Agapito Associates, Inc.
ENGINEERS & GEOLOGISTS

www.agapito.com

July 31, 2024 534-61

Tonia Perkins
Senior Mining Engineer
Trapper Mining Inc.
25910 S. Highway 13
Craig, CO 81625

Re: **Inwall HWM Sequence Analysis Proposed for N-Pit**

Dear Tonia:

As requested by Trapper Mining, Inc. (Trapper), Agapito Associates, Inc. (Agapito) has completed an analysis of highwall mine (HWM) stability in the N-Pit with consideration of a top-down mining sequence. Agapito has developed the mine plan as shown in Figure 1 based on panel orientations and safety factor constraints. Agapito understands that the overlying M Seam must remain stable while the lower seams within the N-Pit are mined out. Because of the top-down mining sequence, it is critical that the highwall mining does not significantly impact highwall stability. On this basis, Agapito has utilized the numerical modeling program FLAC3D to assess highwall stability during the proposed highwall mining sequences.

Empirical Pillar Design

Agapito's approach to web and barrier pillar designs involved two iterative steps: (1) application of empirical pillar design formulas, and (2) numerical modeling analysis to confirm design performance and test its robustness. This section describes the empirical methods used to size the web and barrier pillars for the various cover depths, anticipated mining heights, and stress conditions.

Input Parameters and Methods

The in situ strength of coal serves as a critical input to the pillar design process. In situ coal strengths for the M and Q seams are taken as 766 and 850 pounds-per-square inch (psi), respectively, based on previous work conducted by Agapito for the N-Pit mining area.[1] Other key inputs include the anticipated roadway width and depth of cover. The roadway width was established at 11.5 feet (ft) based on input from Trapper, and the depth of cover is accounted for using a range of possible values in the design tables.

The web and barrier pillar widths for the M and Q seams were calculated under the guidelines set forth in the Analysis of Retreat Mining Pillar Stability-Highwall Mining (ARMPS-HWM), a procedure developed by the National Institute of Occupational Safety and Health (NIOSH). This

[1] Agapito Associates, "Geotechnical Design and Operational Considerations For Highwall Mining, N Dip Pit, Trapper Mine." Project no. 534-36 (2016)

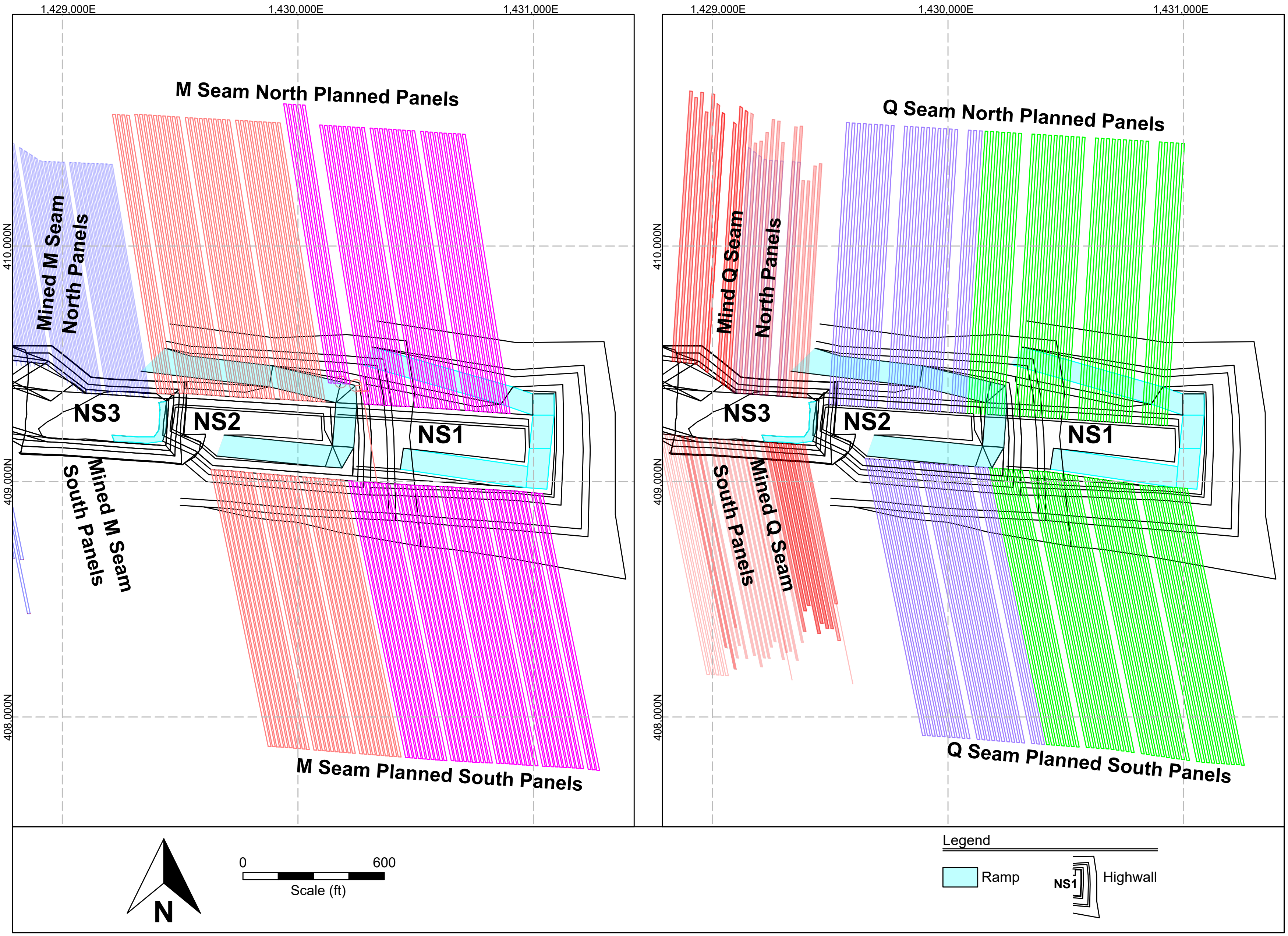
method is readily accepted by the Mine Safety and Health Administration (MSHA) as a design basis for HWM pillars. Agapito specified a minimum allowable pillar width-to-height ratio of 0.8 based on experience with similar HWM projects. In line with design criteria used in the study conducted by Agapito in 2016, a minimum safety factor (SF) criterion of 1.6 was established for web pillars in all the panels where the barrier pillar width-to-height ratio was anticipated to be less than 4.0. The barrier pillar widths for each seam were calculated using the ARMPS-HWM method, and their corresponding safety factors range from 3.5 to 4.5 for the range of conditions considered in the N-Pit analysis.

Separate design charts were developed for web and barrier pillars in the M and Q seams, for a total of four design sets. The design curves incorporate the assumption that all HWM panels in the N-Pit will be comprised of 10 openings, which results in panel widths, calculated center-to-center on barrier pillars, that may range from roughly 180 ft in the south M Seam to 270 ft in the North Q Seam.

Design Charts

Design specifications are given in Figure 2 and Figure 3 for the M and Q seams, respectively. The design tables for each seam are valid in the North and South portions of the N-Pit, as depths of cover are provided to cover both areas. Each figure contains three separate components, labeled (a), (b), and (c). The contents of each figure are arranged as follows:

- The (a) portion of each figure pertains to web pillars. The table provides web pillar widths that are required for corresponding values of mining height and depth of cover. All values are dimensioned in feet. The chart offers a graphical representation of the tabular data for quick reference. The plotted lines flatten at lower depths of cover, which indicates that pillar widths are limited by the minimum 0.8 width-to-height ratio criterion.
- The (b) portion of each figure pertains to barrier pillars. The table provides the required barrier pillar widths for corresponding values of mining height and depth of cover. All values are dimensioned in feet. The chart offers a graphical representation of the tabular data for quick reference.
- The (c) portion of each figure pertains to estimated recovery in plan-view. The table provides an estimated percentage of coal seam recovery for corresponding values of mining height and depth of cover, which affect pillar geometry. The chart offers a graphical representation of the tabular recovery data for quick reference.



534-61 Trapper [Figure1_wbl_rjl.dwg Layout: 1]rjl(7-30-2024)

Figure 1. Overview of the N Pit and Highwall Mining Areas

Design Depth of Cover, ft	Mining Height, ft												
	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8
80	2.3	2.4	2.6	*2.8*	*3.3*	*3.7*	*4.0*	*4.4*	*4.8*	*5.3*	*5.7*	*6.0*	*6.4*
95	2.4	2.7	2.8	3.0	*3.3*	*3.7*	*4.0*	*4.4*	*4.8*	*5.3*	*5.7*	*6.0*	*6.4*
110	2.8	3.0	3.2	3.3	3.5	3.7	*4.0*	*4.4*	*4.8*	*5.3*	*5.7*	*6.0*	*6.4*
125	3.0	3.3	3.5	3.8	3.9	4.1	4.3	*4.4*	*4.8*	*5.3*	*5.7*	*6.0*	*6.4*
140	3.3	3.6	3.8	4.1	4.3	4.5	4.7	4.8	5.0	*5.3*	*5.7*	*6.0*	*6.4*
155	3.5	3.8	4.2	4.4	4.7	4.9	5.1	5.3	5.5	5.7	5.8	*6.0*	*6.4*
170	3.8	4.2	4.5	4.8	5.1	5.3	5.6	5.8	6.0	6.2	6.3	6.5	6.7
185	4.0	4.4	4.8	5.1	5.4	5.7	6.0	6.3	6.4	6.7	6.8	7.1	7.3
200	4.3	4.7	5.1	5.4	5.8	6.1	6.3	6.7	6.9	7.2	7.4	7.6	7.8
215	4.4	4.9	5.3	5.8	6.1	6.5	6.8	7.1	7.3	7.7	7.9	8.2	8.3
230	4.7	5.2	5.7	6.1	6.5	6.8	7.2	7.5	7.8	8.1	8.4	8.7	8.9
245	4.9	5.4	5.9	6.4	6.8	7.3	7.6	7.9	8.3	8.6	8.9	9.2	9.5
260	5.1	5.7	6.3	6.7	7.2	7.6	8.0	8.3	8.8	9.1	9.4	9.8	10.0

Coal strength, psi 766 **Mining width, ft** 11.50 **No. web pillars** 9

Pillar widths in italics have width-to-height ratios of 0.8

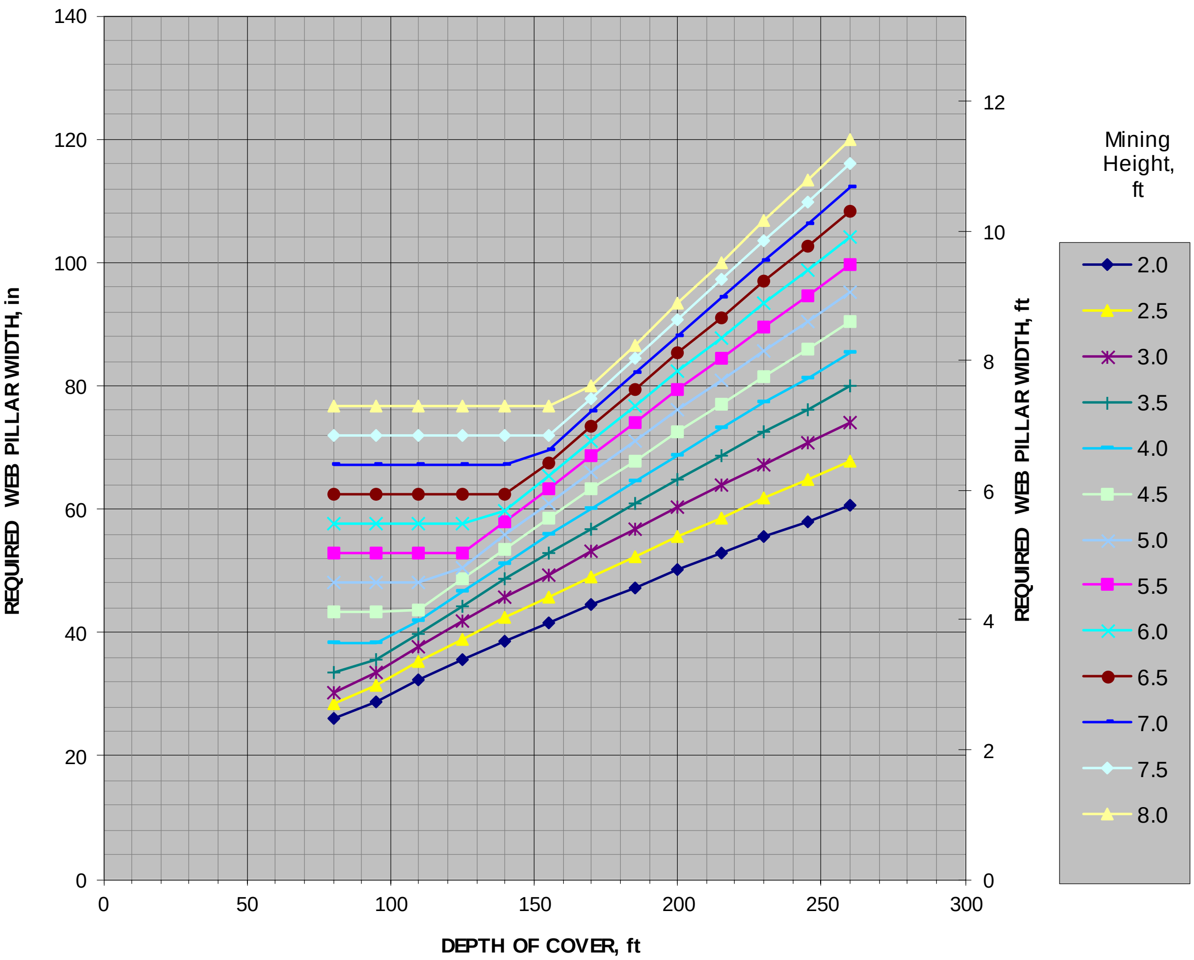


Figure 2(a). **Web Pillar Design Table and Chart for the M Seam in N-Pit**

Design Depth of Cover, ft	Mining Height, ft												
	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8
80	4.7	5.1	5.5	5.7	6.0	6.3	6.6	6.8	7.0	7.2	7.4	7.6	7.8
95	5.6	6.1	6.7	7.1	7.5	7.9	8.2	8.6	8.9	9.2	9.4	9.7	9.9
110	6.6	7.3	7.9	8.5	9.0	9.5	9.9	10.3	10.7	11.1	11.5	11.8	12.1
125	7.6	8.5	9.2	9.9	10.5	11.1	11.6	12.1	12.6	13.1	13.5	13.9	14.3
140	8.0	9.6	10.5	11.3	12.0	12.7	13.3	13.9	14.5	15.0	15.6	16.1	16.5
155	8.2	10.0	11.8	12.7	13.5	14.3	15.1	15.7	16.4	17.0	17.6	18.2	18.8
170	9.1	10.1	12.0	14.0	15.1	16.0	16.8	17.6	18.3	19.0	19.7	20.4	21.0
185	10.0	11.1	12.1	14.0	16.0	17.6	18.5	19.4	20.2	21.0	21.8	22.5	23.3
200	10.9	12.1	13.2	14.2	16.0	18.0	20.0	21.2	22.1	23.0	23.9	24.7	25.5
215	11.8	13.1	14.3	15.4	16.5	18.0	20.0	22.0	24.0	25.0	26.0	26.9	27.8
230	12.6	14.1	15.4	16.6	17.8	18.8	20.0	22.0	24.0	26.0	28.0	29.1	30.0
245	13.4	15.0	16.5	17.8	19.0	20.2	21.3	22.3	24.0	26.0	28.0	30.0	32.0
260	14.2	15.9	17.5	18.9	20.3	21.5	22.7	23.8	24.9	26.0	28.0	30.0	32.0

