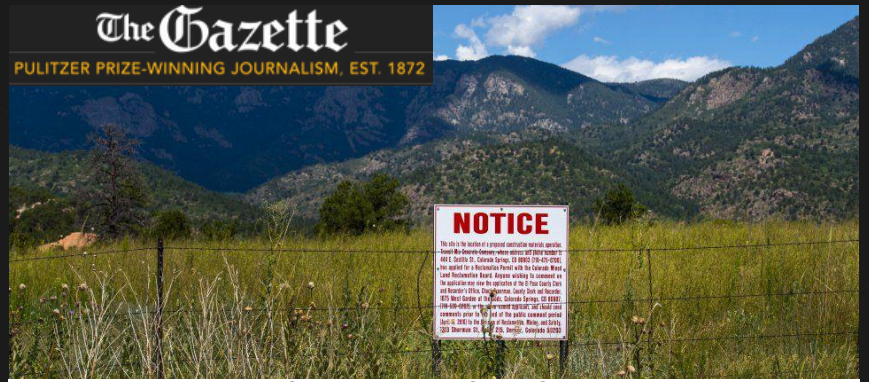
PILLAR AND ROOF SPAN DESIGN FOR UNDERGROUND STONE MINES

ALAN A. CAMPOLI
RESPEC

SPECIAL THANKS TO
P. E. CHRISTENSEN, G.S. ESTERHUIZEN, & J.S.L. MORGAN

WHERE WILL YOUR NEXT SURFACE QUARRY BE?

IT'S BECOMING INCREASINGLY DIFFICULT IN MOST LOCATIONS TO PERMIT NEW QUARRY OPERATIONS



State board rejects application for proposed quarry in El Paso County

By: Rachel Riley Apr 26, 2018 Photo Credit: The Gazette, Christian Murdock

Transit Mix bid for a new quarry faces strong opposition

Quarry query

By John Hazlehurst

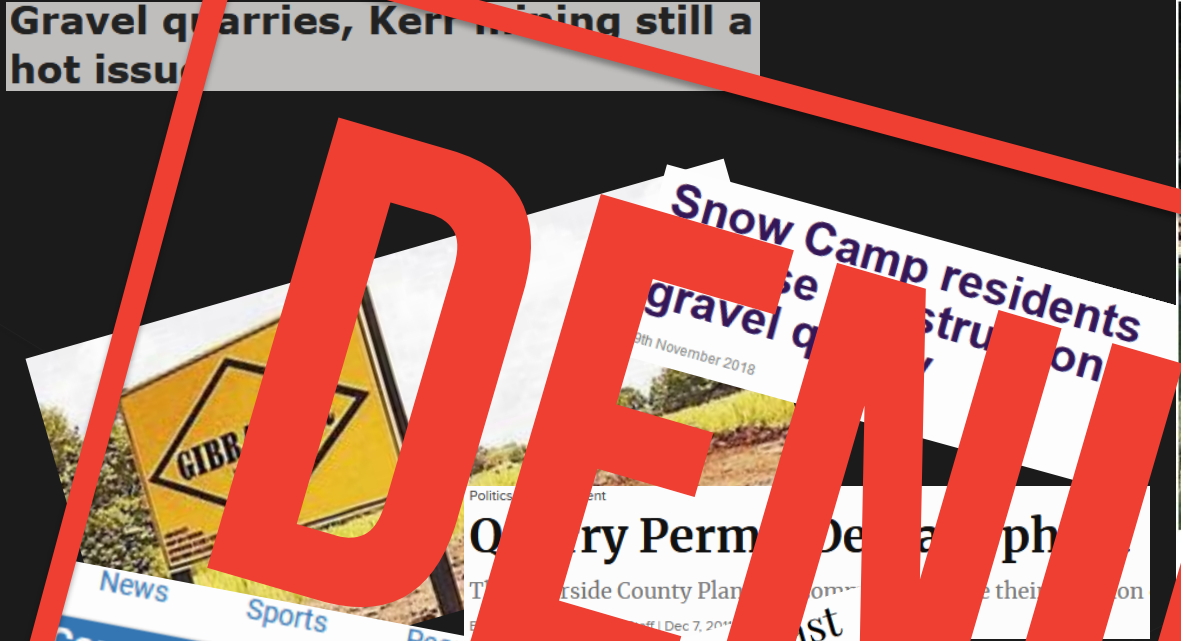
TODAY'S REALITY

SEEMINGLY UNAWARE of the amount of sand, gravel, aggregate, and cement they consume, people are increasingly opposed to quarry development.

ONE SENIOR INDUSTRY OFFICIAL observed that state and federal permitting is difficult, but manageable; however, local action and approvals are full of uncertainty.

ENVIRONMENTAL GROUPS, local activists with the power of internet communication, and social media are opposing almost all quarry development now more than ever.

Gravel quarries, Kerr [illegible] still a hot issue



rry" yard signs created by [illegible] s Against Mining, pe[illegible]ered yards outh Tecumseh Road ne[illegible] High Sch[illegible] cent weekend. In Ju[illegible] the state approved expanded lime[illegible]ng operatio[illegible] River Township, jus[illegible]orth of intensifying op[illegible]om area re[illegible] hoto by Audrey Ha[illegible]tt)

[illegible]ppos[illegible]n ent[illegible]new pha[illegible]e

udrey Hackett
shed: September 21,

No C[illegible]mments

Evan Brandt ebrandt@21st-ce[illegible]

Magruder quarry opposition in Sunrise

By Janet Dabbs Aug 15, 2013

No quarry expansion for Magruder

CAMDEN COUNTY, Mo. — It looks like the end of the road for Magruder, as Camden County commissioners with a unanimous vote squelched the compan…

SUNRISE BEACH, Mo. — Another re[illegible] monolithic opposition from the Sunrise Beac[illegible]

[illegible]TING - [illegible]UARY [illegible]9

Created: Thursday, 17 [illegible] ublished: Thurs[illegible], 17 January 2019

1

Proposed Cemex Quarry Under Fire from California Officials

Published: Saturday, 18 July 2015 23:30 Written by Rock Products News

Washington Q[illegible]rry Faces Oppo[illegible]tion

DENIED

OPTIONS???

OPTION NO. 1
Abandon the market

May affect downstream business

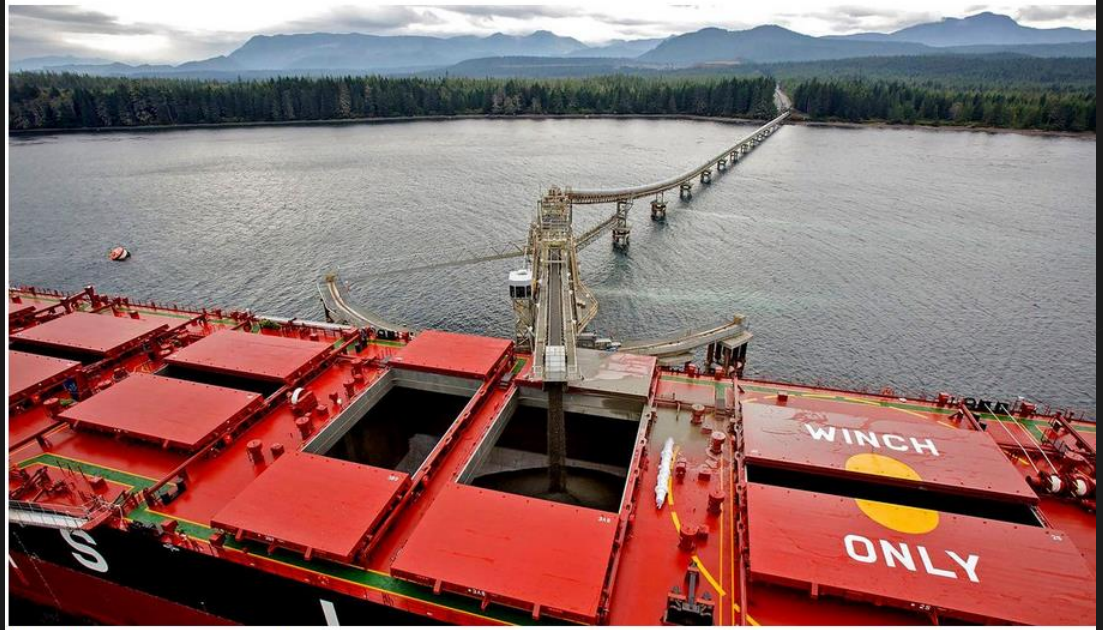
OPTION NO. 2
Transport sand, gravel, and aggregates from sources farther away

Depending on logistics, transportation can be competitive

Assumes you can get permits “farther away”

Why builders of big L.A. projects are making concrete with gravel and sand shipped from Canada

By JAMES RUFUS KOREN NOV 04, 2017 | 6:00 AM



Conveyor belts stretching more than a mile from the Orca quarry on Vancouver Island in Canada carry gravel and sand to a ship off the coast of Port McNeil. (Polaris Materials)

"It's not that California doesn't have enough sand and gravel. But as development has sprawled, quarries or potential quarry sites that were once in sparsely populated areas are ***now surrounded by people*** — who don't want the attendant noise, pollution and truck traffic."

