Department of Environmental Protection
Bureau of Mine Safety

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TITLE: Guidelines for Submittal of Benching Plans

EFFECTIVE DATE: XXXX

AUTHORITY: 25 Pa. Code §§ 207.313 and 207.104(a)(3)

POLICY: It is the Bureau of Mine Safety's (BMS) policy that benching in underground industrial mineral mines will be conducted in manner that protects all individuals working underground by evaluating the integrity of the mine pillars, ensuring adequate roof beam and roof control measures, safety standards during and after benching, and maintaining adequate floor beam.

PURPOSE: The purpose of this guidance document is to reduce the risk of roof and pillar failure during benching and thereafter in underground industrial mineral mines.

APPLICABILITY: This guidance is applicable to all Mine Safety staff and all underground industrial mineral mine operators and personnel.

DISCLAIMER: The policies and procedures herein are not an adjudication or a regulation. There is no intent on the part of the Department to give these rules that weight or deference. This document establishes the framework, within which DEP will exercise its administrative discretion in the future. DEP reserves the discretion to deviate from this policy statement if circumstances warrant.

PAGE LENGTH: X pages

LOCATION: Volume X, Tab X

1. BACKGROUND

BMS's mission is to reduce the possibility of accidents in and about the underground mines, to protect the property connected therewith, to provide for the health and safety of the individuals working underground, and to contribute to the public safety in relation to underground mining activities. To accomplish these objectives, BMS conducts engineering and plan approvals.

Benching is a process where material from the bottom of the existing mine passage is extracted vertically between the existing pillars of an underground industrial mineral mine. The floor of the developed portion of the mine is removed through blasting. During benching, the pillar height increases as stone is removed but the width of the mine passage remains the same. The extracted stone is then processed and sold by the operator.