Coal strength, psi 766 **Mining width, ft** 11.50 **No. web pillars** 9

Pillar widths in italics have width-to-height ratios of 0.8

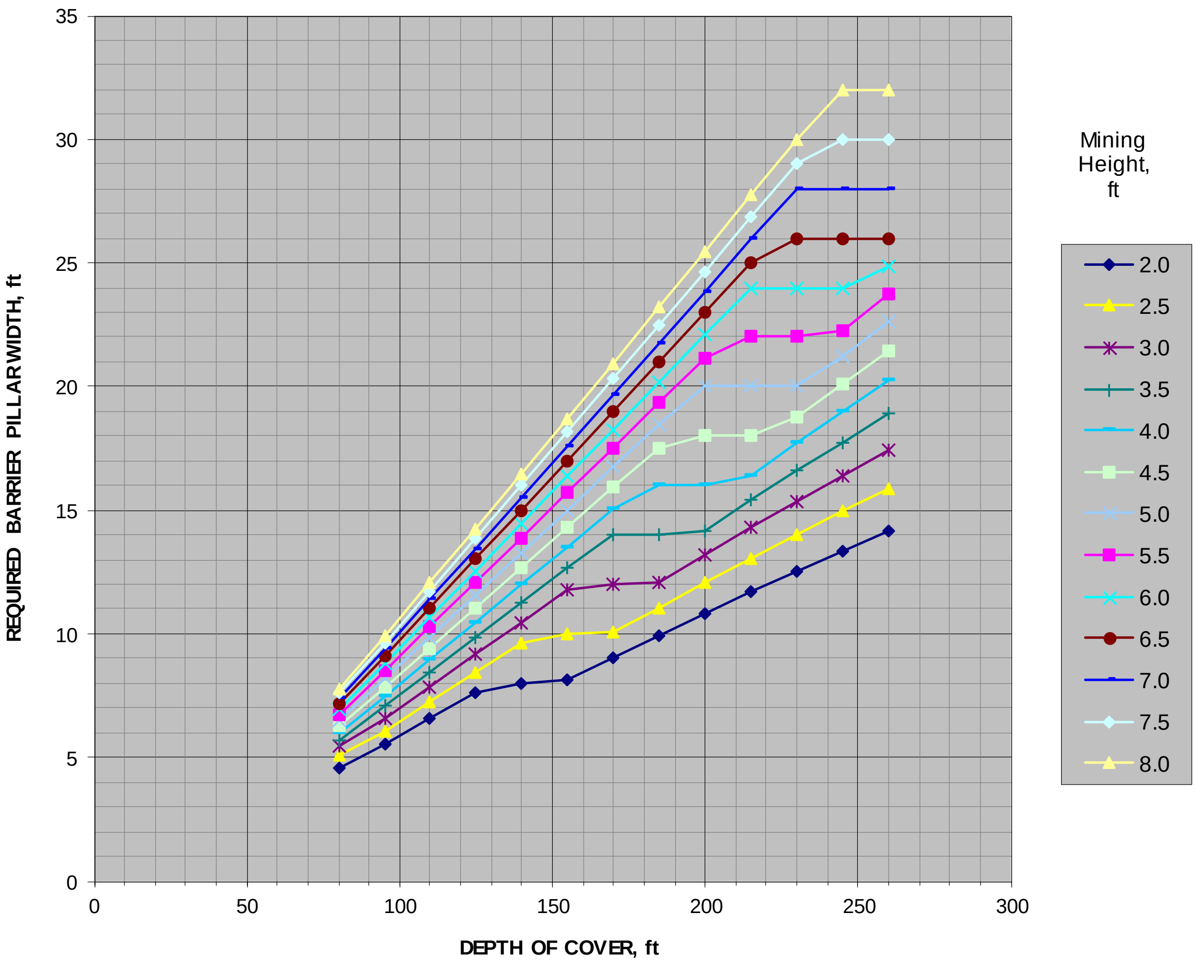


Figure 2(b). **Barrier Pillar Design Table and Chart for the M Seam in N-Pit**

Design Depth of Cover, ft	Mining Height, ft												
	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8
80	82.2	81.1	80.0	78.7	76.5	74.5	73.0	71.2	69.5	67.9	66.3	65.1	63.7
95	80.8	79.3	78.1	77.1	75.8	73.8	72.2	70.4	68.7	67.1	65.6	64.4	63.0
110	78.6	77.0	76.0	74.9	74.0	73.0	71.5	69.7	68.0	66.3	64.8	63.6	62.2
125	76.9	75.3	73.9	72.5	71.5	70.6	69.8	68.9	67.2	65.6	64.1	62.9	61.5
140	75.5	73.3	71.9	70.5	69.3	68.4	67.5	66.7	65.9	64.9	63.3	62.1	60.8
155	74.3	72.1	70.0	68.7	67.4	66.3	65.4	64.4	63.6	62.8	62.1	61.4	60.0
170	72.9	70.7	68.7	67.0	65.4	64.2	63.2	62.4	61.4	60.7	60.0	59.3	58.7
185	71.4	69.3	67.7	65.8	64.0	62.6	61.3	60.3	59.6	58.7	58.0	57.1	56.5
200	70.1	68.0	66.1	64.6	62.9	61.3	59.9	58.6	57.7	56.8	55.9	55.3	54.5
215	69.0	66.7	64.9	63.1	61.7	60.1	58.7	57.3	56.1	55.0	54.2	53.4	52.8
230	67.8	65.5	63.4	61.7	60.1	58.9	57.6	56.2	54.9	53.8	52.6	51.8	51.1
245	66.6	64.3	62.2	60.4	58.8	57.4	56.2	55.1	53.9	52.7	51.5	50.5	49.5
260	65.7	63.2	60.9	59.3	57.6	56.2	54.8	53.8	52.6	51.6	50.5	49.4	48.5

Coal strength, psi 766 **Mining width, ft** 11.50 **No. web pillars** 9

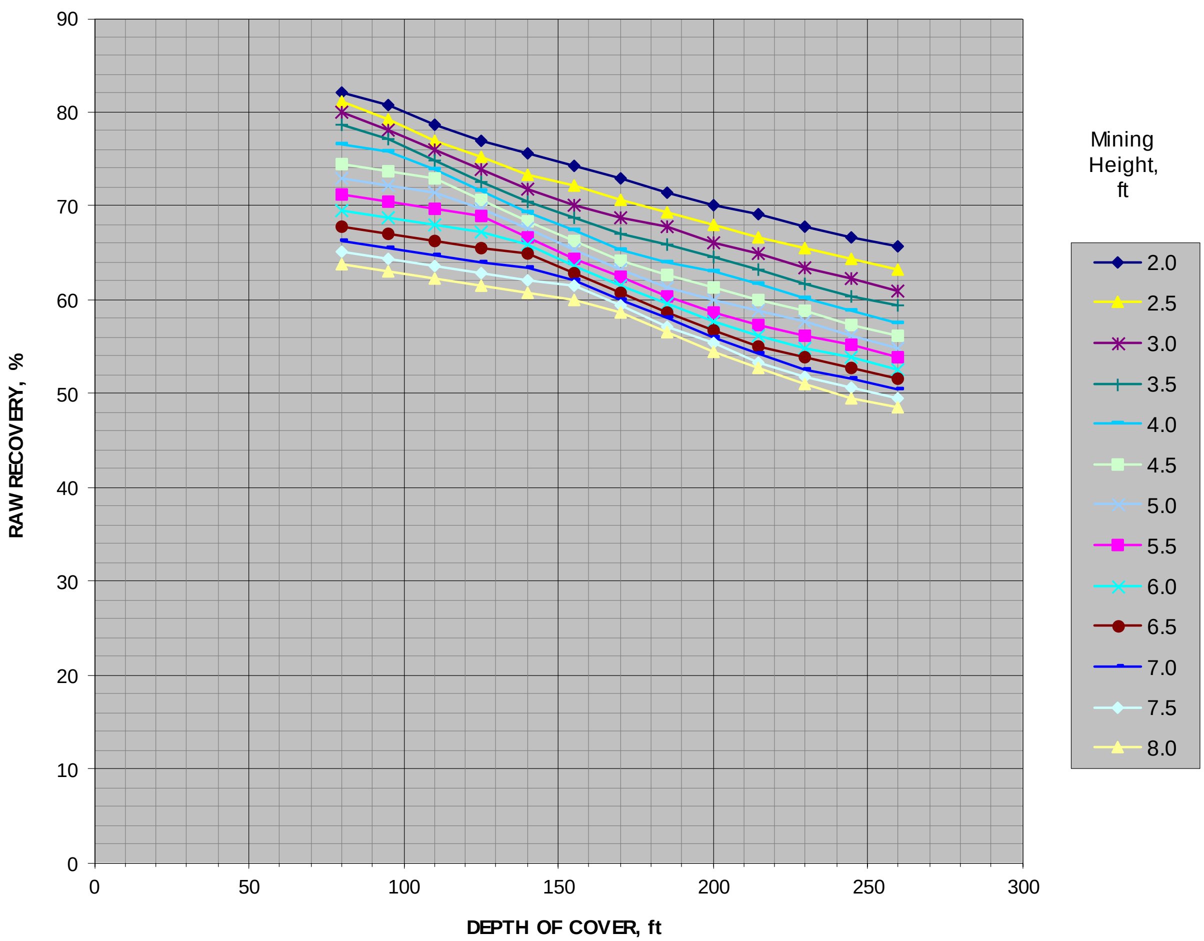


Figure 2(c). Recovery Estimates for the M Seam in N-Pit

Design Depth of Cover, ft	Mining Height, ft												
	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13
110	*5.7*	*6.0*	*6.4*	*6.8*	*7.3*	*7.7*	*8.0*	*8.4*	*8.8*	*9.3*	*9.7*	*10.0*	*10.4*
130	*5.7*	*6.0*	*6.4*	*6.8*	*7.3*	*7.7*	*8.0*	*8.4*	*8.8*	*9.3*	*9.7*	*10.0*	*10.4*
150	*5.7*	*6.0*	*6.4*	*6.8*	*7.3*	*7.7*	*8.0*	*8.4*	*8.8*	*9.3*	*9.7*	*10.0*	*10.4*
170	5.8	*6.0*	*6.4*	*6.8*	*7.3*	*7.7*	*8.0*	*8.4*	*8.8*	*9.3*	*9.7*	*10.0*	*10.4*
190	6.4	6.6	6.8	6.9	*7.3*	*7.7*	*8.0*	*8.4*	*8.8*	*9.3*	*9.7*	*10.0*	*10.4*
210	7.0	7.3	7.4	7.6	7.8	8.0	8.2	*8.4*	*8.8*	*9.3*	*9.7*	*10.0*	*10.4*
230	7.7	7.8	8.1	8.3	8.5	8.8	8.9	9.1	9.3	9.4	*9.7*	*10.0*	*10.4*
250	8.3	8.5	8.8	9.0	9.3	9.5	9.7	9.9	10.1	10.3	10.5	10.7	10.9
270	8.8	9.2	9.4	9.7	9.9	10.3	10.5	10.7	10.9	11.2	11.4	11.6	11.8
290	9.4	9.8	10.1	10.4	10.7	11.0	11.3	11.5	11.8	12.0	12.3	12.5	12.8
310	10.1	10.4	10.8	11.1	11.4	11.8	12.0	12.3	12.6	12.9	13.2	13.4	13.8
330	10.7	11.0	11.4	11.8	12.1	12.5	12.8	13.2	13.4	13.8	14.1	14.4	14.7
350	11.3	11.7	12.1	12.4	12.8	13.3	13.6	13.9	14.3	14.7	15.0	15.3	15.7

Coal strength, psi 850 **Mining width, ft** 11.50 **No. web pillars** 9

Pillar widths in italics have width-to-height ratios of 0.8

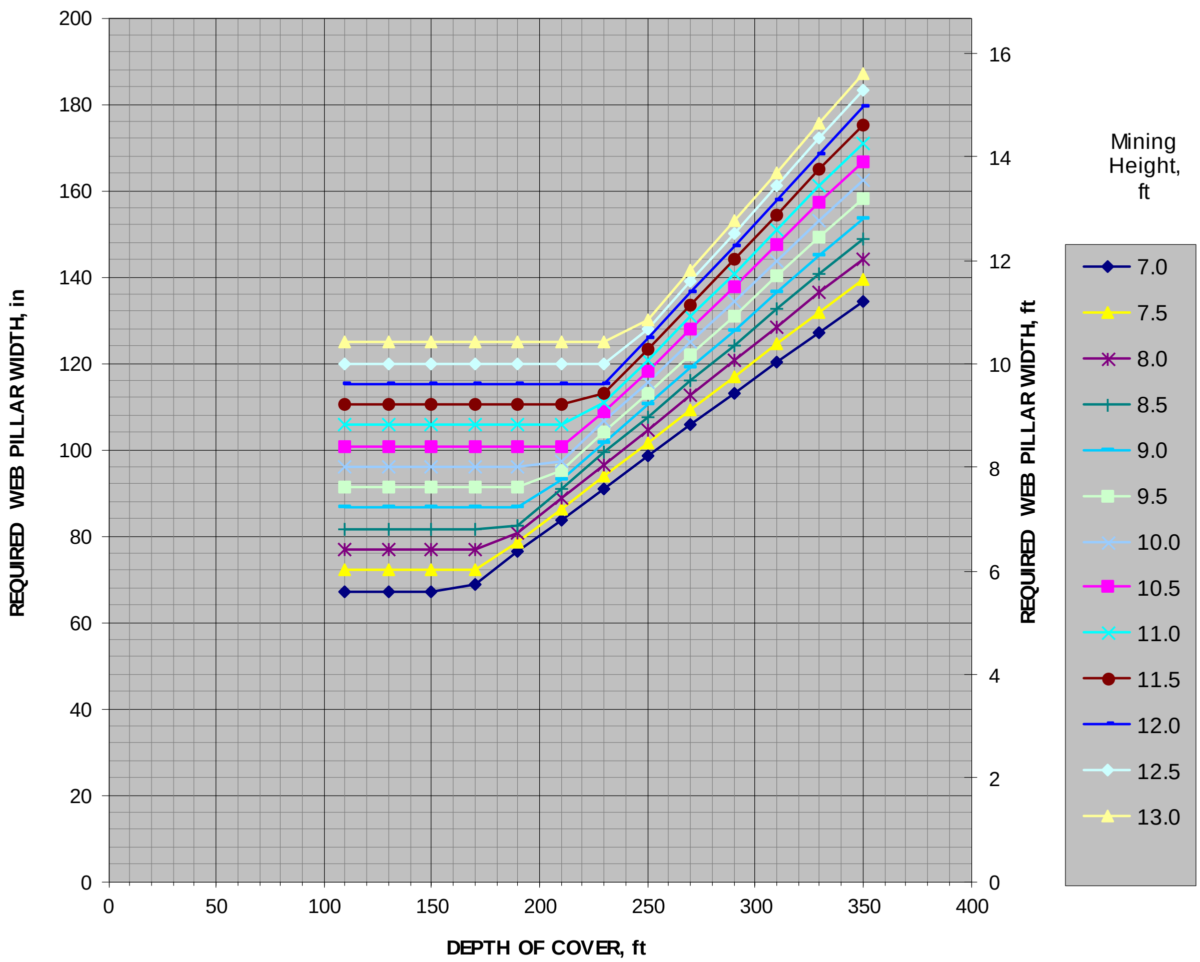


Figure 3(a). Web Pillar Design Table and Chart for the Q Seam in N-Pit

Design Depth of Cover, ft	Mining Height, ft												
	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13
110	10.6	10.9	11.2	11.5	11.7	12.0	12.3	12.5	12.7	12.9	13.2	13.4	13.6
130	13.2	13.6	14.0	14.3	14.7	15.0	15.4	15.7	16.0	16.3	16.6	16.9	17.1
150	15.8	16.3	16.7	17.2	17.6	18.1	18.5	18.9	19.3	19.7	20.1	20.4	20.8
170	18.4	19.0	19.5	20.1	20.6	21.2	21.7	22.2	22.6	23.1	23.6	24.0	24.4
190	21.0	21.7	22.4	23.0	23.7	24.3	24.9	25.5	26.0	26.6	27.1	27.6	28.2
210	23.6	24.4	25.2	26.0	26.7	27.4	28.1	28.8	29.4	30.1	30.7	31.3	31.9
230	26.2	27.2	28.0	28.9	29.7	30.5	31.3	32.1	32.8	33.6	34.3	35.0	35.6
250	28.0	29.9	30.9	31.8	32.8	33.7	34.5	35.4	36.2	37.1	37.9	38.6	39.4
270	28.0	30.0	32.0	34.0	35.8	36.8	37.8	38.7	39.7	40.6	41.5	42.3	43.2
290	28.3	30.0	32.0	34.0	36.0	38.0	40.0	42.0	43.1	44.1	45.1	46.0	47.0
310	30.4	31.5	32.6	34.0	36.0	38.0	40.0	42.0	44.0	46.0	48.0	49.7	50.8
330	32.5	33.7	34.9	36.0	37.1	38.2	40.0	42.0	44.0	46.0	48.0	50.0	52.0
350	34.5	35.8	37.1	38.4	39.6	40.7	41.9	43.0	44.0	46.0	48.0	50.0	52.0

