20-119

GEOTECHNICAL ASSESSMENT FOR THE PURPOSE OF PILLAR EXTRACTION BETWEEN 2 AND 30 CROSSCUTS IN SUNSET SOUTH MAINS

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GEOTECHNICAL ASSESSMENT FOR THE PURPOSE OF PILLAR EXTRACTION BETWEEN 2 AND 33 CROSSCUTS IN SUNSET MAINS

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1 INTRODUCTION

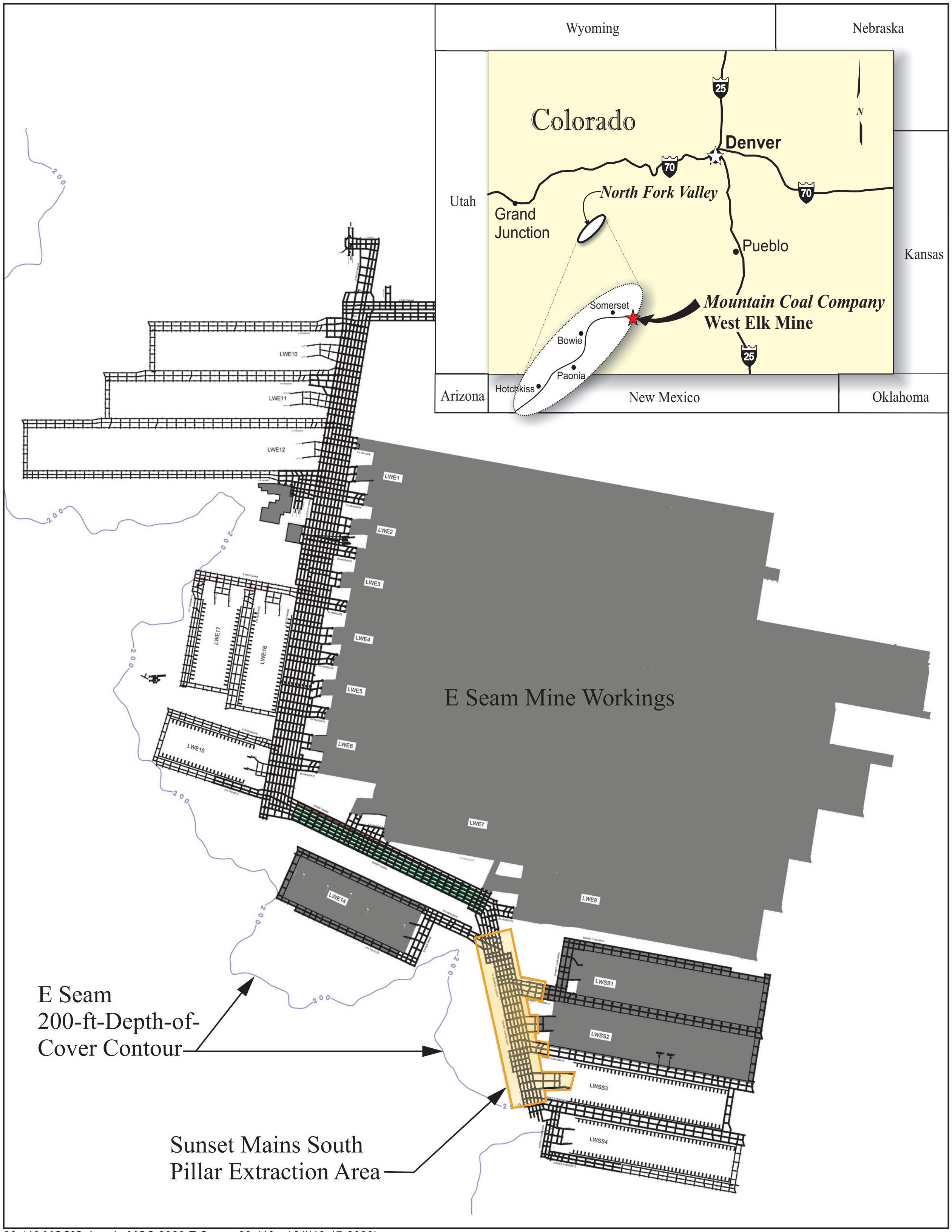
This report provides the assessment of the geotechnical parameters associated with secondary pillar extraction in the E Seam in Sunset Mains South between crosscuts 2 and 30 (see Figure 1-1). Following discussions with Arch West Elk (West Elk Mine), a comprehensive review of the geotechnical environment, and the consideration of the mining constraints for the panel, Agapito Associates, Inc. (Agapito) has made recommendations for maximum pillar extraction. Agapito considered the following requirements:

