equal size pillars.
Head gate- Width of belt entry pillar 80-ft, Width of second pillar 80-ft.

Geometry 2



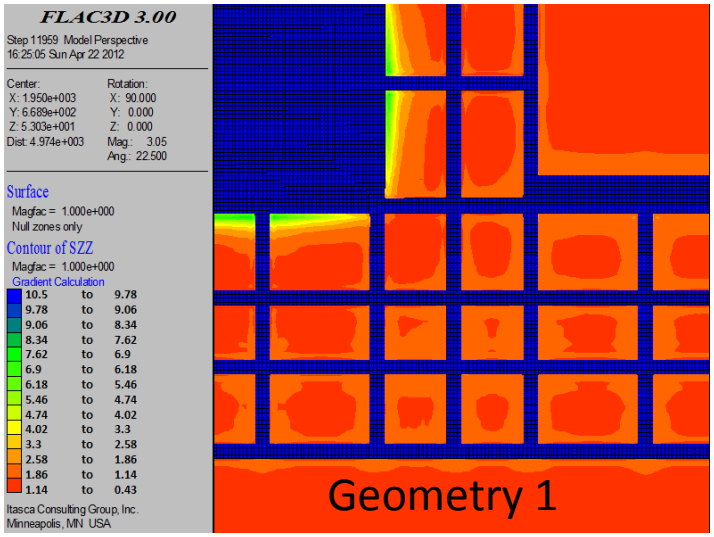
Unequal pillar sizes.
Head gate- Width of belt entry pillar 75-ft, Width of second pillar 85-ft.

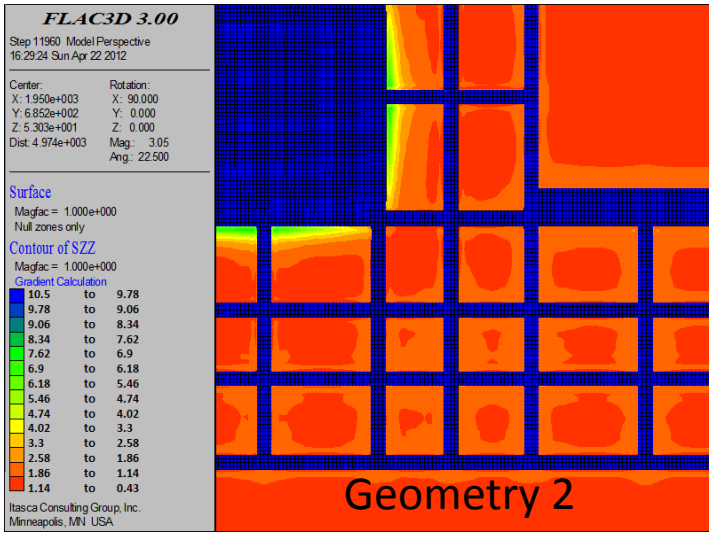
Geometry 3

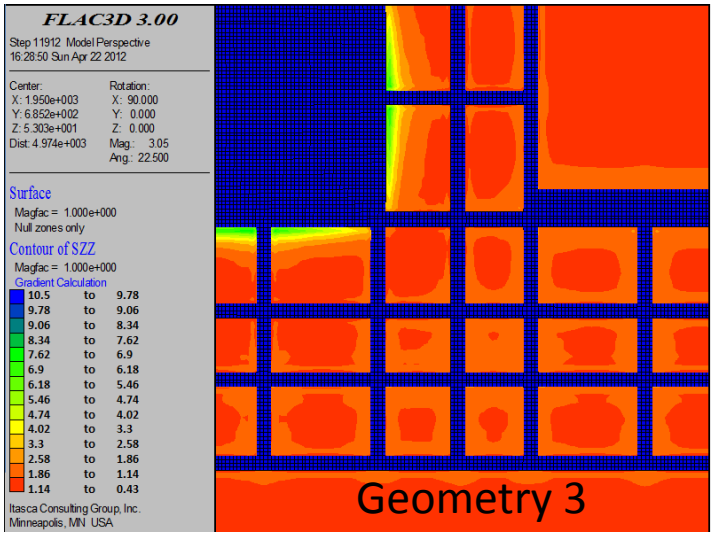


Unequal pillar sizes.
Head gate- Width of belt entry pillar 85-ft, Width of second pillar 75-ft.