Coal strength, psi 850 **Mining width, ft** 11.50 **No. web pillars** 9

Pillar widths in italics have width-to-height ratios of 0.8

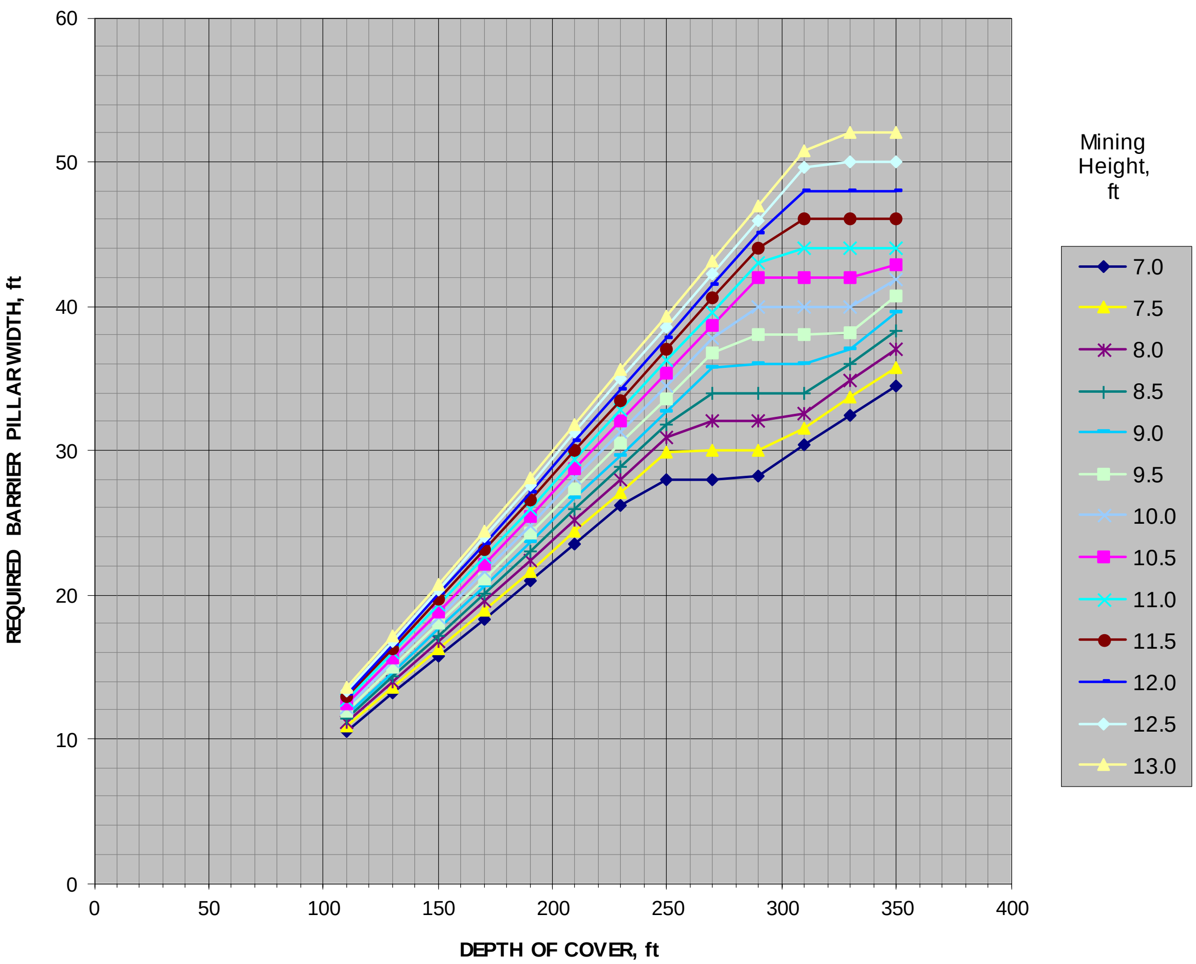


Figure 3(b). Barrier Pillar Design Table and Chart for the Q Seam in N-Pit

Design Depth of Cover, ft	Mining Height, ft												
	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13
110	65.1	63.9	62.5	61.2	59.9	58.7	57.7	56.6	55.5	54.5	53.4	52.7	51.7
130	64.2	63.0	61.6	60.3	59.0	57.8	56.8	55.7	54.6	53.6	52.6	51.8	50.9
150	63.3	62.1	60.7	59.4	58.1	56.9	56.0	54.9	53.8	52.8	51.8	51.0	50.1
170	62.1	61.2	59.8	58.5	57.3	56.0	55.1	54.0	53.0	52.0	51.0	50.2	49.3
190	59.4	58.7	58.0	57.4	56.4	55.2	54.3	53.2	52.2	51.1	50.2	49.4	48.5
210	57.0	56.2	55.6	55.0	54.4	53.6	53.1	52.4	51.4	50.4	49.4	48.7	47.8
230	54.7	54.1	53.3	52.5	52.0	51.3	50.8	50.3	49.8	49.3	48.7	47.9	47.1
250	52.9	51.9	51.2	50.5	49.8	49.1	48.6	48.0	47.5	46.9	46.5	46.1	45.5
270	51.7	50.5	49.6	48.7	47.9	47.1	46.5	46.1	45.5	44.9	44.4	44.0	43.4
290	50.4	49.4	48.4	47.4	46.6	45.6	44.9	44.1	43.6	43.1	42.5	42.0	41.6
310	48.7	47.9	47.1	46.2	45.3	44.4	43.7	42.9	42.2	41.5	40.9	40.3	39.7
330	47.2	46.4	45.5	44.8	44.1	43.3	42.5	41.7	41.1	40.4	39.7	39.0	38.5
350	45.9	45.0	44.1	43.4	42.6	41.8	41.2	40.6	40.0	39.2	38.6	38.0	37.3

Coal strength, psi 850 **Mining width, ft** 11.50 **No. web pillars** 9

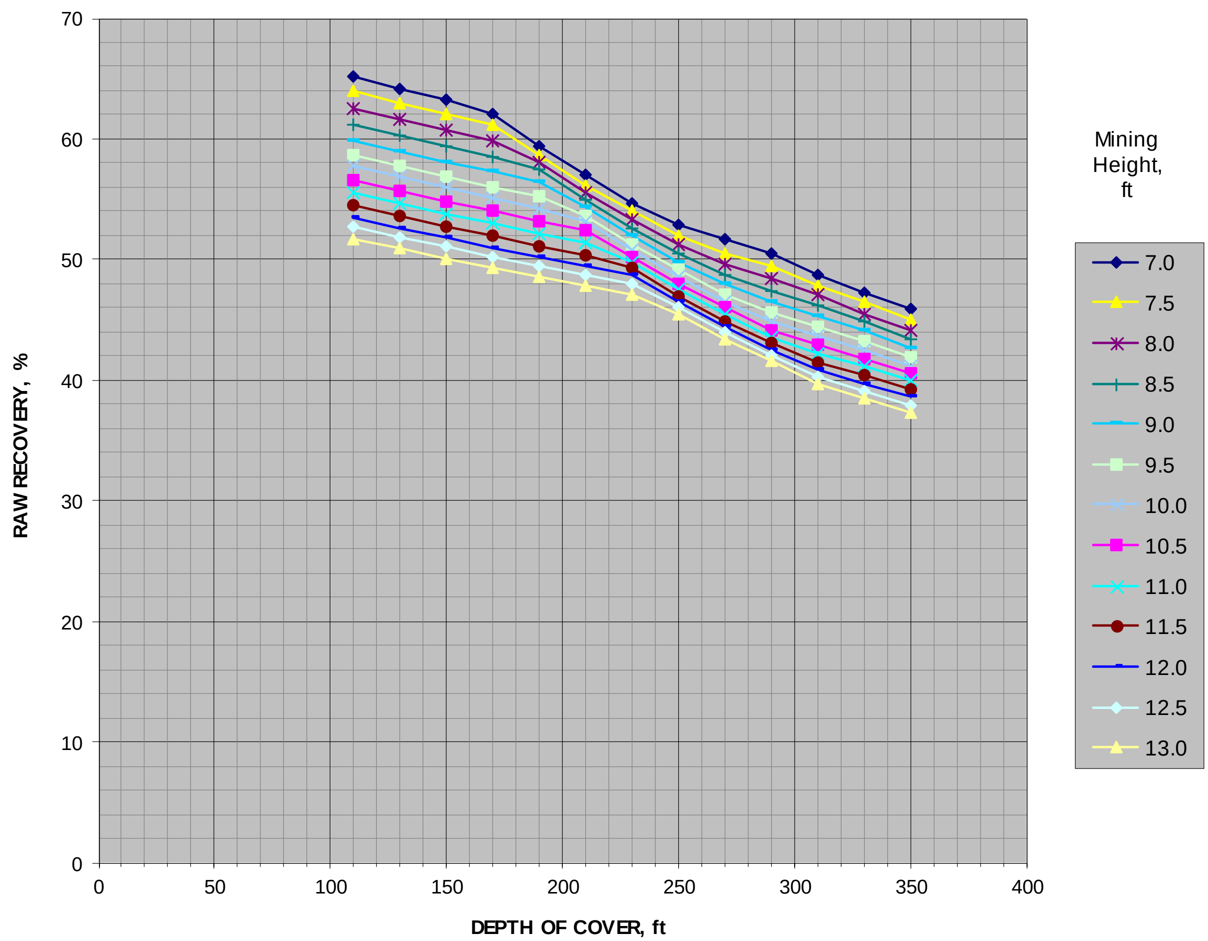


Figure 3(c). Recovery Estimates for the Q Seam in N-Pit

NUMERICAL MODELING ANALYSIS

The empirical methods used for web pillar and barrier pillar design have been validated by experience in a wide variety of mining scenarios and geological conditions. However, they do not account for the variability of material properties or the interaction of multiple coal seams. Since these factors are important to the stability of the proposed highwall mining at Trapper, numerical modeling was used to evaluate the following items:

- Overall stability of empirical pillar designs
- The effects of multi-seam interaction
- The potential for cascading pillar failure
- Stability of the N pit slopes

Overall pillar stability, multi-seam interaction, and the potential for cascading failure were evaluated using the LaModel boundary element software.[2] LaModel employs non-linear methods for the calculation of stress distribution and pillar stability in laminated strata. It allows for the analysis of stress conditions imposed by mining on multiple horizons. Key inputs to the LaModel analysis included excavation geometry, pillar dimensions, seam height, in situ coal strength, and depth of cover.

Stability of the N-Pit slopes was evaluated using the FLAC3D finite difference program.[3] FLAC3D allows stress and displacement to be resolved with incremental changes in excavation geometry and loading conditions using linear and non-linear methods. The three-dimensional (3D) modeling approach also allows additional checks on the overall stability of web pillars, analysis of interaction between the M and Q seams, and evaluation of cascading failure conditions on highwall stability.

For numerical modeling purposes, conservative adjustments were made to seam heights, depths of cover, pillar and entry widths, and interburden thickness to satisfy meshing constraints. Table 1 shows the geometric parameters that were developed using empirical methods and adapted for each numerical modeling approach for the south M and Q Seams.

Although the size of the LaModel and FLAC3D grids are only limited by computer memory, for practical purposes, grid size was limited so that models converged in a reasonable amount of time. There is a tradeoff between element size and the area that can be modeled, wherein a model with smaller elements will give more detail but require more memory and run time. For this study, a minimum element size of 1.5 ft was chosen for both LaModel and FLAC3D to provide sufficient detail in the web pillar analysis.

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[2] Heasley, Keith A. "Numerical Modeling of Coal Mines with a Laminated Displacement-Discontinuity Code." 1990-1999-Mines Theses & Dissertations (1998).

[3] Itasca Consulting Group, Fast Lagrangian Analysis of Continua in 3D (FLAC3D), Finite difference software version 9.00.159 (2024)

Table 1. Geometric Parameters from Empirical Designs Applied in Numerical Models

		Empirical Design (ft)	LaModel (ft)	Flac3D (ft)
M Seam	Depth of cover	170	170	varies
	Seam height	6	6	6
	Entry width	11.5	12	12
	Web pillars	6	6	6
	Barrier pillars	18.3	18	18
Q Seam	Depth of cover	210	210	varies
	Seam height	11	11	12
	Entry width	11.5	12	12
	Web pillars	8.8	9	9
	Barrier pillars	29.4	30	30

LaModel Analysis

The LaModel figures presented in this report provide plan-view representations of the vertical stresses and safety factors of the pillars for a variety of scenarios. The vertical stress plots illustrate the anticipated stress environment, while the safety factor plots show that the web and barrier pillars satisfy the design criteria under the base set of conditions and provide sufficient loading capacity when one or more nearby pillars fail.

Confirmation of Design and *Analysis of Seam Interaction Effects*

LaModel results showing basic design performance are shown in Figures 4 and 5 for the M and Q seams, respectively, on the North side of the N-Pit. Figures 6 and 7 show results for the M and Q seams on the South side of the N-Pit. The (a) portion of each figure shows the vertical stress distribution in units of psi, and the (b) portion shows the safety factors. The web pillars satisfy the minimum safety factor of 1.6 for the design criteria in both seams.

Interaction is minimal between the M and Q seams. Although the web pillars support the highest stress magnitudes on the M Seam, there is no visual evidence of these stress concentrations being transmitted to the Q Seam below. Refer to Figure 5 for contours of the vertical stress in the North Q Seam. Evidence of multi-seam interaction in this scenario would be noted by angled patterns in the stress contours, since the North M Seam excavations are oriented approximately 13 degrees from normal to the pit slope.

Cascading Pillar Failure Analysis

Cascading pillar failures can occur when failure in one pillar results in stress transfer to adjacent pillars, which, in turn, fail. In their mildest form (slow pillar squeezes), this failure may take weeks to progress. In their most severe form, failures can occur almost instantaneously, resulting in severe air blasts, damage to equipment, and loss of life. To check the performance of the web pillar designs against cascading pillar failure, additional LaModel analyses were run. In these models, one web pillar in the center of one panel was removed to see if the remaining pillars could absorb the additional load.

Results of the cascading failure analysis for the North M and Q seams are presented in Figures 8 and 9, respectively, with vertical stress distributions in (a) and resulting safety factors in (b). Results for the South M and Q seams are presented in Figures 10 and 11. In each case, the load transfer to the two adjacent pillars causes an increase in stress and a decrease in the safety factors of those pillars, but they remain in a stable condition. The effect of the stress redistribution from the removal of one pillar in the M Seam is also not significant in the Q Seam.

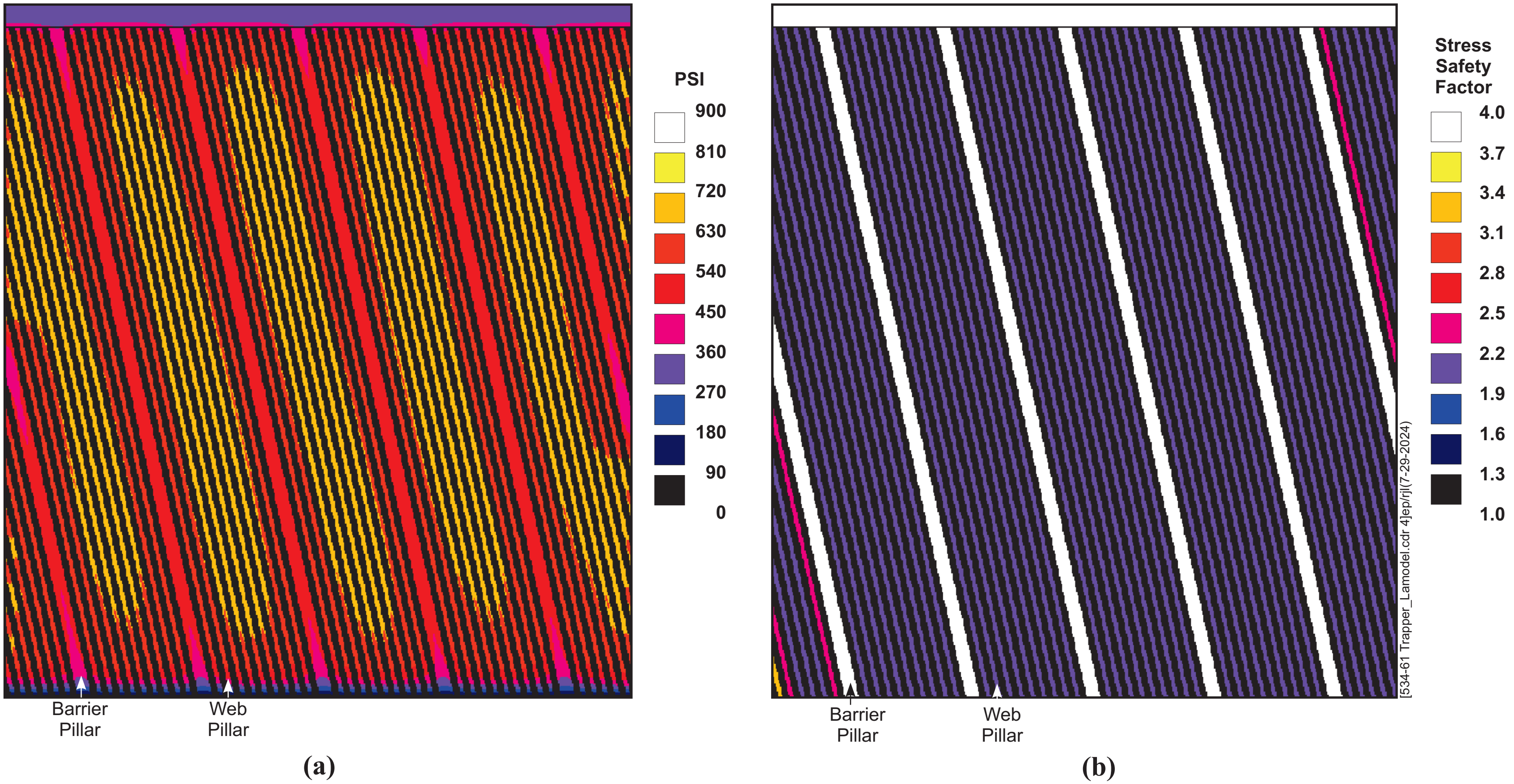


Figure 4. North Side of the N-Pt – M Seam (a) **Vertical Stress** (b) **Pillar Safety Factor**

