Two-Entry Yield Pillar Gateroad Systems in Western U.S. Longwall Mines

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Presented by

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Agapito Associates, Inc.

- Mining and geological engineering firm
- Founded 1978
- Offices in Grand Junction, Denver, and Chicago
- Specialize in geomechanics and mine design
- Western U.S. longwall coal clients (past and present):

<table>
<thead>
<tr>
<th>Andalex/Tower</th>
<th>Skyline</th>
<th>West Ridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bowie No. 2</td>
<td>Soldier Creek</td>
<td>West Elk</td>
</tr>
<tr>
<td>Crandall Canyon</td>
<td>Star Point</td>
<td>Trail Mountain</td>
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<tr>
<td>Dugout Canyon</td>
<td>Sunnyside</td>
<td>SUFCO</td>
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<tr>
<td>Deer Creek</td>
<td>Willow Creek</td>
<td>Shoshone</td>
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<td>San Juan</td>
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Introductory Points

- Two-entry yield pillar system unique to Western U.S. longwall coal mining

- System evolved over time—Sunnyside Mine to present

- Analyzed extensively

- Proved superior over the course of 40 years to other gateroad systems for ground control

- A system tailored to burst prone conditions in the West

- A system used out of necessity
What is different about Western U.S. ground conditions?
Western U.S. Coal Mining Conditions

- Very deep cover—currently reaching 3,000 ft
- Highly variable topography
- Frequent multiseam mining
- High stress environment
- Bump prone geology
Western U.S. Bump Prone Geology

1. Thick and competent overburden strata—causes bridging leading to high abutment stresses
Massive Cliff Forming Overburden

Castlegate Sandstone
Western U.S. Bump Prone Geology

1. Thick and competent overburden strata—causes bridging leading to high abutment stresses

2. Uncleated or weakly cleated, strong coal—leads to storage of strain energy and sometimes violent releases

3. Highly competent roof and floor strata that confine coal and resist breakage—creates a “bounce sandwich”

4. Sand channels—cause stress concentrations

5. Massive overburden—resists caving and increases loads on pillars and longwall face
### Comparison - Typical Conditions

<table>
<thead>
<tr>
<th>Western U.S.</th>
<th>Eastern U.S.</th>
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<tbody>
<tr>
<td><strong>Cover:</strong> deep (typ. 1,500-3,000 ft)</td>
<td><strong>Cover:</strong> shallow (typ. 500-1,800 ft)</td>
</tr>
<tr>
<td><strong>Topography:</strong> rugged</td>
<td><strong>Topography:</strong> limited relief</td>
</tr>
<tr>
<td><strong>Coal:</strong> strong (3,000+ psi)</td>
<td><strong>Coal:</strong> variable strength</td>
</tr>
<tr>
<td><strong>Roof:</strong> strong and stiff</td>
<td><strong>Roof:</strong> weak and soft</td>
</tr>
<tr>
<td><strong>Floor:</strong> strong and stiff</td>
<td><strong>Floor:</strong> weak and soft</td>
</tr>
<tr>
<td><strong>Overburden:</strong> massive strata</td>
<td><strong>Overburden:</strong> highly laminated</td>
</tr>
<tr>
<td><strong>Burst Proness:</strong> high</td>
<td><strong>Burst Proness:</strong> low</td>
</tr>
</tbody>
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Evolution of the Two-entry System and Yield Pillars in the Western U.S.
Origin in Western U.S.

- Two-entry mining system was the predominant method of room-and-pillar mining at Sunnyside Mine since 1897
- Most used historical room-and-pillar method in West
- Established prior to the 1969 Coal Mine Health and Safety Act
- Sunnyside experienced severe bumps and bump-related roof falls at depths greater than about 800 ft
- Solution was to limit the width of the pillar/entry system
- The two-entry system significantly reduced bumping on room-and-pillar development
Sunnyside Room-and-pillar Panel Mining System
Origin in Western U.S.