- Pillar extraction will not take place at depths of cover less than 250 feet (ft).
- Pillar extraction will stop one crosscut outby of the BF Fault at the outby end of Sunset Mains South.
- In order to maintain a bleeder system around areas of gob and to inspect inby seals, a single life-of-mine roadway must remain travelable during and after pillar extraction activities.
- The pillars will be extracted in their current state and, as such, additional development and roof bolting should not be considered for preparation in the pillar extraction plan.
- To avoid unstable remanent pillars, the pillar extraction should aim to mine as much of the pillar as practically possible.
- If a large percentage of the pillar remains following extraction, the remaining pillar should be classed as long-term stable.

The geotechnical environment was characterized from geological and geotechnical information provided by West Elk Mine, including borehole logs from drillholes in the vicinity of the panel, geological structure drawings, surveyed mine plan drawings, and overburden depth contour boundaries. Agapito also drew on its extensive experience of ground condition characterization and geotechnical design in the E Seam at the mine.

The pillar stability assessment utilized industry standard empirical pillar design formula and criteria. The numerical model program LaModel was used to assess the detailed stress environment during pillar extraction following extraction of the pillars in the panel.

Surface subsidence modeling was carried out using the Surface Deformation Prediction System (SDPS) to estimate maximum surface displacement following pillar extraction in the panel.



20-119 MCC[Colorado-MCC 2023 E Seam_20-119.cdr]rjl(10-17-2023)

Figure 1-1. Copy of Current Mine Plan Showing the Sunset Mains South Pillars in the E Seam

2 GEOTECHNICAL ENVIRONMENT

Boreholes indicate that the immediate roof lithology (first 10 feet [ft]) of the Sunset Mains South is comprised of alternating units of soft-to-medium hard mudstone and shale, hard siltstone, and fine-grained sandstone. The overburden is comprised of units of coal, mudstone, shale, siltstone, and sandstone, with approximately half of the lithology being dominated by the hard siltstone and sandstone units.

The geological structure information provided by the West Elk Mine indicates a large normal fault (BF Fault) is located across the north end of Sunset Mains South (see Figure 2-1). The reported offsets for the fault range between 20 and 60 ft. No other significant geological structures are indicated in the Sunset Mains South.

The competency of the immediate roof has been estimated by using the Coal Mine Roof Rating (CMRR). The CMRR classification system was developed by the National Institute for Occupational Safety and Health (NIOSH) for use in bedded Coal Measure rock (Molinda and Mark 1994). The parameters of the classification system are the Unconfined Compressive Strength (UCS) of the intact rock, intensity of bedding and other discontinuities, shear strength of the bedding and other discontinuities, moisture sensitivity of the rock, and the presence of a strong bed in the bolted horizon. These parameters have been estimated from the geological descriptions recorded on the borehole logs noted above. The logs indicate that the CMRR is likely to range between 45 and 55, which indicates moderate to strong roof competency.

The depth of cover ranges between 50 ft at the inby end of the mains to 650 ft around the mid-point of the mains, and, from there, ranges between 250 and 600 ft outby to the fault crossing (see Figure 2-1). In the context of coal mining in the Western United States, this depth equates to a reasonably low vertical stress regime.

Previous in-situ stress measurements at the mine indicate the major horizontal stress is aligned in an east–northeast direction with a major horizontal-to-vertical stress ratio (k-ratio) around 1.5:1. At the depths considered in this assessment and taking into account the close proximity of surrounding longwall gob, it is anticipated that the horizontal stress will have a negligible effect on ground conditions during pillar extraction.