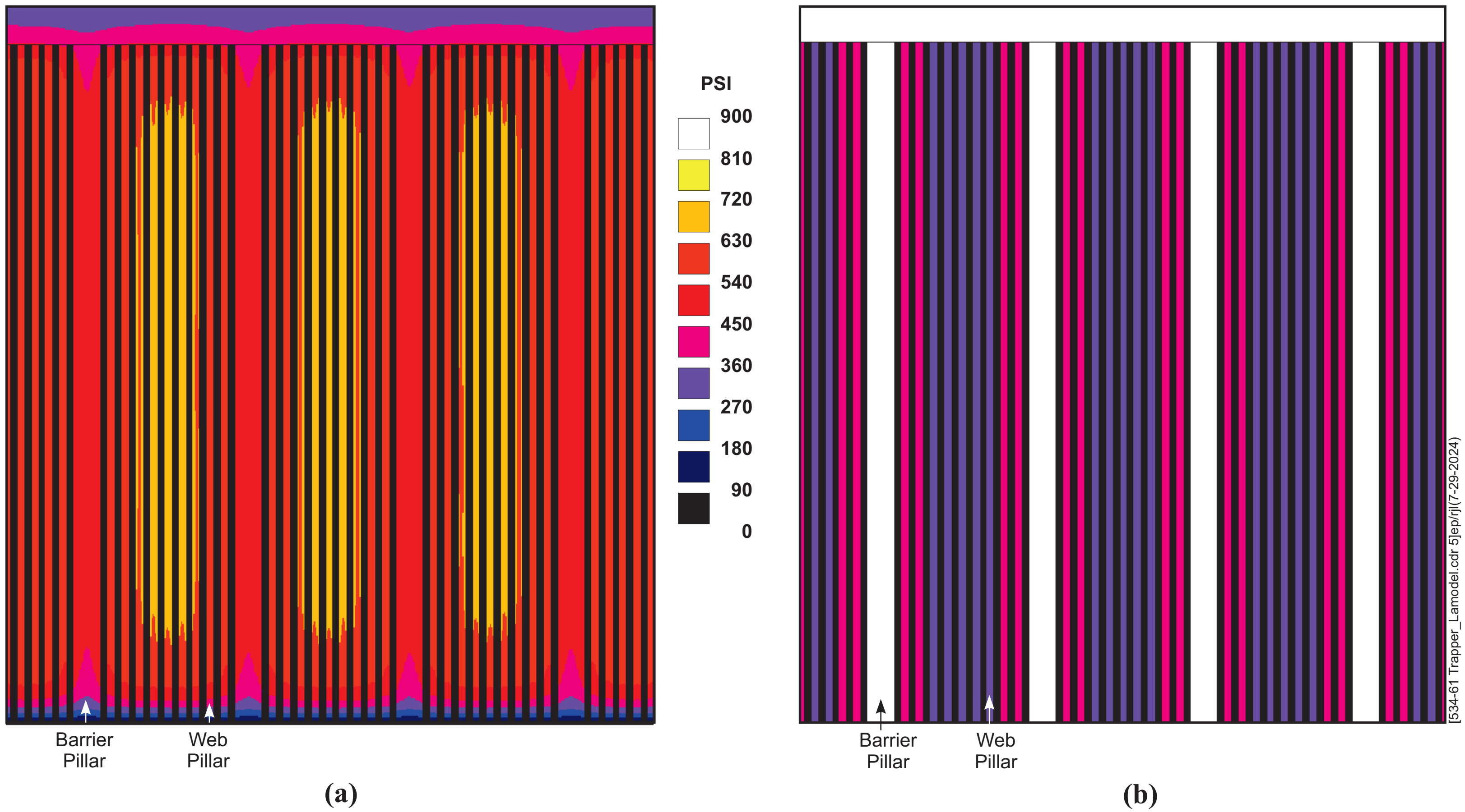


Figure 5. North Side of the N-Pit – Q Seam (a) Vertical Stress (b) **Pillar Safety Factor**

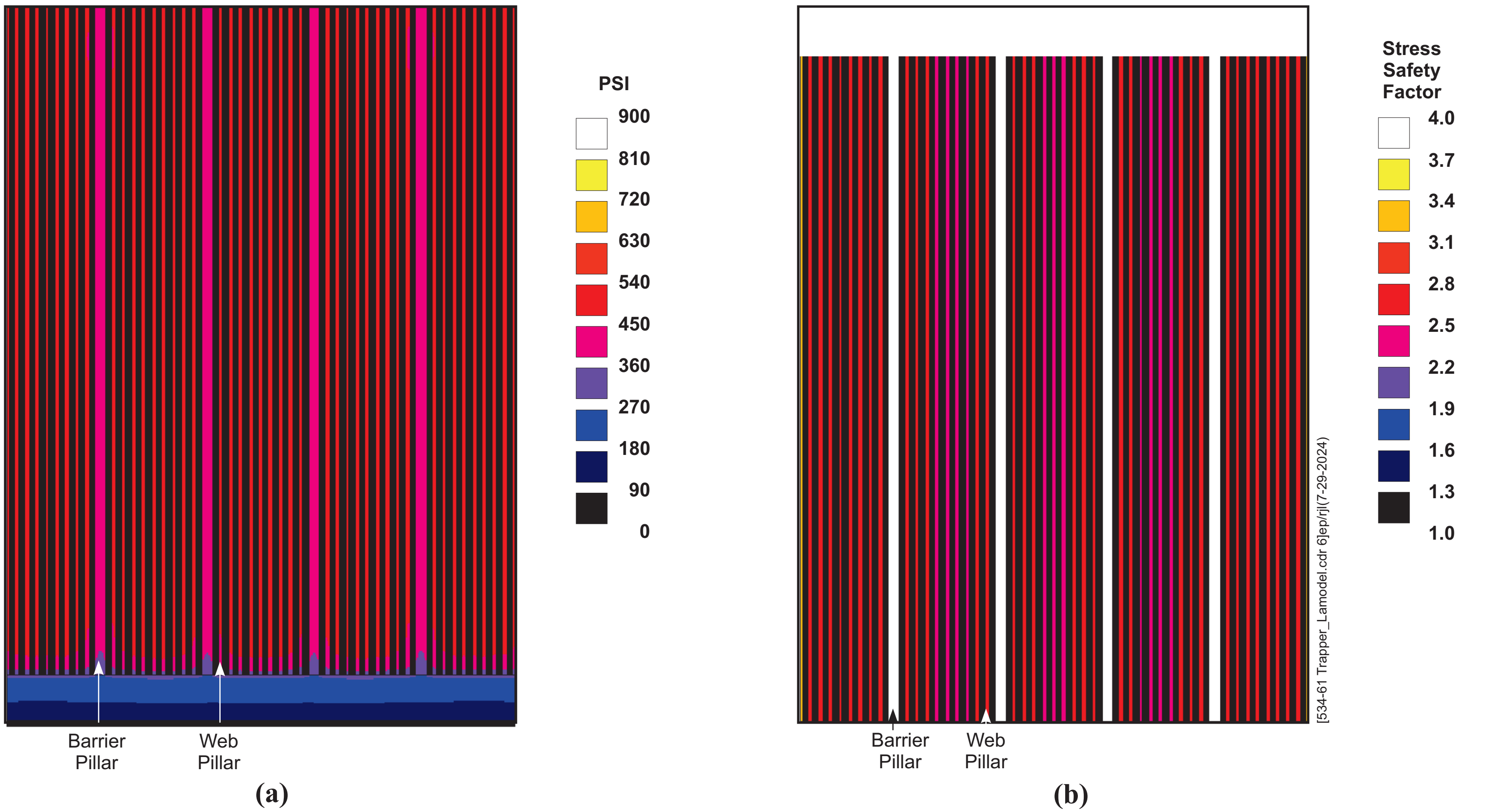


Figure 6. South Side of the N-Pit – M Seam (a) **Vertical Stress** (b) **Pillar Safety Factor**

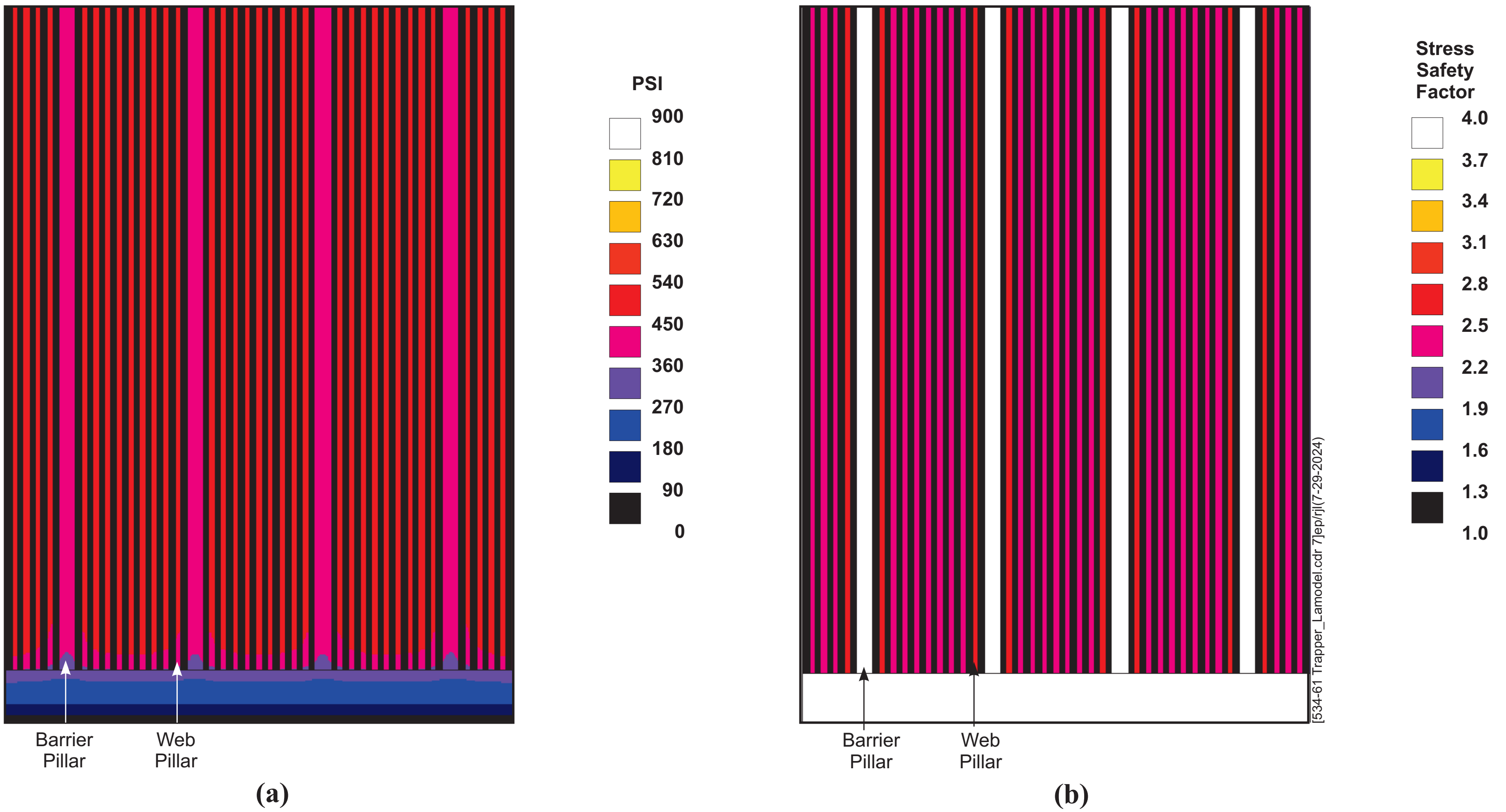


Figure 7. South Side of the N-Pit – Q Seam (a) **Vertical Stress** (b) **Pillar Safety Factor**

