

Stone Mine Pillar Stability and Design

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NIOSH Mining Program

Outline

1. Pillars and pillar failure in stone mines
2. The S-Pillar program to design and assess pillar stability

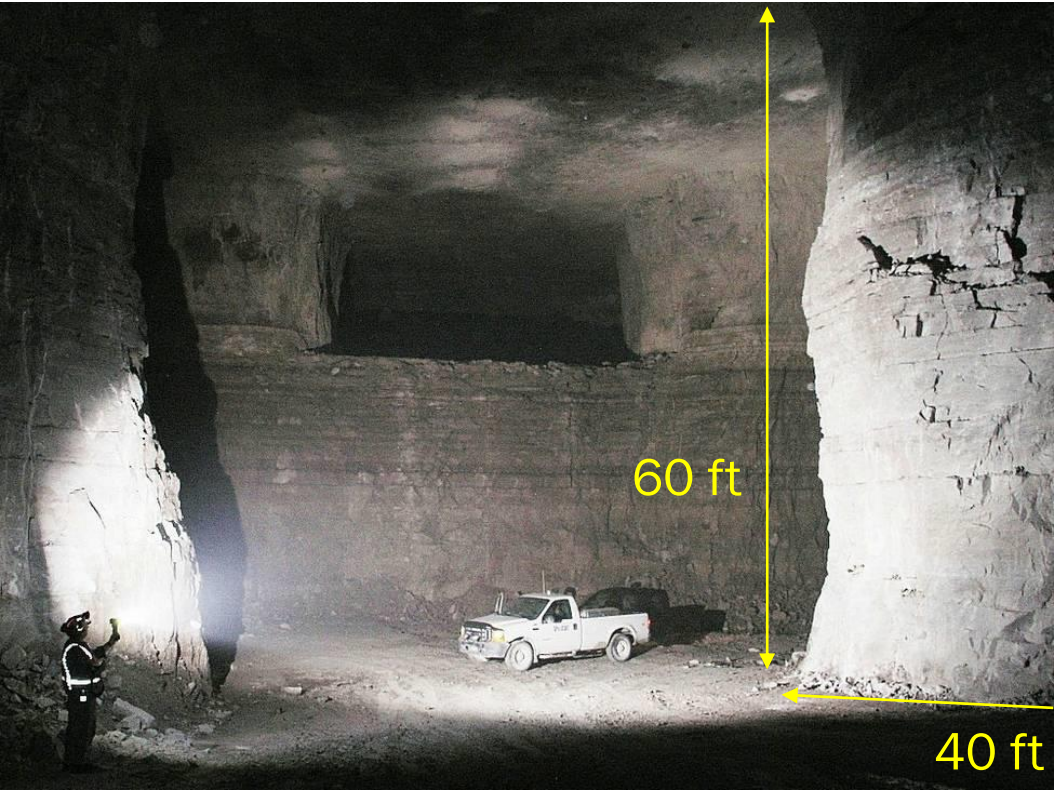
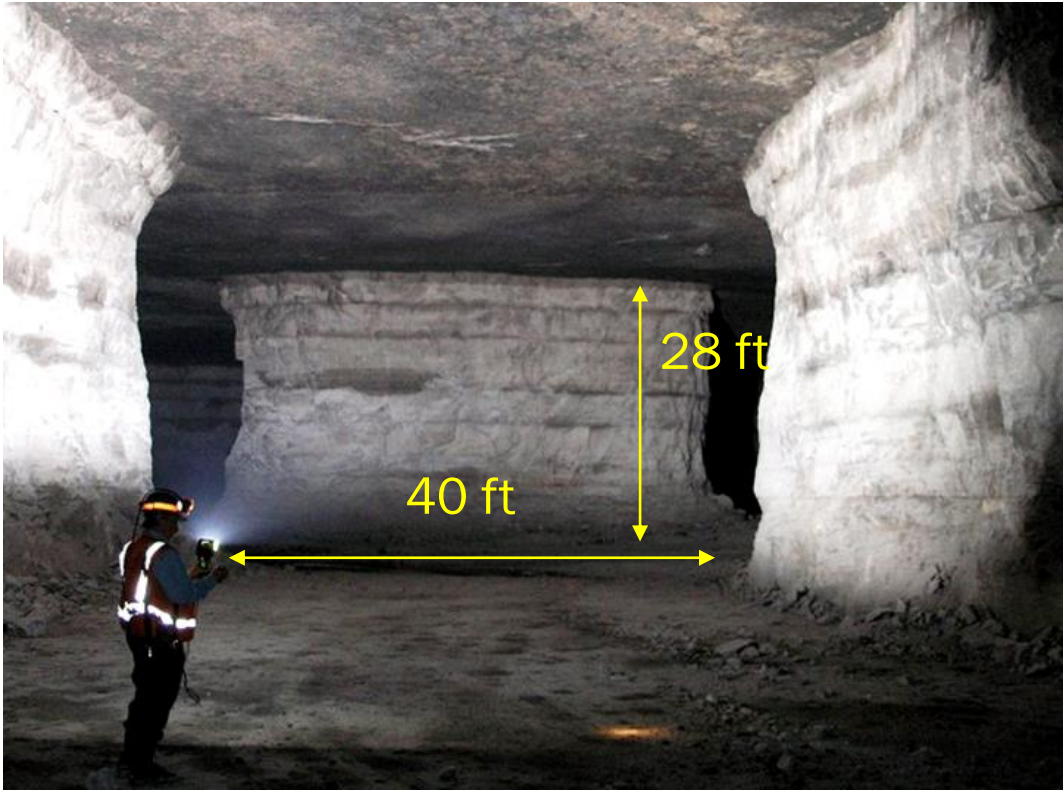
1. Pillars and pillar failure in stone mines

- A look at stone mine pillars
- Signs of potential overloading
- Geologic factors that weaken pillars

Bench mining in stone mines produces tall narrow pillars

First mining 28 ft high

Floor benching to 60 ft



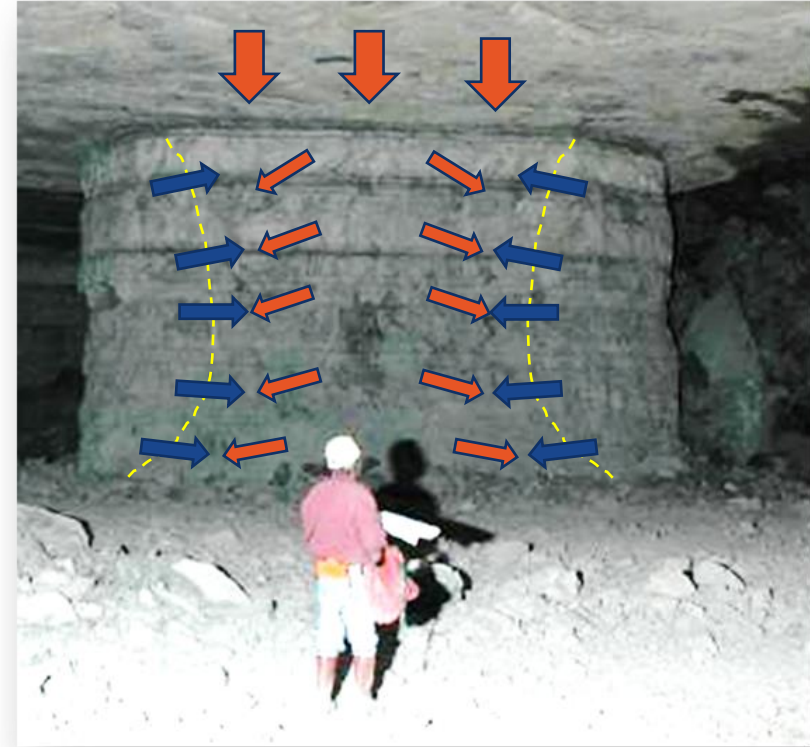
During benching pillar height is increased but width remains the same

