Assessing Pillar Collapse and Airblast Hazards in Underground Stone Mines
Pillars are blocks of rock left to support the overlying strata. A pillar collapse is when an array of pillars fail suddenly. Pillar collapses can occur with very little warning, and can affect miners far away from the collapse.
Overburden rock
Collapse material
Rock shaken down from the roof
Rock thrown into the roadway
The total collapse of the overburden typically causes a subsidence feature (sinkhole) on the surface.
An airblast is a rapid displacement of large quantities of air, often under pressure, caused by a fall of ground in a constrained underground environment.
Miners located in high-velocity air pathways are at most risk.
During the years 2015-2021, five major pillar collapses occurred at four underground stone mines.

These events resulted in three injuries and numerous near-misses.

Similar events have occurred in previous years in marble mines and in lead/zinc mines.
It is not possible to predict when, or even whether, a particular array of pillars will collapse.

However, experience has shown that certain factors are associated with an increased likelihood of a pillar collapse.
MASSIVE PILLAR COLLAPSES

Stopping destroyed by airblast

Large collapse area
Pillar Design for Underground Stone Mines
Proper pillar design is a necessary first step for new workings.

NIOSH developed the S-Pillar program in 2010 and it is widely known in the industry.
Slender Pillars, with width-to-height ratios less than 0.8, are at risk of collapse.

In this photo, the w/h ratio is $30/50 = 0.6$. 
Limestone is a very strong rock.

However, it often contains joints or other geologic features.

These can greatly reduce the strength of a slender pillar, particularly when they “daylight” on both sides of the pillar.
Benching

Mining the floor increases the pillar height.
Poor mining practices (blasting, surveying) can result in undersized pillars.
Many active underground stone mines contain “legacy” areas where pillars, particularly in benched areas, may be prone to collapse.

Mine operators should assess the risk of pillar collapse in these areas.
**Risk Assessment** requires rating the **likelihood** and the **consequences** of an unwanted event. The greatest risk is when both the likelihood and the consequences are high.

<table>
<thead>
<tr>
<th>Consequence</th>
<th>Likelihood of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Value</td>
<td>High value</td>
</tr>
<tr>
<td></td>
<td>Medium value</td>
</tr>
<tr>
<td></td>
<td>Low Value</td>
</tr>
<tr>
<td>High Value</td>
<td>High risk</td>
</tr>
<tr>
<td>Medium Value</td>
<td>Moderate risk</td>
</tr>
<tr>
<td>Low Value</td>
<td>Low Risk</td>
</tr>
</tbody>
</table>

Source: Iannacchione, Varley, and Brady (2008). *The application of major hazard risk assessment (MHRA) to eliminate multiple fatality occurrences in the US mineral industry. NIOSH IC 9508.*
Factors contributing to the likelihood of pillar collapse

A pillar design method, like S-Pillar, is the primary tool for evaluating the likelihood of a pillar collapse.

The pillar’s width-to-height ratio is an essential part of the pillar stability analysis.
Many pillar design methods assume the pillars carry tributary area loading. Where the panels are deep or narrow, and the overburden strong, the actual loading may be less due to pressure arch behavior.
A larger pillar array is more likely to collapse because there is less pressure arch potential, and it will also cause a greater airblast.
Major geologic features, like faults or karst, can reduce pillar strength or weaken the overburden.
Weak bands or soft floor can cause rib slabbing and reduce pillar strength.
Blasted stone, shot in the floor (benched), ready to be loaded

Collapsed pillars

Consequences of a Pillar Collapse

Miners working in the area of a pillar collapse would likely be killed. In one recent instance, miners were engaged in benching operations just days before a pillar collapse.
Miners working nearby a collapse, or traveling in an adjacent haulroad, could be killed or injured by falling rock or extremely high air velocities.
Miners located at some distance from the collapse can be at risk if they are working or traveling in high velocity air pathways.
Tech Support Study of Airblasts in Underground Mines Worldwide