VSCF contours for Equal and unequal pillar sizes





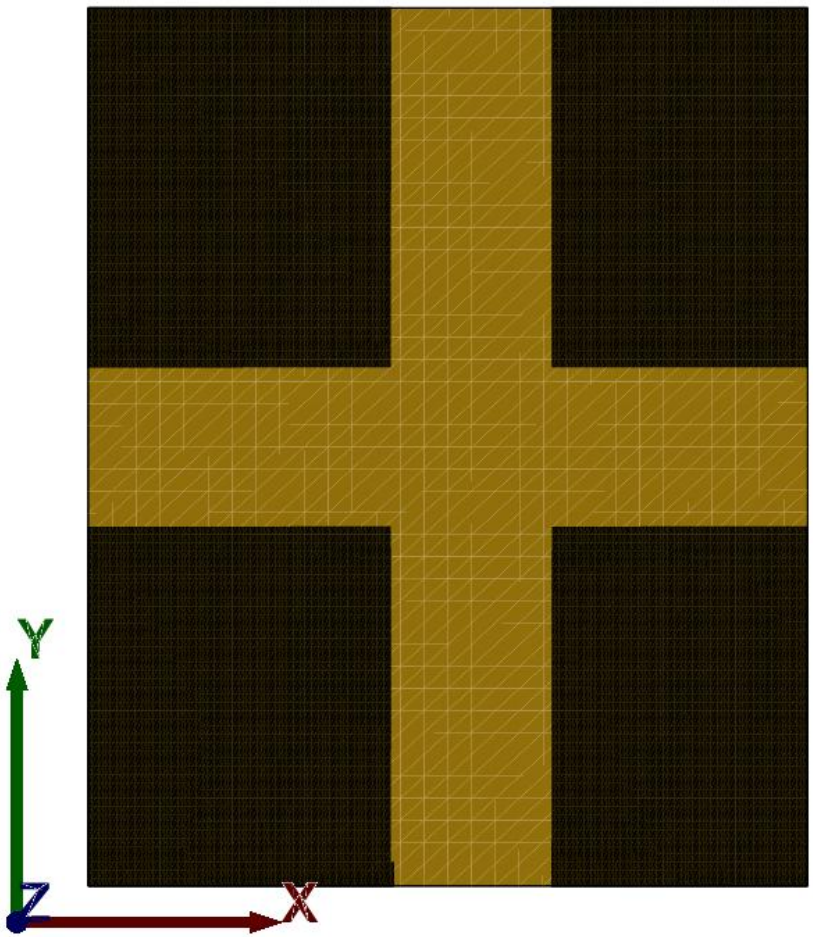


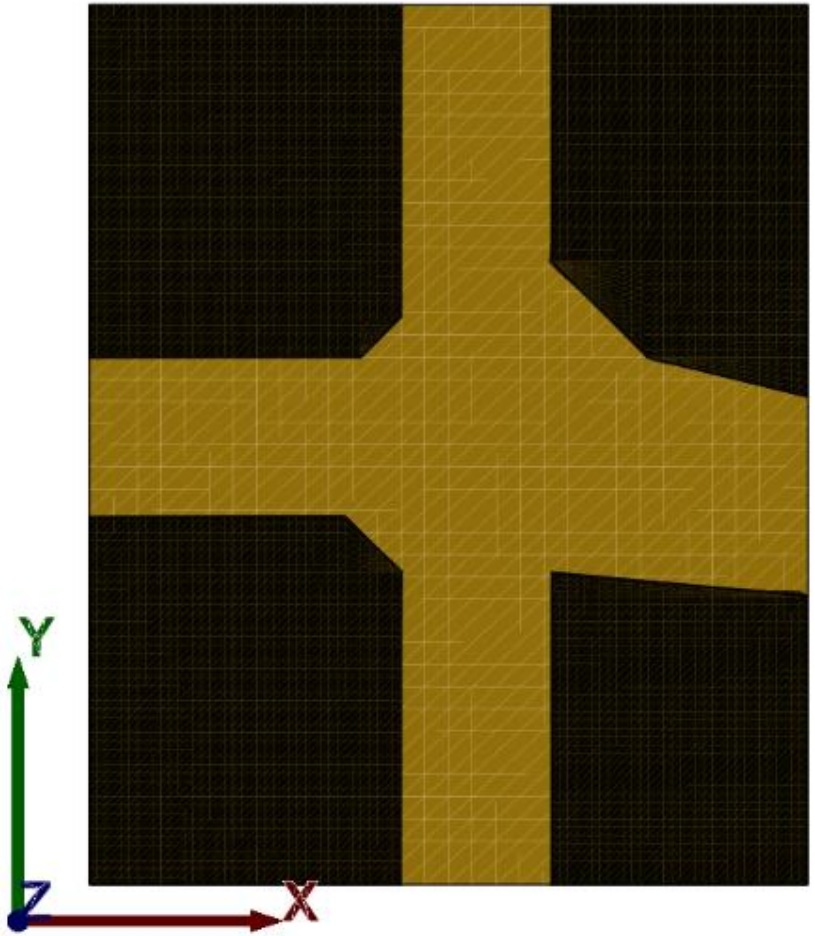
Modeling Results

- Mining company currently uses Geometry III.
- Numerical analysis suggests that pillar geometry II would be better from ground stability point of view.