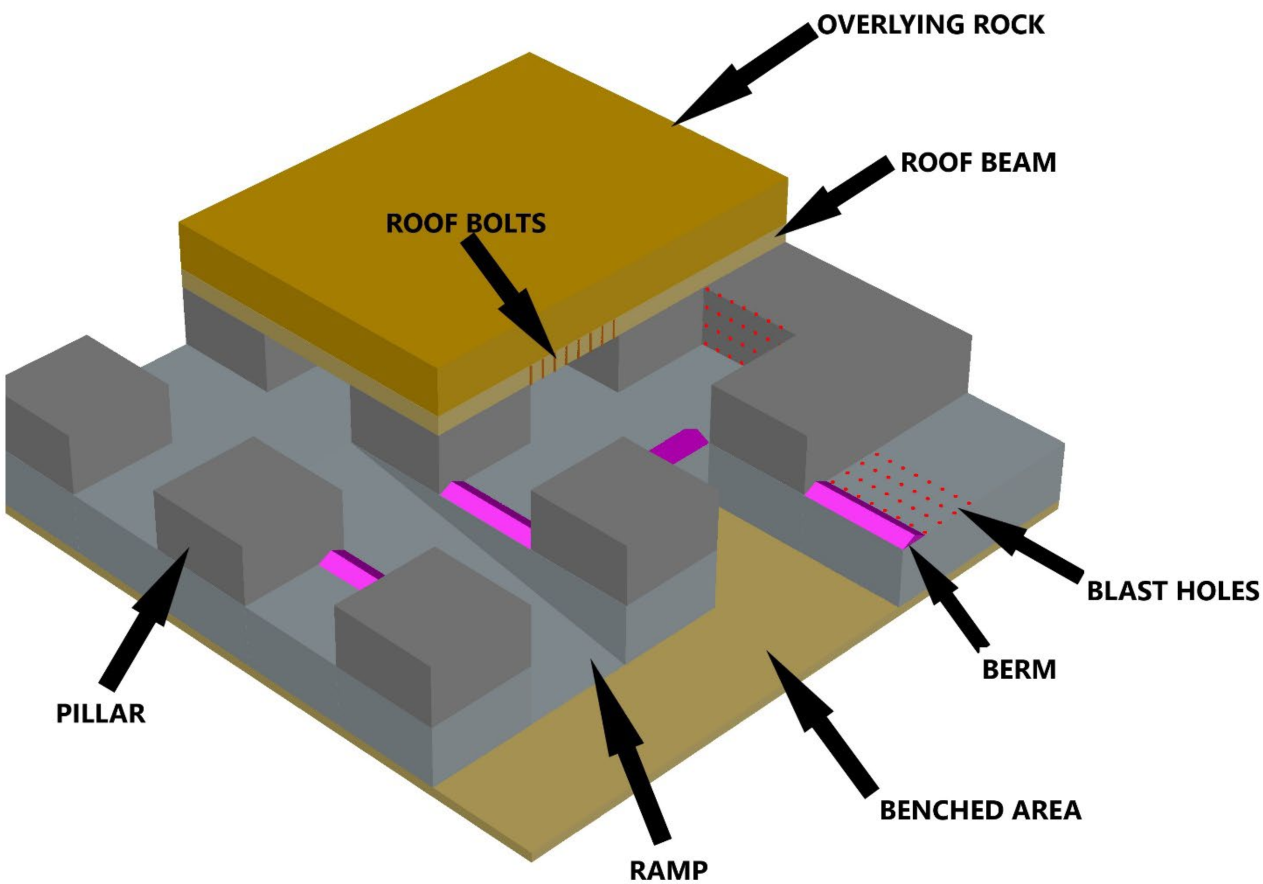

Figure 1: Room and pillar mining including a benched area where the floor has been removed between existing pillars. Shot holes are drilled vertically into the floor of the initial mine heading and a thickness of the initial mine floor is removed after blasting. The area is ramped down for access and haulage. Berms are placed between the initial developed portion of the mine and the benched area. The darker gray colored material represents the upper part of the mined geologic formation with the lighter gray colored material being the lower portion of the mined geologic formation.

To reduce the potential risks to the health and safety of underground workers and to protect the stability of underground industrial mineral mines from potential collapse due to proposed benching activities, the mining operator will conduct a risk assessment for pillar failure; analyze the roof beam, pillars, and floor; and model the post structure stresses. This information is presented to BMS as a benching plan.

Benching plans have been required by BMS due to catastrophic pillar failures that have occurred in historically benched areas at Pennsylvania industrial mineral mines. These instances have been documented by the Mine Safety & Health Administration (MSHA), National Institute for Occupational Safety and Health (NIOSH), and BMS. Resources utilized to create this guidance document are included in Appendix A.

A. Assessment Process

The mine risk assessment process consists of the following steps. First, a proposed benching area is identified. Then, the likelihood of a collapse of the pillars in that area is evaluated using the likelihood matrix. The matrix helps to define the geotechnical and mining geometry data that is necessary to conduct the assessment. The overall likelihood of a collapse can then be assessed based on a qualitative evaluation of all the factors in the likelihood matrix.

Pillar Collapse Likelihood Matrix

	Low	**Moderate**	**High**
Pillar Stability	Meets all applicable design criteria	Meets some of the applicable design criteria	Does not meet applicable design criteria
Width/Height (w/h) Ratio	w/h > 1.0	w/h between 0.8 and 1.0	w/h < 0.8
Pillar dimension variability	All pillars approximately equal size	A few pillars smaller than average	Many pillars smaller than average
Spanning potential of panel/benched area	Strong overburden/deep cover/narrow pillar array	Moderate strength overburden/moderate cover/moderate pillar array width	Weak overburden/shallow cover/wide pillar array
Size of benched area	Small	Moderate	Large
Major geologic features	None	If a fault or other major geologic feature is present, assess its potential contribution for collapse	
Soft floor	None	Possible, but minimal evidence of pillar distress	Thick weak floor causing pillar dilation
Weak bands in the pillars	None	Possible, but minimal evidence of pillar distress	Thick, weak band causing pillar dilation

The next step is to evaluate the consequences of a potential collapse. The consequence matrix guides the evaluation, which considers both the potential hazards that would be present in different locations in the mine, and the exposure of the individuals working underground to those hazards.

