UNDERGROUND STONE MINE REHABILITATION AND MONITORING

KCSA – UNDERGROUND STONE SAFETY CONFERENCE

DECEMBER 5-6, 2023

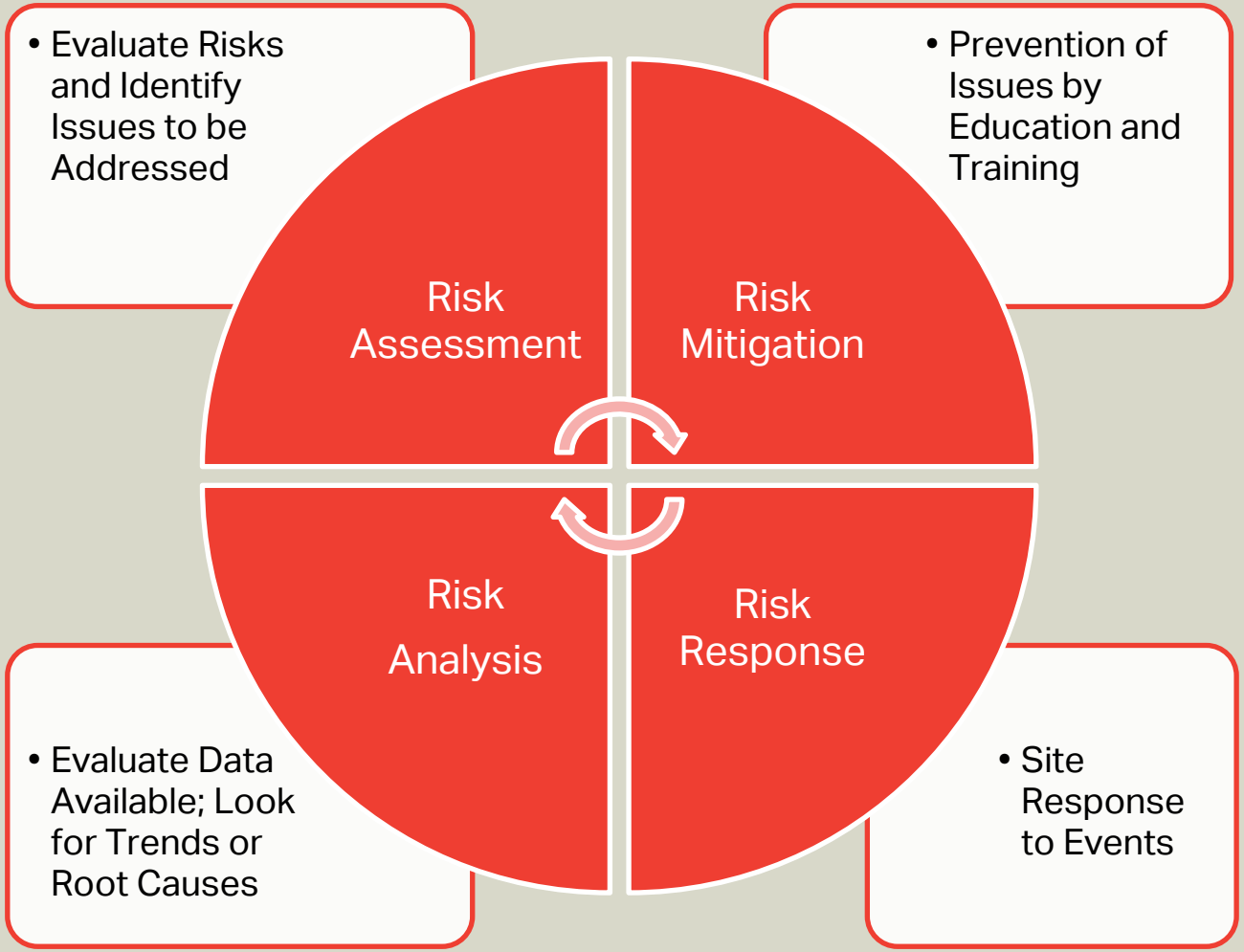
AGENDA

- Risk Management
- Risk Assessment
- Materials and Rehabilitation Options
- Case Studies / Examples
- Monitoring Equipment and Instrumentation

RISK MANAGEMENT

Risk management is the continuing process to identify hazards, analyze, evaluate, respond and monitor to mitigate or control adverse effects.