- Results have been discussed with company.
- Implementation of this concept is currently being considered by the company.

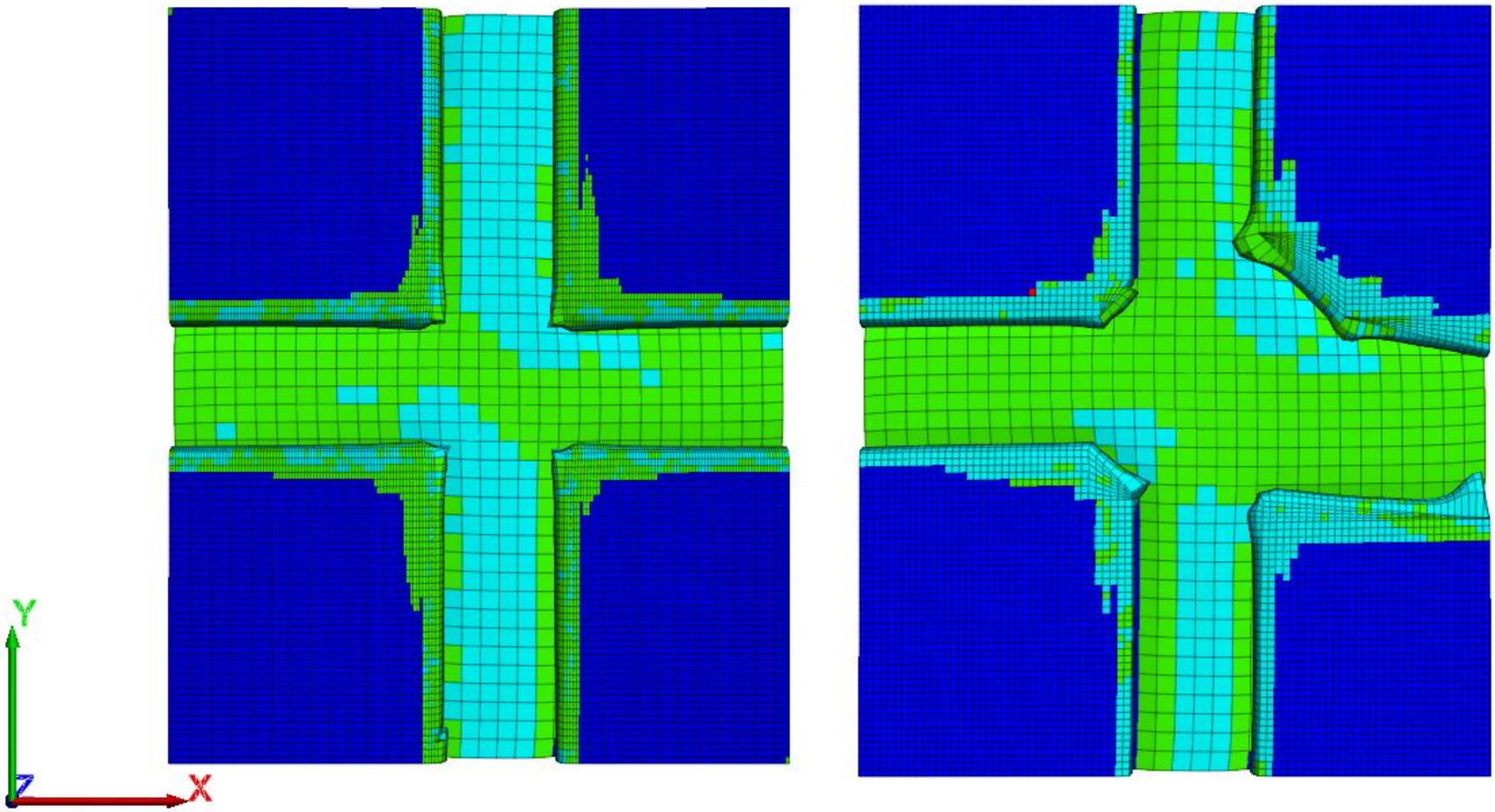
Stress and Displacement Comparisons for Regular and Realistic Field Geometries