Pillar Collapse Consequences Matrix

Location of Miners	Condition/Hazards	Consequence
Working within pillar collapse area, engaged in active benching operations	Massive rock fall, no warning	Death
Working or traveling in travelways or haul roads directly adjacent to pillar collapse area	High air velocities, flying debris, small rock falls	Death or severe injury
Working or traveling directly above a pillar collapse area	Sudden development of a surface sinkhole	Death or severe injury
Working or traveling in high velocity air pathways leading from pillar collapse area to portals	Diminishing air velocities depending on the number of pathways and distance from pillar collapse	Injury
Other locations in the mine	Damage to ventilation controls or egress routes	Indirect hazards

Finally, for those areas where the combination of likelihood and consequence is great enough, potential steps to mitigate the risk can be considered if benching is desired in those areas.

B. Likelihood of a Pillar Collapse

Developed by The National Institute for Occupational Safety and Health (NIOSH), S-Pillar is the primary software tool used to evaluate the likelihood of a pillar collapse in areas where the proposed rock unit to be mined is of relatively low dip (typically of less than 5 degrees), single level mining, strong strata, lack of clayey bands in pillars, and a strong floor and roof. In areas that do not meet these requirements, S-Pillar may still be utilized for guidance. Alternate numeric modeling evaluation to analyze the likelihood of a pillar collapse may be utilized to supplement the evaluation or as required by BMS.

S-Pillar has two parts:

- The first part is the safety factor calculation. S-Pillar estimates the strength of the pillars based on their width-to-height (w/h) ratio, the uniaxial compressive strength (UCS) of the strata, and most importantly, the presence of discontinuities (typically joints) within the pillars. The impact of the joints on pillar strength depends on their spacing and dip angle. The Factor of Safety (FS) is calculated by comparing the pillar strength to the tributary area load. S-Pillar recommends that the FS for a stone pillar layout should exceed 1.8.

  The second part of an S-Pillar analysis is the width-to-height ratio. S-Pillar recommends that the w/h should exceed 0.8, regardless of the FS.

In both stages of the S-Pillar assessment, it is important to use the typical as-mined pillar dimensions rather than the planned dimensions. The remaining factors in the likelihood matrix supplement the S-Pillar analysis:

i. ***Pillar Dimension Variability***: If the pillar array contains some pillars that are significantly smaller than the typical dimensions, these small pillars can fail first and potentially trigger a larger collapse. Additionally, signs of pillar overloading (rib spalling, hourglass shaped, rounded) suggest that the area may not be well supported by the existing pillars.

ii. ***Pressure Arch Potential:*** The tributary area loading model used by S-Pillar assumes that the pillars carry the full weight of the overburden. In reality, with typical overburden geologies and panel widths, only a few pillars in the center of the panel may carry the full tributary area load, while the pillars near the edges of the panel are somewhat shielded. More of the pillars would be expected to see the full tributary area load when the overburden is weak or shallow, or where the panel is very wide. On the other hand, where the panel is narrow, the cover is deep, and/or the overburden is strong, a pressure arch can transfer enough weight that none of the pillars see the full tributary area load, thus decreasing the likelihood of a collapse.

iii. ***Size of Benched Area:*** All things being equal, a larger benched area is more likely to collapse and also have larger consequences if it does.

iv. ***Major Geologic Features:*** Faults come in many forms, and so one fault's effect on any particular benched area needs to be evaluated on a site-specific basis. For example, the fault that was present at a southwestern Pennsylvania Loyalhanna limestone mine collapse may have contributed to weakening the overburden, thereby increasing the pillar load. Karst features might also influence the likelihood of a pillar collapse. (***Note: It is not necessary to consider the effect of joints, bedding planes, and similar geologic discontinuities here, because their effect on pillar strength has already been incorporated into the S-Pillar evaluation).***

v. ***Soft Floor:*** Soft floor can reduce pillar strength by squeezing out and causing pillar dilation.

vi. ***Weak Bands in the Pillars:*** Thick bands of weak material, like clay, can cause rib dilation and slabbing, thereby reducing a pillar's strength and load bearing area.

vii. ***Roof Beam Competency and Thickness***: Roof beams consisting of discontinuities, thinly bedded intervals, or areas of groundwater infiltration should be evaluated and potentially avoided by for benching, as these areas are typically already geologically weakened.

C. Consequences of Pillar Collapse

The assessment assumes that a collapse would create two kinds of hazard, rock falls and airblast. It also assumes that a potential collapse could occur at any time, without warning.