It allows risk events and overall risk to be understood and managed proactively.



RISK ASSESSMENT

- Knowing when to Rehab and How Intensive:
  - Has there been a change in conditions?
    - Mine life is now extended
    - Increased traffic/infrastructure underground
    - End use of areas of the mine
- Reinforce, Rehabilitate, or Abandon
  - Reinforce before a problem escalates
  - Rehabilitate areas that have had partial failures
  - Location importance / impact
    - Can areas be safely abandoned without any action?
    - Extent of problem areas?

RISK ASSESSMENT

What action is sufficient to minimize risk to acceptable levels?

Likelihood of Instability or Failure

Level of Impact:

Low

Moderate

High

Low

- Accept Risks
- Accept Risks with Monitoring
- Need Management

Bolt mains

Medium

- Accept but Monitor
- Manage and Resolve
- Manage and Monitor

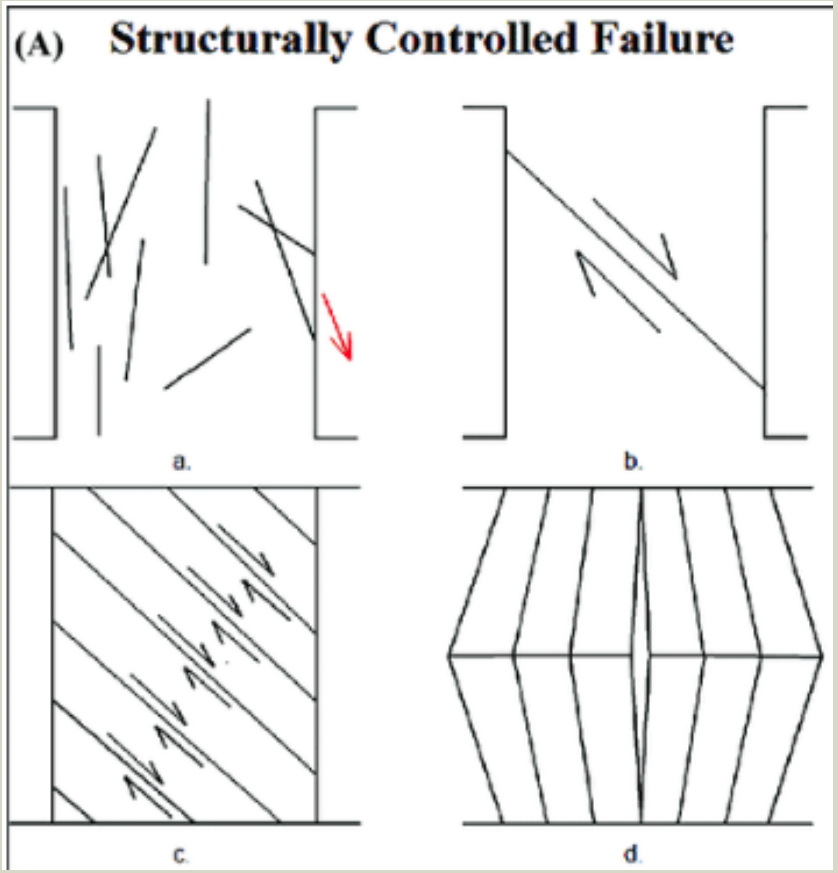
Benching old works

High

- Manage and Monitor
- Management Required
- Extreme Management and Remedy

Array of failing pillars along main haul road

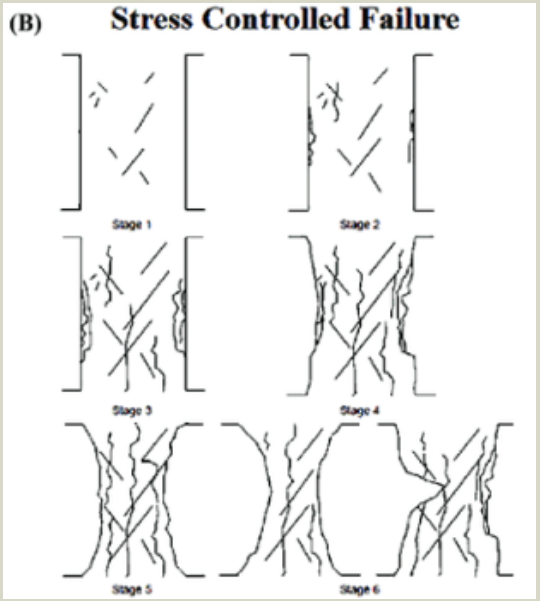
RISK ASSESSMENT



a) Rock block sliding
b) Throughgoing shear failure
c) Shear failure along joints
d) Buckling