Comparison of regular and realistic field geometries (20 foot entries)





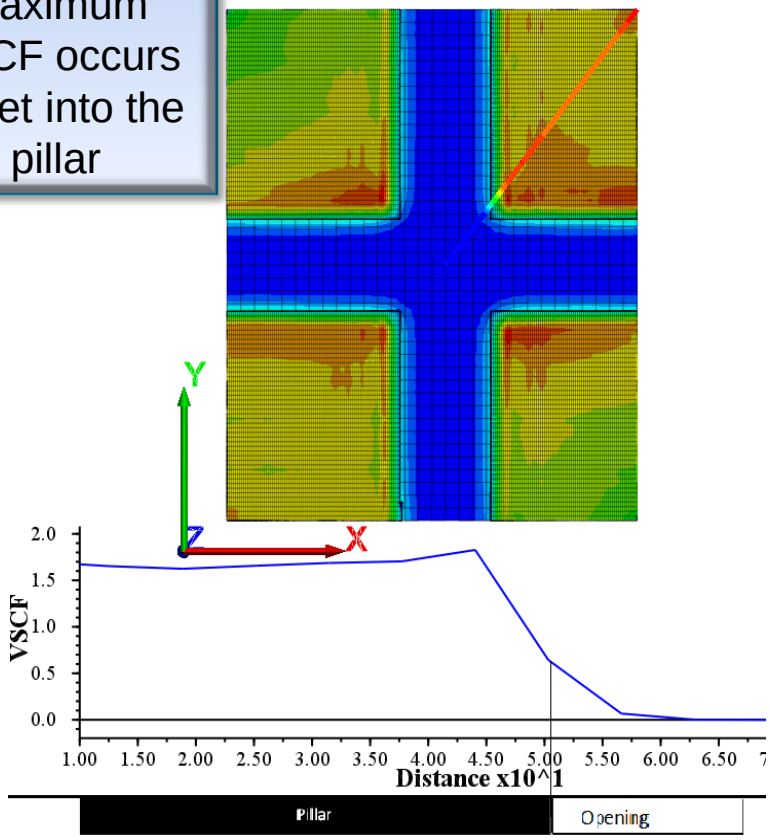
Pillar distortions for regular and realistic field geometry