Tall narrow pillars:

1) Weaker because lack of confined core



Too tall to develop confined core



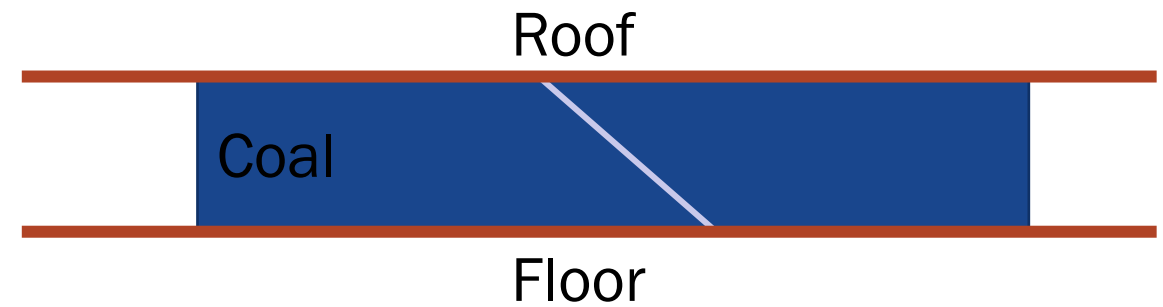
Outer material resists and strengthens inner core

Tall narrow pillars:

2) High impact of slips and joints



Slip has major impact on pillar strength



Slip has little impact on pillar strength

Tall narrow pillars:

3) Can fail suddenly with air blast as roof collapses

Air blasts associated with three recent pillar collapse events in USA



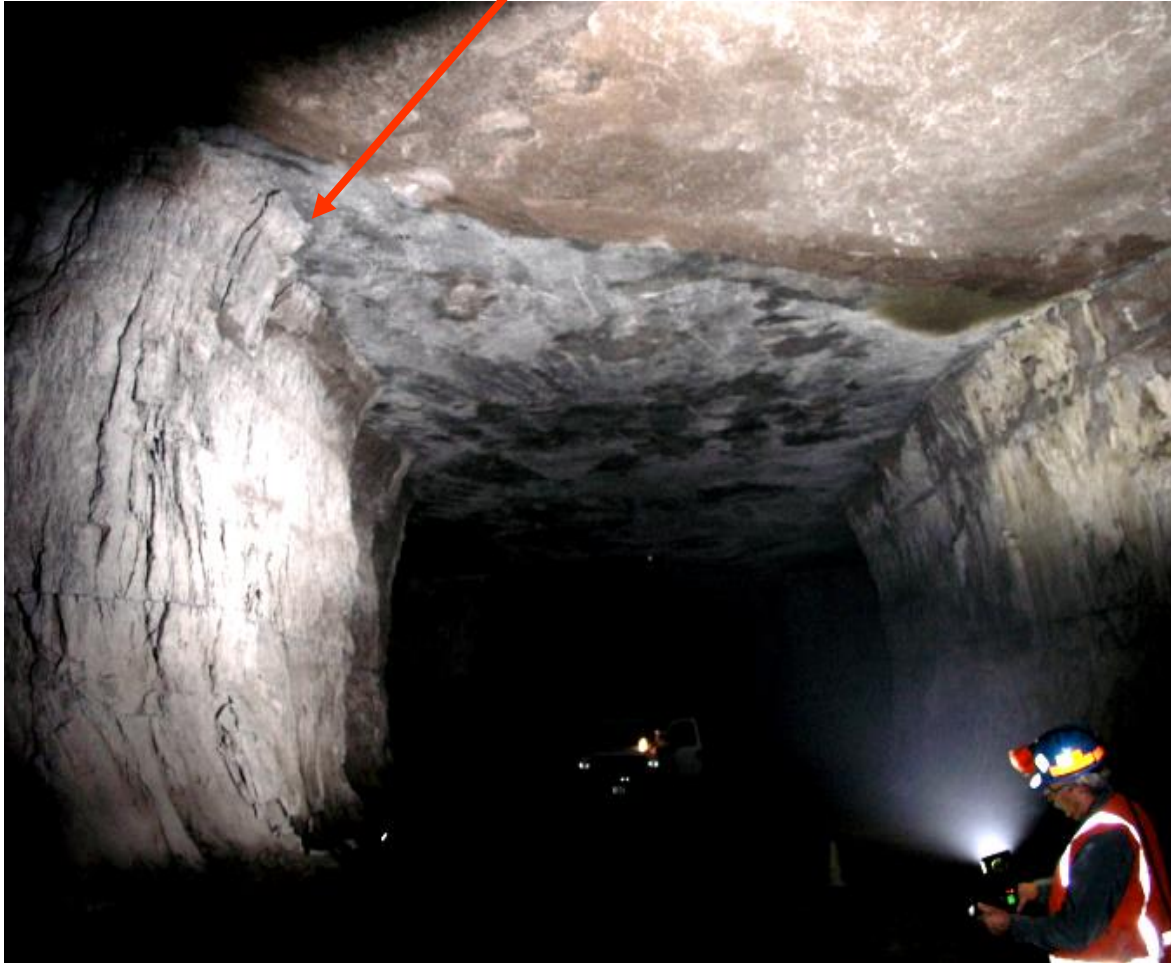
Edge of collapsed area near portal – mine in PA

1. Pillars and pillar failure in stone mines

- A look at stone mine pillars
- Signs of potential pillar overloading
- Geologic factors that weaken pillars