WHAT ABOUT GOING UNDERGROUND?

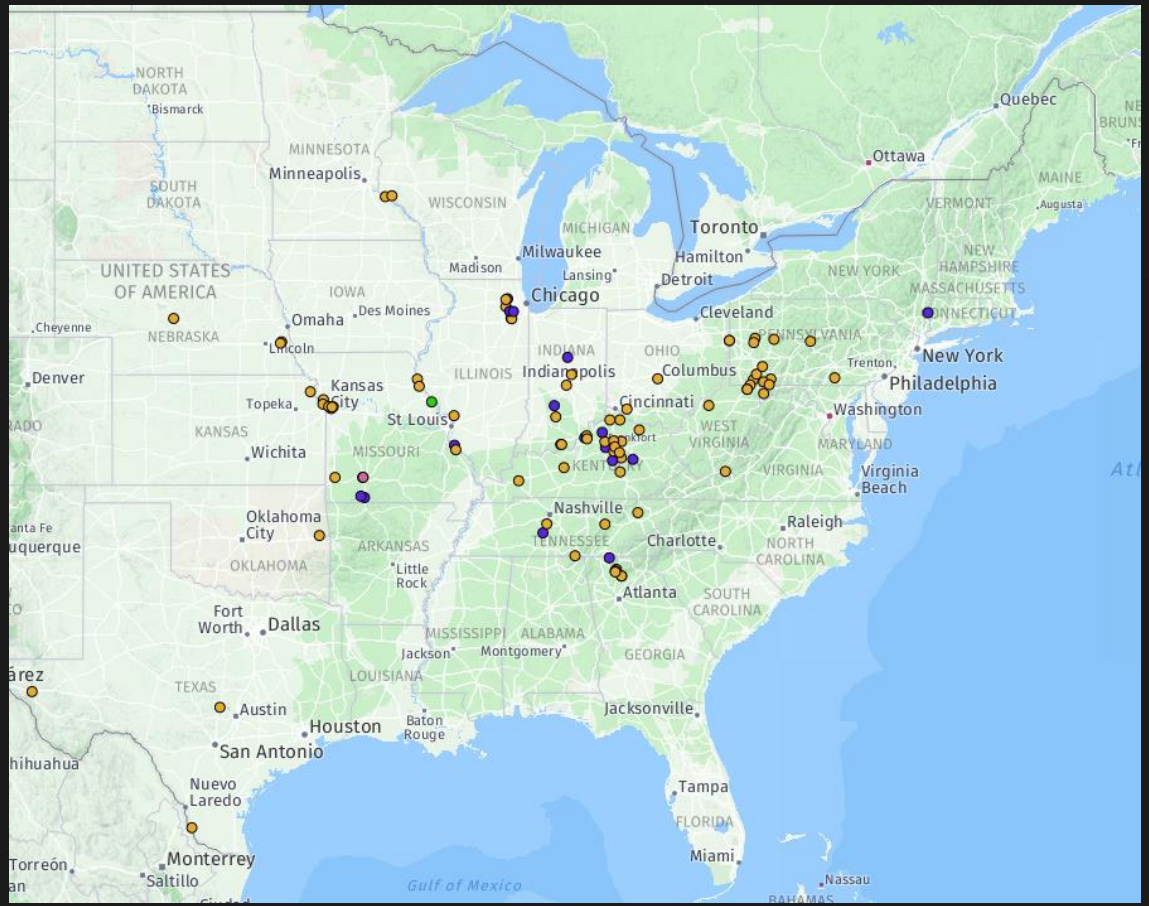
OPTION NO. 3
Going underground

Continues life at existing industrial facility
// Although still expect opposition

Reduces some of the impacts of a surface facility

Can be a competitive option if the geology extends deeper than the surface can access within existing permit area

UNDERGROUNDS OPERATIONS ARE WIDESPREAD



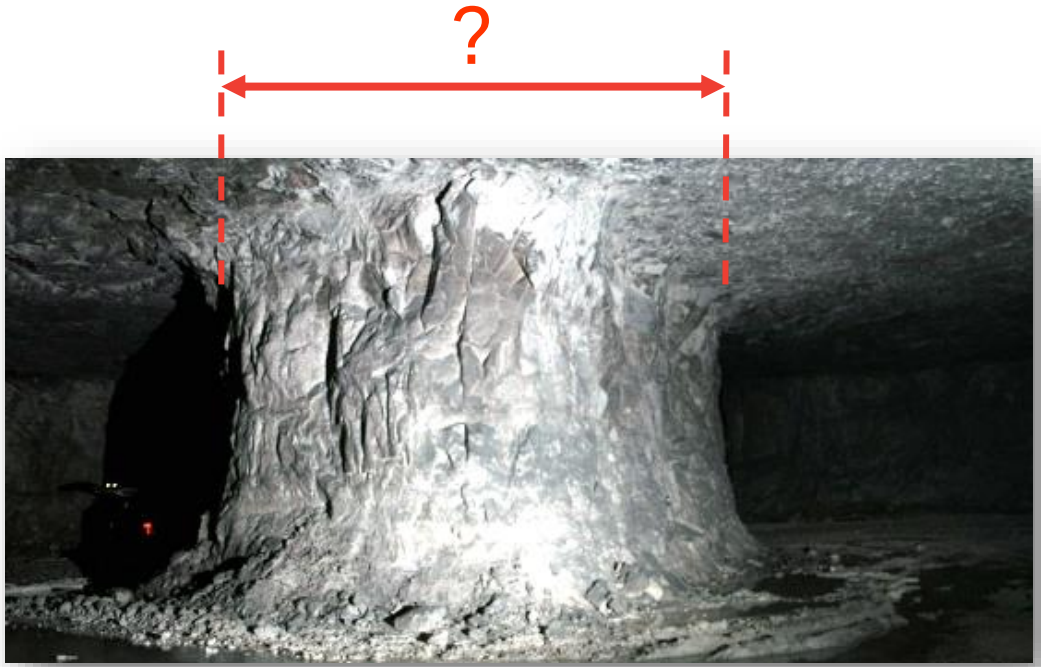
WHAT DO I NEED TO KNOW?