Monsalve, 2020

- Mode of Failure in stone mines:
  - Typically no gradual convergence (soils / yielding material)
  - Geologic anomaly or larger trend?
  - Structurally controlled vs. Stress controlled

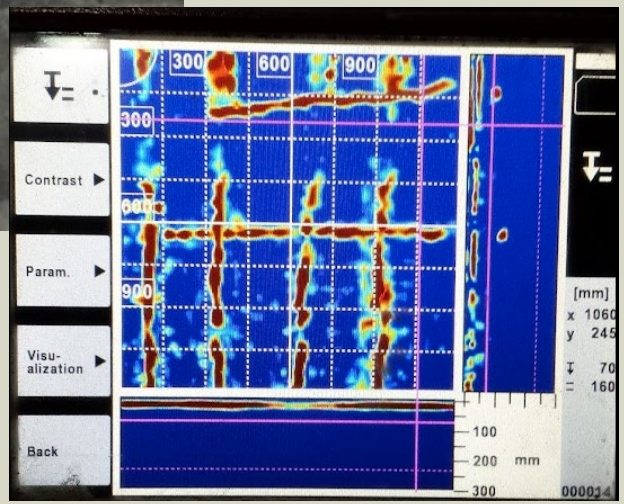


Stress controlled failure: hourglass shape and loss of confining strength

Esterhuizen, Dolinar, Ellenberger

RISK ASSESSMENT

- Review Previous Ground Control Records
  - Older reports, daily logs, correspondence
  - Historical mapping
- Collect Data if Unknown
  - Borescope or scratch tool for roof holes
  - LiDAR or survey of problem and surrounding area (pillar or rib issues)
  - Depth of cover mapping: Topo and XYZ survey
- Identify solutions for acceptable level of risk
  - Find out why falls are happening
  - Cost appropriate solution



Legacy tunnel conditions: scanning to determine rebar pattern in concrete

MATERIALS AND REHAB OPTIONS

Material	Use	Considerations / Comments
Roof Bolts	Fully-grouted bolts preferred in UG limestone Length of bolt and spacing of pattern (end use and geology considerations)	Dependent on historic bolting performance, status, and how jointed roof is
Straps	Galvanized/black, depending on moisture	Span across joints that may produce unstable blocks
Mesh (wire or minegrid type)	Welded wire mesh in different gauges and sizes Minegrid sizing to hold smaller material	Corrosion and strength considerations
Shotcrete	Fiber-reinforced (different types of fibers)	Drainage considerations
Steel sets/ canopies	Steel sets can have timber, metal or concrete lagging	Dimensions of equipment, infrastructure, ventilation considerations
Concrete works	Constructed pillars with rebar and concrete	Expensive
Pressure Grouting	Building a roof support beam to bolt Forepoling to stabilize roof or remedy a problem	Poor ground, near outcrops Controls water inflow