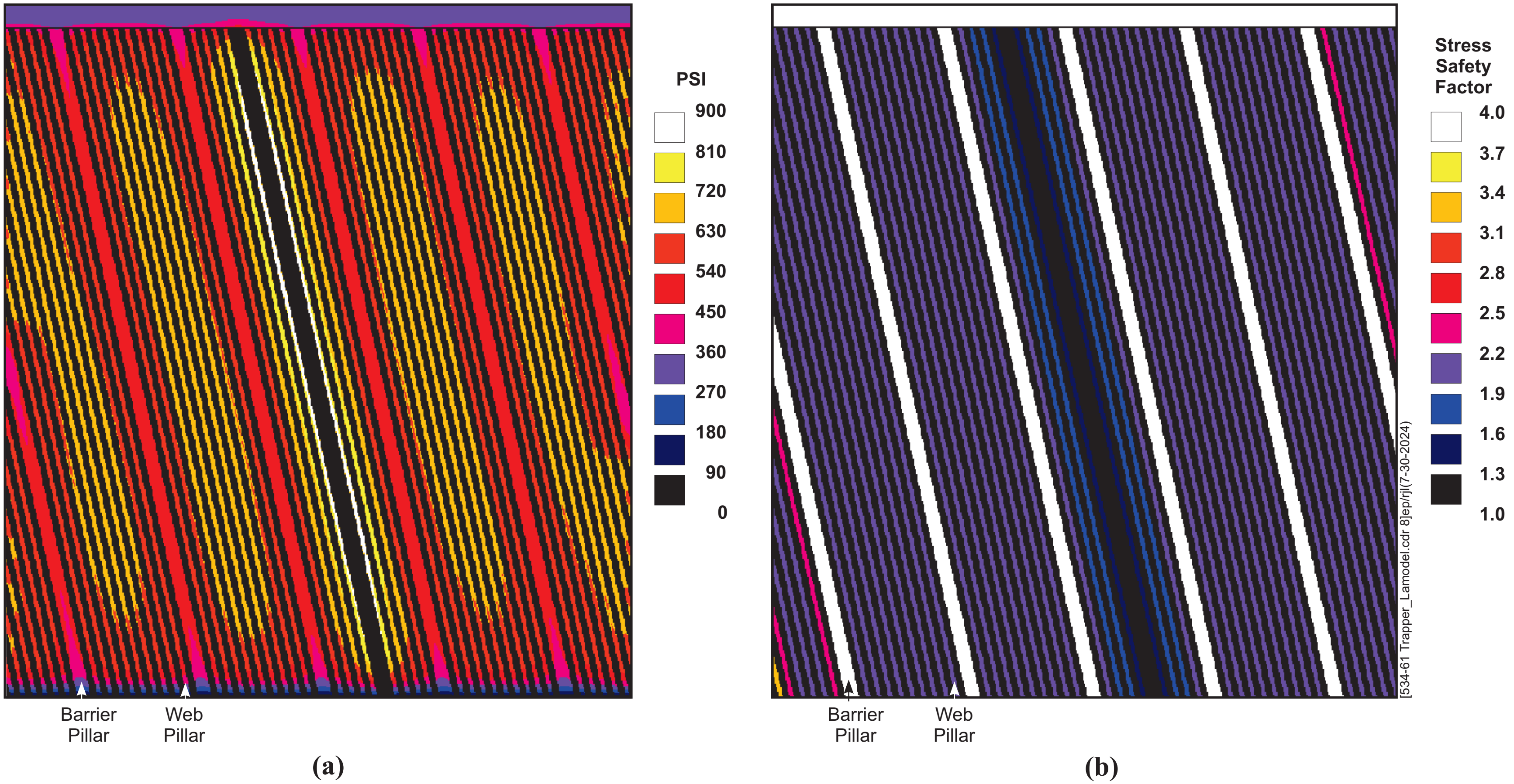
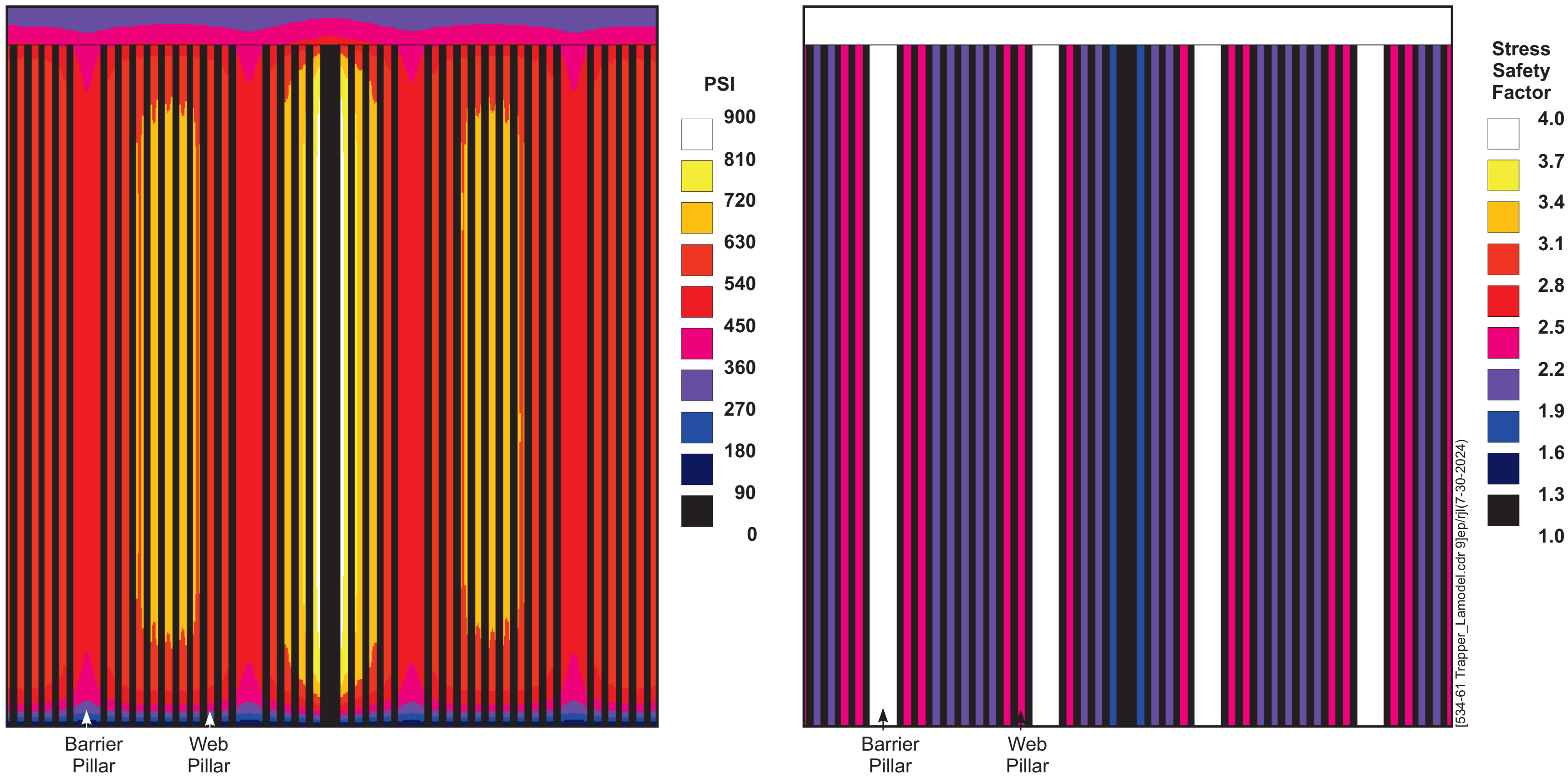
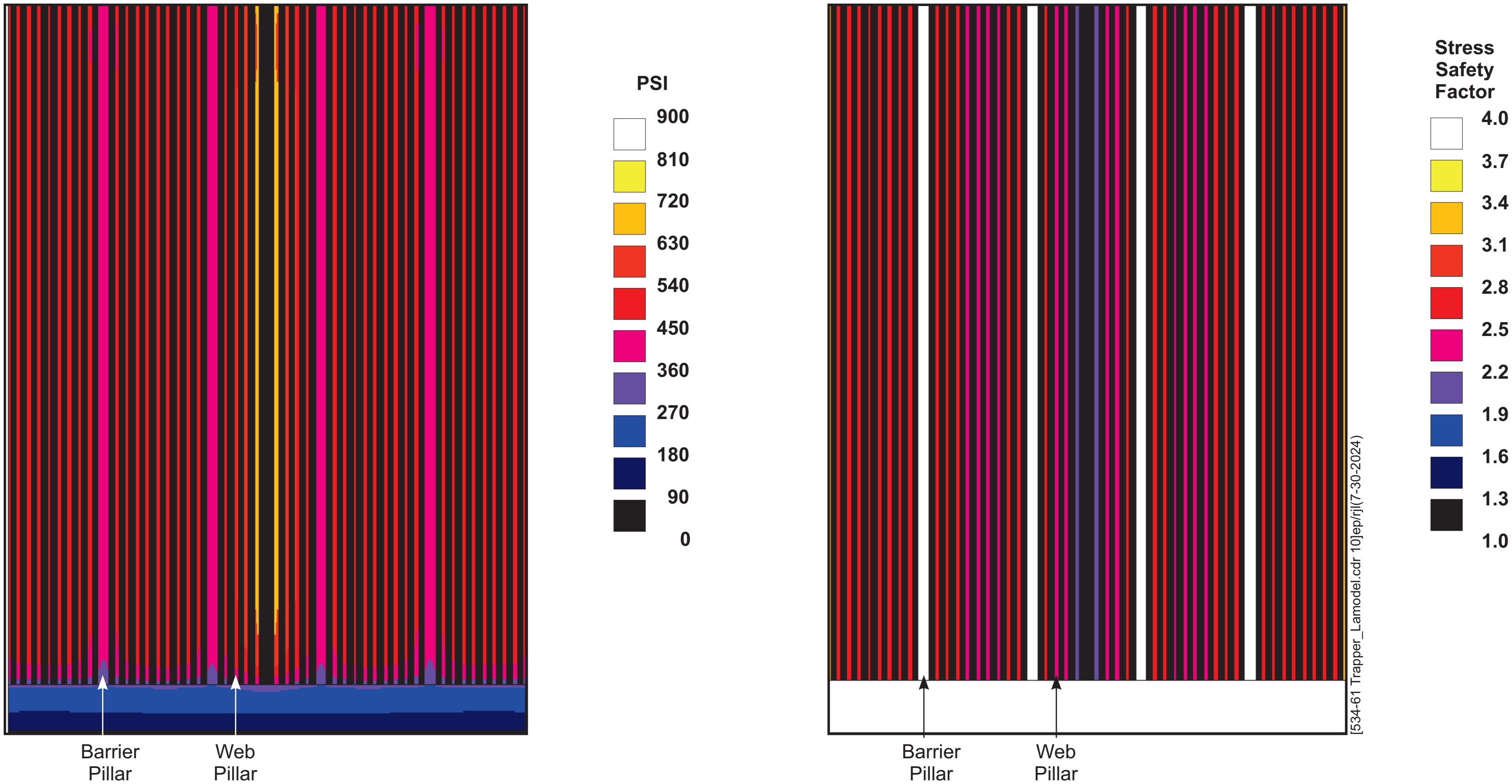


Figure 8. North Side of the N-Pit – M Seam Cascading Failure Analysis (a) **Vertical Stress** (b) **Pillar Safety Factor**



(a) **(b)**

Figure 9. North Side of the N-Pit – Q Seam Cascading Failure Analysis (a) **Vertical Stress** (b) **Pillar Safety Factor**



(a) **(b)**

Figure 10. South Side of the N-Pit – M Seam Cascading Failure Analysis (a) **Vertical Stress** (b) **Pillar Safety Factor**

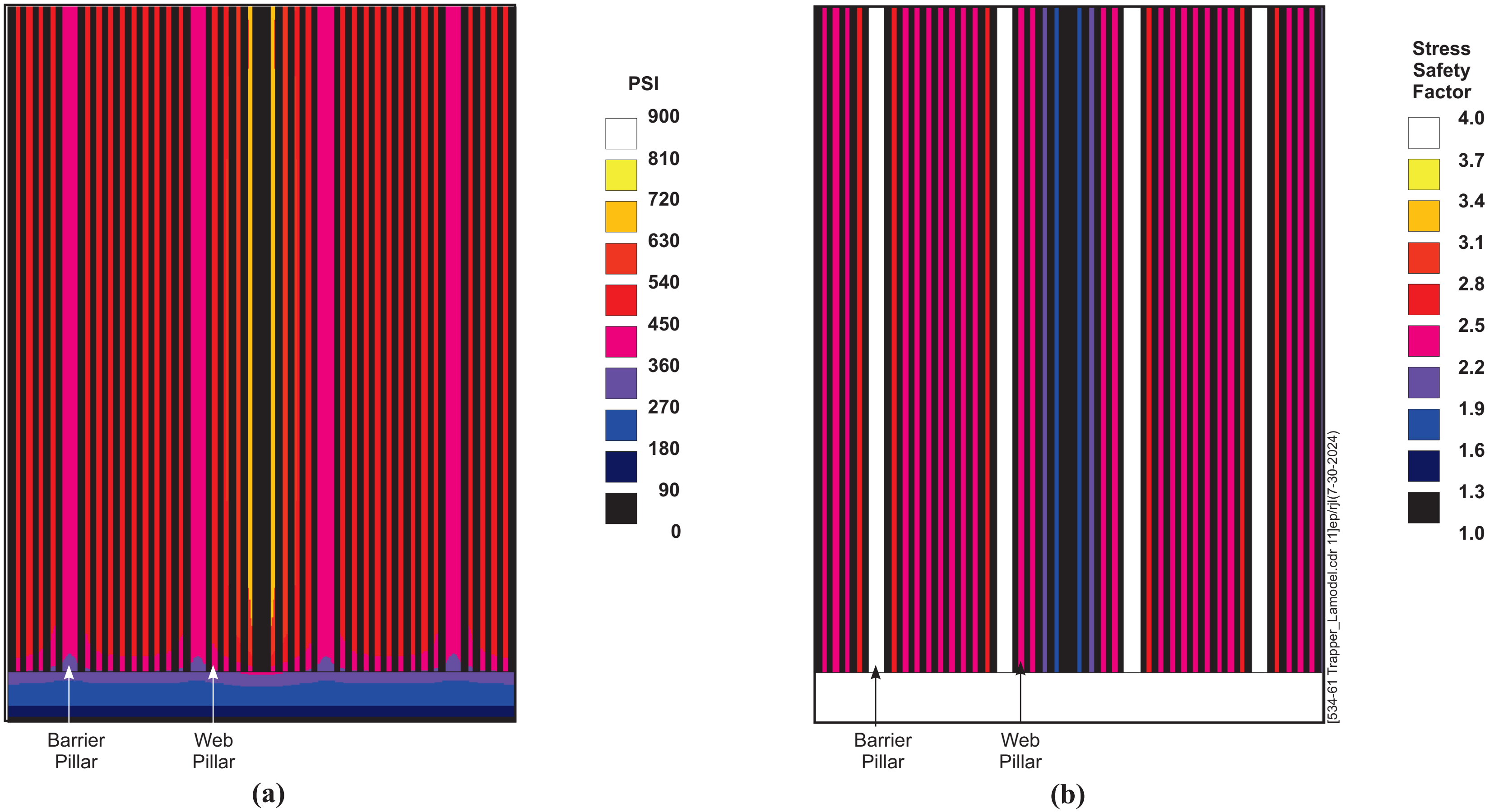


Figure 11. South Side of the N-Pit – Q Seam Cascading Failure Analysis (a) **Vertical Stress** (b) **Pillar Safety Factor**

FLAC3D Analysis

A model was constructed in FLAC3D to perform additional checks on the safety factors of the web pillars and evaluate the global stability of the slope by assessing the likelihood of a block sliding failure along the mined coal seams.

The modeled geometry represents the fully excavated state of the N-Pit south wall, with the pit floor at the base of the Q Seam and mining completed in both the M and Q Seams. The south wall was chosen to evaluate slope stability because the bedding dips out of the highwall and represents the more conservative condition from a kinematic perspective compared to the North wall. Figure 12 shows an oblique view of the FLAC3D model colored by geologic domain. The domains in the model include fill at the ground surface, coal seams L, M, Q, and R, and various overburden and interburden units referred to as “shale”.

Model Inputs

The physical properties of the overburden and interburden units were calculated from weighted averages of the shales, sandstones, and mudstones between each coal seam, as described in the 2016 site investigation program for the N-Pit mining area.[1] A list of the geologic units and their in situ strength parameters is provided in Table 2 for reference.

Table 3 provides a summary of the homogeneous overburden and interburden strength parameters applied to each domain in the FLAC3D model. The materials are listed in order from top to bottom of the model.

Model geometry

The FLAC3D model represents a 63-ft wide “slice” of the south N-Pit wall. The model width was chosen to satisfy symmetry conditions at the model boundaries in both the M and Q Seams using the same web pillar designs from the LaModel analysis. The 63-ft width allows for 3 full pillars and entries in the Q Seam and 3.5 pillars and entries in the M Seam. Figure 13 shows the excavated state of the M and Q Seams in the FLAC3D model.

Barrier pillars are not represented in the FLAC3D model. The 63-ft slice approximately represents the middle third of a 10-room panel, where influence of the barrier pillars is minimal.

Results – Base Case

Using base case material strengths, summarized above, the model came to equilibrium with no indication of yield in any of the coal pillars. This result verifies that the safety factors are well above 1.0 but requires further analysis to identify the actual range of safety factors. Figure 14 shows an oblique view of the model with yield indicators visible only in the fill near the surface after excavation is complete. Figure15 shows yield indicators in a cross section through the pillars at a distance of roughly 570 ft from the entries. Again, no yield indicators are present in the coal.

Figure 16 shows vertical displacement contours after completion of mining in both seams, with magnitudes on the order of 0.025 ft, or 0.3 inches, above the M Seam. Vertical displacement was lowest near the entries and exhibited a relatively smooth transition toward the maximum displacements in the areas of deepest cover. The absence of sharp transitions in the displacement contours verifies that the slope remains stable in response to mining, as no shearing planes were formed in the rock mass.

Figure 17 shows major principal stress contours through the pillars. Note that in FLAC3D, compressive stresses are negative, and thus, the major principal stress is referred to as the minimum principal stress because it has a large negative value. The yellow contours through the pillar ribs, indicating a current support capacity of 60,000 to 70,000 psf, or 416 to 486psi.

Overall, the results of the base case model show that the pillars perform as expected, and the global stability of the N-Pit slope is not impacted by highwall mining of the M and Q seams.

Results – Strength Reduction

To further evaluate the stability of the pillars and the slope, the model was run with strength reduction factors of 2.0 and 2.5 in the coal seams. These represent 50% and 60% reductions in strength, respectively.

Figure 18 shows yield indicators in the pillars with a strength reduction factor of 2.0. In this case, the onset of yield through the coal is evident, but the pillars remain stable. The stability is verified by the convergence of the model to a state of equilibrium. Figure 19 shows major principal stress contours through the pillars, with reduced stress magnitudes at the ribs verifying the yielded state of that material. Figure 20 shows displacements throughout the model at equilibrium, which are slightly higher than the base case. The color scale is kept the same as the base case figure to accommodate a comparison. Overall, the results of the model with a stress reduction factor of 2.0 suggest that the coal pillars are approaching a state of limit equilibrium, but the safety factors are still above 1.0.

With a strength reduction factor of 2.5, the pillars in the M Seam fail before excavation commences on the Q Seam. The model did not converge at this stage, but was terminated when displacements surpassed 1.5 ft. Figure 21 shows the yield indicators through the pillars in the M Seam, where the pink color indicates that shearing was occurring when the model was terminated (the “shear-n” designation refers to “shearing now” in FLAC3D). Figure 22 shows displacements exceeding 1.0 ft throughout the overburden when the model was terminated.

Overall, the results of the strength reduction technique suggest the pillars have a safety factor closer to 2.0. The relative quickness in which the pillars failed with a strength reduction factor of 2.5 indicates that limit equilibrium was surpassed by a significant margin.

