

PILLAR AND ROOF SPAN DESIGN FOR UNDERGROUND STONE MINES



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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 mining still a hot issue

DENIED

Snow Camp residents oppose gravel quarry construction



Quarry Permit Denied

Commissioners deny quarry permit after 'overwhelming' opposition

Magruder quarry opposition in Sunrise

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 company...

Proposed Cemex Quarry Under Fire from California Officials

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

Quarry yard signs created by Citizens Group for the Mountains Against Mining, posted yards along South Tecumseh Road near High School last weekend. In July the state approved expanded limestone mining operations in River Township, just north of the intensifying opposition from area residents. (Photo by Audrey Hackett)

Created: Thursday, 17 January 2019
Published: Thursday, 17 January 2019
1

Washington Quarry Faces Opposition

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 McNeill. (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

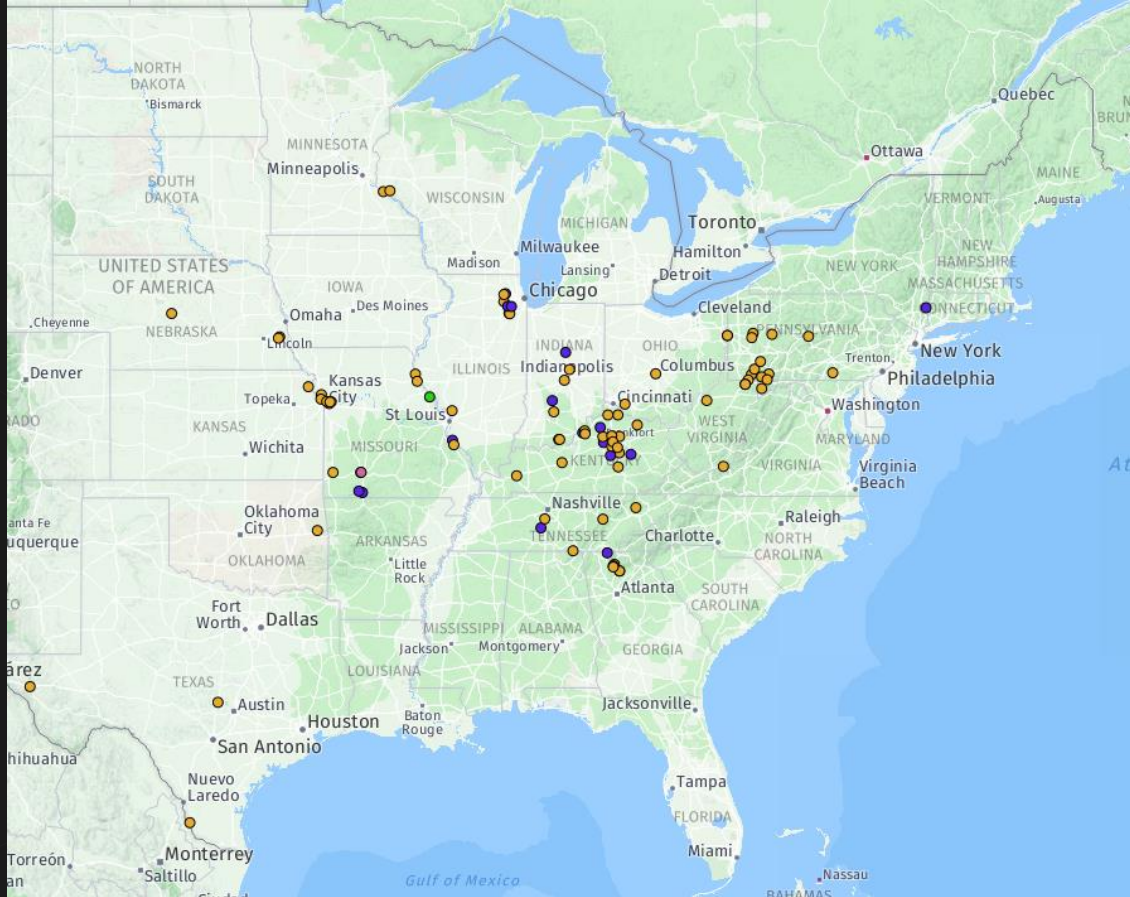


Reduces some of the impacts of a surface facility



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

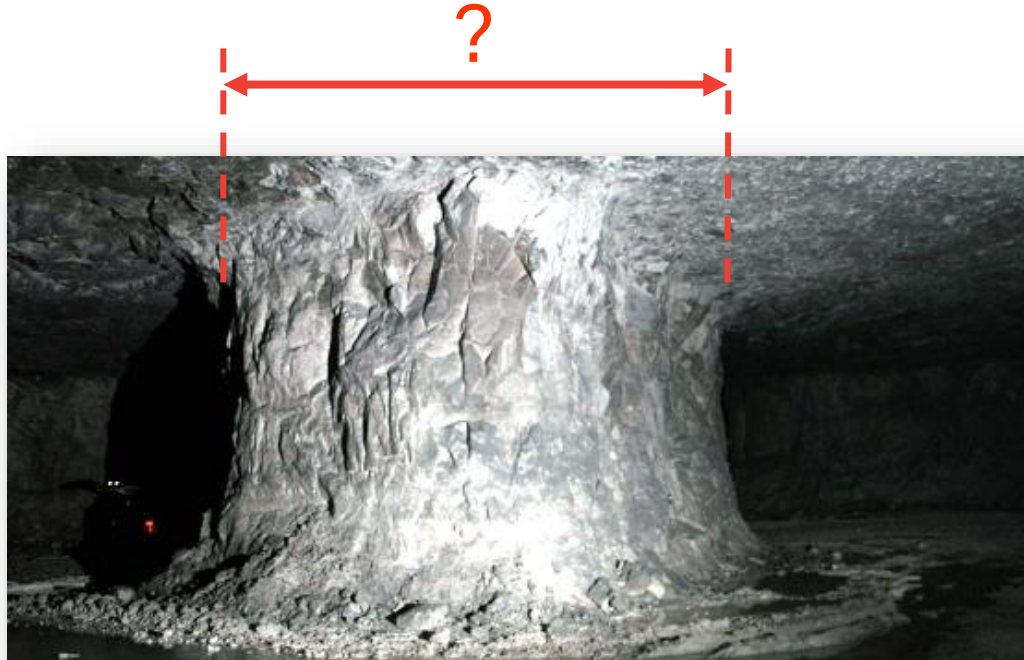
Geotechnical

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**



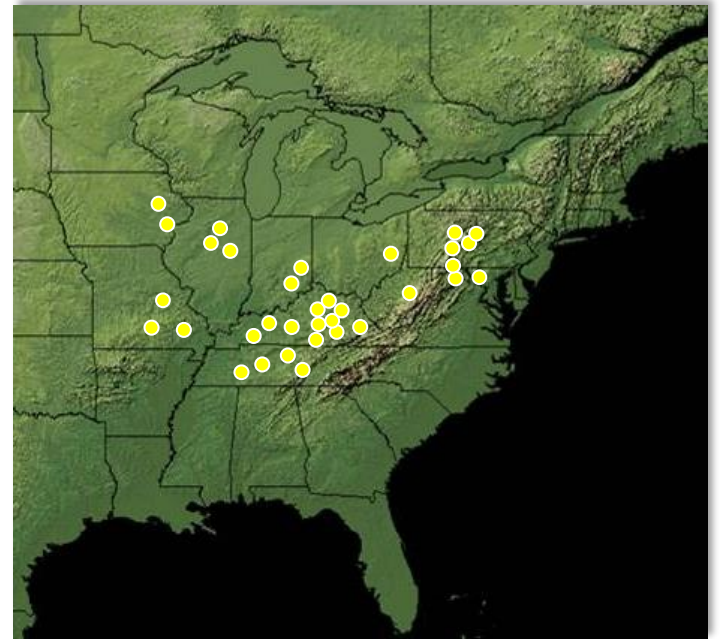
DESIGNING STABLE PILLARS....



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

RESEARCH APPROACH

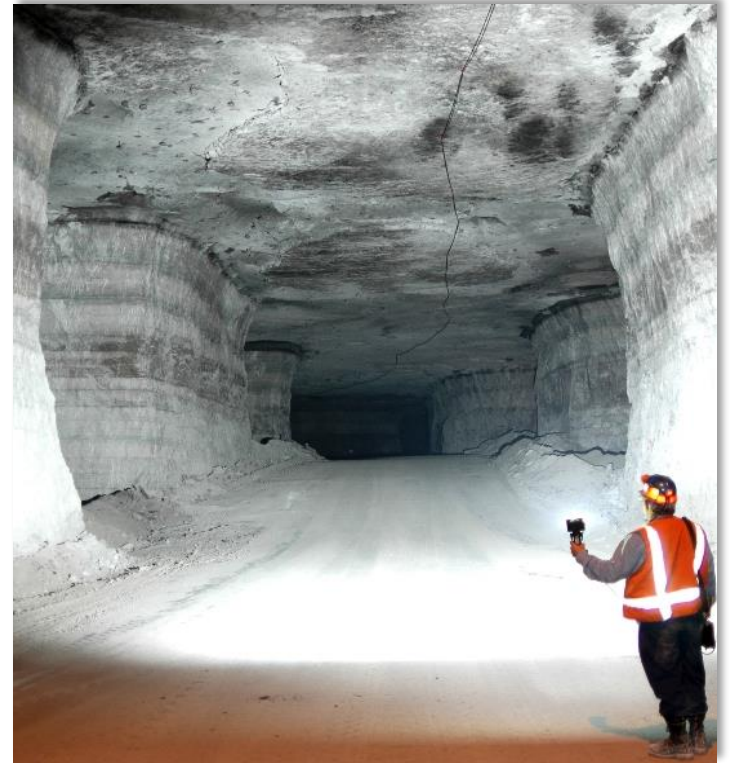
- › OBSERVE PILLAR PERFORMANCE IN OPERATING STONE MINES
- › DEVELOP UNDERSTANDING OF STABILITY ISSUES
- › CONDUCT ENGINEERING ANALYSIS
- › DEVELOP DESIGN PROCEDURE