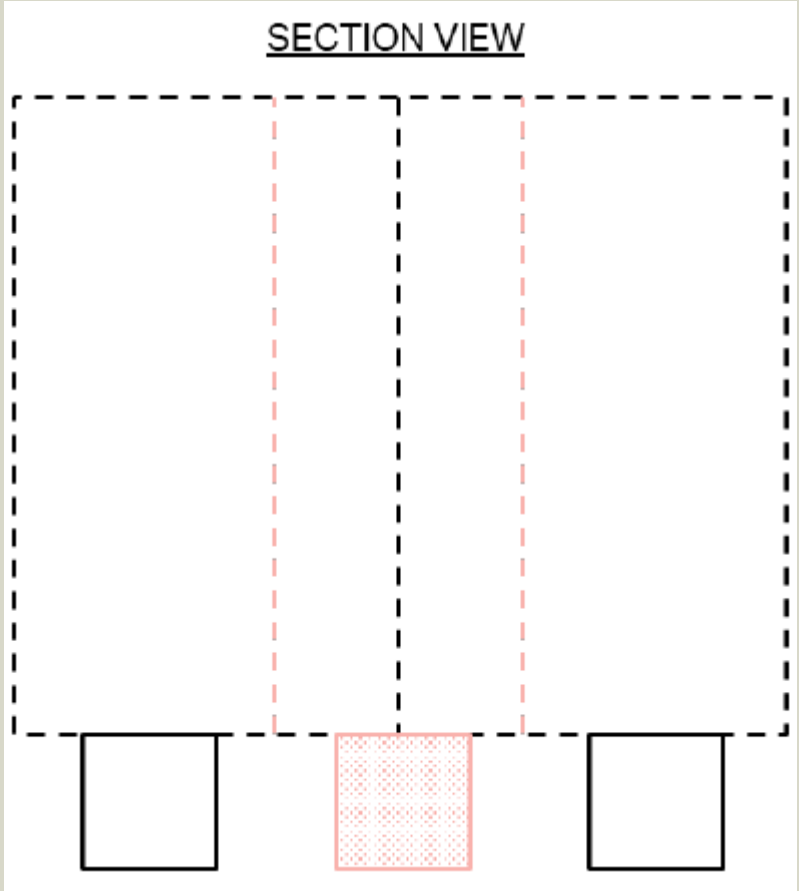
CASE STUDIES AND EXAMPLES

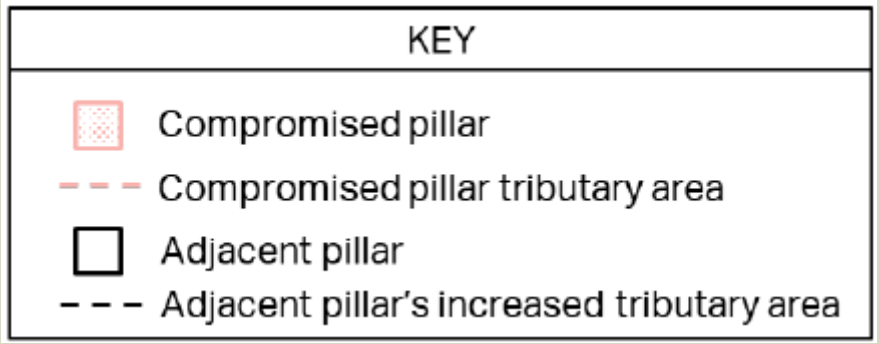
- Deteriorated Pillar Rehab
  - Higher risk area, risk of cascading effect of high stress to additional pillars
  - Welded wire mesh, bolts, and shotcrete to prevent further deterioration.
  - Monitoring of spans via roof holes and extensometers over time to see if the stress is running on to other pillars.
  - If movement is detected, then the area can be barricaded off.
  - 2D modeling, S-Pillar.
  - Global stability models for the mine if this is a chronic condition (not isolated)

- Monitoring over time:
  - Painting cracks, using crack slides and tile spacers also good inexpensive options

CASE STUDIES AND EXAMPLES

- Deteriorated Pillar: where is load transferring to? What does the effective span become if that pillar fails completely?