Signs of potential pillar overloading

Rib slabbing and spalling continues long after initial mining



Signs of potential pillar overloading

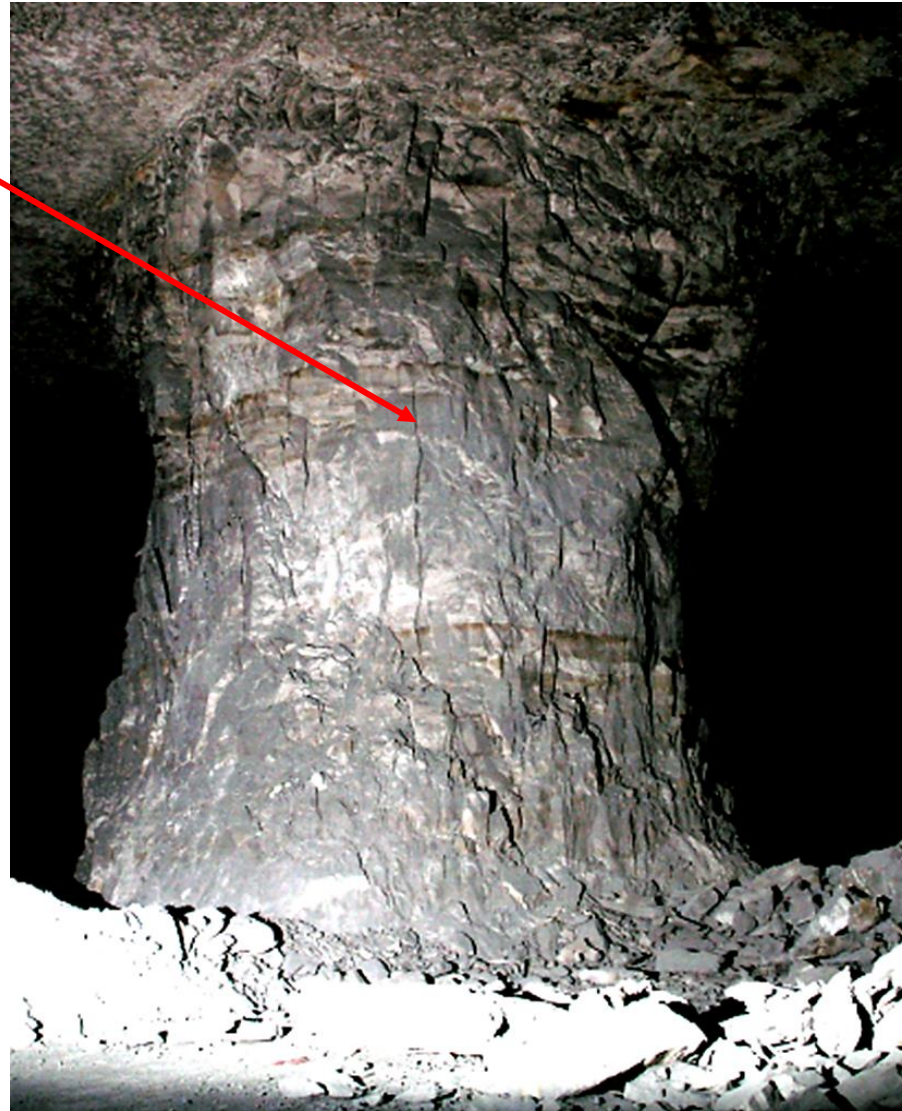
Overloaded pillar is “hour-glassing”



Signs of potential pillar overloading

Open fractures develop

Spalling of fractured materials
results in rounded shape

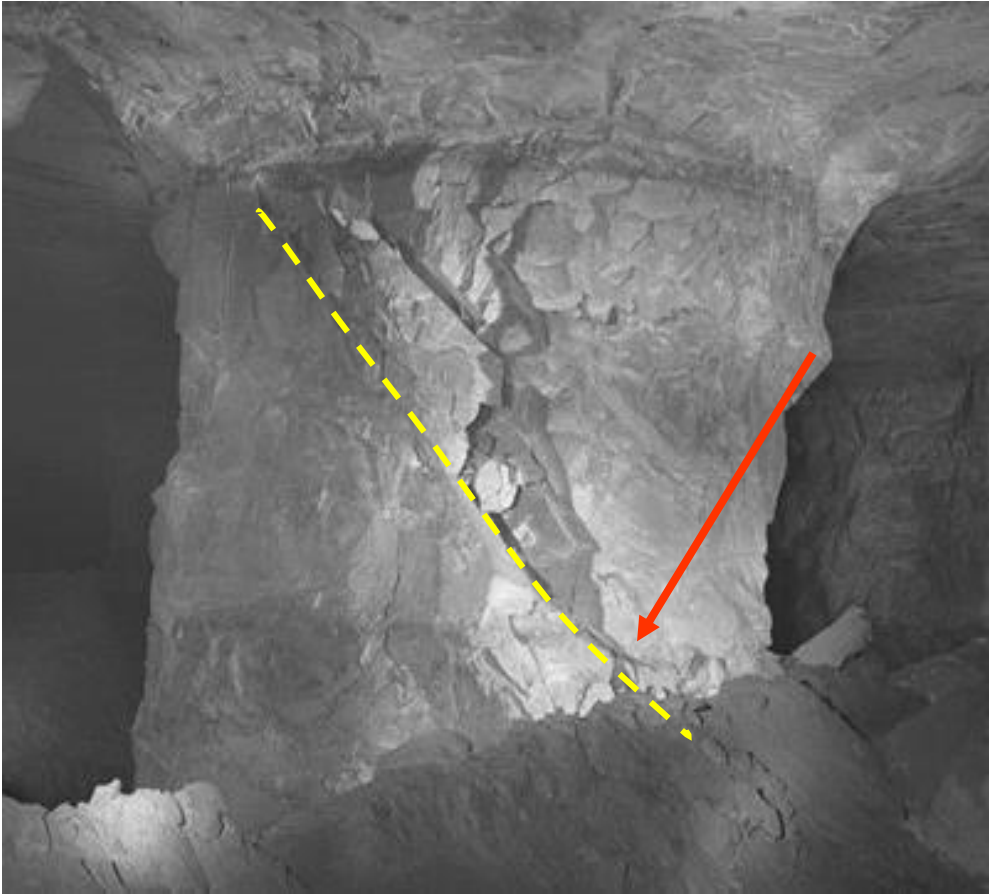
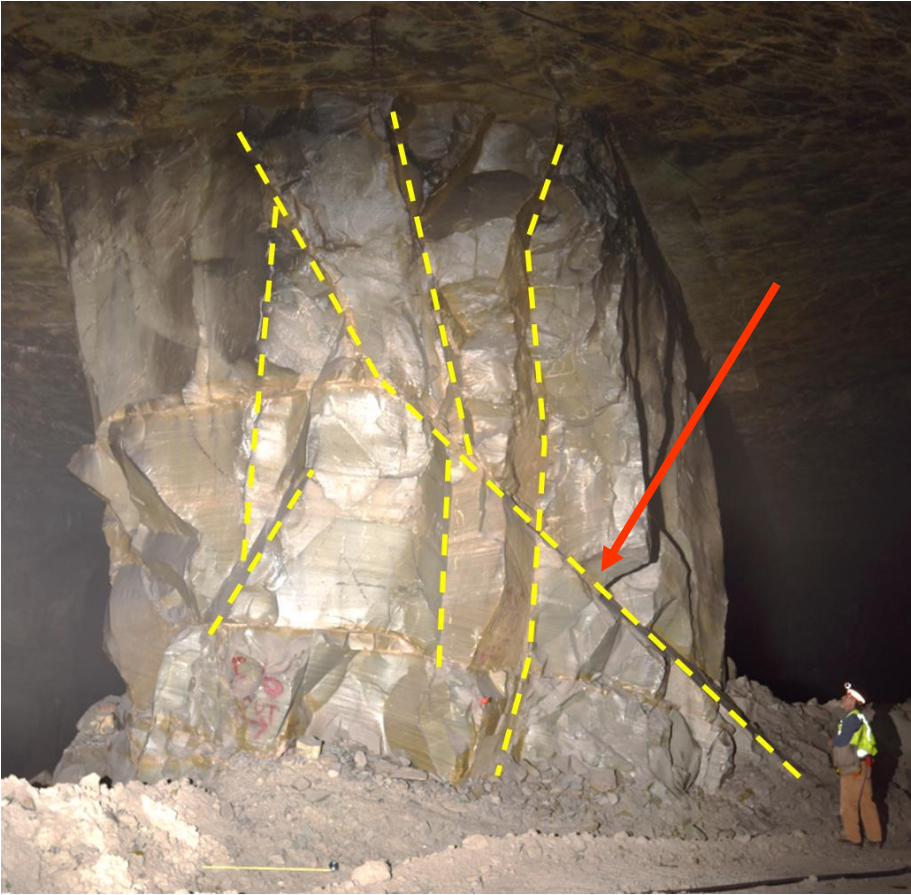