PRIMARY QUESTIONS

1. Geology
2. Anomalies
3. Geotechnical
4. Groundwater

QUESTION:

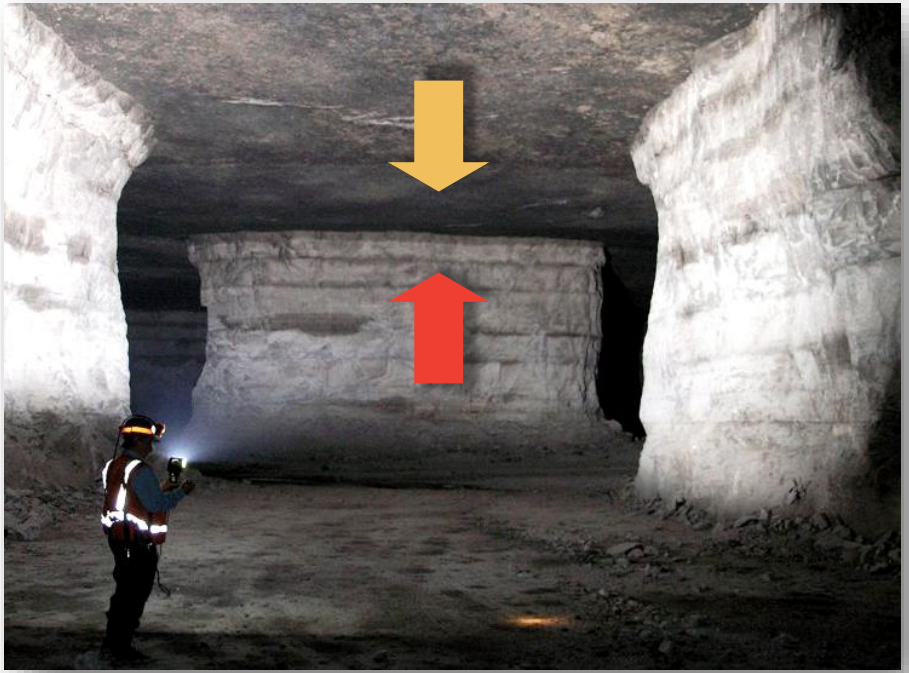
- WHAT PILLAR SIZE IS REQUIRED TO ALLOW SAFE EXTRACTION OF STONE?



PILLAR SIZE DICTATED BY TWO REQUIREMENTS:

1

PILLAR STRENGTH SHOULD BE SUFFICIENT TO SUPPORT THE OVERBURDEN LOAD



PILLAR SIZE IS DICTATED BY TWO REQUIREMENTS:

2

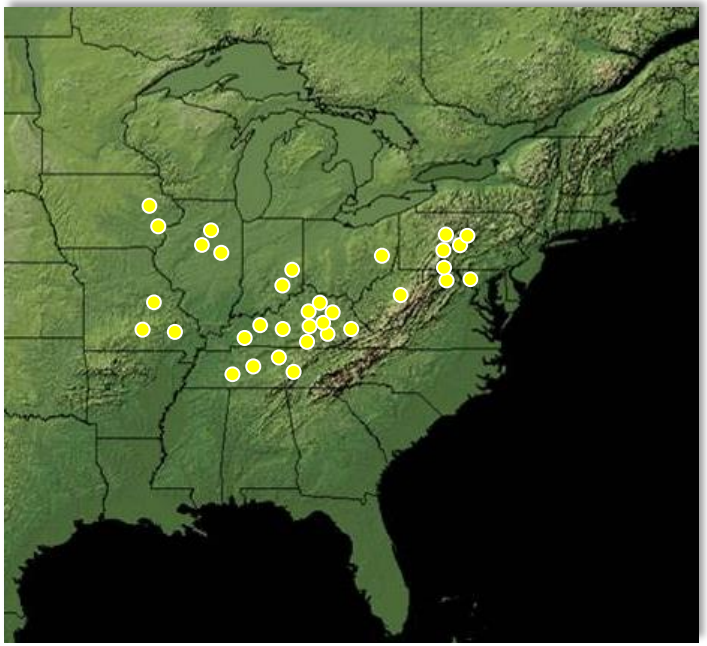
PILLAR LOAD SHOULD NOT RESULT IN UNSTABLE RIBS THAT POSE HAZARD TO MINE OPERATIONS

DESIGNING STABLE PILLARS....

- WHAT IS PILLAR STRENGTH?
- WHAT IS PILLAR LOAD?
- WHAT MARGIN OF SAFETY IS REQUIRED BETWEEN STRENGTH AND LOAD?

RESEARCH APPROACH

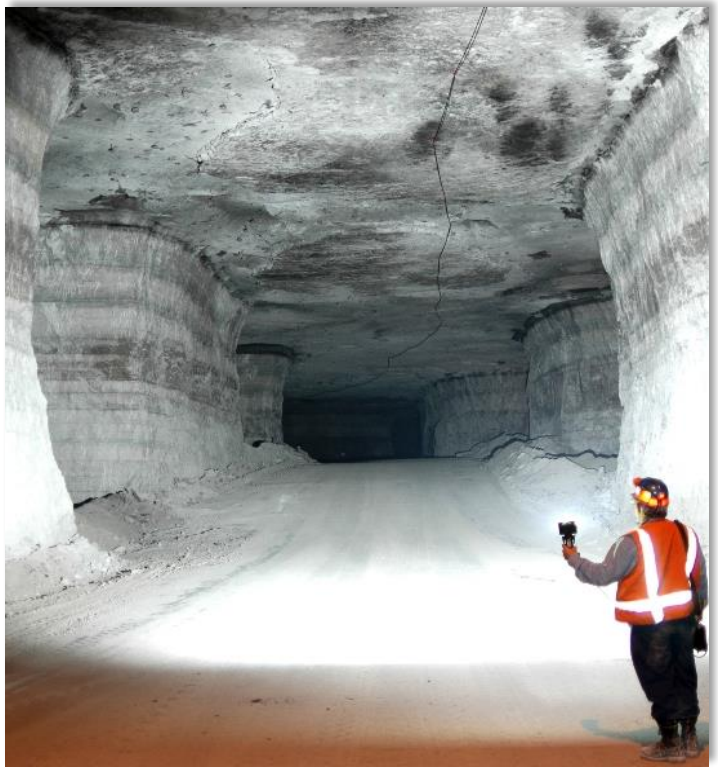
- OBSERVE PILLAR PERFORMANCE IN OPERATING STONE MINES
- DEVELOP UNDERSTANDING OF STABILITY ISSUES
- CONDUCT ENGINEERING ANALYSIS
- DEVELOP DESIGN PROCEDURE



Operating Mines Included in the Study

PILLAR PERFORMANCE IN OPERATING MINES

- ALL PILLAR SYSTEMS OBSERVED WERE SUCCESSFUL IN SUPPORTING THE OVERBURDEN – NIOSH DID NOT SEE ANY COLLAPSED PILLAR SYSTEMS
- NIOSH FOUND A SMALL NUMBER OF SINGLE FAILED PILLARS IN OTHERWISE STABLE LAYOUTS



FACTORS CONTRIBUTING TO PILLAR INSTABILITY

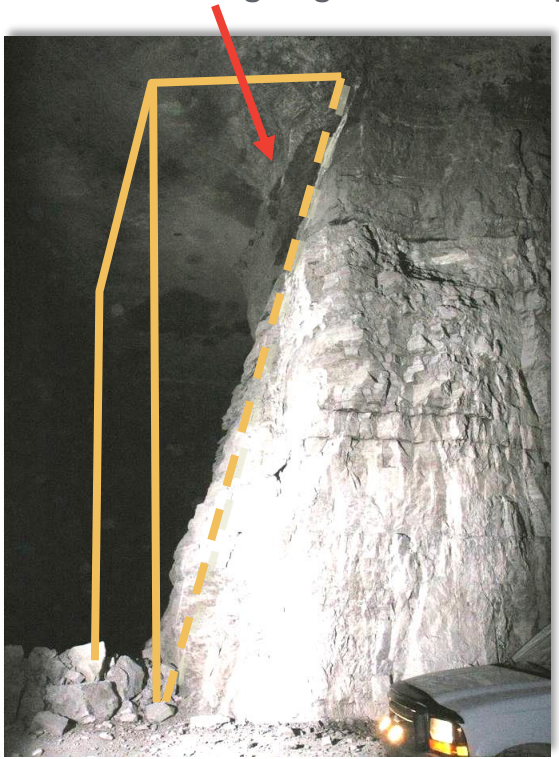
Pillar Bisected by Large Angular Discontinuity

FACTORS CONTRIBUTING TO PILLAR INSTABILITY

Failing along angular discontinuities

FACTORS CONTRIBUTING TO PILLAR INSTABILITY

Pillar failure along large discontinuity



FACTORS CONTRIBUTING TO PILLAR INSTABILITY

Overloaded pillar is “hour-glassing”