- Bumps continued to occur on room-and-pillar retreat
- **Narrow** “yielding” pillars were tested to control bumping in the room-and-pillar panels
- 25- to 35-ft-wide pillars virtually eliminated bumping
- 50-ft-wide pillars were tried to improve roof stability, but proved dangerously bump prone
Critical Pillar Concept

Represented by a graph with two axes: GATE ROAD PERFORMANCE on the vertical axis and INCREASING PILLAR WIDTH on the horizontal axis. The graph illustrates the transition from YIELDING pillar systems to ABUTMENT pillar systems as the pillar width increases. The term "Critical" pillar is highlighted along the transition point.
Origin in Western U.S.

- Yield pillars ultimately proved successful eliminating bumps, but resulted in lower pillar recovery on retreat because of roof falls
- A higher recovery system was sought...
Origin in Western U.S.

- Longwall mining was introduced to Sunnyside in 1961 by John Peperakis and others based on the German method.
- Longwall improved safety, resource recovery, and productivity.
- Gateroad development proved analogous to room-and-pillar development...bumping was a problem >800 ft deep with large pillars.
- The two-entry system previously used for room-and-pillar development proved to be the solution for controlling bumps during longwall development.
Sunnyside conducted numerous trials to find the right gateroad pillar geometry—one that yielded nonviolently, yet provided adequate tailgate stability.

Three-entry yield pillar systems were tested—resulted in large roof deflections, floor heave, and unstable conditions in the headgate and tailgate gateroads.

Two-entry yield pillar systems provided significantly better pillar, roof, and floor conditions.

Single-entry systems provided the best overall ground conditions, but proved impractical for ventilation, access, and water control.
Origin in Western U.S.

- Key conclusions from 32 years of longwall mining at Sunnyside with single and multiple seam mining and at depths approaching 3,000 ft:
  - Minimizing overall span of gateroad is key—two entries with narrow (yield) pillars optimal
  - Yield pillars are critical for controlling pillar bumps, roof damage, and floor heave
  - 25- to 35-ft wide yield pillars work best
  - Yield pillar gateroads with more than two entries result in significant increases in floor heave and roof falls
Since Sunnyside... the two-entry yield pillar system has become the *de facto* standard for deep longwall mining in the Western U.S.

- 30-ft-wide yield pillars typical
Engineering Research

- Significant research has been conducted to evaluate the two-entry yield pillar system and alternative systems:
  - Decades of application and observation
  - Laboratory measurements of rock properties
  - Stress and convergence measurements
  - Numerical modeling
  - Many published papers
Example of Engineering Study—Cottonwood Mine

Example of Coal Burst Events in Cottonwood Mine
Example of Engineering Study—Deer Creek Mine

[Diagram of Deer Creek Mine showing various levels and sections labeled as First Right, Second Right, Third Right, Fourth Right, Fifth Right, Sixth Right, Seventh Right, Instrumentation Site, Modeled Area, and Coal Bursts.]

Scale: 0 - 500' - 1000'
Example of Instrumentation—Borehole Pressure Cells and Convergence Stations, Deer Creek Mine
Installing Fiber Optic Roof Sag Meters to Measure Gateroad Pillar Performance—SUFCO Mine
Installing Fiber Optic Borehole Pressure Cells—SUFCO Mine
Example of Measured Stress Profile through Yield Pillar—Deer Creek Mine

Maximum Measured Pillar Load Profile in a 30 ft Wide Pillar for the Western Area

VERTICAL STRESS (PSI)

PILLAR WIDTH (FT)

AVERAGE PILLAR STRENGTH

3960
Example of Modeled Stress Profile—Deer Creek Mine

Vertical Stress Profile Along North-South Section of Eastern Area

80' PILLARS
5E PANEL
45' x 80' PILLARS
6E PANEL
30' x 80' PILLAR

A
GOB
GOB
A'
BLIND CANYON

Stress (psi)

6000.
4000.
2000.
0.

Distance (feet)

0.
500.
1000.
1500.
2000.