1. Pillars and pillar failure in Stone Mines

- A look at stone mine pillars
- Signs of potential pillar overloading
- Geologic factors that weaken pillars

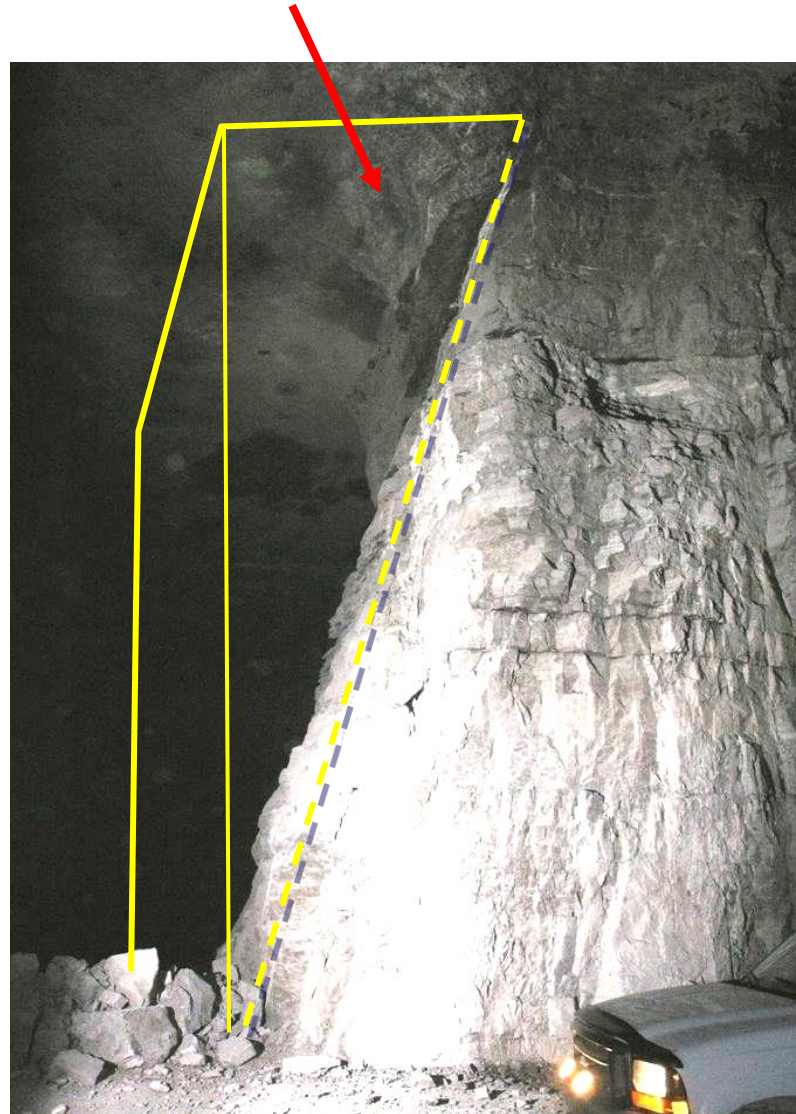
Geologic factors that weaken pillars

Through-going angular joints provide sliding surface



Geologic factors that weaken pillars

Angular joint causes rib collapse and significant reduction in pillar width



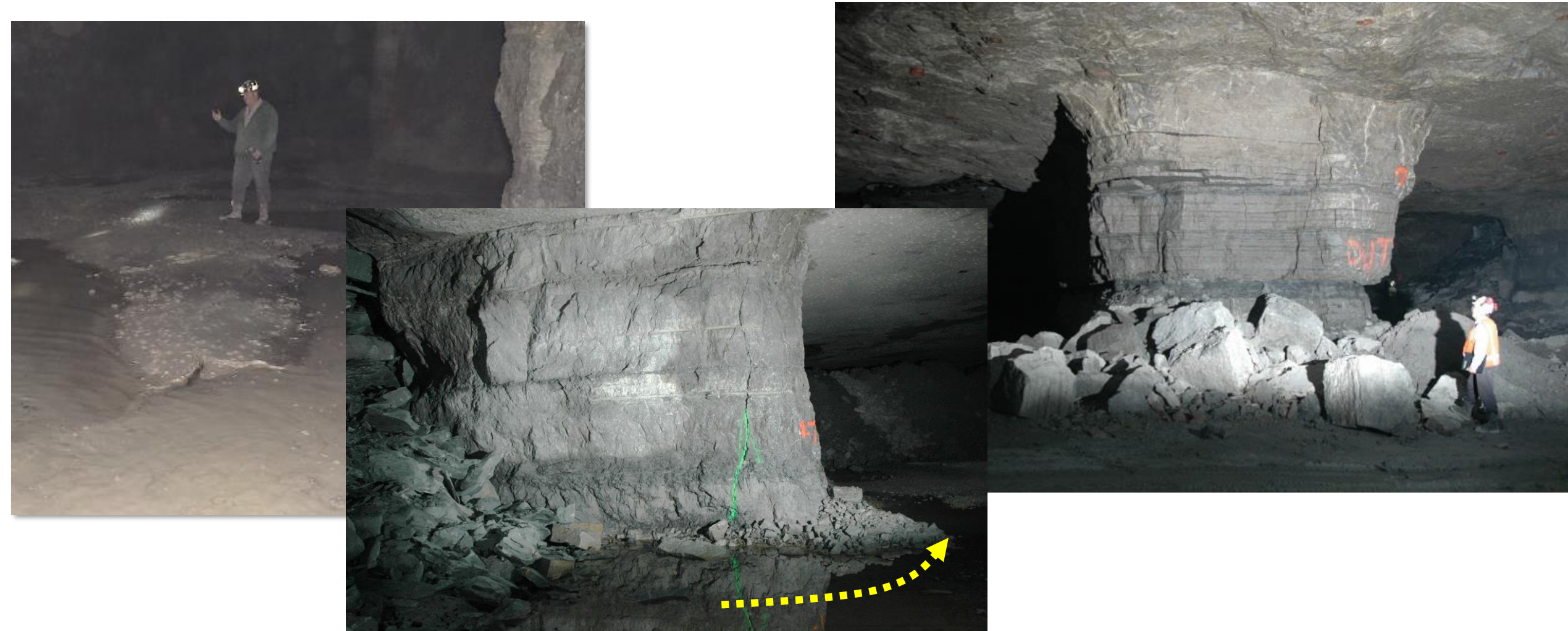
Geologic factors that weaken pillars

Thin soft/clayey weak bands extrude and result in progressive slabbing of pillar ribs



Geologic factors that weaken pillars

1) Soft floor weakened by flooding – pillar punching, and extrusion produces open tension cracks in pillar