FACTORS CONTRIBUTING TO PILLAR INSTABILITY

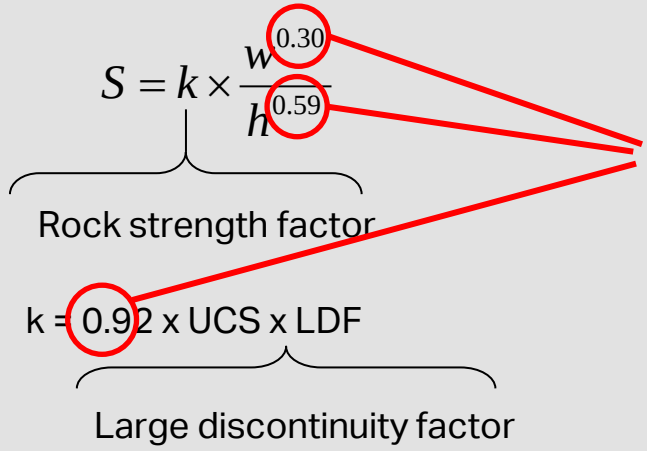
Thin weak bands result in progressive slabbing of pillar ribs

ONSET OF RIB INSTABILITY

Rib slabbing can start when the pillar stress exceeds 10% of intact rock strength

PILLAR STRENGTH DETERMINATION

- USE CLASSIC PILLAR STRENGTH EQUATION: ROCK STRENGTH, WIDTH, HEIGHT
- ACCOUNT FOR LARGE ANGULAR DISCONTINUITIES
- EFFECT OF WEAK BANDS NOT INCLUDED – NEEDS SPECIALIZED ANALYSIS



PILLAR STRESS DETERMINATION

- ASSUME FULL OVERBURDEN LOAD IS CARRIED BY THE PILLARS
- PILLAR STRESS IN A REGULAR ARRAY OF PILLARS IS GIVEN BY:

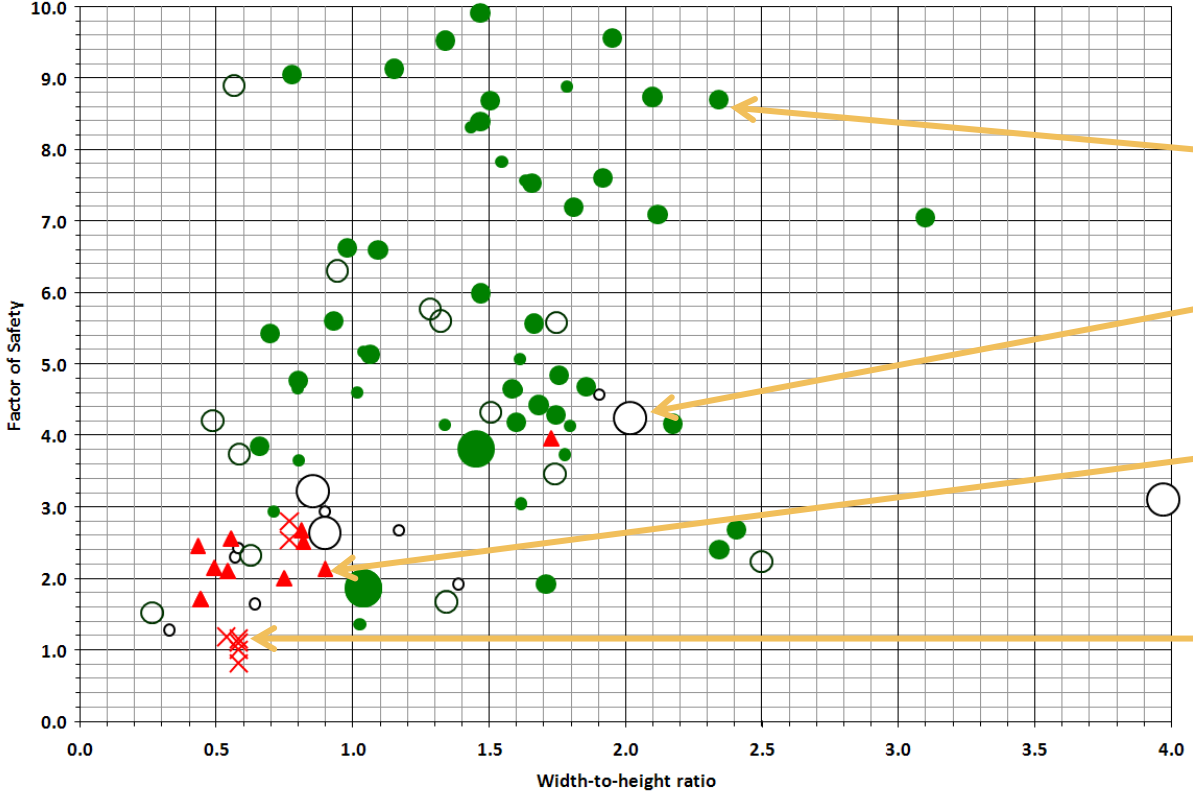
$$Pillar\ stress = \frac{Overburden\ \ stress}{1 - extraction\ \ ratio}$$

- IF PILLAR LAYOUT IS IRREGULAR NUMERICAL MODELS CAN BE USED TO DETERMINE PILLAR STRESS

WHAT SAFETY FACTOR TO USE?