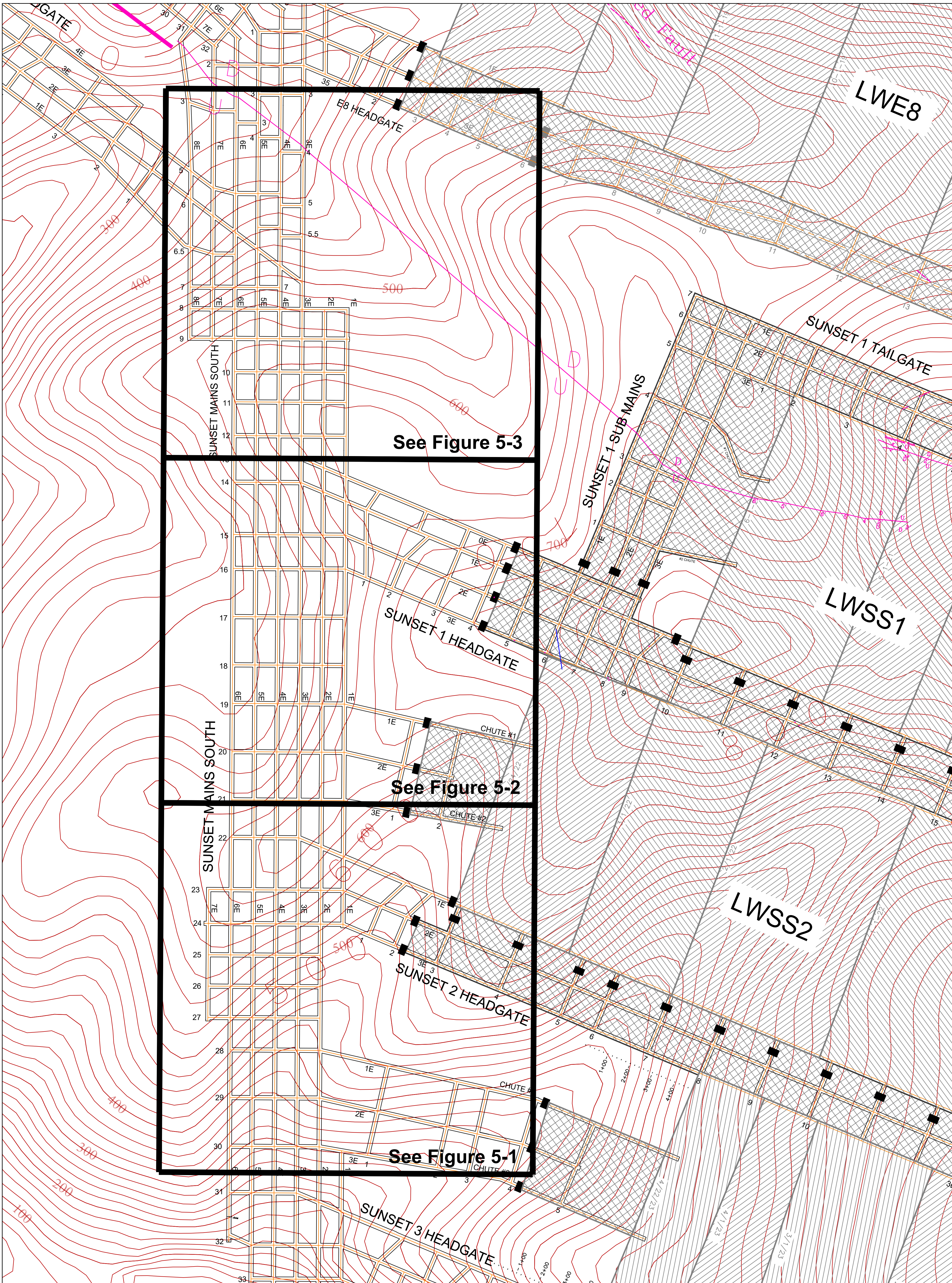
As shown in Figure 2-1, the pillars in Sunset Mains South are flanked by previously extracted longwall gob to the east of the panel. The gob from LW SS2 extraction, which is the closest of the longwall panels to the mains pillars, is located more than 500 ft from the nearest pillars. Measured relationships between depth of cover and the lateral extent of abutment loading indicate that the pillars in Sunset Mains South are located a sufficient distance away from the gob to be considered outside the influence of the abutment loads. The horizontal distance to which the resulting abutment load will be redistributed away from the failed overburden onto neighboring pillars and/or barriers (D) can be estimated using the following equation presented by Peng and Chiang (1984):

$$D = 9.3\sqrt{H} \qquad \text{(Eqn. 2-1)}$$

This relationship suggests that any measurable abutment loads from LW SS2 will be limited to a lateral extent of approximately 250 ft.

This area of the mine is absent of any underlying mine workings in the B seam and, as such, the pillars are not subject to multi-seam stress.

In terms of the existing roof support installed in Sunset Mains South, the mine indicates the roadways were typically supported with a four to five ⅞-inch, Grade 75 partially encapsulated bolts every 5 ft. To date, there has not been any major roof falls in the travel-ways, which suggests that the installed roof support density was sufficient for the purpose of maintaining roof stability.