Geologic factors that weaken pillars

2) Pillars sagging into soft floor – roof breaks-up, caving to surface



Summary

1) Limestone mine pillars are narrow and tall:

Increased height after benching weakens pillars, sensitive to joints & slips, potential violent failure

2) Signs of pillar overloading are:

Continued rib spalling, hourglass, rounded shape

3) Geologic factors that weaken pillars:

Large angled joints, soft clayey bands, weak floor with moisture

2. The S-Pillar program to assess or design pillars

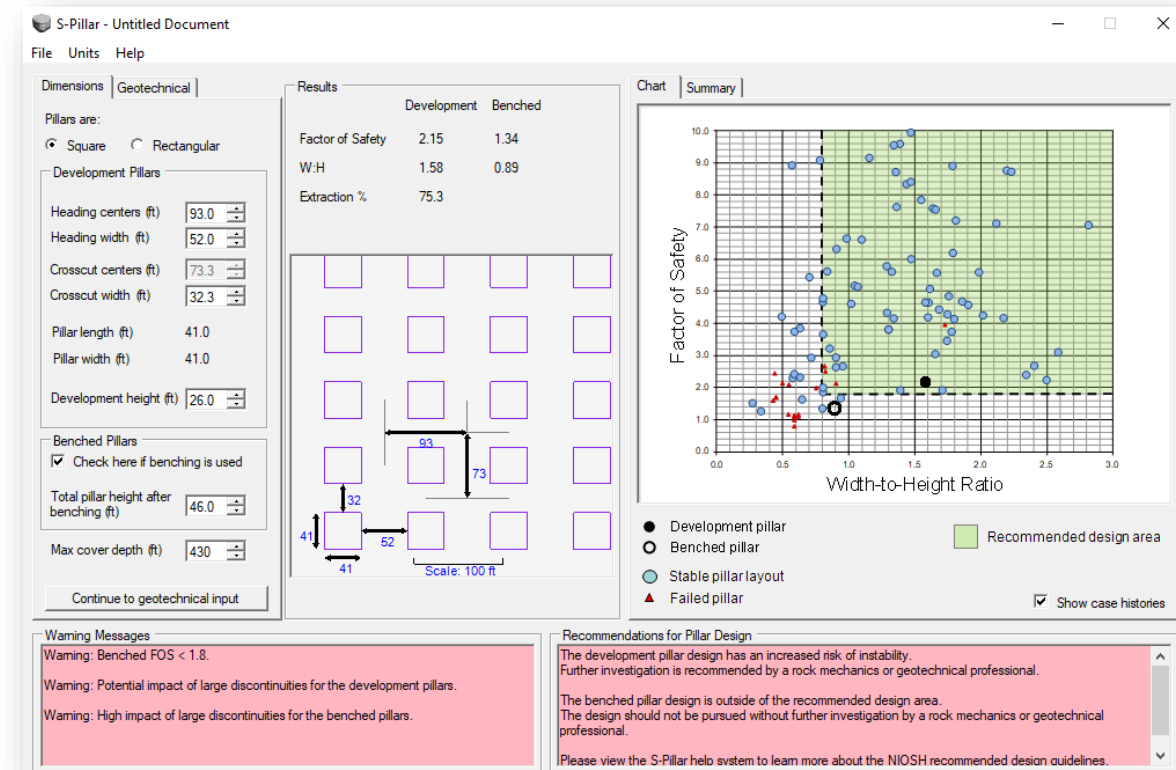
- S-Pillar program what does it do?
- S-Pillar Inputs and results
- Safety factor and design limits
- Design example
- When is S-Pillar applicable?

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The S-Pillar program application

- Calculates average loading, strength and safety factor of pillars in stone mines
- Used to assess stability of existing or planned stone mine pillars



Developed by NIOSH – free download:

<https://www.cdc.gov/niosh/mining/works/coversheet1817.html>

2. The S-Pillar program to design and evaluate stone pillars

- The S-Pillar program – what does it do?
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S-Pillar - Program

Geology data

Calculated results

Plotted results

Pillar dimensions

Benching data

Depth of cover

Messages

The screenshot displays the S-Pillar software interface with the following components:

- Dimensions / Geotechnical Panel:**
 - Pillars are: Square Rectangular
 - Development Pillars:
 - Heading centers (ft): 93.0
 - Heading width (ft): 52.0
 - Crosscut centers (ft): 73.3
 - Crosscut width (ft): 32.3
 - Pillar length (ft): 41.0
 - Pillar width (ft): 41.0
 - Development height (ft): 26.0
 - Benching Pillars:
 - Check here if benching is used
 - Total pillar height after benching (ft): 46.0
 - Max cover depth (ft): 430
- Results Panel:**

	Development	Benchd
Factor of Safety	2.15	1.34
W:H	1.58	0.89
Extraction %	75.3	

Below the table is a diagram of a pillar grid with dimensions: 93 (width), 73 (height), 41 (pillar width), and 52 (pillar spacing). Scale: 100 ft.
- Chart Panel:**

Factor of Safety vs Width-to-Height Ratio

 - Y-axis: Factor of Safety (0.0 to 10.0)
 - X-axis: Width-to-Height Ratio (0.0 to 3.0)
 - Legend:
 - Development pillar
 - Benchd pillar
 - Stable pillar layout
 - ▲ Failed pillar
 - Recommended design area (shaded green)
- Messages Panel:**

Warning Messages

 - Warning: Benchd FOS < 1.8.
 - Warning: Potential impact of large discontinuities for the development pillars.
 - Warning: High impact of large discontinuities for the benchd pillars.

Recommendations for Pillar Design

 - The development pillar design has an increased risk of instability. Further investigation is recommended by a rock mechanics or geotechnical professional.
 - The benchd pillar design is outside of the recommended design area. The design should not be pursued without further investigation by a rock mechanics or geotechnical professional.
 - Please view the S-Pillar help system to learn more about the NIOSH recommended design guidelines.

2. The S-Pillar program to design and evaluate stone pillars

- The S-Pillar program – what does it do?
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Pillar strength, load and safety factor calculation

Strength

- Pillar strength calculated from rock strength, W:H ratio, presence of large slips/joints in pillars