Block Sliding Analysis

To evaluate the likelihood of a block sliding mechanism due to failure of the M Seam web pillars, an additional model was constructed to represent half of one panel, with support from the barrier pillar explicitly represented. The revised model accounts for a 96-ft wide “slice” of the south slope of the N-Pit, with 5 entries, 4.5 web pillars, and half of a barrier pillar. With symmetry conditions on each of the lateral boundaries, the model behaves as if it were situated within an infinitely long array of panels in the South M Seam, each having 10 entries. Mining in the Q Seam was excluded from this analysis.

To assess potential block sliding conditions, a strength reduction factor of 2.5 was applied to the coal in the M Seam, which was shown to induce failure of the web pillars in the previously described models. With support from the barrier pillar, the model came to a state of equilibrium, meaning the panel and slope remained stable.

Figure 23 shows the final vertical displacements, with magnitudes on the order of 0.025 ft, or 0.3 inches above the center of the panel. Figure 24 shows yield through a cross section of the pillars. In this plot, it is evident that the web pillar at the center of the panel is fully yielded while the barrier pillar is intact.

Figure 25 shows horizontal displacements toward the pit, which are on the order of 0.0075 ft, or 0.09 inches, and considered negligible. The model illustrates that even with web pillar failure initiating at the center of the panel beneath the deepest cover, the barrier pillar prevents the failure from spreading laterally along strike of the slope, and the reduced depth of cover on the pillars nearest the slope face provide web pillars with a higher factor of safety that prevents failure from spreading laterally toward the pit. The likelihood of block sliding failure along the coal seam is interpreted to be relatively low.

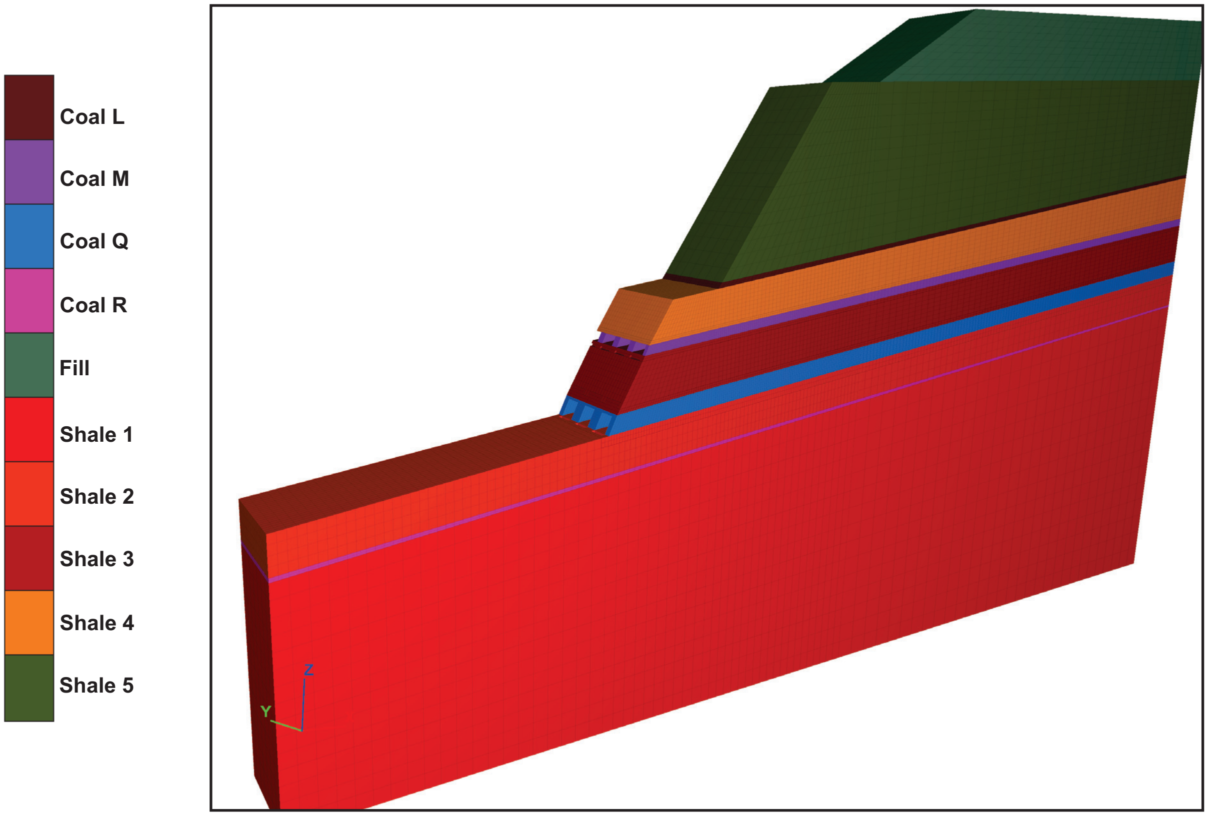


Figure 12. FLAC3D Model of the N- Pit South Wall Colored by Geologic Domain

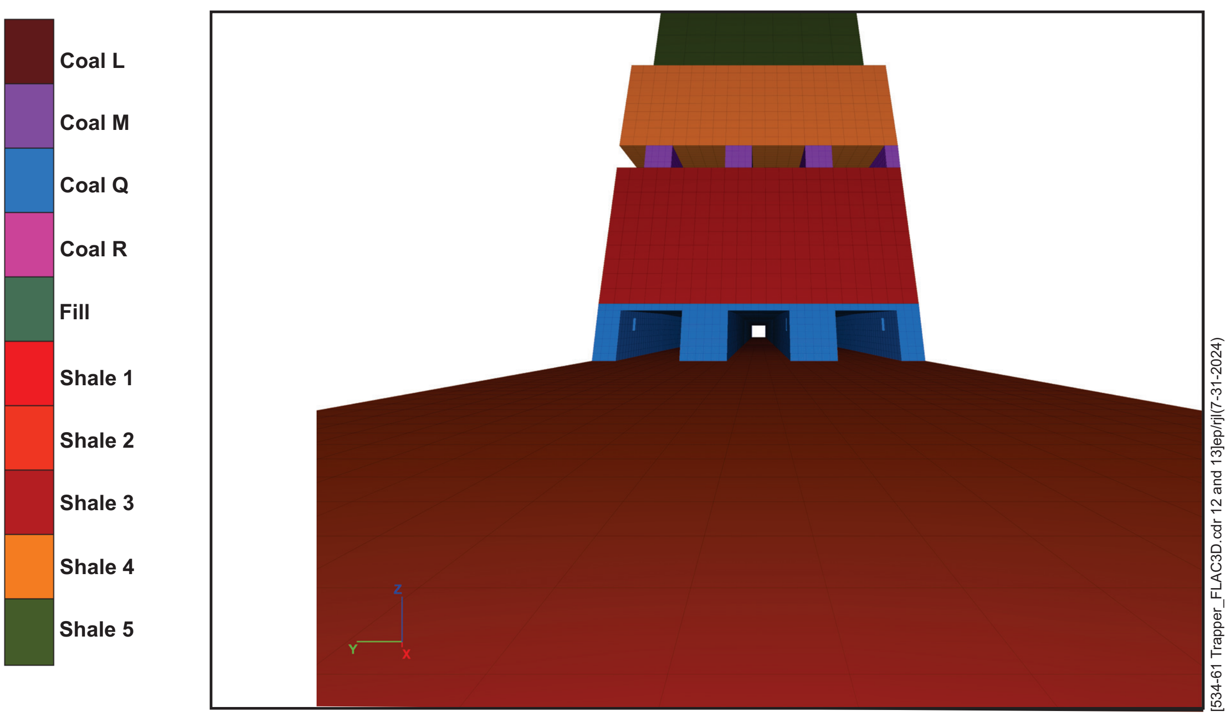


Figure 13. View of the Fully Excavated M and Q Seams in N-Pit in the FLAC3D Model

Table 2. In Situ Properties from Agapito (2016) Study, which served as the Basis for FLAC3D Overburden and Interburden Properties

Unit	Thickness (ft)	Density (pcf)	Youngs Mod (psf)	Poisson	Cohesion (psf)	Friction angle	Tensile (psf)
ML UR Mudstone	6.8	147.8	74,880,000	0.39	68,688	36.8	32,400
ML UR Sandstone	3.1	138.3	108,000,000	0.34	38,160	35.5	17,424
ML IR Mudstone	15.1	147.8	74,880,000	0.39	64,512	38.8	32,400
ML IR Carbonaceous Shale	0.5	109.6	24,480,000	0.35	12,240	15.7	3,456
Main L Seam	7	81.8	43,200,000	0.35	31,824	25	11,030
ML IF Carbonaceous Shale	1.6	109.6	24,480,000	0.35	21,312	27.9	7,920
ML IF Mudstone	1.3	147.8	74,880,000	0.39	49,536	35.4	22,464
ML IF Siltstone	1.7	150.4	97,920,000	0.36	29,952	37.5	14,400
ML IF Coal	2	92	43,200,000	0.35	37,440	25	25,920
ML IF Carbonaceous Shale	0.5	109.6	24,480,000	0.35	25,344	20.7	7,920
M IR Mudstone	22.5	147.8	74,880,000	0.39	52,272	35.8	24,048
M IR Carbonaceous Shale	0.4	109.6	24,480,000	0.35	20,448	29.5	7,920
M Seam	5	79.4	33,120,000	0.35	31,824	25	11,030
M IF Carbonaceous Shale	0.6	109.6	24,480,000	0.35	46,080	25.1	15,984
M IF Mudstone	4.5	147.8	74,880,000	0.39	74,880	39.3	38,160
M IF Sandstone	3	138.3	108,000,000	0.34	30,384	42.9	17,424
UQ MR Mudstone	1	147.8	74,880,000	0.39	78,480	37.7	38,160
UQ MR Sandstone	2.4	138.3	108,000,000	0.34	32,544	40.8	17,424
UQ IR Mudstone	7.9	147.8	74,880,000	0.39	73,008	39.2	37,152
UQ IR Carbonaceous Shale	0.6	109.6	24,480,000	0.35	26,784	28.4	10,080
UQ	1.7	80.8	40,320,000	0.35	35,280	25	12,240
Carb Shale	1.1	109.6	24,480,000	0.35	29,664	28.3	11,088
MQ	7	82.3	36,000,000	0.35	35,280	25	12,240
MQ IF Carbonaceous Shale	1.3	109.6	24,480,000	0.35	23,616	19.6	7,200
MQ IF Mudstone	4.2	147.8	74,880,000	0.39	22,752	31.1	9,216
MQ IF Sandstone	0.7	138.3	108,000,000	0.34	30,816	42.5	17,424
MQ IF Mudstone	13.7	147.8	74,880,000	0.39	22,752	31.1	9,216
MQ IF Sandstone	9	138.3	108,000,000	0.34	30,816	42.5	17,424

Table 3. Material Properties applied to the FLAC3D Model

Domain	Density (lb/ft^3)	Young's Modulus (ksi)	Poisson Ratio	Friction Angle (degree)	Cohesion (psi)	Tensile Strength (psi)	Dilation Angle (degree)
Fill	110	22	0.2	38	0.7	0	0
Shale 5	145.9	541	0.38	37.5	426	208	4.2
L seam	81.8	300	0.35	25	221	77	4.2
Shale 4	141	485	0.38	34.5	329	154	4.2
M seam	79.4	230	0.35	25	221	77	4.2
Shale 3	143.1	563	0.37	39.3	419	213	4.2
Q seam	85.1	246	0.35	25	240	84	4.2
Shale 2	142.9	581	0.37	34.9	177	83	4.2
R seam	85.1	246	0.35	25	240	84	4.2
Shale 1	142.9	581	0.37	34.9	177	83	4.2

*Note: the FLAC3D Model is constructed in units of pounds per feet. For this reason, plots of stresses are in units of pounds per square foot (lb/ft^3 or psf), and plots of displacement are presented in units of feet.
*ksi=one thousand pounds per square inch

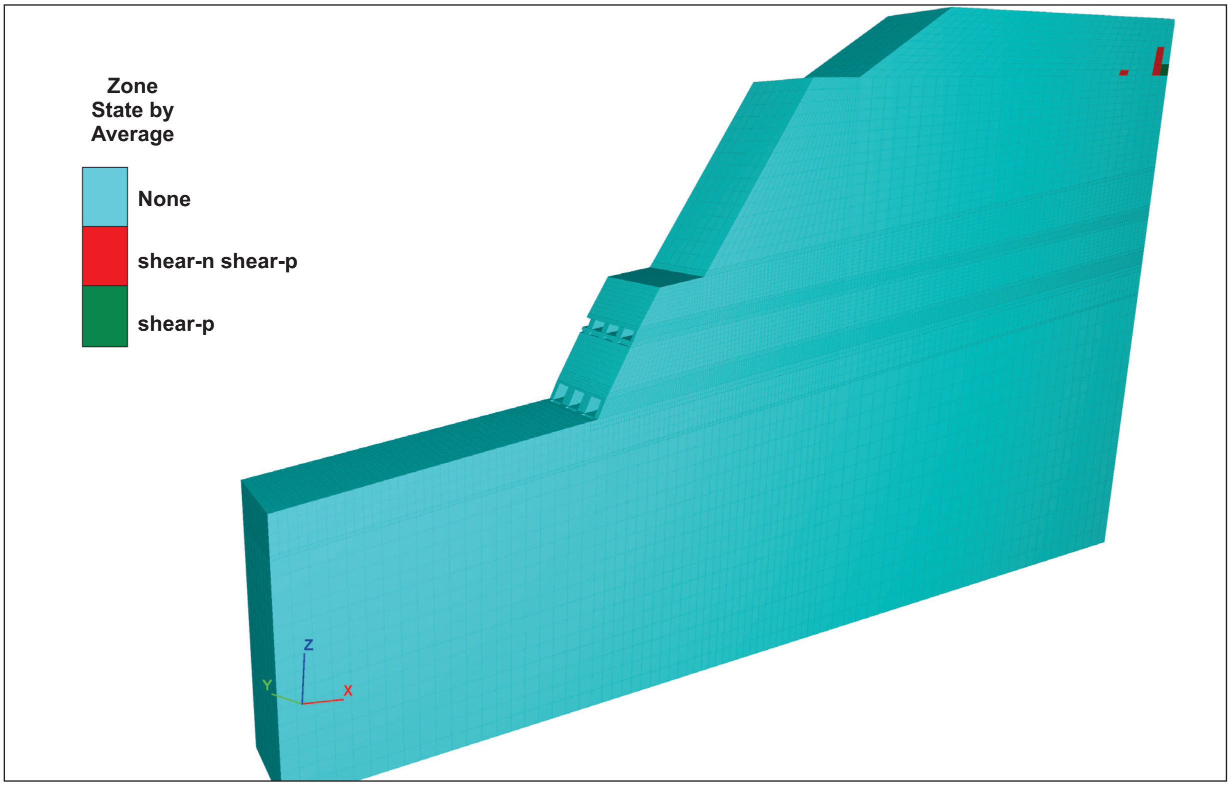


Figure 14. Yield Indicators Throughout the Model after Mining is Complete with Base Case Material Strengths

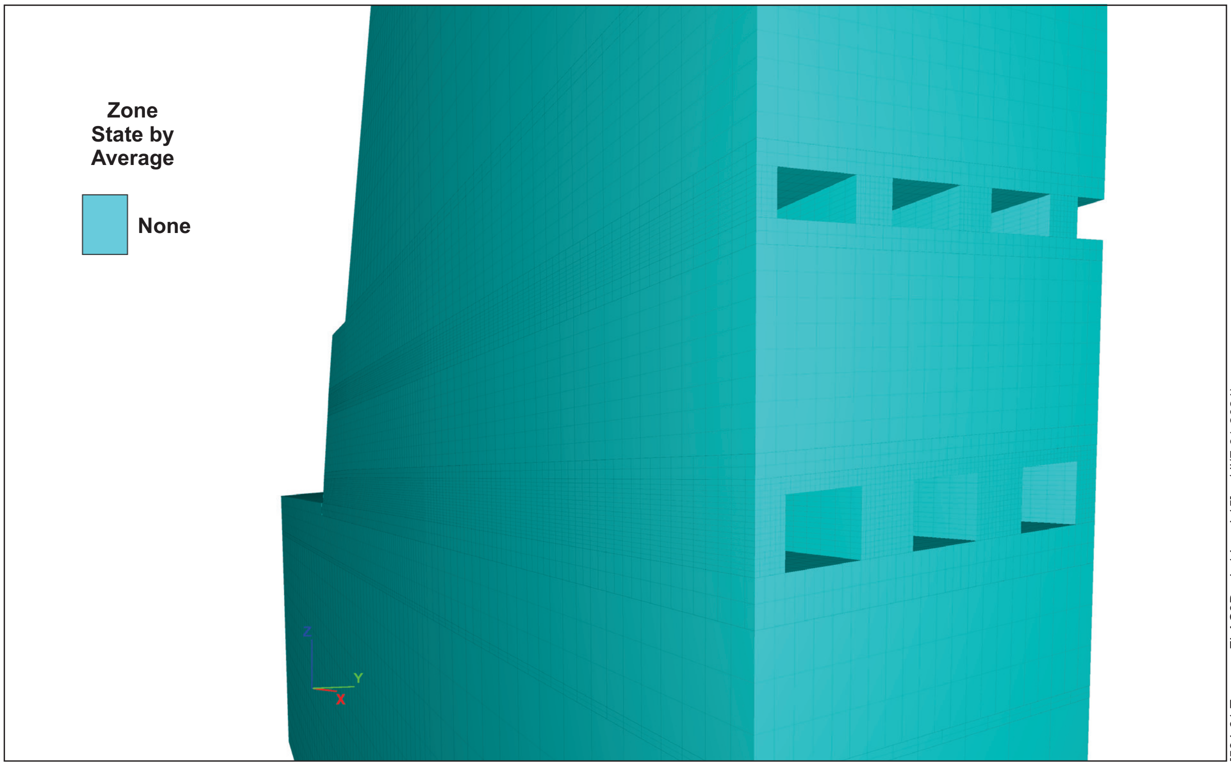


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Figure 15. Yield Indicators in the Coal Pillars after Mining with Base Case Strengths