$$SF = \frac{Strength}{Stress}$$

DETERMINING AN ADEQUATE SAFETY FACTOR



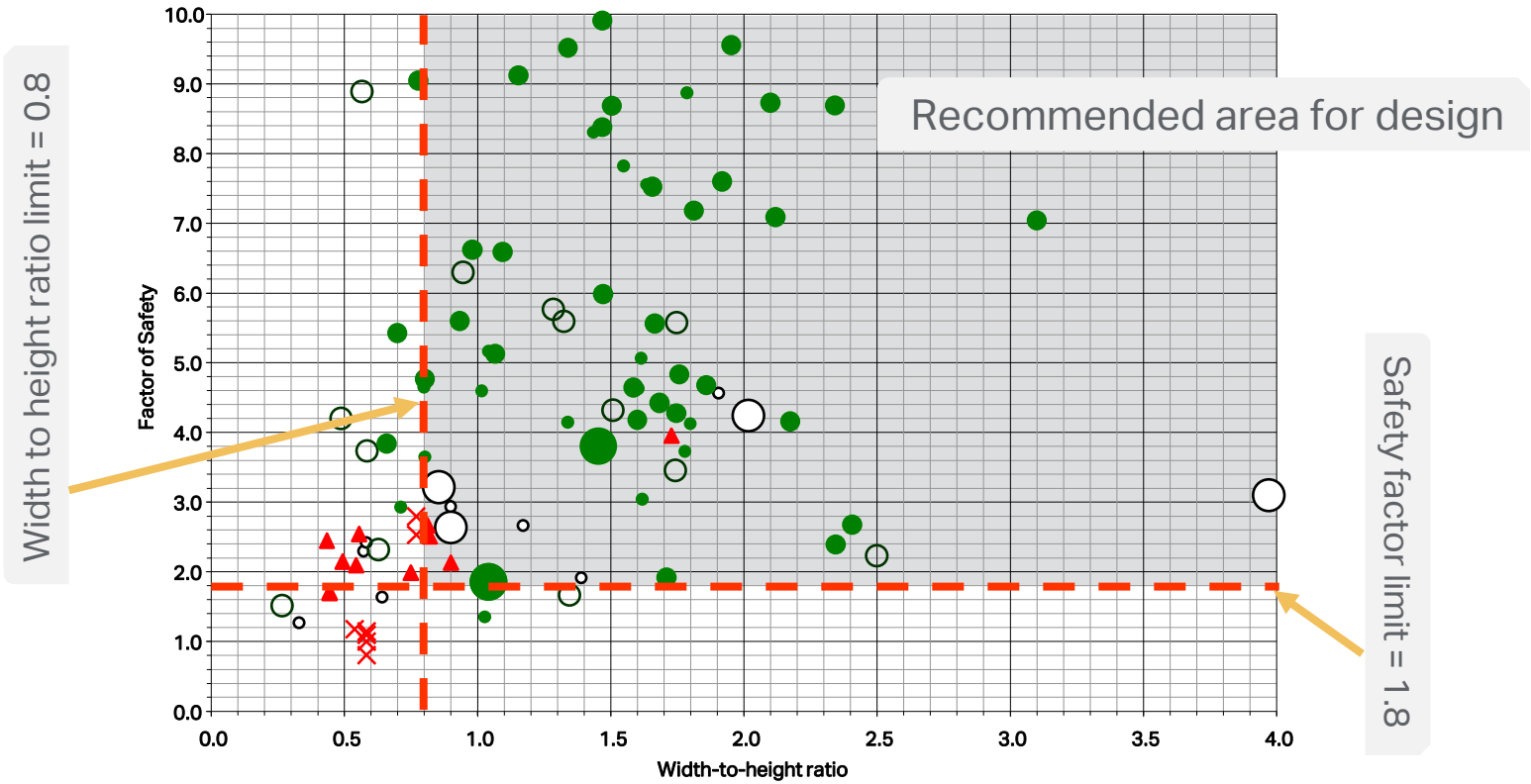
Active layouts

Disused layouts

Failed single pillar - overloaded

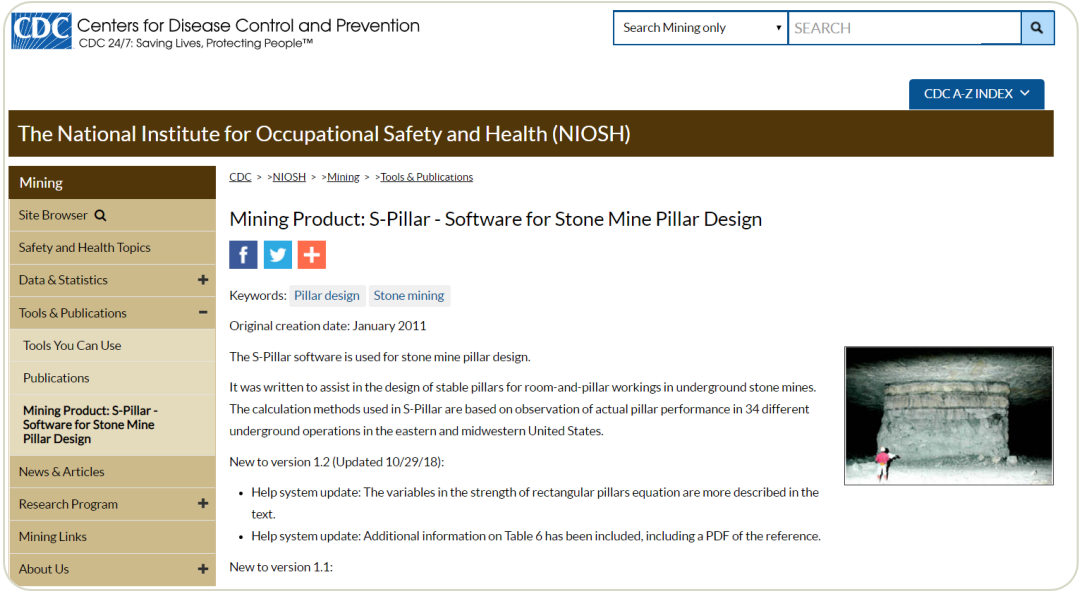
Failed single pillar– angular discontinuity

DETERMINING AN ADEQUATE SAFETY FACTOR

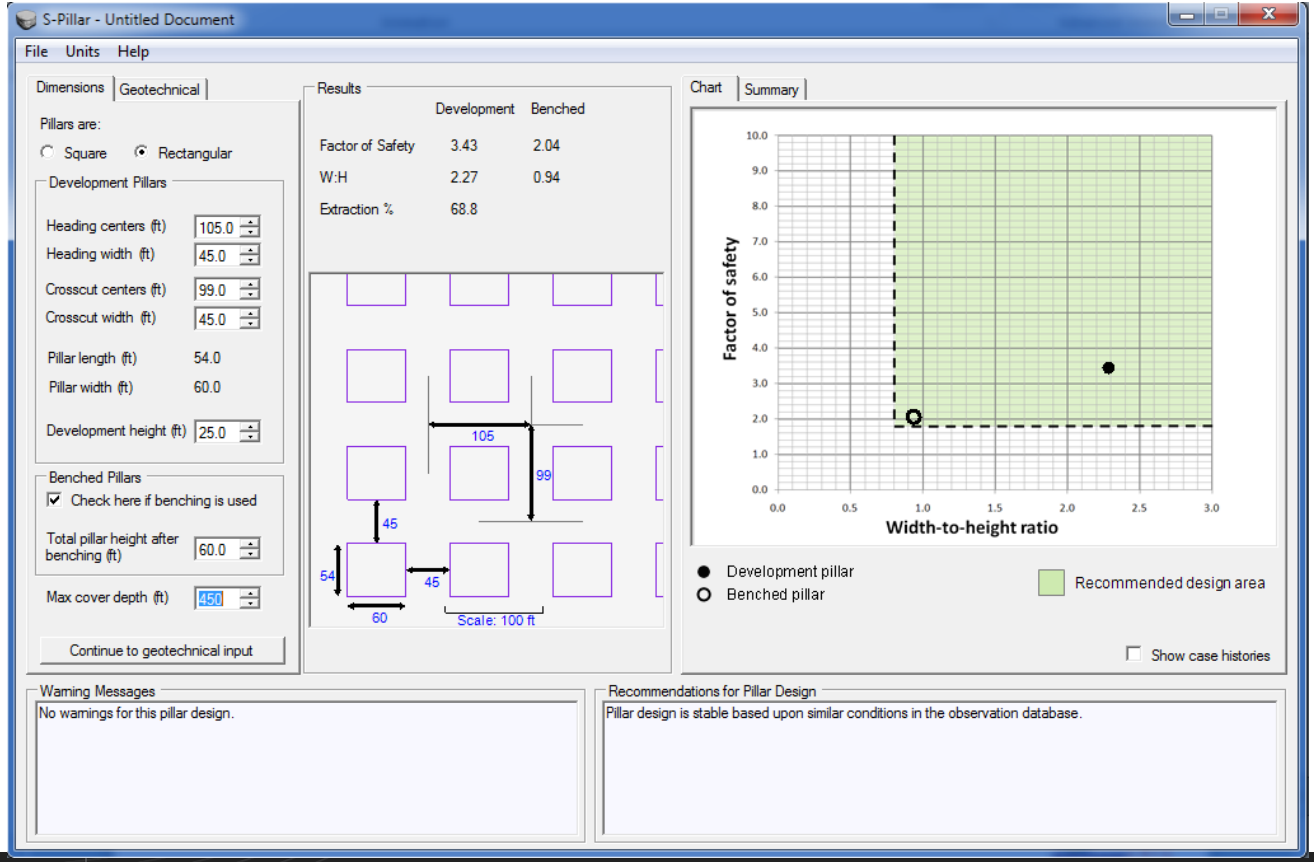


S-PILLAR SOFTWARE FOR PILLAR DESIGN

S-Pillar software does all calculations and checks for limitations of the method:



S-PILLAR SOFTWARE



PILLAR DESIGN GUIDELINES

- UNDERSTAND ROCK PROPERTIES:
  - Rock strength
  - Large angular discontinuities
  - Weak bedding bands
- WIDTH-TO-HEIGHT RATIO > 0.8
- CALCULATED FACTOR-OF-SAFETY > 1.8
- USE S-PILLAR FOR CALCULATIONS

LIMITATIONS OF PILLAR DESIGN METHOD:

- EMPIRICALLY DEVELOPED DESIGN METHOD – ONLY APPLICABLE FOR SIMILAR CONDITIONS AS THOSE USED TO DEVELOP THE EQUATIONS:
  - Flat lying stone deposits in Eastern and Midwestern US
  - Similar mining dimensions
  - Good quality rock mass (RMR > 60)
  - Weak clay bands should not be present

ROOF SPAN STABILITY

- 68% OF ROOF SPANS ARE IN RANGE OF 40 FT TO 50 FT
- ABOUT 49% OF MINES USE REGULAR ROOF BOLTING
- ALL MINES HAVE EXPERIENCED ROOF INSTABILITY
- MAIN STABILITY ISSUES:
  - Stability of bedded roof beams
  - High horizontal stress