BURST-PRONE STRESS LEVEL
PREMINING STRESS
Example of Stress Modeling
Displacement Discontinuity Model

Vertical Stress

- 5000 psi
- 4000 psi
- 3000 psi
- 2500 psi
- 2000 psi
- 1500 psi
- 1000 psi
- 500 psi
- 0 psi

Panel 6
Panel 5
Barrier (600 ft)
Panel 4
Barrier (400 ft)
Panel 3
Barrier (400 ft)
Gob
Gob
Example of Stress and Displacement Modeling
2D Finite Difference Model
FLAC

Simulation of Longwall Side-abutment Stress Arch
Example of Stress and Displacement Modeling
3D Finite Difference Model
FLAC3D

Sandstone Channels in Roof

Simulation of Retreat Stresses and Subsidence
Example of Longwall Face Loading Modeling
2D Distinct Element Model
UDEC

<table>
<thead>
<tr>
<th>JOB TITLE : CONVERGENCE OF LOADING BLOCK INTO FACE AREA</th>
</tr>
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<tbody>
<tr>
<td>UDEC (Version 3.00)</td>
</tr>
</tbody>
</table>

**LEGEND**

- cycle 110400
- time 2.589E+01 sec
- Vertical Displacement Contours (ft)
  - Conversion 1m=3.28 ft
  - contour interval= 5.000E-01
  - min=-2.500E+00 max= 0.000E+00

- -2.500E+00  
- -2.000E+00  
- -1.500E+00  
- -1.000E+00  
- -5.000E-01  
- 0.000E+00  

- block plot
- displacement vectors
  - maximum = 3.154E+00

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Diagram showing convergence of loading block into face area with various color-coded regions and displacement vectors. The legend provides details on the color scale and displacement vectors.
Why yield pillars instead of rigid pillars?
Rigid Pillar

Yield Pillar

At risk for bumping under high stress conditions

Yielding prevents dangerous build-up of strain energy
Gateroad Pillar Loading Simulated in Models

- **Initial Loading**
- **Critical Loading**
- **Dynamic Pillar Failure** (bumping, bump-related roof falls, dynamic floor heave)
- **Yield Pillar** Peak Strength Reached (Typically 4,000 to 5,000 psi)
- **Controlled Yielding**
- **Residual Strength Reached** Controlled Crushing (Typically < 1,000 psi)
Bump in Overloaded Rigid Pillar
Dynamic Floor Heave with Rigid Pillars

Can
Rigid Pillar Bump and Dynamic Floor Heave

- Methane Drainage Line
- Roof
- Buckled Can
- Heaved Floor
- Crib
Longwall Face Burst

Can be triggered by gateroad pillar bursting
Simulated Stages of Gateroad Pillar Loading

Development

Headgate Mining

Bleeder Loading

Tailgate Mining

Isolated Loading

Legend:
- Red: Yielded
- Orange: Yielding
- 80%-100% of Yield Stress
- 60%-80%
- 40%-60%
- 20%-40%
- 0%-20%
- Gob
Rigid Gateroad Pillars at Depth—3 Entry

Vertical Stress

Gob

Tailgate

Face

Headgate

Solid

Stable Pillars

1,000 ft Deep
Rigid Gateroad Pillars at Depth—3 Entry

- Heavily Loaded Pillar
- Burst Prone Pillar

Vertical Stress

Gob
Tailgate
Headgate
Face
Solid

1,500 ft Deep
Rigid Gateroad Pillars at Depth—3 Entry

Gob

Tailgate

Headgate

Face

Solid

Burst Prone Pillars

2,000+ ft Deep

Vertical Stress

0 500 1,000 2,000 3,000 4,000 5,000 6,000
Yield-Abutment Gateroad System at Depth

Bursting can cause dynamic loading of longwall face.
Why a two-entry yield pillar system instead of three-entry yield pillar system?
Two-Entry and Three-Entry Yield Pillar Gateroad Systems
Two-Entry Yield Pillar Gateroad at Depth

Yield Gate Pillar Concept

- **TWO-ENTRY SYSTEM** MINIMIZES GATEROAD SPAN:
- REDUCES ROOF WEIGHTING ON TAILGATE CORNER OF FACE
- REDUCES ROOF CONVERGENCE AND OCCURRENCE OF FALLS

**LEGEND**
- STRESS VECTOR
- LOAD SUPPORTED BY YIELD PILLARS

Pillar yield causes much of the abutment and overburden stresses to be transferred to the unmined coal block.