The consequence matrix begins by defining four possible locations of those individuals working underground relative to a potential collapse. The hazards, and the potential consequences of a collapse to the individuals working underground in those locations are then described. The assessment consists of estimating the exposure of individuals within each of the four areas, based on the number of individuals exposed and the frequency of their exposure:

i. ***Working within collapse area:*** This includes individuals that are actively engaged in benching operations. A collapse would entail a massive rock fall that would almost certainly kill any individual exposed to it.

ii. ***Working or traveling directly adjacent to collapse area.*** Fortunately, most previously benched areas have been bermed off to prevent personnel access. However, haulroads and other travelways may be located adjacent to or very near the potential collapse area. Individuals located in the immediate vicinity of a collapse would likely be exposed to extremely high air velocities and entrained flying debris. There might also be small rock falls from the back or pillar ribs as loose rock is detached by the vibrations. Death or severe injury would be the likely result to individuals in these locations.

iii. ***Working or traveling in high velocity air pathways***: Research has shown that the real hazard to individuals from an airblast is high velocity air. When a collapse occurs, the air will travel the path of the least resistance to the outside of the mine, and the individuals located in those airways are at risk. Individuals located outside of a direct air pathway are unlikely to be hurt. In general, the more air pathways, the larger the combined cross-sectional area for air movement to occur. Therefore, the further the air has to travel to reach any given point, which subsequently lowers the air velocity at that point. Estimates of the air velocity would be very complex, however, even if characteristics of the initial air pulse were known.

iv. ***Working or travelling in portal area***: The air would be expected to coalesce as it exits the mine, with the air velocity depending on number of air pathways, the distance from collapse, and the number of portals.

D. Areas to Avoid

If a proposed benching area falls into one or more of the listed areas, then additional rationale, including supporting engineering calculations, safety precautions, etc., to avoid adverse safety impacts may be necessary or requested by BMS. Or the area should be avoided for benching. This list in not all-inclusive and is intended to provide guidance to mine operators on certain areas about which BMS may have additional safety concerns.

- Areas not already developed and surveyed.
- Areas that do not comply or will not comply with the Roof Control Plan.
- Areas that do not meet or exceed the minimum FS or w/h ratio.
- Areas defined as safety zones.
- Areas of overburden cover of less than 100 feet.
- Areas within 150 feet of the crop line.
- Areas surrounding an oil and gas well.
- Areas above gas storage fields
- Areas of excessive scaling of the pillars or roof, or where pillar shape may indicate signs of instability.
- Areas of or immediately adjacent to previous roof falls or pillar failures.
- Areas where geologic discontinuities may adversely affect pillar or roof stability.
- Areas with significant groundwater inflows that may affect pillar stability.
- Areas that do not meet permit requirements.
- Any other areas deemed relevant to avoid by BMS or the operator.

Should a pillar be considered questionable due to under-sizing, geologic instability, etc., the operator may submit a specific area plan for benching. For example, the operator may consider one or more of the following situations which will be evaluated by BMS on a case by case basis:

a) Reduce the benching depth around the questionable pillar. A ramp may be constructed from the normal benching depth to a reduced benching depth around the designated questionable pillar. Therefore, the benching area plan will include a discussion and the mapping should depict the ramp location, berms, etc.

b) Improve the pillar conditions through roof control measures. This may include rib bolting, rib mesh, narrowing of the bench width near the questionable pillar, etc.

c) Abandon the area surrounding the questionable pillar.

d) Prior to submittal to BMS, discuss with BMS potential other solutions to improve the conditions around the questionable pillar to allow for benching activities to safely occur.

2. BENCHING PLAN SUBMITTAL PROCEDURES:

The initial steps to benching plan approval involve identifying a portion(s) of the developed and surveyed mine to propose for benching and supplying the following information in Sections A, B, C, and D below. An example benching plan is included as Appendix B. All submittals shall include an Industrial Mineral Plan Approval Routing Slip with the appropriate signatures and section of law referenced.