ROOF SPAN STABILITY

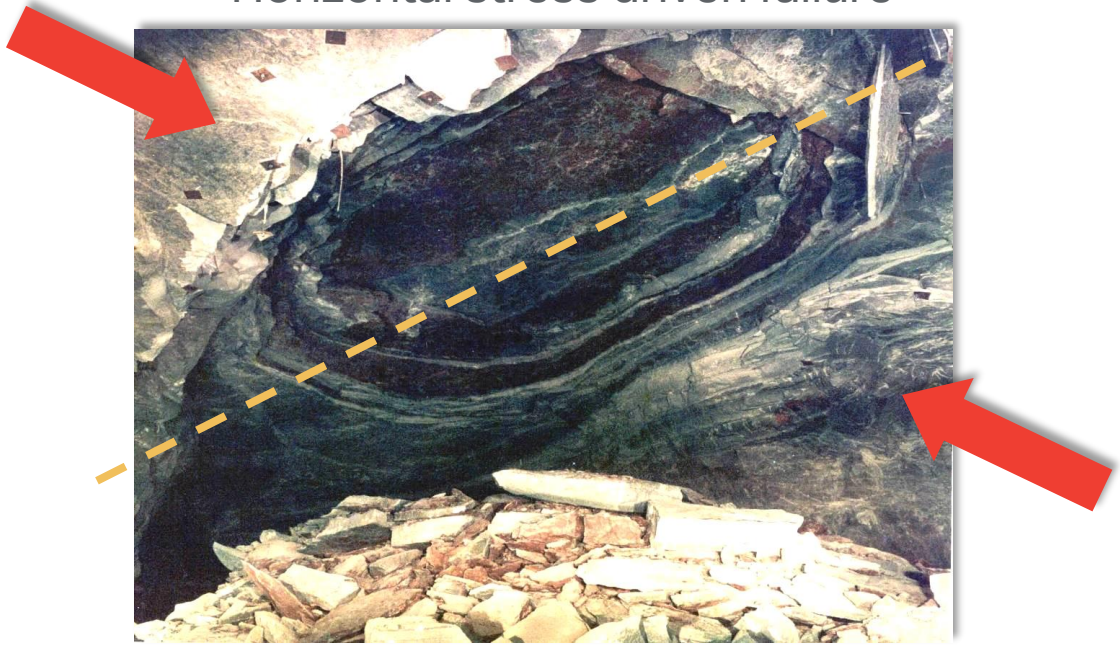
HIGH RISK OF INSTABILITY (>80%) IF FIRST ROOF BEAM LESS THAN 10% OF SPAN

ROOF SPAN STABILITY

Unsupported roof beam 3ft thick in 50 ft wide headings. Ratio 17:1

ROOF SPAN STABILITY

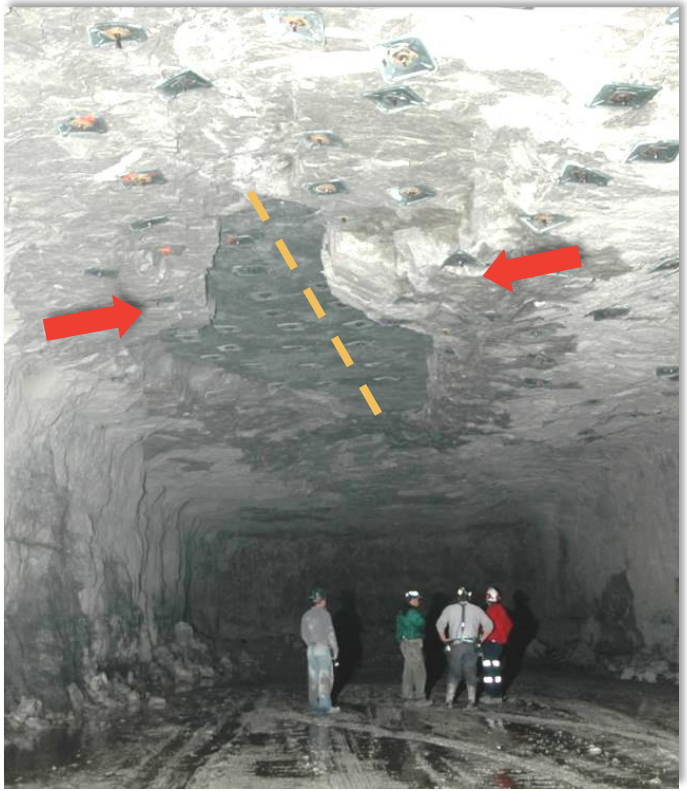
Horizontal stress driven failure



...regardless of first roof beam thickness

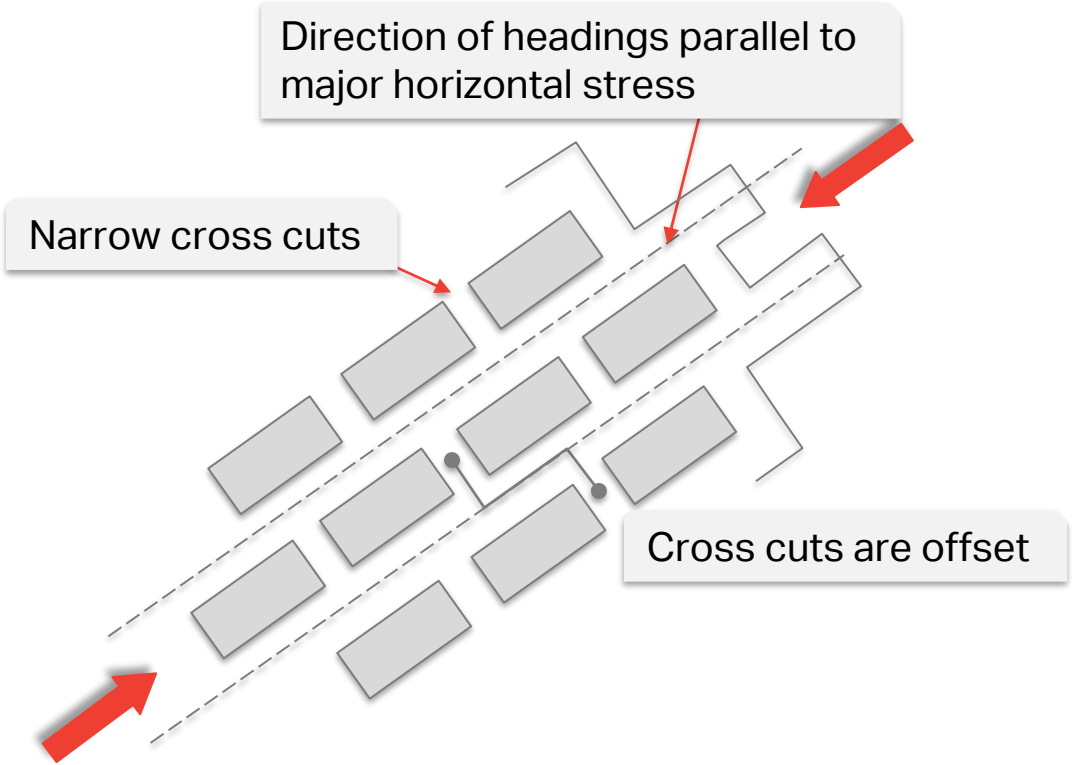
ROOF SPAN STABILITY

...CAN OCCUR AT ANY DEPTH OF COVER



At 150 ft depth of cover..