Loading

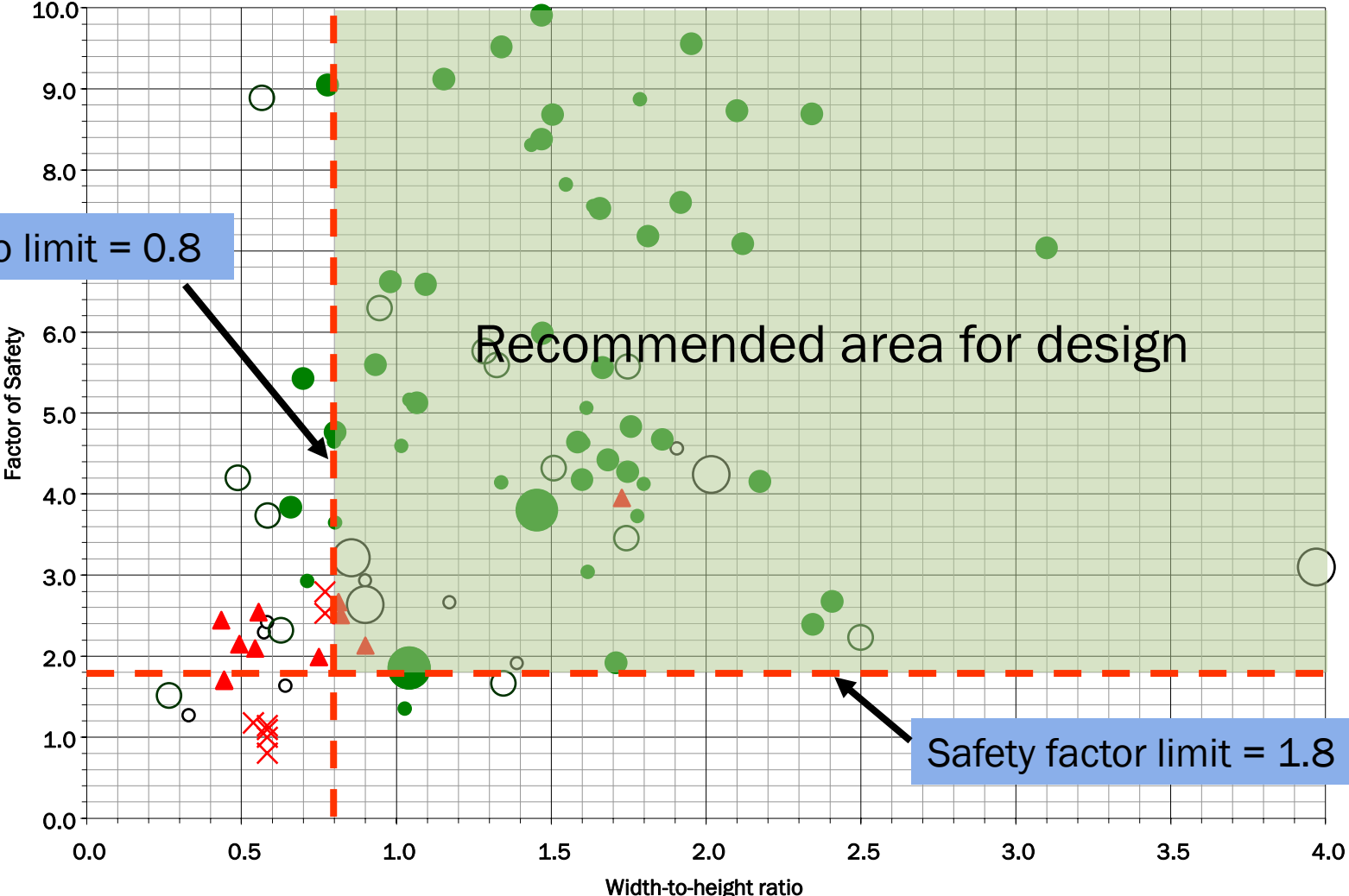
- Pillars carry full overburden weight to surface: tributary load

Safety Factor

- $SF = \frac{\textit{Strength}}{\textit{Tributary Load}}$
- If strength is twice the tributary load: $SF = 2.0$

Safety factor and design limits

Width to height ratio limit = 0.8



Safety factor limit = 1.8

S-Pillar run through and help system

S-Pillar - Untitled Document
File Units Help

Dimensions | Geotechnical

Pillars are:
 Square Rectangular

Development Pillars

Heading centers (ft)

Heading width (ft)

Crosscut centers (ft)

Crosscut width (ft)

Pillar length (ft) 41.0

Pillar width (ft) 41.0

Development height (ft)

Benched Pillars

Check here if benching is used

Total pillar height after benching (ft)

Max cover depth (ft)

Continue to geotechnical input

Results

	Development	Benched
Factor of Safety	2.15	1.34
W:H	1.58	0.89
Extraction %	75.3	

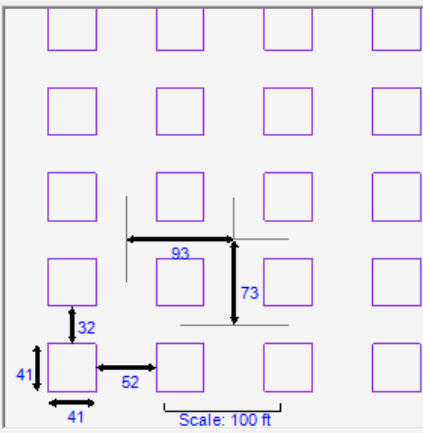
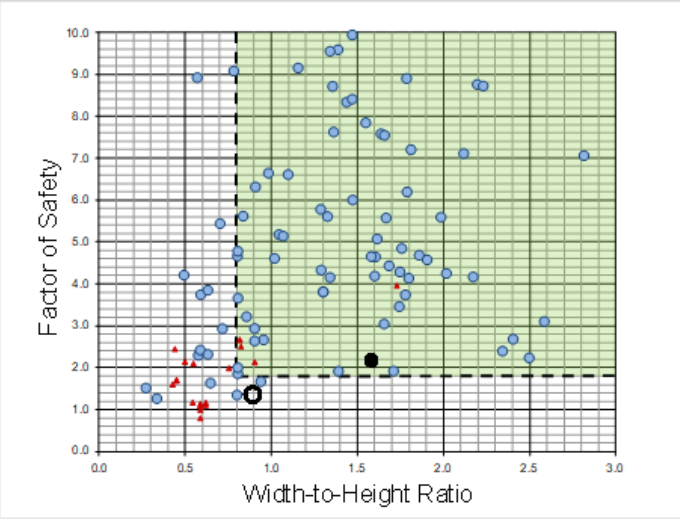


Chart | Summary



Factor of Safety

Width-to-Height Ratio

- Development pillar
- Benched pillar
- Stable pillar layout
- ▲ Failed pillar
- Recommended design area

Show case histories

Warning Messages

Warning: Benched FOS < 1.8.

Warning: Potential impact of large discontinuities for the development pillars.

Warning: High impact of large discontinuities for the benched pillars.