The plan shall be initially submitted to the Underground Mine Inspector and will subsequently be reviewed by the BMS Engineering Group, BMS Mine Safety Engineer Manager, BMS Industrial Minerals Mine Safety Program Manager, and the BMS Director. The information contained within will be verified through field and desktop reviews. The mine inspector shall conduct a visual and situational analysis of the proposed benched area(s). Should any safety or additional information become necessary as a result of the review, BMS will contact the operator to address those concerns. Written approval will be provided by BMS should the plan adequately address potential adverse safety concerns.

The area(s) chosen for benching should be areas where benching activities are anticipated to be conducted within the next six (6) months. The purpose of the time frame restriction is in case of changing mine conditions. A written extension may be requested by the mining operator to the BMS mine inspector to extend the approval should benching not occur within the six-month time frame from the initial BMS approval.

A. Plan Narrative

At a minimum, the narrative should include the following information.

- Cover letter on company letterhead including the date, contact information, mine name, permit number, company name, and the purpose of the plan.

- Specific location(s) of the proposed benching area(s) within the mine utilizing the location grid system on the annual maps for the mains and crosscuts. For example, 3E-5E/12N-15N.

- Development heights/pillar heights of the area(s) proposed for benching.

- Thickness of stone to be removed during benching and if applicable, state if benching will leave a floor beam of the same mineral being mined or if benching will occur to the geologic formation contact. If benching is to occur to the formation contact, describe the composition of the underlying geologic unit.

- Maximum pillar height after benching is completed for each proposed area.

- The actual dimensions of the smallest pillar within each proposed area to be benched (length and width).

- The maximum depth of cover for each proposed benching area.

- Indicated if the escapeways are to be rerouted for each proposed benching area. Escapeways shall be bermed from areas being benched and if applicable, those areas where benching previously occurred.

- Indicate that after benching is completed in the designated area(s), berms shall be placed between the pillars on the drift level around the benching area to prevent access.

- If a roof beam is required by the permit, indicate the minimum roof beam thickness for each proposed benching area. Include a statement how the roof bench thickness was determined, such as scoping, scrape tests, etc., and where those records can be obtained.

- If applicable, state if any areas within the proposed benching areas have roof supports installed (i.e., bolted, glued, etc.) and the specifications, such as being installed in accordance to the roof control plan

- State if any roof stability monitoring systems are currently utilized or proposed to be utilized within or in the vicinity of the proposed benching area. If none, are existing or proposed, indicate under what conditions may a roof monitoring system be utilized.

- Presence and identification of the types of geologic features and discontinuities within or adjacent to the proposed benching area. This should include, but not limited to, the locations of faults, fractures, prominent joints, karst/solution cavities, slickensides, mineralization zones, thin clay seams, groundwater infiltration zones etc. that could impact roof or pillar stability during or after benching. The narrative should note the approximate steepness (dip) of fractures, joints, or faults, if present, and if these features are open, mineralized, or closed.

- Statement regarding the groundwater conditions in the area to be benched. Is groundwater currently present or expected to accumulate after benching?

- Uniaxial Compressive Strength (UCS) used in the S-Pillar modeling (general, actual) and why the UCS is appropriate for modeling.

- If any areas in the proposed benching areas have an area already benched included, discuss the benched height and if further benching is proposed to occur.

- Any other information deemed relevant by the mining operator or BMS.

B. <u>Stability Analysis</u>

The submittal shall include a stability analysis utilizing software, such as S-Pillar, or industry accepted methods and models that are also accessible to the BMS. The stability analysis must utilize the smallest pillar dimensions and highest depth of cover for the proposed benching area(s). If present, large angular discontinuities within the proposed benching area must be accounted for in the stability analysis. Justification for the UCS utilized in the calculations should be included in the submittal. At a minimum, the results must indicate a safety factor exceeding 1.8 and w/h ratio of greater than 0.8. Greater safety factors and/or ratios may need to be increased for adverse conditions.

- The submittal shall include all modeling inputs and results thereof for each proposed benching area.

C. <u>Map(s)</u>

The submittal shall include scaled map(s) depicting the following. An updated mine development-ventilation map may be utilized for the submission in lieu of creating a map for the proposed benching.

- Include a title, legend, north arrow, and scale/scalebar.

- Entries (Mains) and crosscut designations that matches the mine development-ventilation map.