ROOF SPAN STABILITY



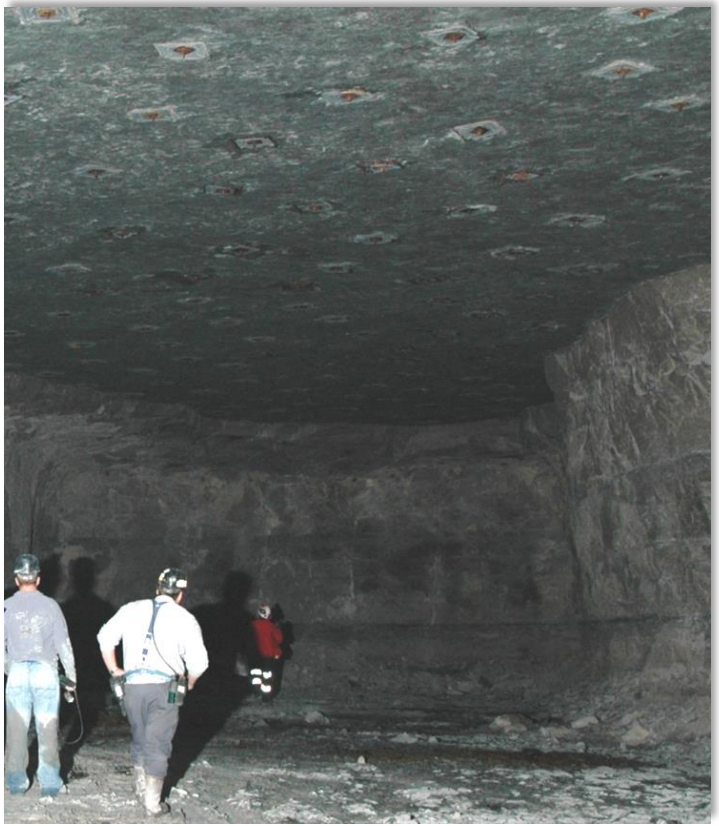
Mine layout to accommodate high horizontal stress

ROOF SPAN DESIGN

- UNDERSTAND ROCK PROPERTIES:
  - Parting planes in roof
  - Horizontal stress
  - Orientation of joint sets
- SELECT ROOF HORIZON
- SELECT MINING DIRECTION
- SELECTION OF ROOF SPAN
- PILLAR LAYOUT MODIFICATION
- MONITOR AND VERIFY

CONCLUSION

- NIOSH GUIDELINES BASED ON ACTUAL PILLAR AND ROOF SPAN PERFORMANCE IN US STONE MINES
- STABLE MINE LAYOUTS CAN BE DESIGNED WITH GOOD UNDERSTANDING OF ROCK BEING MINED



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ROOF SUPPORT METHODOLOGIES FOR UNDERGROUND STONE MINES

ALAN A. CAMPOLI
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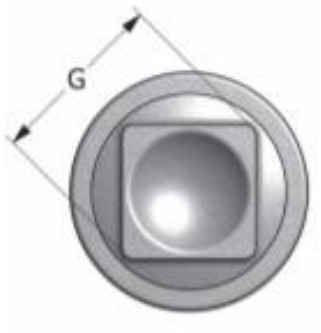
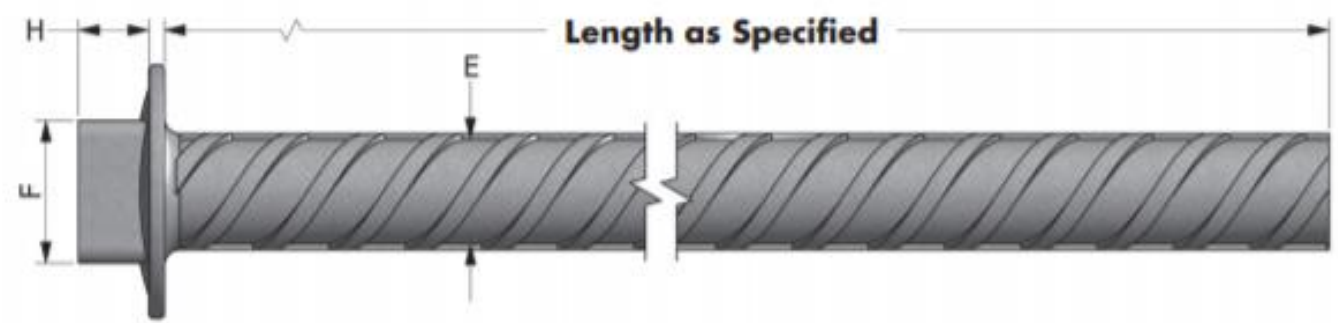
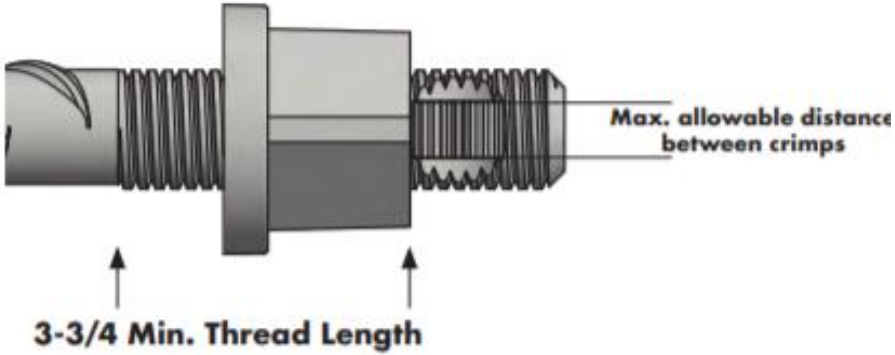
HEADED REBAR GRADE 60

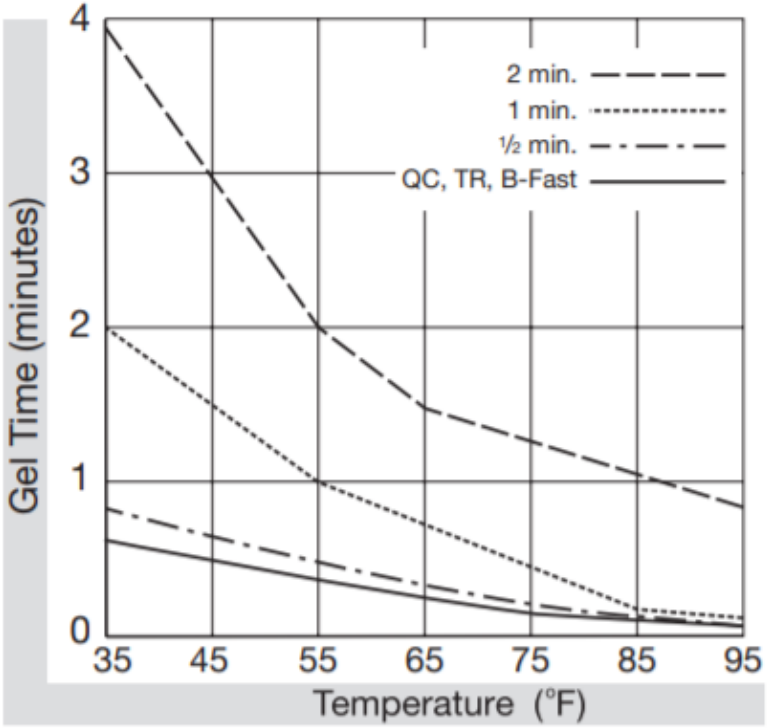


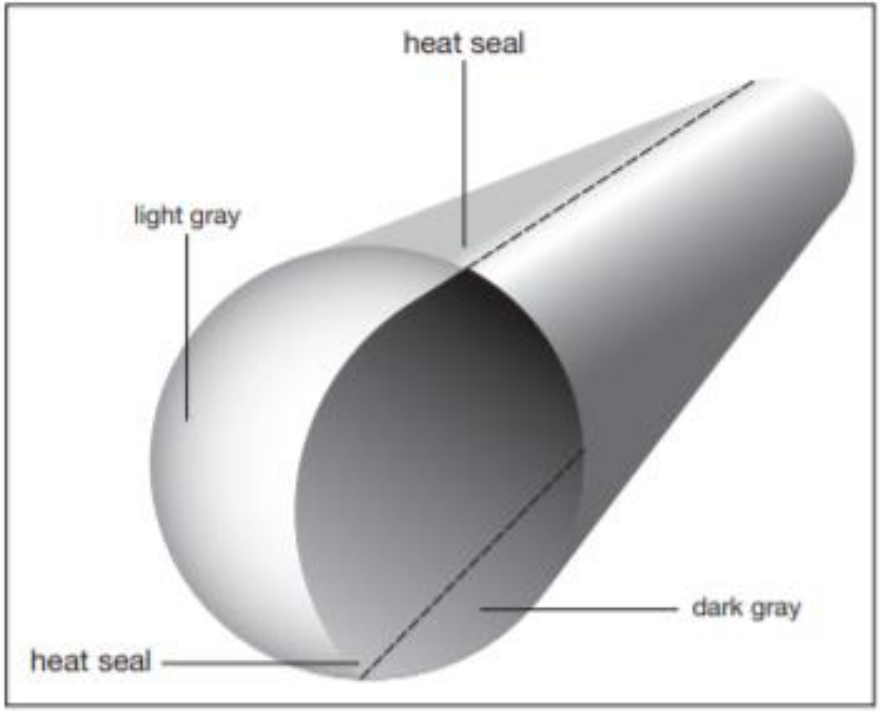


- 1 1/8 inch forged head
- Yield strength
  - 5/8 inch (no. 5) 18,600 lb
  - 3/4 inch (no. 6) 26,400 lb
  - 7/8 inch (no. 7) 36,000 lb