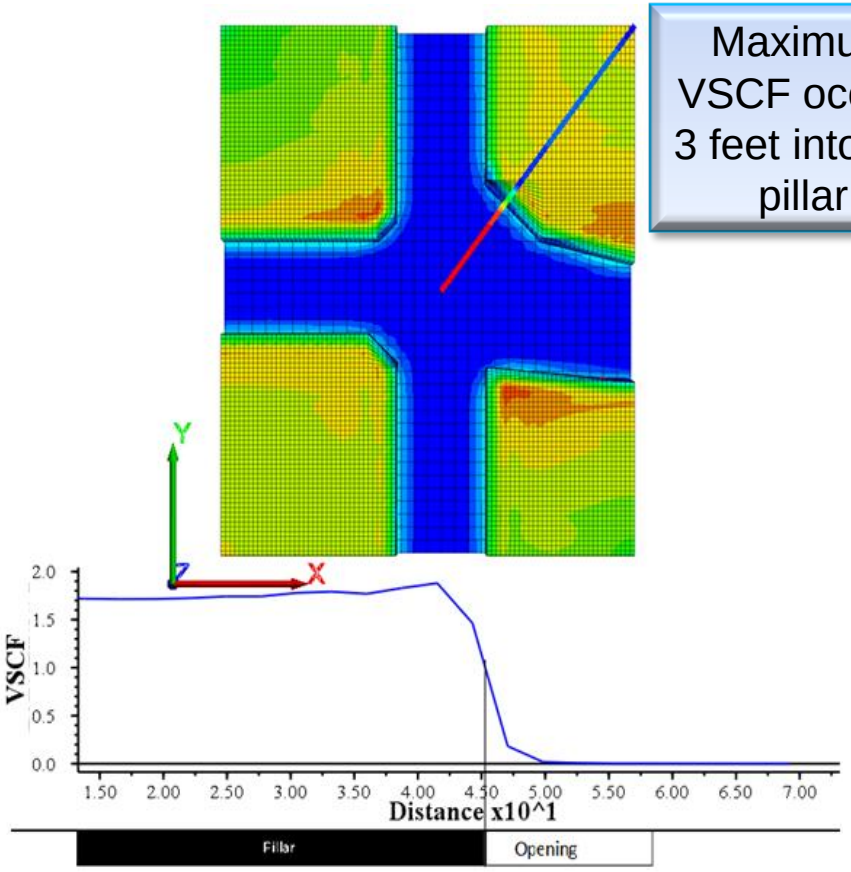
Illustrated distortion is 10 times actual – for visualization purposes.