Recommendations for Pillar Design

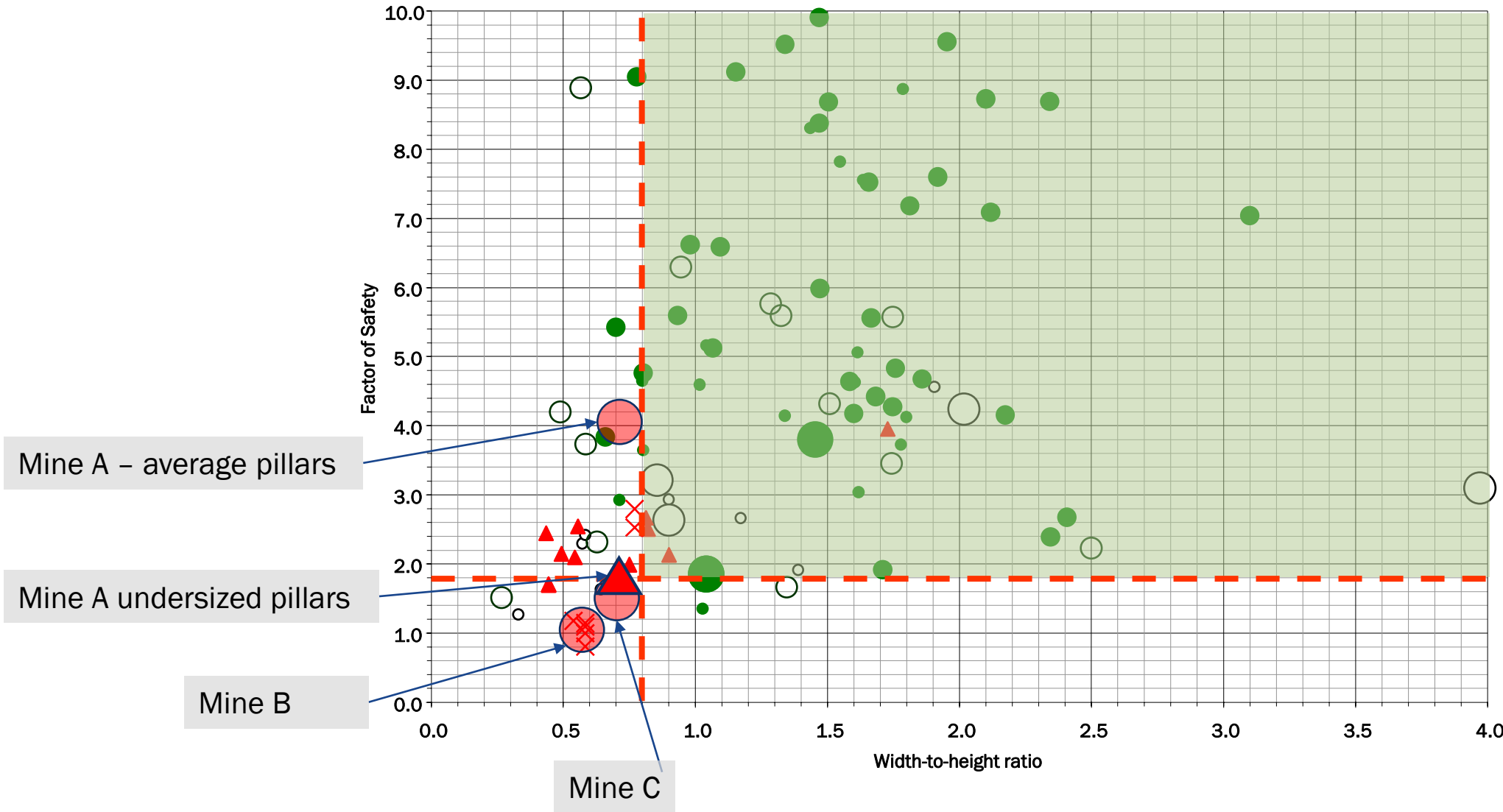
The development pillar design has an increased risk of instability. Further investigation is recommended by a rock mechanics or geotechnical professional.

The benched pillar design is outside of the recommended design area. The design should not be pursued without further investigation by a rock mechanics or geotechnical professional.

Please view the S-Pillar help system to learn more about the NIOSH recommended design guidelines.

Safety factor and design limits

Recent collapsed cases - based on provisional information on pillar as-mined dimensions and geology



2. The S-Pillar program to assess or design pillars

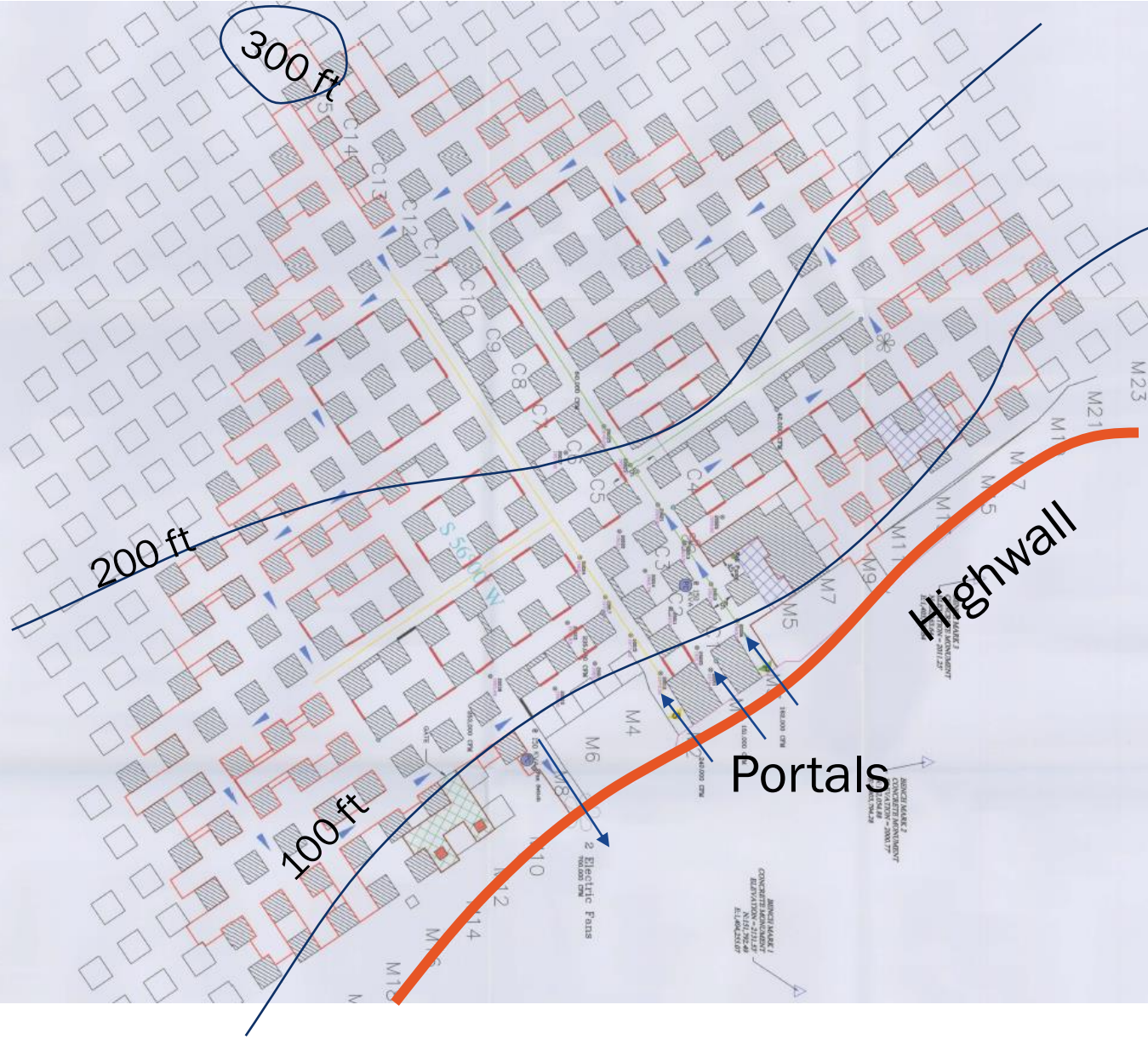
- Pillar strength, load, and safety factor
- S-Pillar Layout and Inputs
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- Design example
- When is S-Pillar applicable?