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

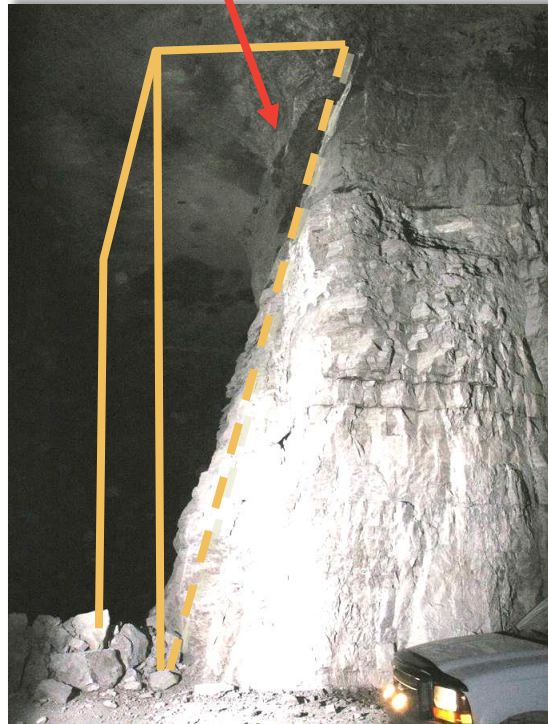
FACTORS CONTRIBUTING TO PILLAR INSTABILITY

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

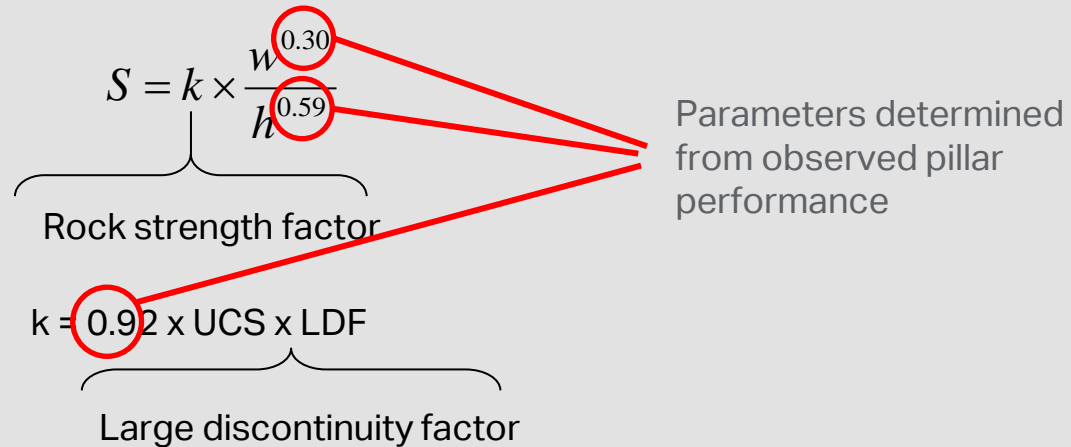
$$S = k \times \frac{w^{0.30}}{h^{0.59}}$$

Rock strength factor

$$k = 0.92 \times \text{UCS} \times \text{LDF}$$

Large discontinuity factor

Parameters determined from observed pillar performance



PILLAR STRESS DETERMINATION

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

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

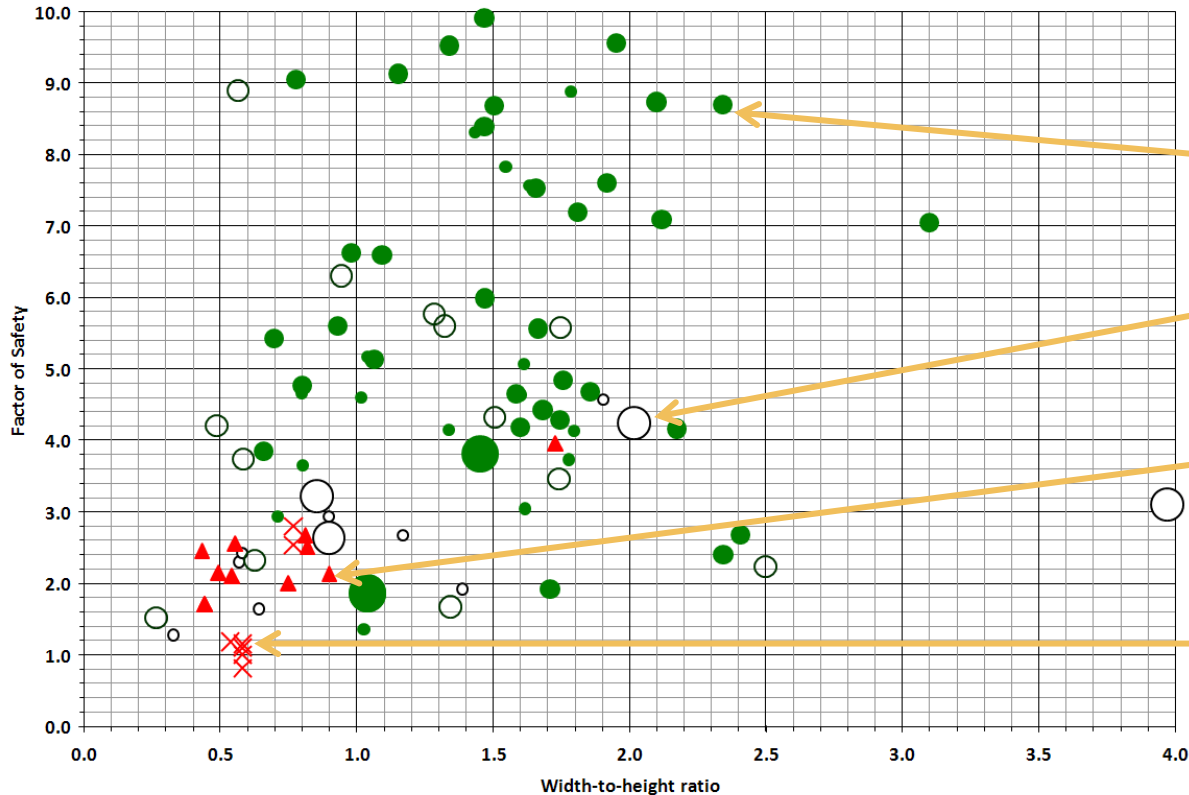
- › IF PILLAR LAYOUT IS IRREGULAR NUMERICAL MODELS CAN BE USED TO DETERMINE PILLAR STRESS

WHAT SAFETY FACTOR TO USE?