LONGWALL FACE

TAILGATE

YIELD PILLAR
Three-Entry Yield Pillar Gateroad at Depth

Wider gateroad span with three-entry generally results in larger cantilever roof load on TG corner of face, as well as roof falls and floor heave in tailgate entries.

Heavy Loading on TG Corner

Yielded Yield Pillars

Vertical Stress

2,000+ ft Deep
Three-entry system proved problematic at most mines:

- Sunnyside
- Cottonwood
- Deer Creek
- Aberdeen
- Dugout
- Star Point

Conditions typically made worse with three entries.
What does the future hold for Western U.S. longwall design?
Alternative Longwall Designs

Panel-Barrier Gateroad System

• Uses an interpanel barrier between every panel
• Preserves first-panel conditions
• An attractive alternative when crosscuts become too long for adequate face ventilation or economic development
• Advantages:
  (1) Allows mining safely under extreme bump prone conditions
  (2) Flexibility to isolate individual panels with squeeze stoppings
  (3) Improved ventilation
Alternative Longwall Designs

Panel-Barrier Gateroad System

Disadvantages:

1. Doubling of gateroad footages
2. Increase mains and bleeder development
3. Sterilization of large amounts of longwall reserves
4. Complicates multiseam mining
Alternative Longwall Designs

“Checkerboard” Panel Layout

- Mining every other panel under deep cover

- Limited applications…mainly to constrained layouts subject to variable cover
Alternative Longwall Designs

Interpanel Barrier Sizing

- Longwall Face
- Gob
- Retrace Direction
- Tailgate Gateroad
- Headgate Gateroad
- 600-ft-wide Interpanel Barrier

Pressure ratings:
- 7,000 psi
- 6,000 psi
- 5,000 psi
- 4,000 psi
- 3,000 psi
- 2,000 psi
Alternative Longwall Designs

Interpanel Barrier Sizing
Alternative Longwall Designs

Interpanel Barrier Sizing

✓ Simulation shows that average tailgate corner vertical stress levels increase by approximately 1,000 psi by reducing a typical barrier from 600- to 200-ft-wide

✓ Results indicate that 400- to 600-ft-wide barriers can maintain tailgate stresses at historically safe Western U.S. levels when mining 2,500 to 3,000 ft deep
Is there an optimal gateroad solution for deep Western U.S. longwall mines…?
Conclusions

- No gateroad system is optimal
- The two-entry yield pillar system is demonstrated by science and experience to be the best tradeoff for deep Western U.S. longwall mining
- It is a system used out of necessity to control the ground in a highly bump prone environment
- The two-entry yield pillar system has significantly reduced the risk of pillar bursting, bump-related roof falls, and floor heave and has made safe longwall mining possible at depths reaching more than 2,500 ft
Conclusions

- Three-entry yield pillar systems are not a good replacement for two-entry systems
- Three-entry yield pillar systems normally result in problematic roof and floor conditions
- Experience has shown that the added advantage of having a third entry in the tailgate is normally lost because of excessive roof and floor instability
Conclusions

- Rigid pillar systems risk pillar bumping in both the tailgate and headgate at depth
- Pillar bumping, even in the gob, can be hazardous in the gateroads and on the longwall face
- Bumping cannot necessarily be prevented by making a rigid pillar larger
- Developing very large rigid pillars is operationally difficult
- When rigid pillars become very large, interpanel barriers become an option
Conclusions

- Interconnecting crosscuts in large interpanel barriers are not practical and increase geotechnical and ventilation risks
The Future

- The two-entry yield pillar system eventually may not be able to protect the longwall face from severe abutment loads at future mining depths (>3,000 ft)
- Alternative systems will most likely be required
- The panel-barrier system is being used by three Utah mines
Non-Geotechnical Issues

- The two-entry yield pillar system was used at Cyprus Shoshone Mine (formerly Carbon County Coal Co.), Hanna, Wyoming, to manage spontaneous combustion events – a report justifying two entry longwall development was submitted to MSHA early 1988 (?)

- Sunnyside Mine successfully used squeeze stoppings in conjunction with two entry longwall gates to isolate individual longwall panel gobs to control methane and spontaneous combustion
Thank you.