- Survey spads and elevations within the proposed benching area. The area proposed for benching must be surveyed.

- Include surface/overburden contours, and seam contours. Contour shall be 20 feet maximum or less.

- Identification of the smallest pillar within the proposed benching area(s).

- Locations where roof anchoring system are installed within or adjacent to the proposed benching area(s).

- The primary and/or secondary escapeways in the vicinity of the proposed benching area(s).

- Bermed or backfilled areas adjacent to the proposed benching area(s).

- Previously benched areas near the proposed benching area(s) and the maximum pillar heights in those areas.

- The locations of any currently installed or proposed roof monitoring systems.

- The locations of geologic features or discontinuities in the roof, pillars, and floor within or immediately adjacent to the proposed benching area(s). If poor roof conditions appear to be a result of horizontal stresses, indicate the primary horizontal stress direction.

- The locations of oil and gas wells with the appropriate barrier.

- If applicable, safety zones and/or limited extraction areas.

- If applicable, roadways, structures, or known utilities on the surface and overtop the area(s) proposed for benching.

- Any other relevant features that may improve or adversely impact the stability of the roof beam and pillars.

- Provide a generalized blasting diagram for the benching area. The diagram should include the if the blasting will be vertical and/or horizontal, spacing, hole diameter, and depth of the shot holes.

- Any other information deemed relevant by either the mining operator or BMS.

D. <u>Risk Assessment</u>

The risk assessment is where the mining operator acknowledges that the risks were evaluated, and the threat of pillar collapse is not likely to occur. The two tables listed below and shown in Section A of this document shall be included in the benching plan submittal.

- Pillar Collapse Likelihood Matrix table
- Pillar Collapse Consequence Matrix table

3. POST BENCHING EVALUATION

After benching is approved and completed by the mining operator, a post evaluation shall be conducted by the mining operator, and verified by BMS, to ensure compliance with the plan and that adequate safety measures are in place.

APPENDIX A- Resources

Christopher Mark and Gregory Rumbaugh, (2022). International Experience with Airblasts and Its Relevance to Underground Stone Mines (msha.gov). MSHA, 18 pp.

Gregory M. Rumbaugh, Christopher Mark, and Todd Kostecki (2022). Massive Pillar Collapses in U.S. Underground Limestone Mines: 2015-2021 (msha.gov). MSHA, 12 pp.

Gabriel S. Esterhuizen, Paul L. Tyrna, and Michael M. Murphy (2019). A Case Study of the Collapse of Slender Pillars Affected by Through-Going Discontinuities at a Limestone Mine in Pennsylvania (msha.gov). MSHA, 12 pp.

Gabriel S. Esterhuizen, Anthony T. Iannacchione, John L. Ellenberger, Dennis R. Dolinar (2006), Pillar Stability Issues Based On A Survey Of Pillar Performance In Underground Limestone Mines (cdc.gov), NIOSH, 8pp.

Gabriel S. Esterhuizen, Dennis R. Dolinar, John L. Ellenberger, and Leonard J. Prosser (2011). Pillar and Roof Span Design Guidelines for Underground Stone Mines (msha.gov). MSHA, 75 pp.

G. S. Esterhuizen, D.R. Dolinar, and J.L. Ellenberger (2007). Observations and Evaluation of Floor Benching Effects on Pillar Stability in U.S. Limestone Mines (cdc.gov). NIOSH, 7 pp.

G. S. Esterhuizen, (2021). Stone Mine Pillar Stability and Design. NIOSH, 36 pp.

Gamal Rashed, Brent Slaker, Michael Murphy (2021), Exploration of Limestone Pillar Stability in Multiple-Level Mining Conditions Using Numerical Models (nih.gov). NIOSH, 27 pp.

MSHA. Safety Alert Stone Mine Massive Pillar Collapses (msha.gov). 1pp.

Iannacchione AT and Varley F (2008). The Application of Major Hazard Risk Assessment (MHRA) to Eliminate Multiple Fatality Occurrences in the U.S. Minerals Industry (cdc.gov). NIOSH 1C 9508, 142 pp.

MSHA (2021). Assessing Pillar Collapse and Airblast Hazards in Underground Stone Mines. 36 pp.

APPENDIX B-Example Benching Plan