Hypothetical mine – planning to mine and bench under 300 ft cover

- Heading centers: 80 x 80 ft
- Entry widths: 40 ft
- Development height: 25 ft
- Bench 1 floor-cut: 15 ft
- Bench 2 floor-cut: 15 ft

Rock formation: Vanport

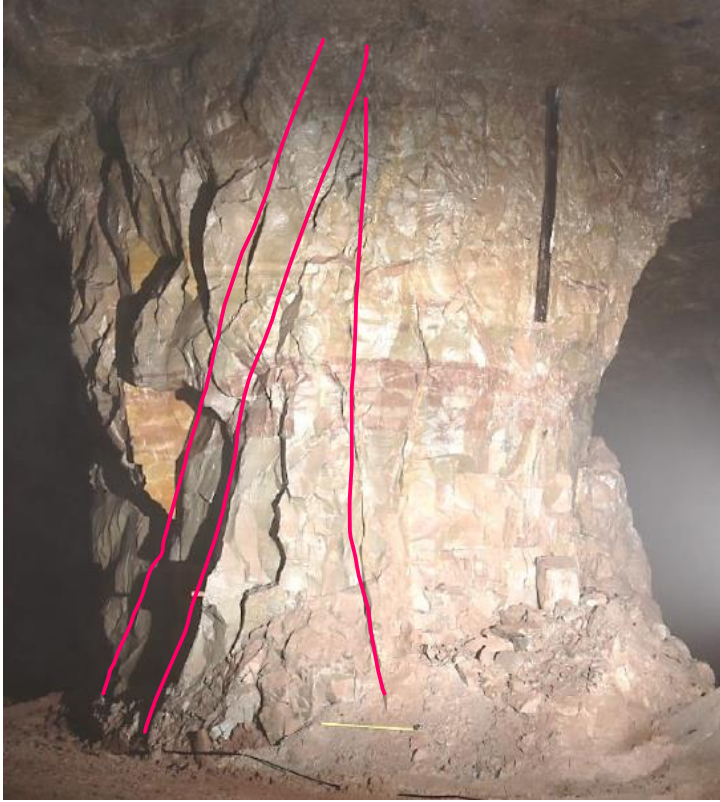
No strength or other geologic data



Observation of existing pillars



Average dip: ?



Average frequency per pillar: ?



S-Pillar Analysis:

Heading centers: 80 x 80 ft

Heading widths: 40 ft

Development height: 25 ft

Bench 1 floor cut; 15 ft

Bench 2 floor cut: 15 ft

Benching total heights:

1: 40 ft

2: 55 ft

Depth of cover: 300 ft

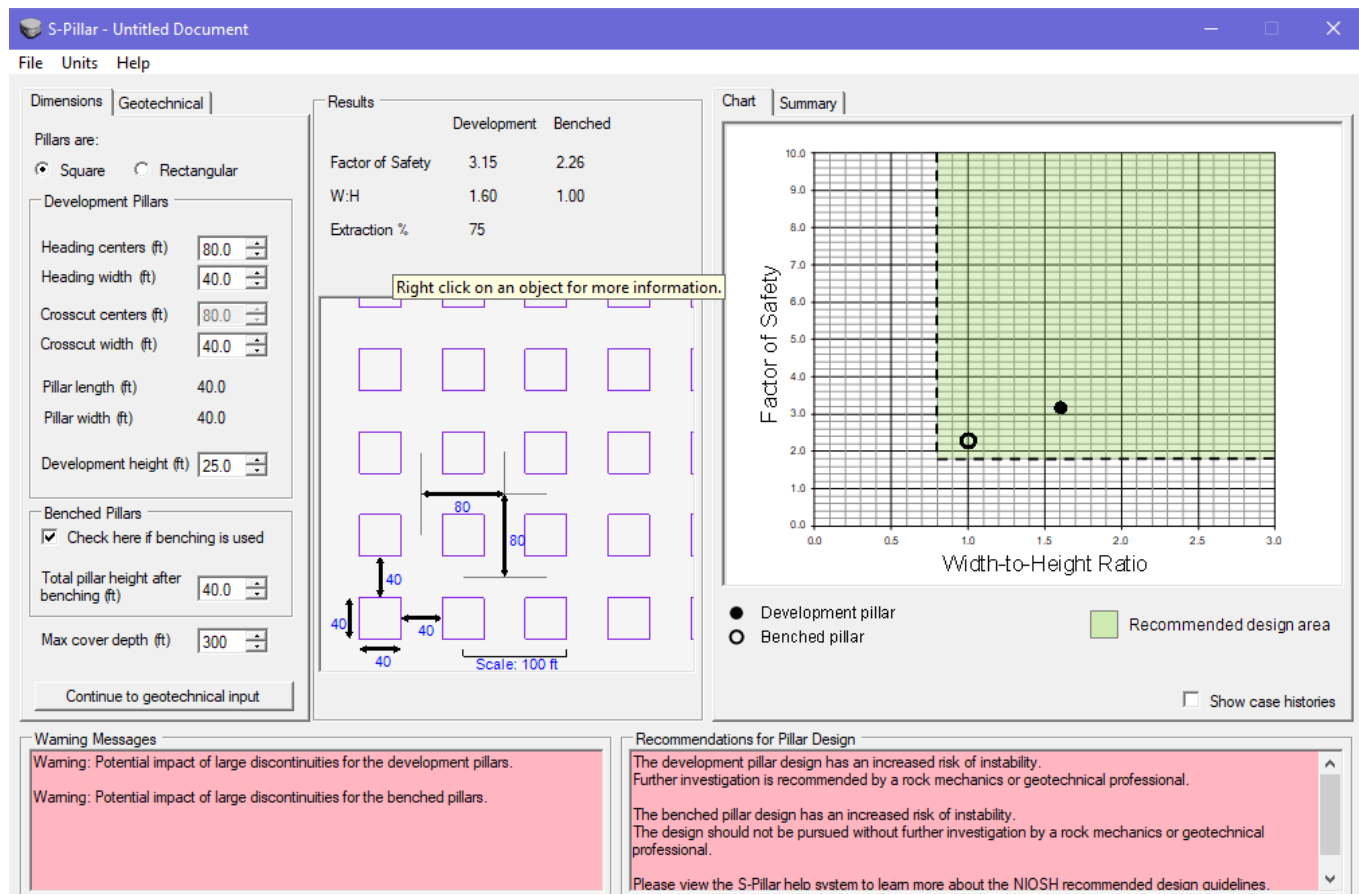
Rock formation: Vanport

Rock strength:

Large discontinuities:

Dip 45-75 deg

Spacing: 2 to 4 per pillar



2. The S-Pillar program to design and evaluate stone pillars

- Pillar strength, load, and safety factor
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When is S-Pillar applicable?

- Eastern/Midwestern US limestone mines
- Pillars are near horizontal ($< 5^\circ$ dip)
- Single level mining
- Strong limestone strata (6,000 psi)
- Weak clayey bands not be present in pillars
- Strong floor and roof, no punching



Summary

- 1) S-Pillar can be used to assess stability conditions of existing pillar layouts and to design new layouts
- 2) Careful observation needed to identify presence and spacing of large joints/slips/faults that can compromise pillar strength
- 3) Thin weak bands in pillars and soft floor not accounted for in S-Pillar but can have detrimental impact on pillar strength



This presentation presents only the highlights of stone pillar stability and design using S-Pillar. For full information regarding this topic please review the help-system in S-Pillar and visit:
<https://www.cdc.gov/niosh/mining/works/coversheet1817.html>

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