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



DETERMINING AN ADEQUATE SAFETY FACTOR



Active layouts

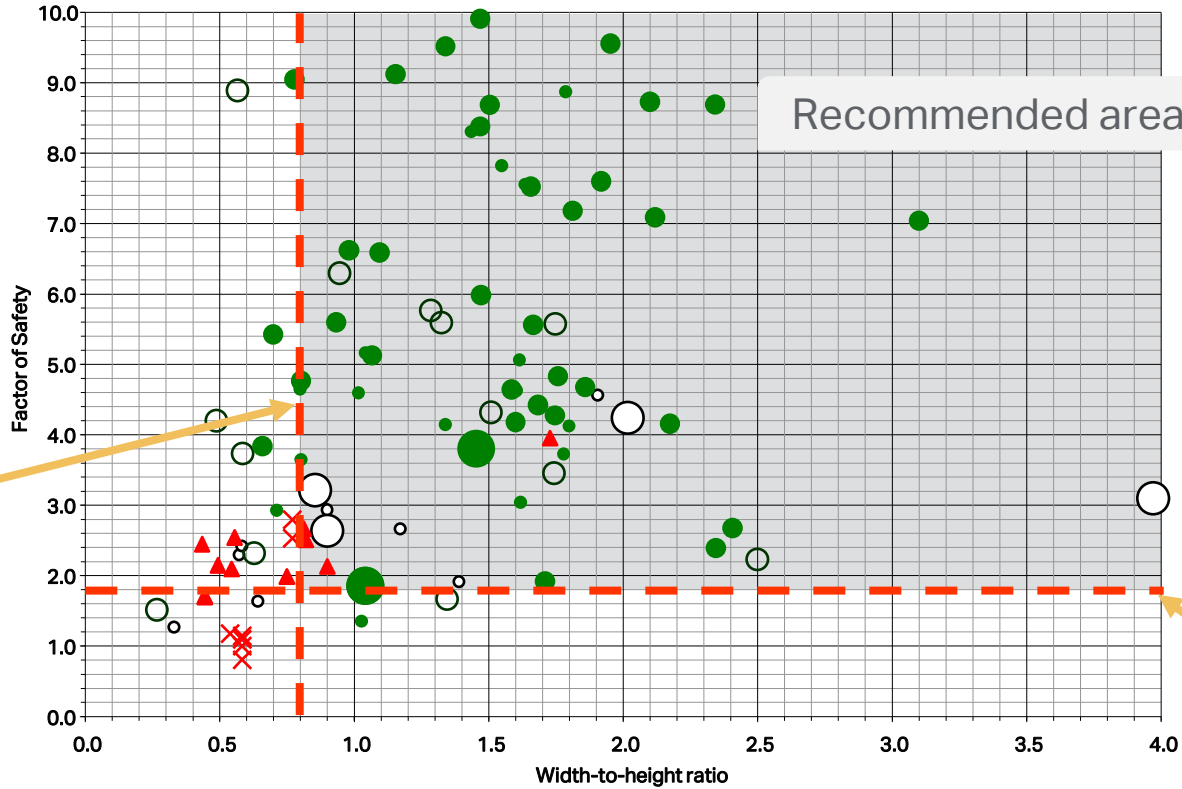
Disused layouts

Failed single pillar - overloaded

Failed single pillar - angular discontinuity

DETERMINING AN ADEQUATE SAFETY FACTOR

Width to height ratio limit = 0.8



Recommended area for design

Safety factor limit = 1.8

S-PILLAR SOFTWARE FOR PILLAR DESIGN



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

The screenshot shows the NIOSH website page for the S-Pillar software. At the top, there is the CDC logo and the text "Centers for Disease Control and Prevention CDC 24/7: Saving Lives, Protecting People™". A search bar contains the text "Search Mining only" and "SEARCH". A "CDC A-Z INDEX" button is visible on the right. Below this is a dark brown header with the text "The National Institute for Occupational Safety and Health (NIOSH)".

The main content area has a left sidebar with a navigation menu:

- Mining
- Site Browser
- Safety and Health Topics
- Data & Statistics
- Tools & Publications
- Tools You Can Use
- Publications
- Mining Product: S-Pillar - Software for Stone Mine Pillar Design**
- News & Articles
- Research Program
- Mining Links
- About Us

The main content area displays the breadcrumb "CDC > >NIOSH > >Mining > >Tools & Publications" and the title "Mining Product: S-Pillar - Software for Stone Mine Pillar Design". Below the title are social media icons for Facebook, Twitter, and a plus sign. The keywords are "Pillar design" and "Stone mining". The original creation date is "January 2011".

The description states: "The S-Pillar software is used for stone mine pillar design. It was written to assist in the design of stable pillars for room-and-pillar workings in underground stone mines. The calculation methods used in S-Pillar are based on observation of actual pillar performance in 34 different underground operations in the eastern and midwestern United States."

There is a photo of a large, rectangular stone mine pillar in an underground setting, with a person standing next to it for scale.

Under the heading "New to version 1.2 (Updated 10/29/18):", there are two bullet points:

- Help system update: The variables in the strength of rectangular pillars equation are more described in the text.
- Help system update: Additional information on Table 6 has been included, including a PDF of the reference.