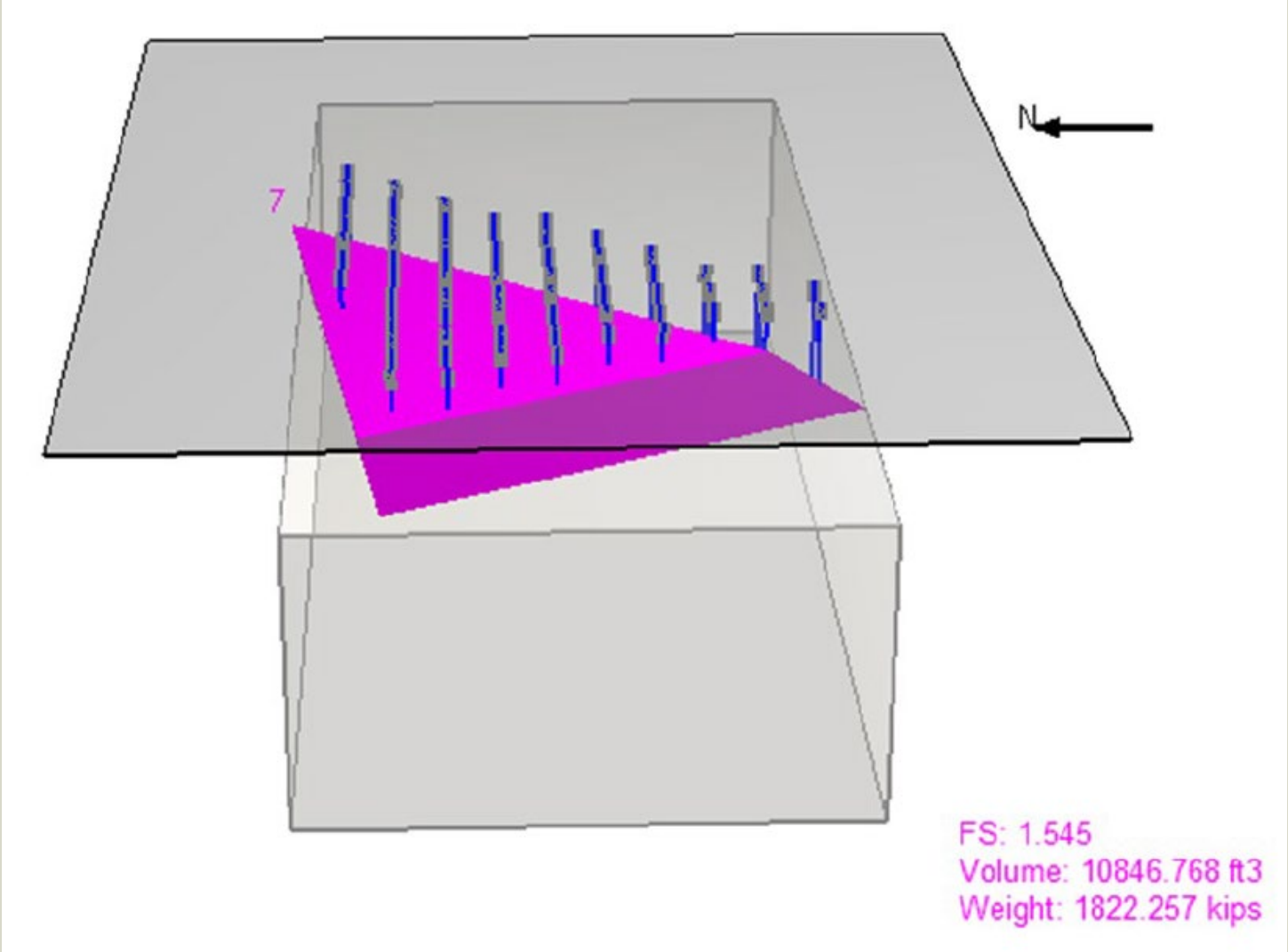


CASE STUDIES AND EXAMPLES

- Safe Access to Main Portals
  - Mine grid vs. welded wire mesh (corrosion or overall strength rating)
  - Size and energy of falling material (rock and plates)
  - Freeze/thaw impact and corrosion due to water
  - Consider cost and overall timeline of the portal
  - Leaving old bolts in place and adding bolts & mesh

CASE STUDIES AND EXAMPLES

- Is Existing Bolting Adequate:
  - Collect data - joint mapping and borescope data
  - UnWedge software to model for the worst condition, largest wedge that can form
  - Determine if pattern bolting is needed: spacing, sizing, & length of bolts needed



CASE STUDIES AND EXAMPLES

- Reinforcement of previously supported areas
  - Infill pattern bolting: fully grouted new bolts to supplement previous bolting pattern around a pillar with potential for roof crack progression