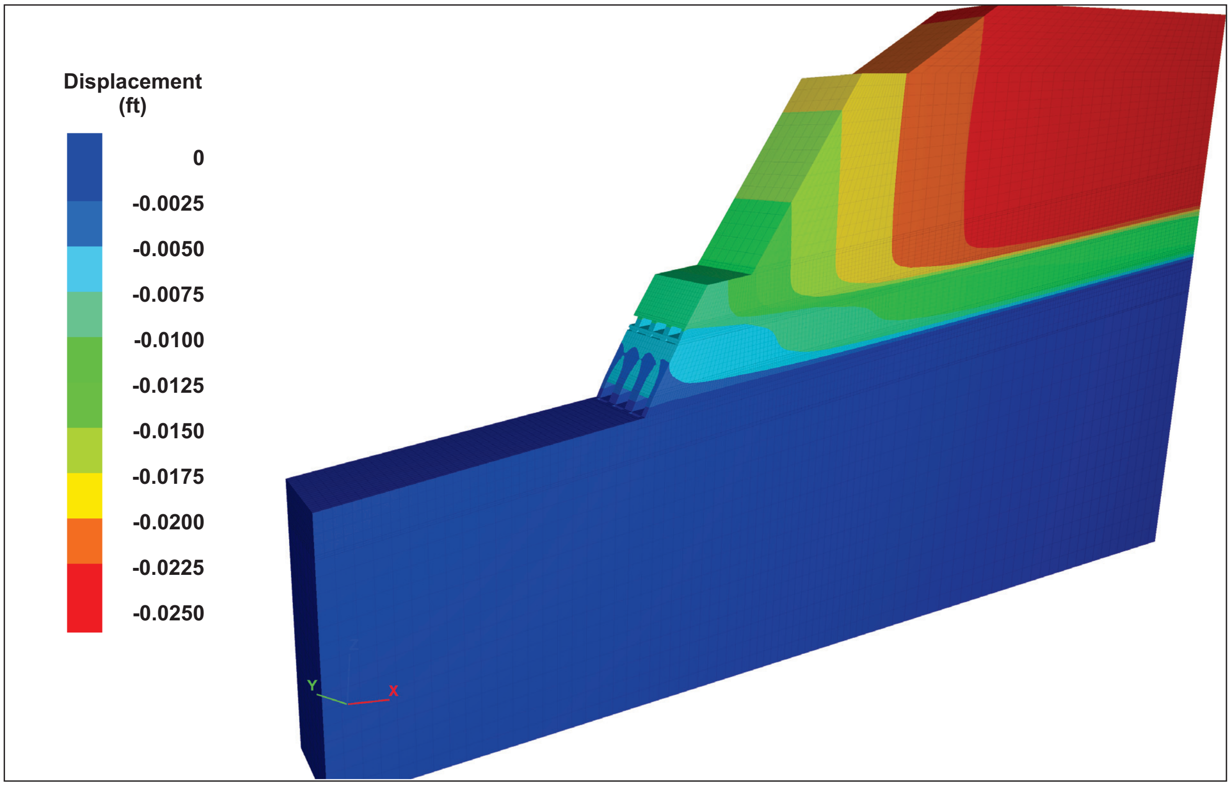
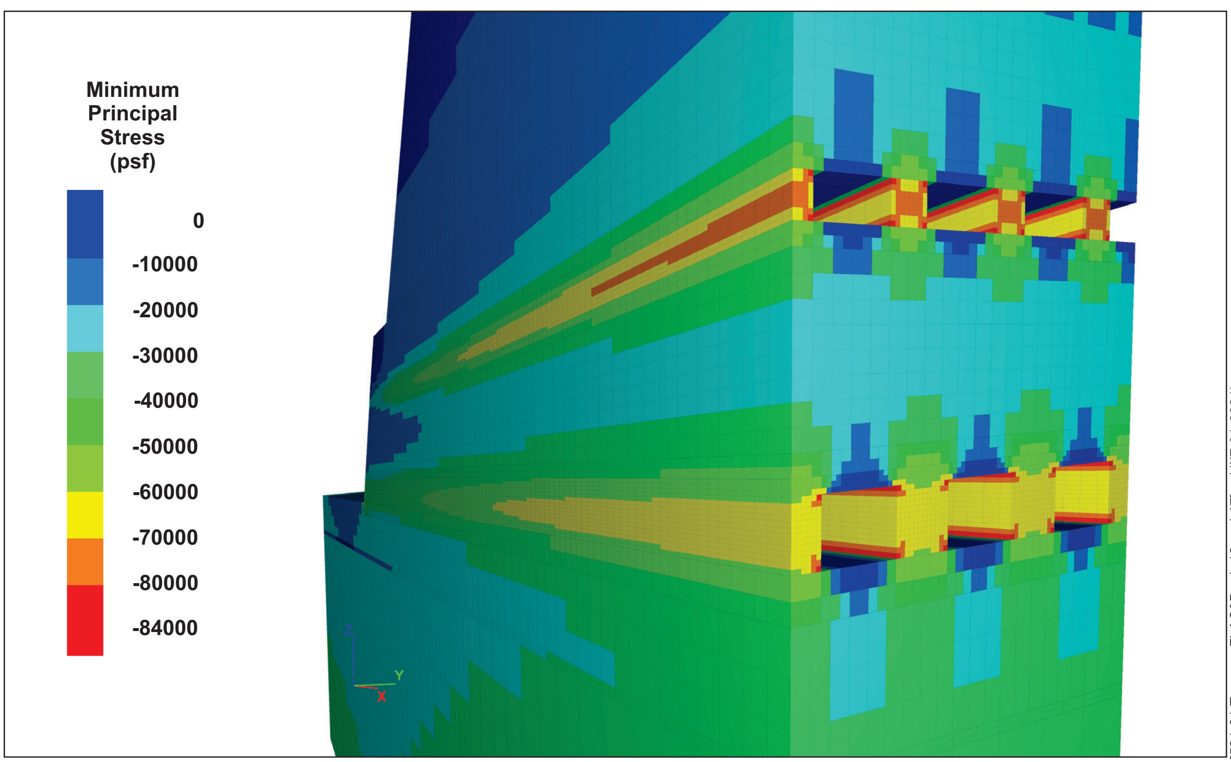


Figure 16. Vertical Displacement Contours after Mining is Complete, with Maximum Values of Approximately 0.025 ft, or 0.3- inches



[534-61 Trapper_FLAC3D.cdr 16 and 17]ep/rjl(7-31-2024)

Figure 17. Major Principal Stress Contours with Base Case Strengths

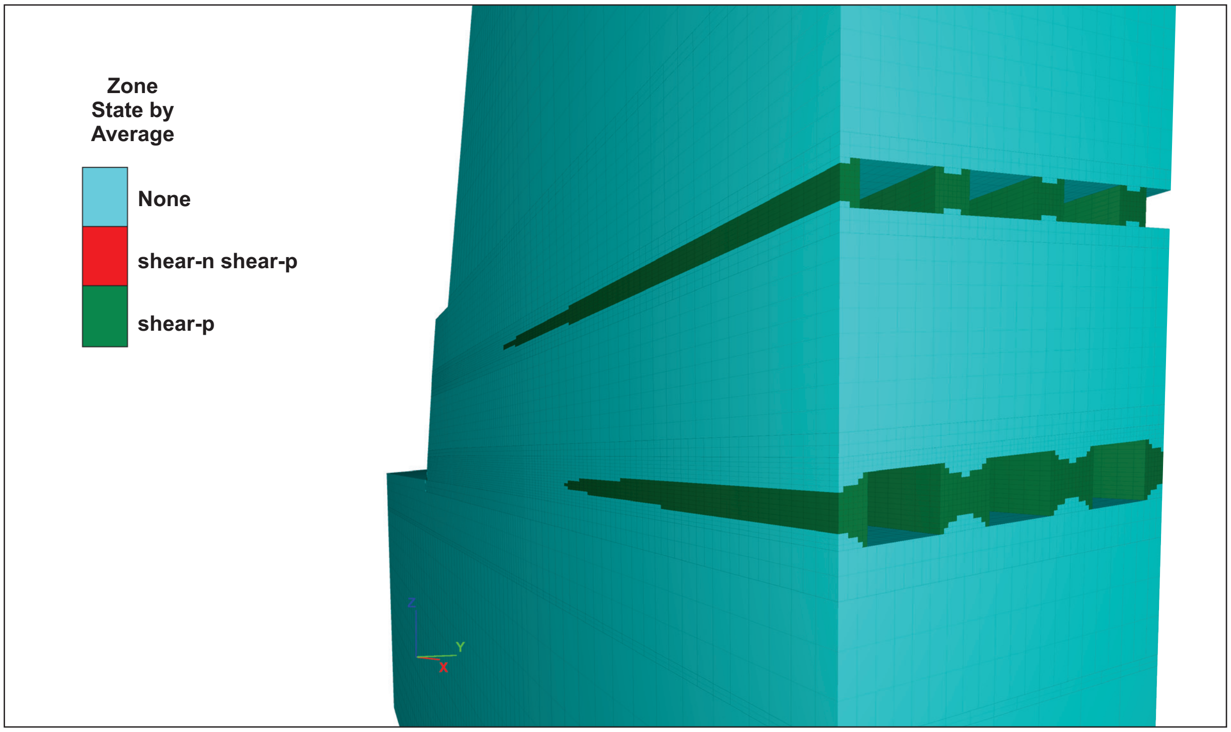
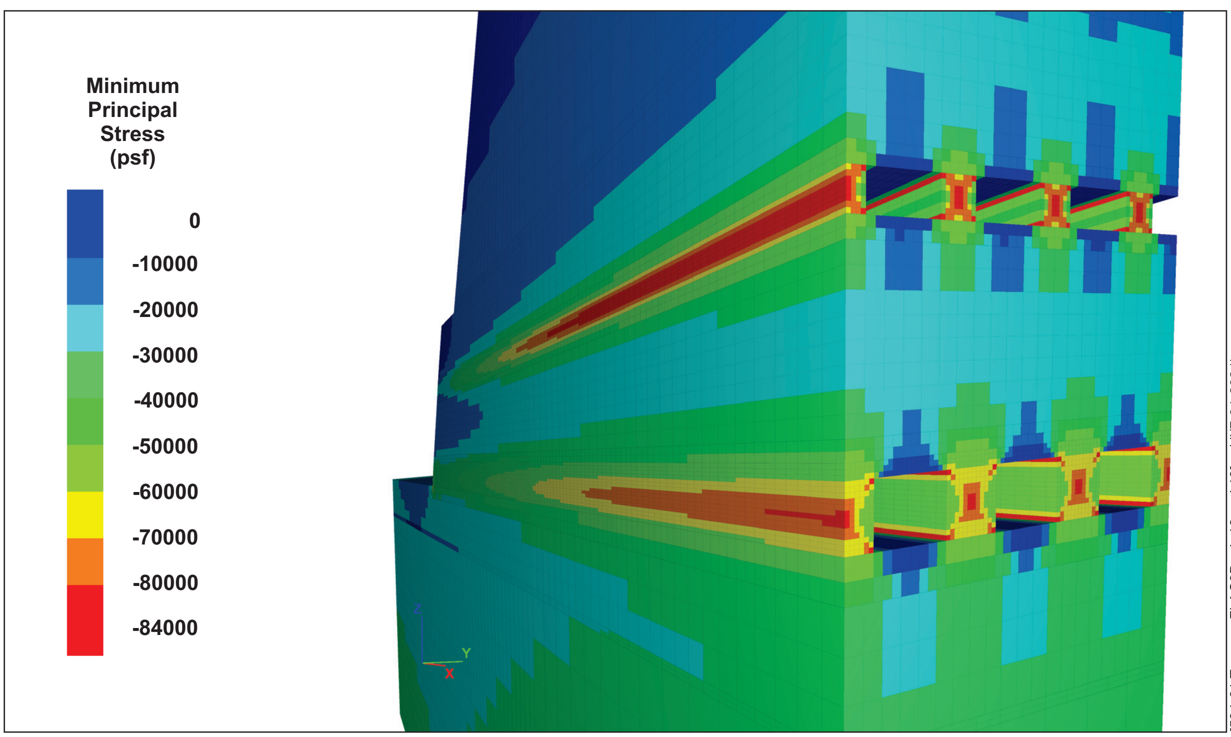


Figure 18. Yield Indicators with a Strength Reduction Factor of 2.0 in the Coal



[534-61 Trapper_FLAC3D.cdr 18 and 19]ep/rj(7-31-2024)

Figure 19. Major Principal Stress Contours with a Strength Reduction Factor of 2.0 in the Coal

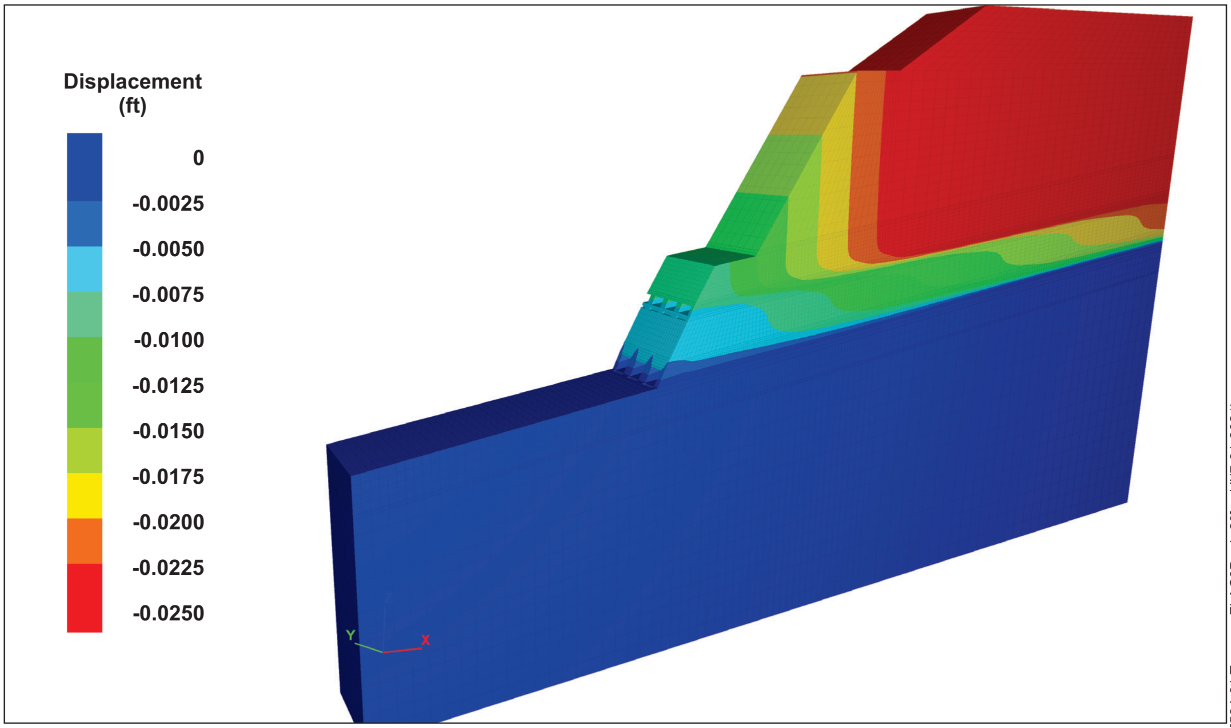


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Figure 20. Vertical Displacement Contours with a Stress Reduction Factor of 2.0 in the Coal