Under the heading "New to version 1.1:", there is one bullet point:

- New to version 1.1:

S-Pillar - Untitled Document

File Units Help

Dimensions | Geotechnical | Results | Chart | Summary |

Pillars are:
 Square Rectangular

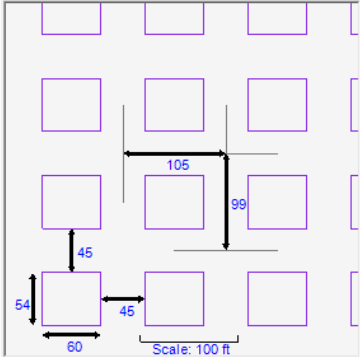
Development Pillars

Heading centers (ft) 105.0
 Heading width (ft) 45.0
 Crosscut centers (ft) 99.0
 Crosscut width (ft) 45.0
 Pillar length (ft) 54.0
 Pillar width (ft) 60.0
 Development height (ft) 25.0

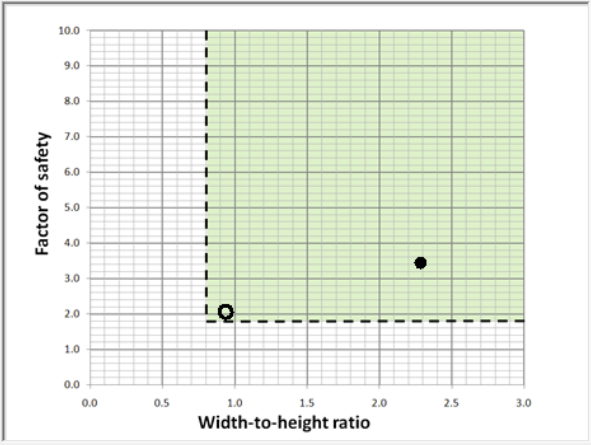
Benching Pillars
 Check here if benching is used
 Total pillar height after benching (ft) 60.0
 Max cover depth (ft) 45.0

Continue to geotechnical input

	Development	Benching
Factor of Safety	3.43	2.04
W:H	2.27	0.94
Extraction %	68.8	



Scale: 100 ft



● Development pillar
 ○ Benching pillar
 Recommended design area
 Show case histories

Warning Messages
 No warnings for this pillar design.

Recommendations for Pillar Design
 Pillar design is stable based upon similar conditions in the observation database.

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

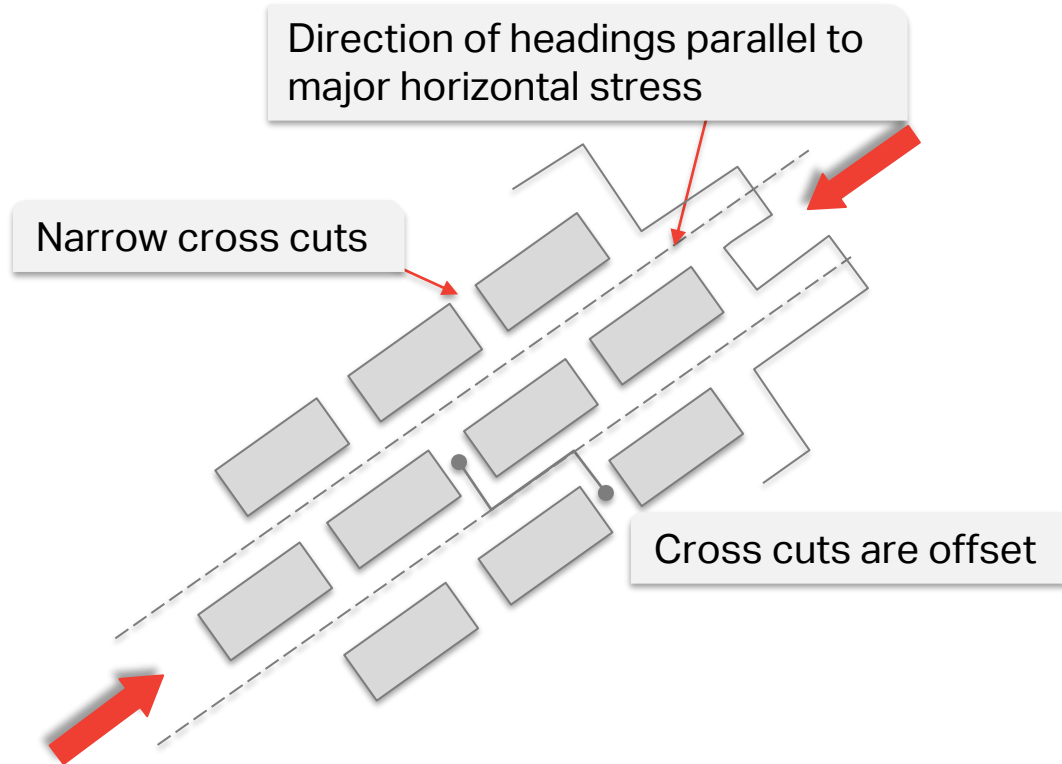
ROOF SPAN STABILITY

...CAN OCCUR AT ANY DEPTH OF COVER



At 150 ft depth of cover..

