Stone Mine Pillar Stability and Design

G.S. (Essie) Esterhuizen
Pittsburgh Mining Research Division
Mining Systems Safety Branch

Presented at MSHA Roof Control Specialists Seminar
October 2021
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 little impact on pillar strength

Slip has major 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?
2. The S-Pillar program to assess or design pillars
   • The S-Pillar program what does it do?
   • S-Pillar Inputs and results
   • Safety factor and design limits
   • Design example
   • When is S-Pillar applicable?
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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2. The S-Pillar program to design and evaluate stone pillars
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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
• $SF = \frac{\text{Strength}}{\text{Tributary Load}}$
• If strength is twice the tributary load: $SF = 2.0$
Safety factor and design limits

- Safety factor limit = 1.8
- Width to height ratio limit = 0.8

Recommended area for design

Graph showing the relationship between factor of safety and width-to-height ratio with recommended limits.
S-Pillar run through and help system
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
   • Safety factor and design limits
   • 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?
When is S-Pillar applicable?

- Eastern/Midwestern US limestone mines
- Pillars are near horizontal (< 5° 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

NIOSH contacts: Essie Esterhuizen eee5@cdc.gov  Michael Murphy mmu5@cdc.gov  Nicole Evanek kri5@cdc.gov

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