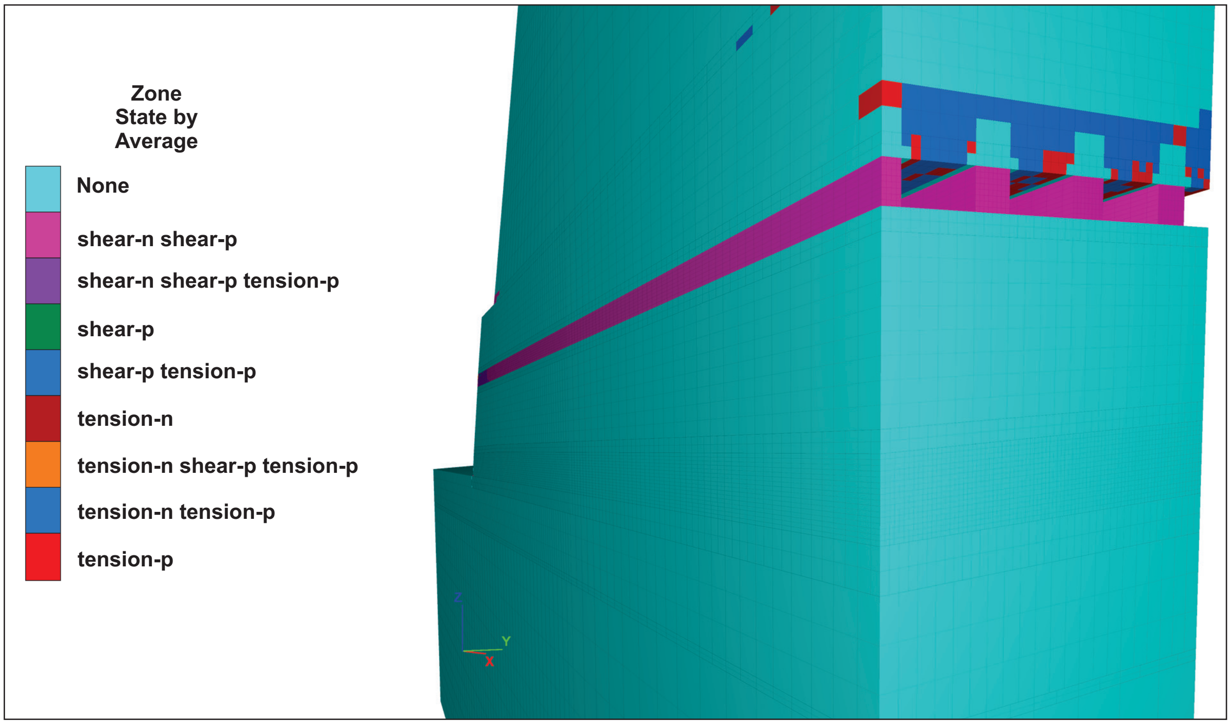

Figure 21. Yield Indicators with a Strength Reduction Factor of 2.5 in the Coal

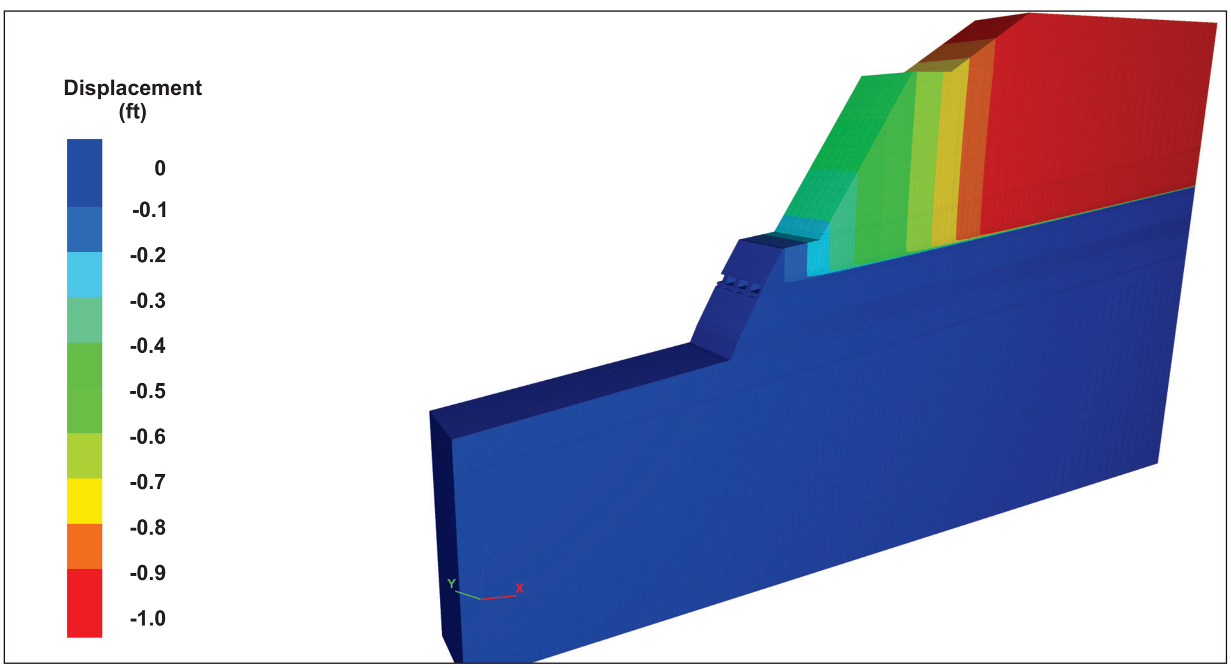

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Figure 22. Vertical Displacements in the Model with a Strength Reduction factor of 2.5

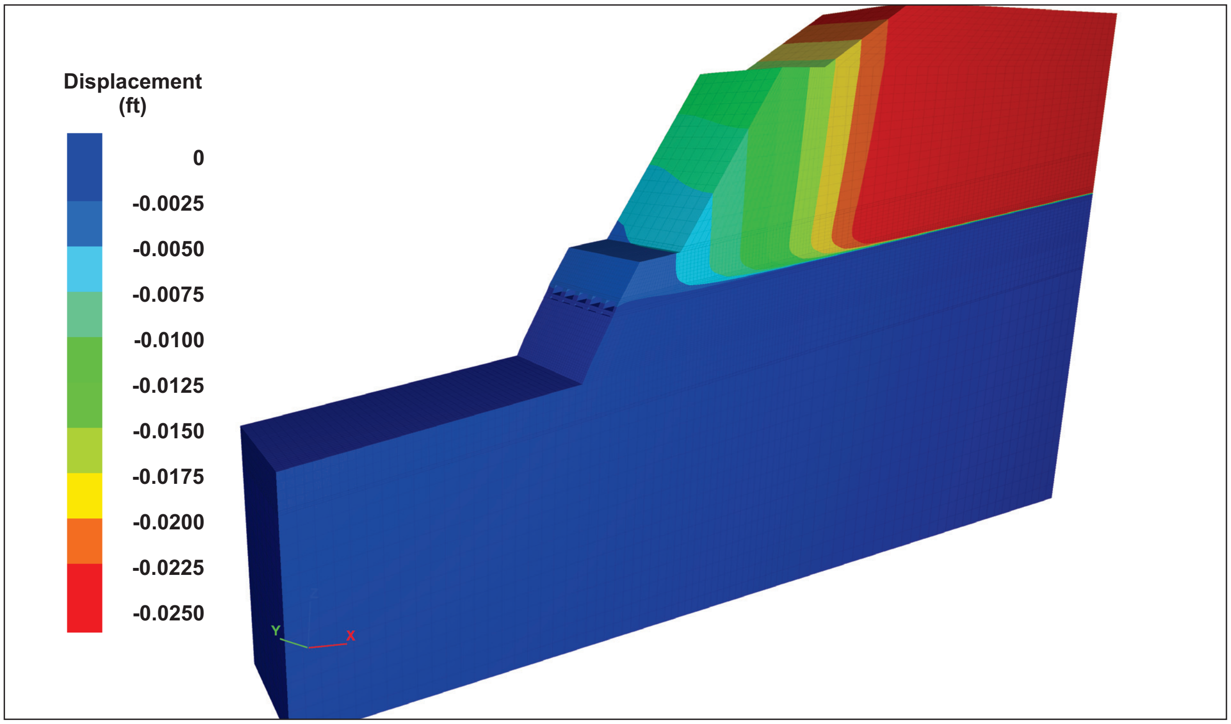

Figure 23. Vertical Displacements with a Strength Reduction Factor of 2.5 Applied in the Half-panel Model of the South M Seam

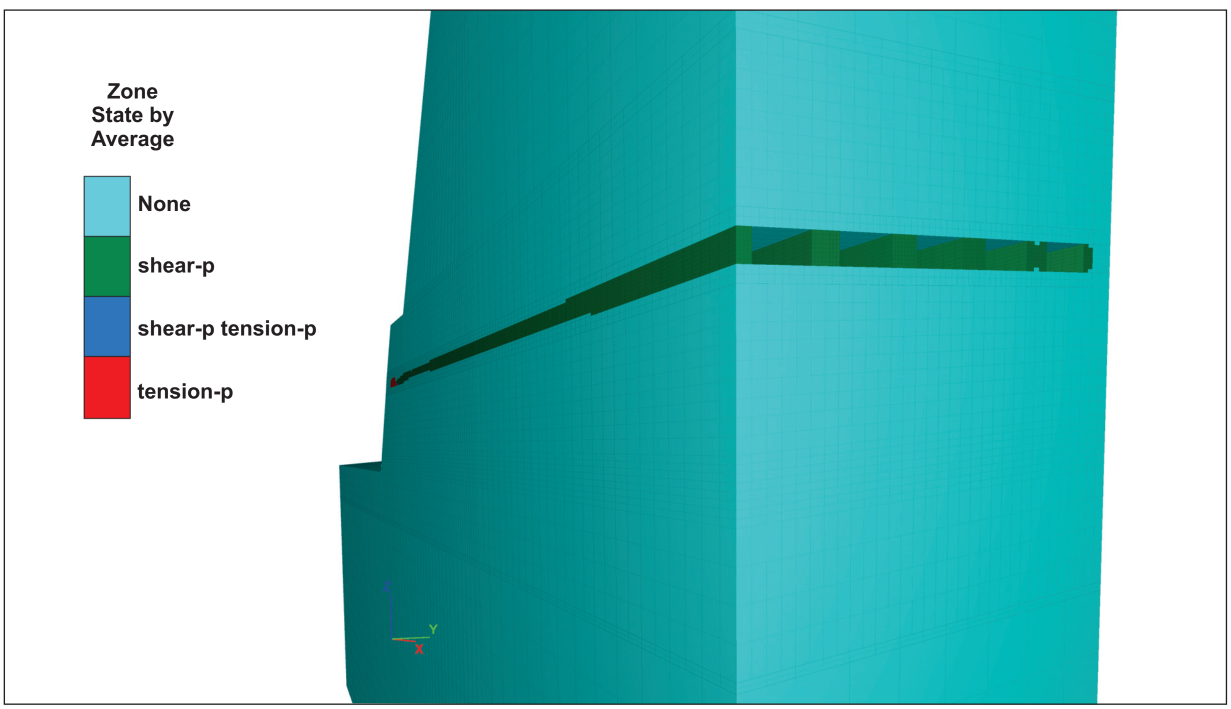

Figure 24. Yield Indicators with a Strength Reduction Factor of 2.5 Applied in the Half-panel Model of the South M Seam.

[534-61 Trapper_FLAC3D.cdr 23 and 24]ep/rjl(7-31-2024)

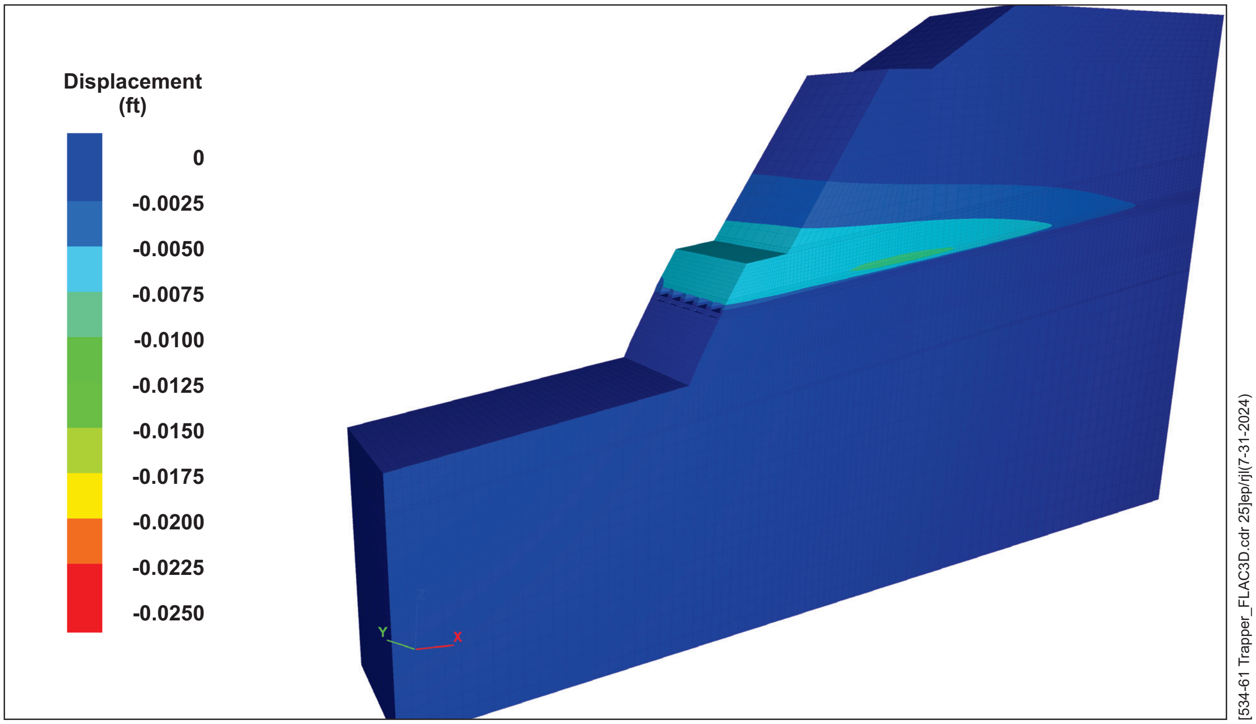

Figure 25. Negligible Lateral Displacements in the Slope with a Strength Reduction Factor of 2.5 Applied in the Half-panel Model of the South M Seam

Discussion

Although the slope is expected to remain stable, the risk of rock fall from disturbed ground at or above the M Seam will present a hazard to the working area below when the pit progresses down to the Q Seam. Agapito recommends placement of a catch bench in the slope at the base of the M Seam to reduce the risk of falling objects from the free face that will exist above the Q Seam working level. The width of the catch bench should be calculated using the modified Ritchie criterion, which is a widely accepted method of calculating catch bench widths for open pit mine slopes.[4]

Using the modified Ritchie criterion, catch bench width is calculated based on the height of the bench face above, in units of meters (m), according to the following equation:

$$bench\ width\ (m) = 0.2 * bench\ height + 0.45\ m$$

For a free face 30 ft in height (9.1 m) between the floor of the M Seam and the next catch bench or roadway above, the recommended width of a catch bench located at the M Seam floor level would be calculated as:

$$bench\ width\ (m) = 0.2 * 9.1 + 0.45 = 2.3\ m = 7.6\ ft$$

The width of the catch bench should be adjusted incrementally as the height of the free face above the M Seam changes.

Conclusions and recommendations

The web and barrier pillar designs provided in this report for the M and Q seams were derived using widely accepted empirical methods and validated using numerical modeling techniques. By using these design curves to determine the minimum pillar width for each panel as mining progresses and adjusting the width as conditions warrant, maximum resource recovery can be attained.

With the safety factors specified in the design criteria and the confirmation of sufficient support capacity exhibited in the numerical modeling results, it is anticipated that the M Seam will remain stable during mining of the Q Seam in the top-down mining approach. Results of the FLAC3D model suggest that the global stability of the N-Pit slope is not impacted by mining of the M and Q seams under the guidance of the given design specifications.

Although the slope is expected to remain stable, Agapito recommends placement of a catch bench in the slope at the base of the M Seam to reduce the risk of falling objects from the free face that will exist above the Q Seam working level.

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[4] Ryan, Thomas M., and Paul R. Pryor. "Designing Catch Benches and Interramp Slopes." *Slope Stability in Surface Mining* (2000): 27-38

Sincerely,

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