ROOF SPAN STABILITY



Mine layout to accommodate high horizontal stress

› UNDERSTAND ROCK PROPERTIES:

- / Parting planes in roof
- / Horizontal stress
- / Orientation of joint sets

› SELECT ROOF HORIZON

› SELECT MINING DIRECTION

› SELECTION OF ROOF SPAN

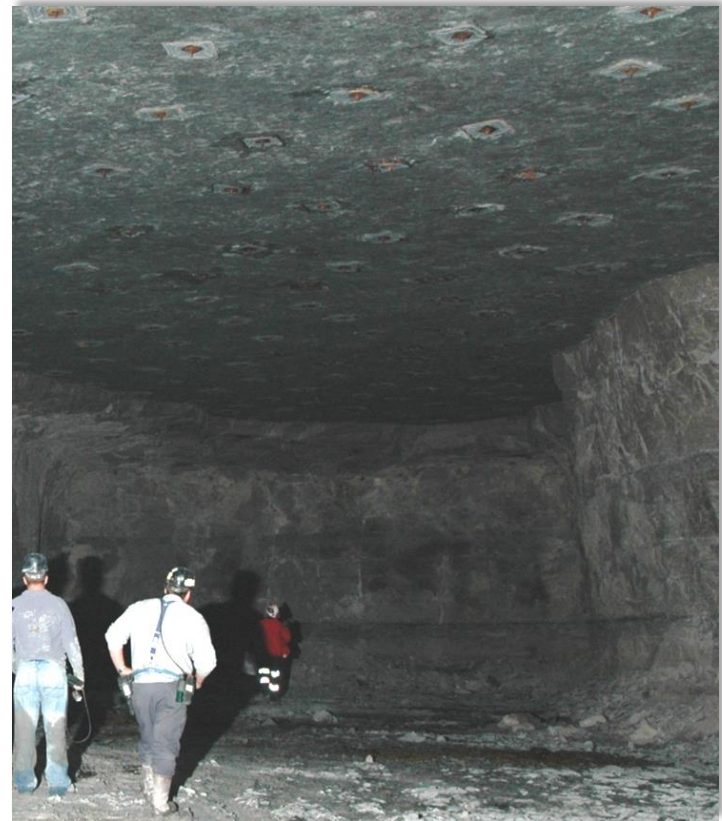
› PILLAR LAYOUT MODIFICATION

› 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**



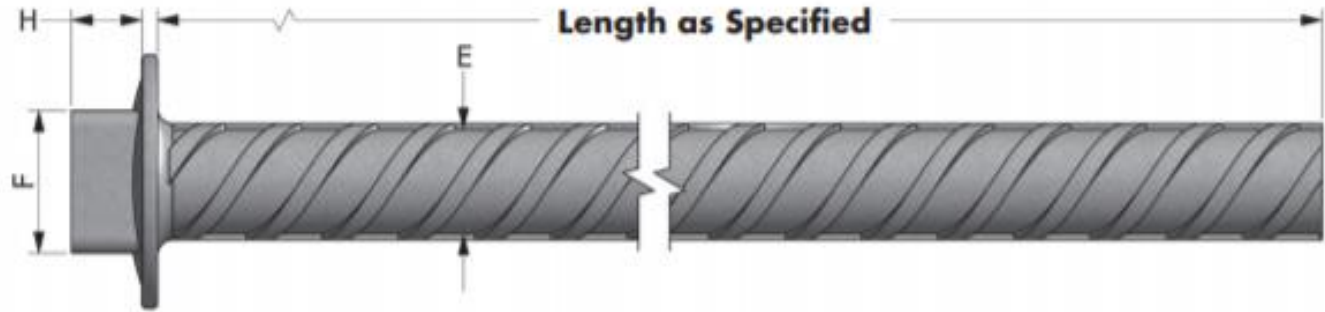
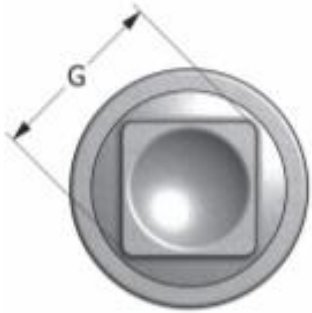