- 40 documented airblasts
- Coal, trona, potash, copper/gold, lead/zinc
- Pillar Collapses
- Caving Events (longwalls, room and pillar, block caving)
Northparkes Mine Disaster (1999)

- 10 million tons fell 500 feet
- 4 Miners killed
- 57 other miners unhurt
Miners can also be harmed if fans or other ventilation controls are damaged by an airblast, or if egress from the mine is blocked.
Miners working in front of the portals, or on the surface, could also be harmed by a pillar collapse.
Control techniques that can reduce the risk from pillar collapse

1. Relocate travelways and other mine infrastructure to areas of lower risk.
2. Construct bulkheads or rock barriers to redirect airblast away from miners.
3. Airblast relief openings can provide a direct ventilation pathway that does not expose miners to the hazard.
4. Backfill?
5. Underground observations and monitoring
The Pillar Collapse Likelihood Matrix. The top two parameters are most important. A “high” value for a parameter correlates with a greater likelihood of collapse.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pillar Stability</strong></td>
<td>Meets all applicable design criteria</td>
<td>Does not meet applicable design criteria</td>
<td></td>
</tr>
<tr>
<td><strong>Width-to-height ratio (average)</strong></td>
<td>w/h&gt;1.0</td>
<td>0.8&lt;w/h&lt;1.0</td>
<td>w/h&lt;0.8</td>
</tr>
<tr>
<td><strong>Pillar Dimension Variability</strong></td>
<td>All pillars approximately equal sized</td>
<td>A few pillars smaller than average</td>
<td>Many pillars smaller than the average</td>
</tr>
<tr>
<td><strong>Pressure Arch Potential</strong></td>
<td>Strong overburden/Deep cover/Narrow pillar array</td>
<td>Moderate strength overburden/Moderate cover/Moderate pillar array width</td>
<td>Weak overburden/Shallow cover/Wide pillar array</td>
</tr>
<tr>
<td><strong>Size of Benched Area</strong></td>
<td>Small</td>
<td>Moderate</td>
<td>Large</td>
</tr>
<tr>
<td><strong>Major Geologic Features (Faults, karst)</strong></td>
<td>None</td>
<td>If a fault, karst, or other major geologic feature is present, assess its potential contribution to the collapse likelihood</td>
<td></td>
</tr>
<tr>
<td><strong>Soft Floor</strong></td>
<td>None</td>
<td>Possible, but minimal evidence of pillar distress</td>
<td>Thick weak floor causing pillar dilation</td>
</tr>
<tr>
<td><strong>Weak Bands in the Pillars</strong></td>
<td>None</td>
<td>Possible, but minimal evidence of pillar distress</td>
<td>Thick, weak band causing pillar dilation</td>
</tr>
</tbody>
</table>
The Pillar Collapse Consequences Matrix helps evaluate the hazards at different locations in the mine, and the potential exposure of miners.

<table>
<thead>
<tr>
<th>Location of miners</th>
<th>Conditions/Hazards</th>
<th>Consequence if miners are present</th>
<th>Number of miners exposed</th>
<th>How often are miners exposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working within collapse area, engaged in active mining/benching operations</td>
<td>Massive rock fall, no warning</td>
<td>Death</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working or traveling in roadways directly adjacent to collapse area</td>
<td>High air velocities, flying debris, small rock falls</td>
<td>Death or severe injury</td>
<td></td>
<td></td>
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<tr>
<td>Working or traveling directly above a collapse area</td>
<td>Sudden development of a surface sinkhole</td>
<td>Death or severe injury</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working or traveling in high velocity air pathways leading from collapse area to portals</td>
<td>Diminishing air velocities depending on number of pathways and distance from collapse</td>
<td>Injury</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other locations in the mine</td>
<td>Damage to ventilation controls or egress routes</td>
<td>Indirect hazards</td>
<td></td>
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</tbody>
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