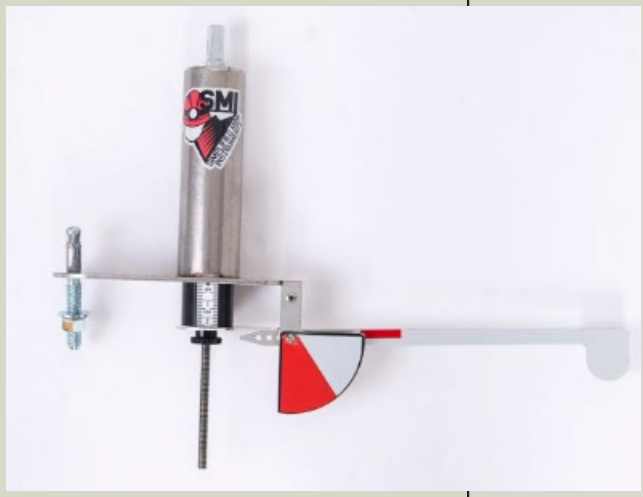
CASE STUDIES AND EXAMPLES

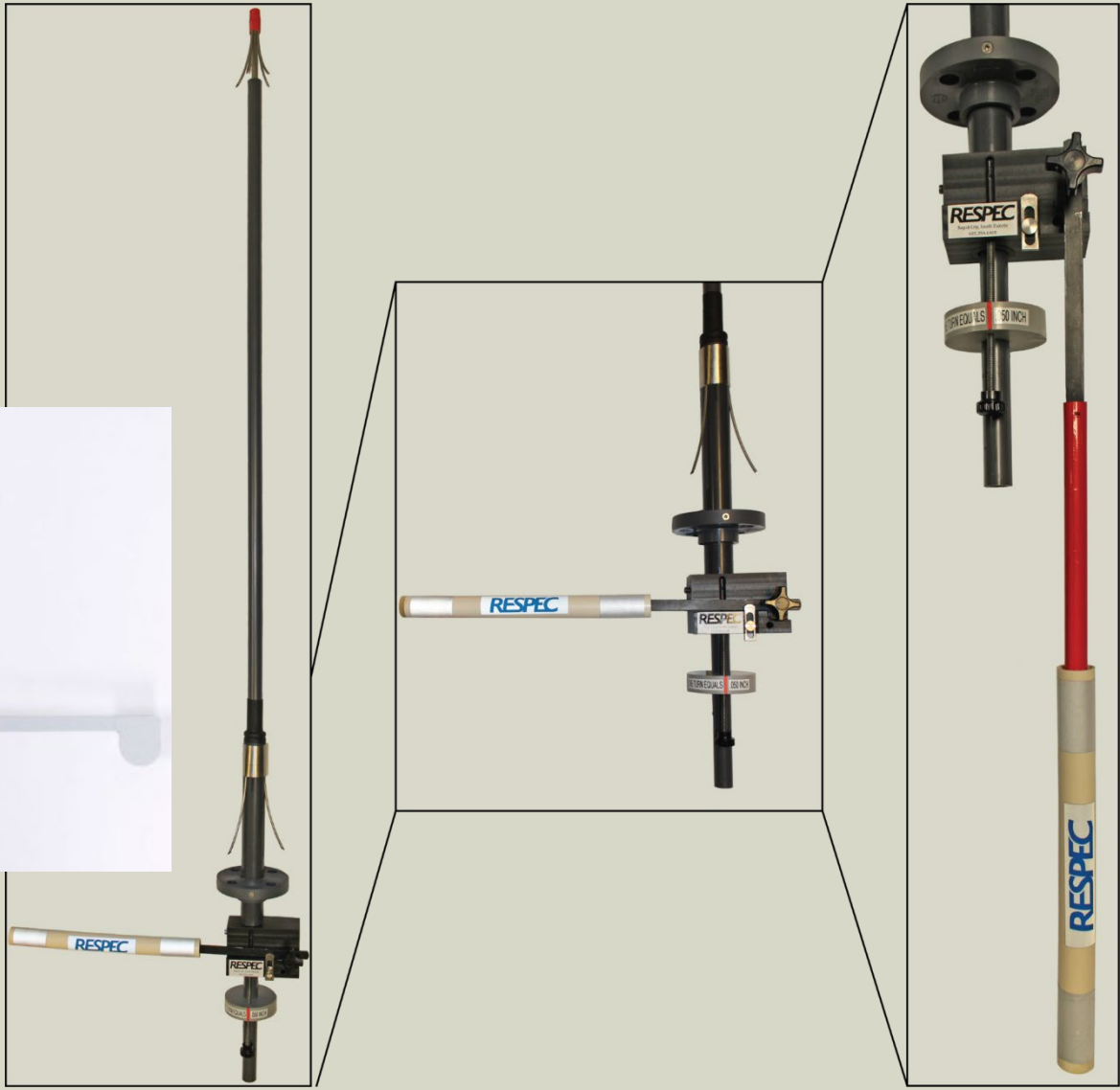
- Legacy Benched Areas - When W:H ratio is not ideal
  - Increased risk associated with pillars with W:H > 1
  - Can create a modified FS chart specific to site conditions: identify and prioritize pillars with the highest risk