RESPEC

ROOF SUPPORT METHODOLOGIES FOR UNDERGROUND STONE MINES

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RESPEC**

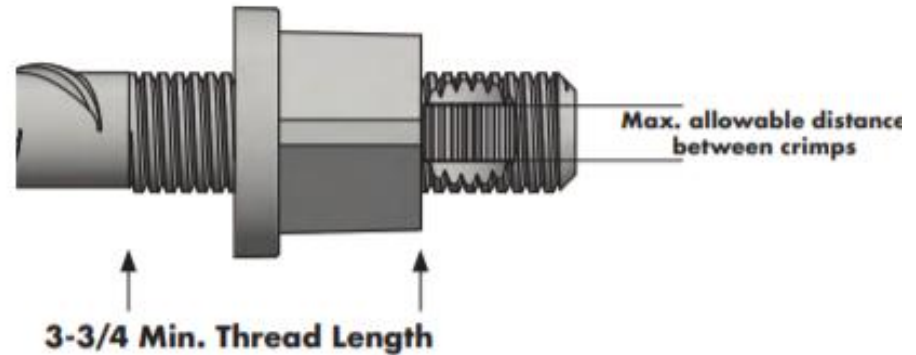
HEADED REBAR GRADE 60



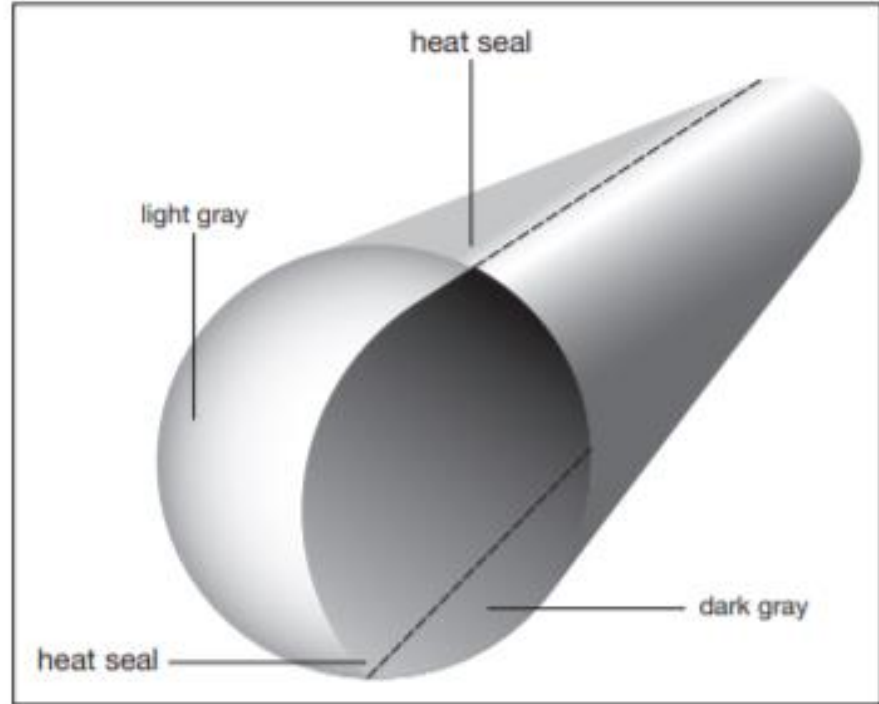
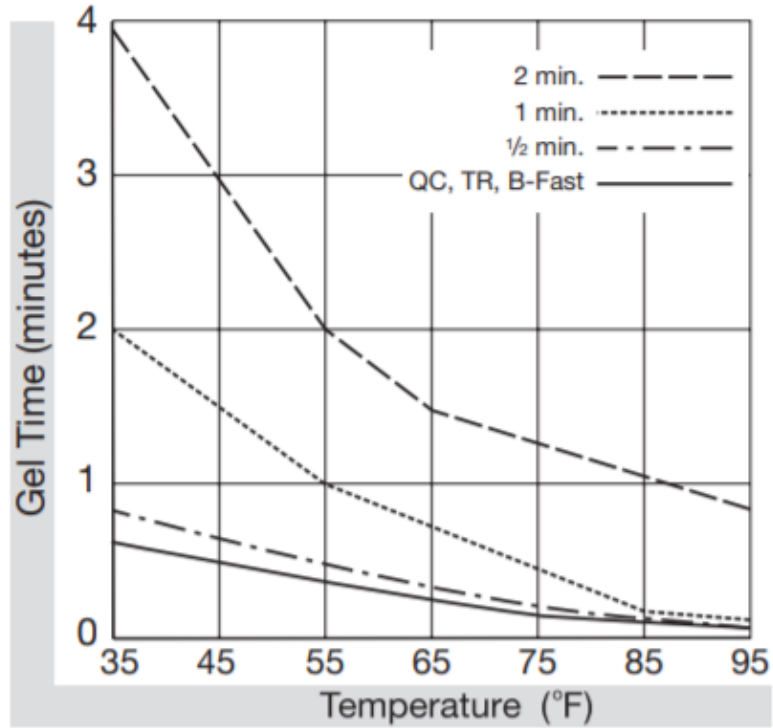
/ 1 1/8 inch forged head