POLYESTER RESIN CARTRIDGE





Nominal Rebar		Drill Hole Diameter, in.						
		1	1-1/4	1-3/8	1-1/2	1-3/4	2	2-1/4
		Resin Cartridge Diameter, in.						
Rebar	Diameter, in.	0.9	1-1/8	1-1/4	1-1/4	1-3/8	1-9/16	1-9/16
#6	3/4	19.6	12.7					
#7	7/8		15.9	14.7				
#8	1		22.5	18.6	13.2			
#9	1-1/8			26.5	16.8			
#10	1-1/4				24.1	13.2		
#11	1-3/8					16.9	12.3	
#12	1-1/2					24.4	14.8	9.2
#13	1-5/8						19	10.7
#14	1-3/4							12.9

SURFACE CONTROL





T-Channels

- Increased strength, compared with roof mats
- Easily installed with regular bolting cycles
- T5 channels for higher strength, less resistance to ventilation
- Available in 4' through 20' sections with other lengths on request
- Gauges range from 12 gauge to 5/16" Channels have tensile strength of 36,000 to 80,000 psi
- High beam strength resists roof sag

SEVEN STRAND NON-TENSIONED CABLE BOLTS

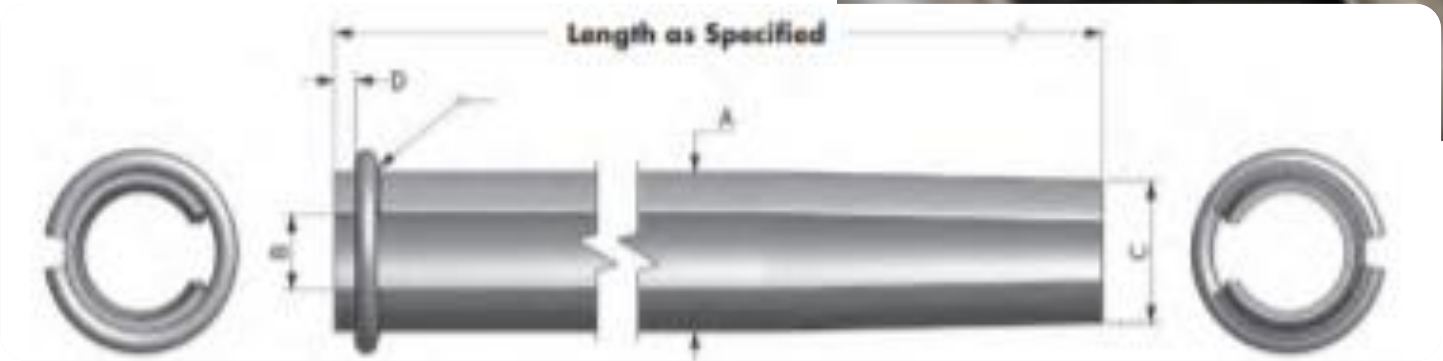
- .6 inch - 30 tons
- .7 inch - 60 tons

FULLY GROUTED CABLE BOLT

- Polyester anchor
- Polyurethane or silicate grout
- Fracture sealing
- Rock strength

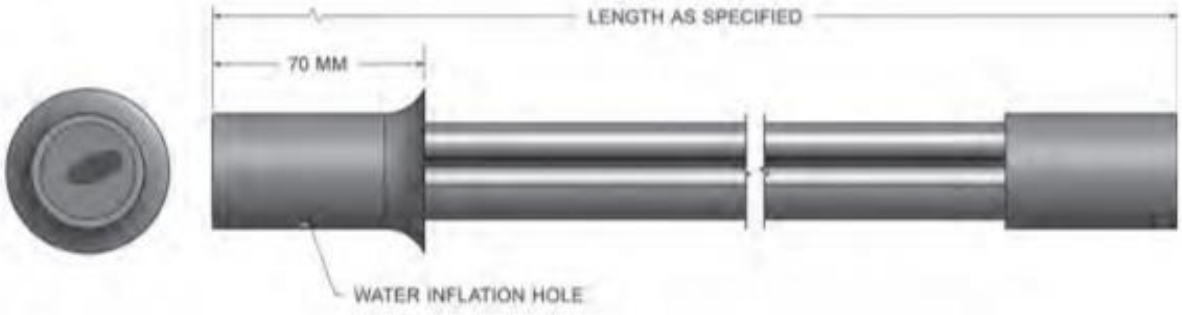
FRICTION STABILIZER

- 12 to 20 tons



EXPANDABLE

- Water pressure
- Hydraulic
- Electric



UMBRELLA TUBES

UMBRELLA TUBES

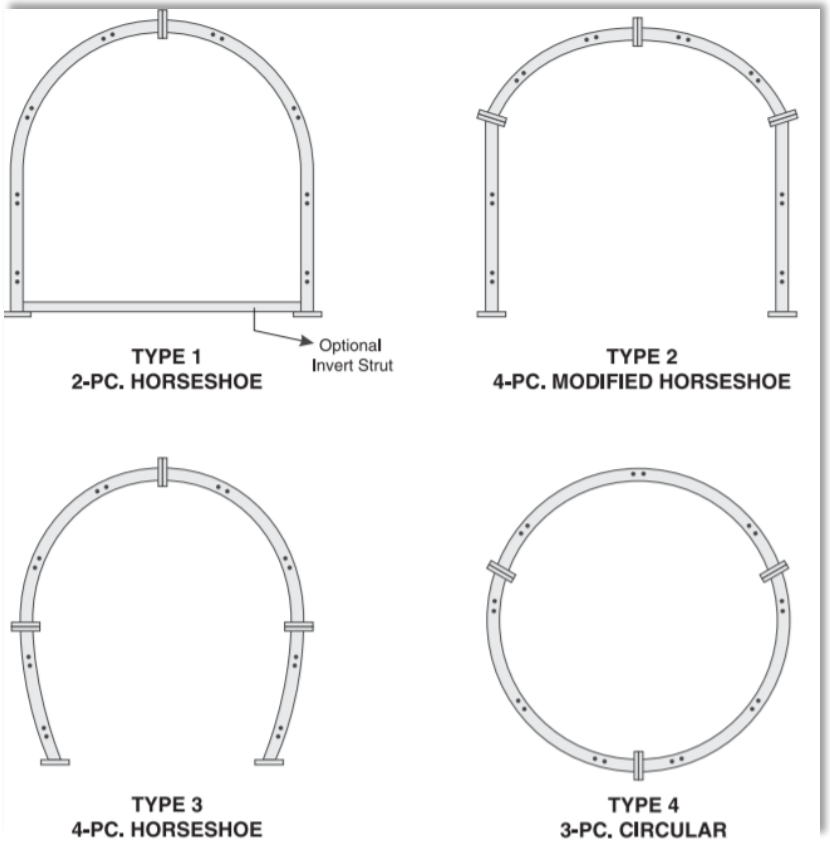
PROPS

- Extendable
- 40 to 70 tons

GROUT INJECTION

- **POLYURETHANE**
  - Rock reinforcement
    - Duel component
    - 10,000 psi compressive strength
  - Leak sealing
    - Single component
    - Hydrophobic foam
- **SILICATE**
  - Foam
  - Grout
- **ACRYLATE**
  - Water sealing
  - Super low viscosity

STEEL RIBS


Optional
Invert Strut
TYPE 1
2-PC. HORSESHOE
TYPE 2
4-PC. MODIFIED HORSESHOE
TYPE 3
4-PC. HORSESHOE
TYPE 4
3-PC. CIRCULAR

CONCLUSION

- PROBLEM AREAS CAN BE IDENTIFIED BY GEOLOGIC MAPPING.
- NUMEROUS ROOF SUPPORT OPTIONS ARE AVAILABLE.
- SUPPORT METHODOLOGY MUST BE COMPATIBLE WITH GEOLOGIC CONDITIONS.