Width-to-Height Ratio	Factor of Safety	Comments/ Description
≥ 1.0	≥ 1.8	Design is expected to be stable
	<1.8	Design has an unacceptable risk of instability
0.8–1.0	≥ 2.8	Design is expected to be stable
	≥ 1.8	Design requires trial implementation and site-specific geotechnical review
	< 1.8	Design has an unacceptable risk of instability

MONITORING EQUIPMENT AND INSTRUMENTATION

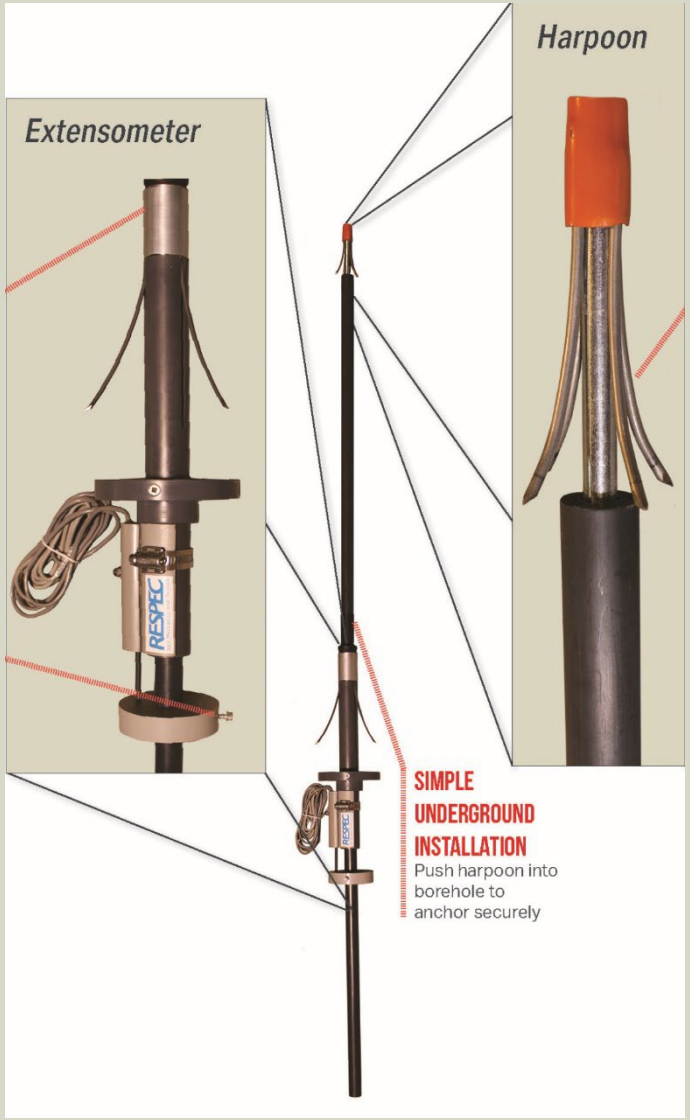
- Borescopes or scratch tools
  - Check for separations within the roof
- Roof Monitor Flags
  - Keep routine monitoring logs
  - Can set up with strobe





MONITORING EQUIPMENT AND INSTRUMENTATION

- Extensometers
  - High precision to detect sub-mm separation in the roof over time
  - Multiple types to fit a site's needs:
    - single point / multipoint: One or more anchors and a reference plate
    - electrical / mechanical
    - Datalogger
- LiDAR Scanning
  - High precision point cloud scans, use for S-Pillar calculations, modeling, and quantitative comparison to scans over time
- Distometer / Laser Measures
  - Good for measuring general distances; not a great monitoring tool



QUESTIONS?

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