/ 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



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



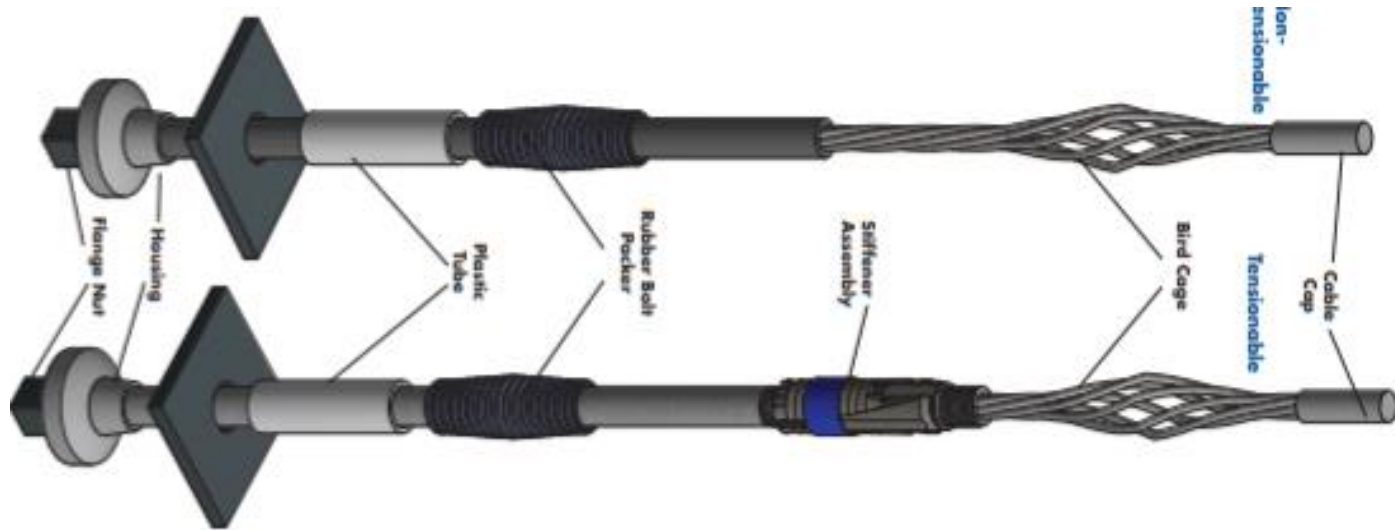
SEVEN STRAND NON-TENSIONED CABLE BOLTS



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

FULLY GROUTED CABLE BOLT

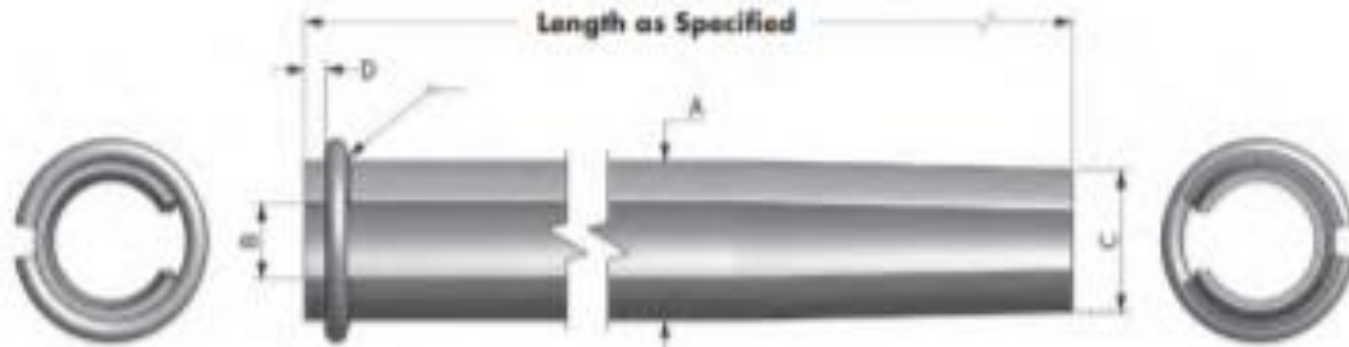
- / Polyester anchor
- / Polyurethane or silicate grout
- / Fracture sealing
- / Rock strength





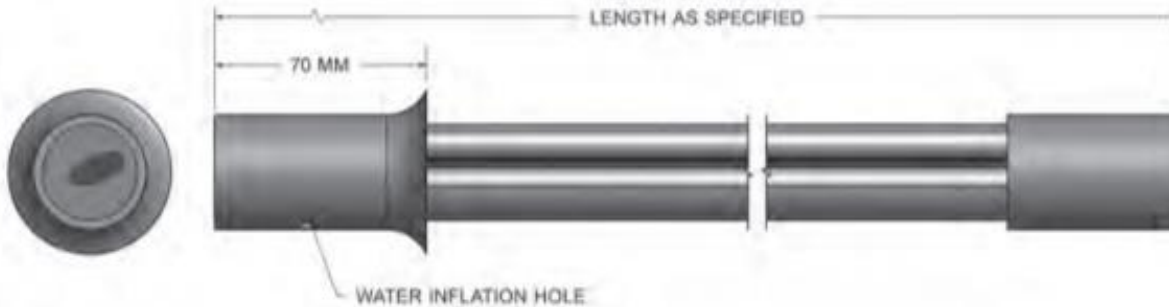
FRICTION STABILIZER

/ 12 to 20 tons



EXPANDABLE

- / Water pressure
- / Hydraulic
- / Electric



UMBRELLA TUBES



UMBRELLA TUBES



PROPS

- / Extendable
- / 40 to 70 tons



GROUT INJECTION

› POLYURETHANE

- / Rock reinforcement
 - » Dual component
 - » 10,000 psi compressive strength
- / Leak sealing
 - » Single component
 - » Hydrophobic foam

› SILICATE

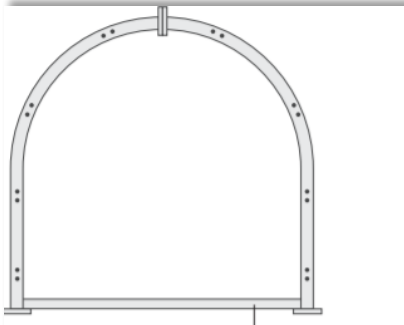
- / Foam
- / Grout

› ACRYLATE

- / Water sealing
- / Super low viscosity

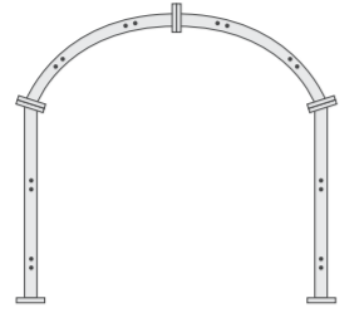


STEEL RIBS

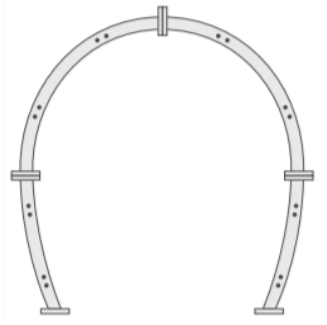


TYPE 1
2-PC. HORSESHOE

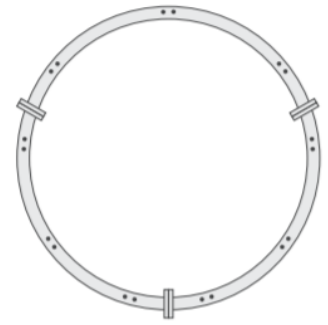
Optional
Invert Strut



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.**