Comparison of VSCF for regular and realistic field geometry

Maximum VSCF occurs 7 feet into the pillar

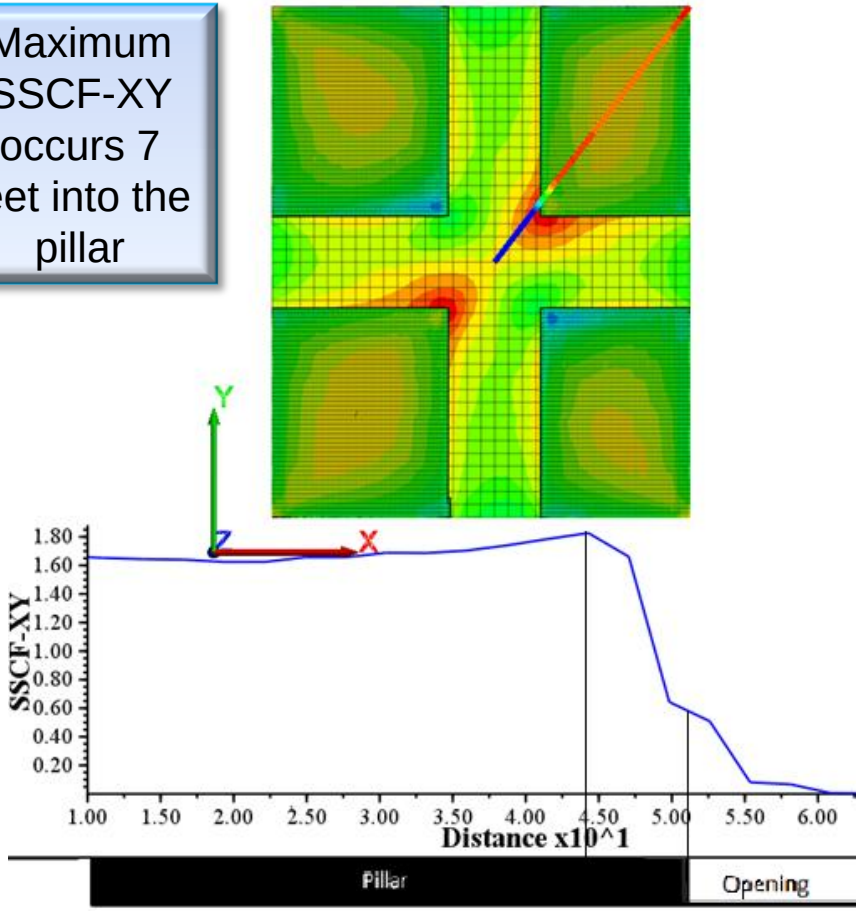


Maximum VSCF occurs 3 feet into the pillar

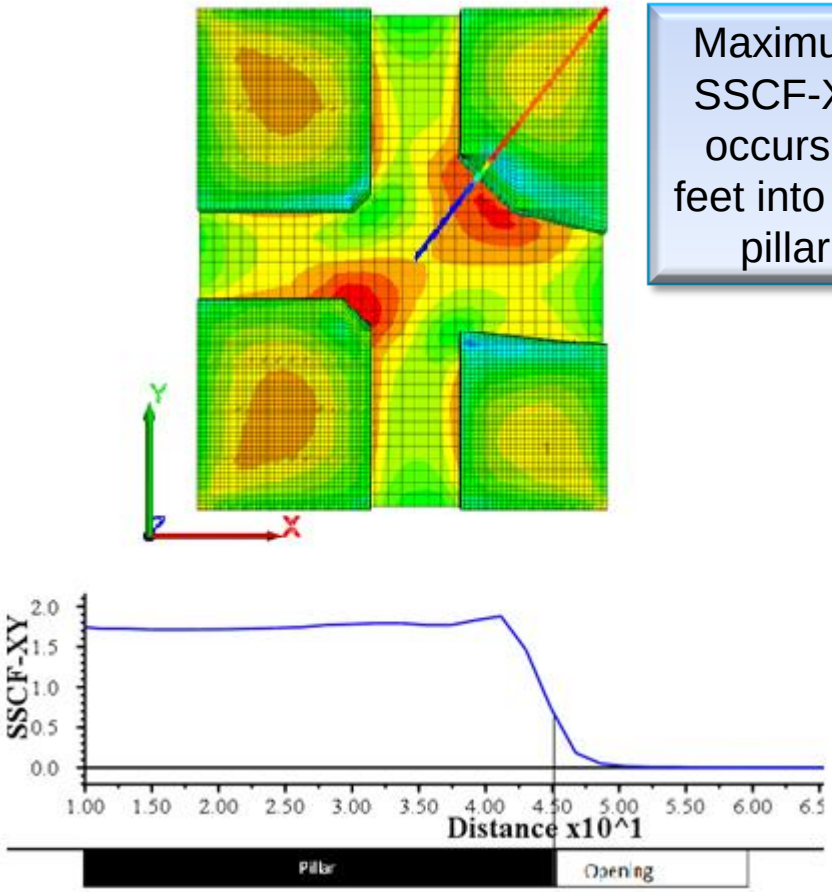


Comparison of SSCF-XY For Regular and Realistic Field Geometry

Maximum SSCF-XY occurs 7 feet into the pillar

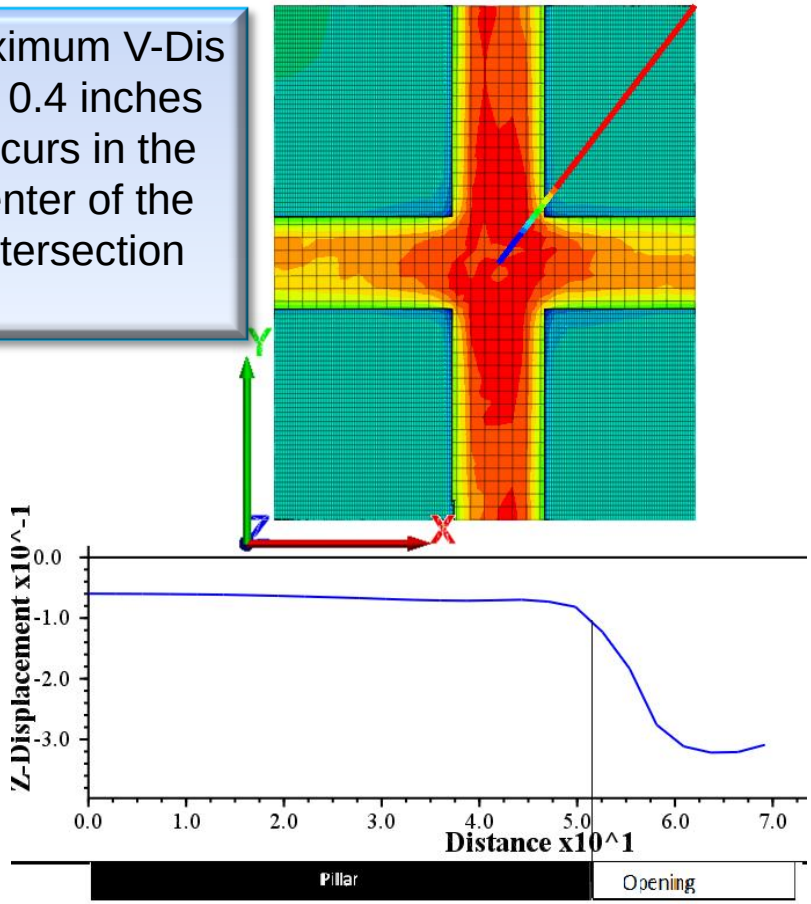


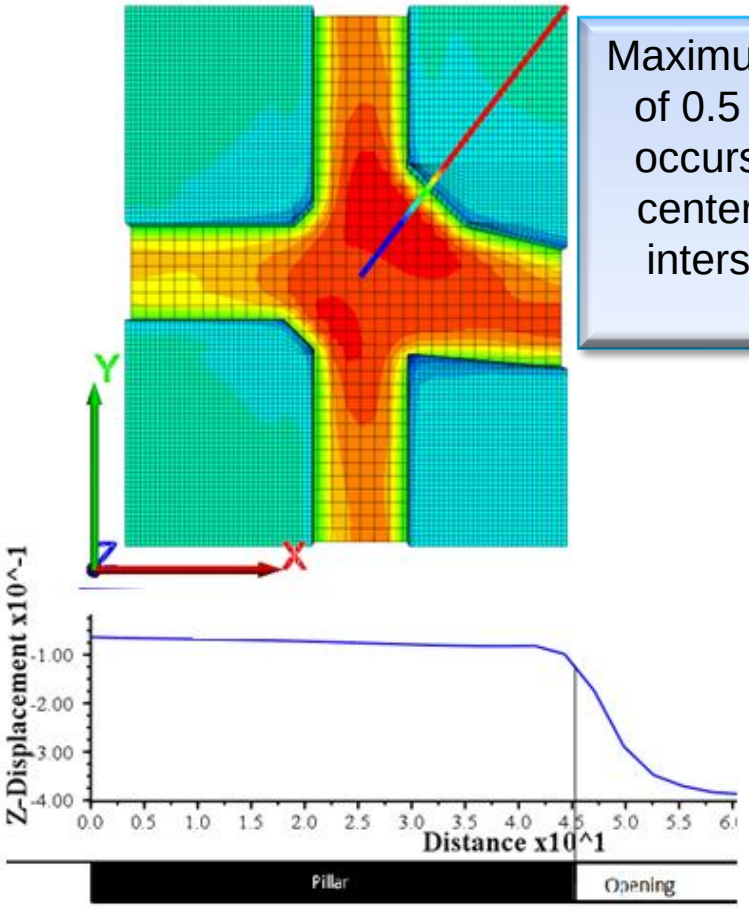
Maximum SSCF-XY occurs 3 feet into the pillar



Comparison of Vertical Displacement For Regular and Realistic Field Geometry

Maximum V-Dis of 0.4 inches occurs in the center of the intersection





Maximum V-Dis of 0.5 inches occurs in the center of the intersection

Concluding Remarks

- Strong collaborative engineering effort for planning efficient and safe longwall mining layouts.
- A numerical model has been developed and validated for structural analysis of longwall mining layouts at the mine.
- Notable success over last 12- months to improve stability of set-up rooms and development entries through implementation of new concepts.
- Additional improvements are expected at New Era mine next 12-months.

Thank you!!
Questions and Comments??