Legend

- 480 — E Seam Depth of Cover Contour (ft) C.I. = 20 ft
- Faults
- Downroll
- Previously Mined and Sealed

N

0 375
Scale (ft)

Copy of Current Mine Plan Showing the Depth of Cover Contours, and Mapped and Inferred Geological Structure in Sunset Mains South

ARCH West Elk

Figure 2-1

Job No.: 20-119
Scale: As Shown

Date: 11-27-2023
Drawn by: RJL

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20-119 MCC [UGM - E Seam Mine Base Master_AAI_rjl.dwg Layout: Fig2_2-1]

3 PILLAR EXTRACTION METHODS

Previous research has shown that sudden massive collapse of coal pillars is associated with slender pillars (i.e., width-to-height [w/h] ratio <3) and a pillar safety factors (SF) <1.5 (Mark et al. 1997). At low w/h ratios (<3), overloaded coal pillars tend to fail in a brittle, uncontrolled fashion, whereas at greater w/h ratios (>4), the overloaded pillars demonstrate a more plastic form of deformation. Significant displacement may still take place in the form of roof-to-floor convergence, as well as rib spall. However, the pillar core remains confined and tends to retain its load carrying ability, generally without failing in the commonly understood sense. This behavior was shown by Das (1986) in tests on Indian coals (see Figure 3-1).

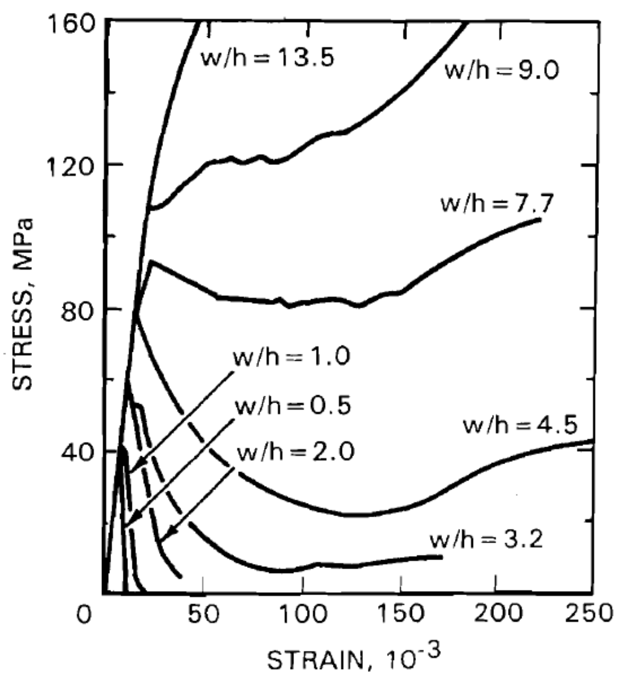


Figure 3-1. Complete Stress-Strain Curves for Indian Coal Specimens Showing Increasing Residual Strength with Increasing w/h Ratio (Das 1986)

There are typically three design approaches utilized during coal pillar extraction to help control massive pillar collapse. These design approaches are summarized below:

- *Prevention*—The resulting pillars are designed so that after partial pillar extraction, pillar collapse is highly unlikely. This is achieved by stipulating a minimum w/h ratio of 4 and a minimum SF of 1.5 for the remnant pillars.
- *Containment*—High extraction ratios are practiced within individual compartments that are separated by barrier pillars.
- *Full Extraction*—Mining all or most of the coal of the pillars removes the support to the main roof, thereby limiting the potential width of the pressure arch and, in doing so, limiting the load on the surrounding pillars.

In the Sunset Mains South, full extraction of the existing mains pillars is considered the most appropriate mining method from a geotechnical and economic standpoint. Constraints imposed by the reach of the continuous miner and geometry of the existing pillars will result in a <10 ft wide remnant left after mining of each pillar. Because of the extremely low w/h ratio, the remnant pillars will almost certainly undergo significant deformation during the extraction process resulting in their inability to retain any significant amount of load. In turn, the vertical load will transfer to the stiffer surrounding unmined pillars and abutments. This geomechanical concept has been assessed using numerical methods in subsequent sections of this report.

The most widely practiced pillar extraction processes in the industry include split-and-fender, pocket-and-wing, outside lifts, Christmas tree, and open-ending (Kauffman et al. 1981). Considering the full extraction approach recommended for use in the Sunset Mains South and the geometry of the existing pillars, the most suitable pillar extraction process is therefore assessed to be the Christmas tree method. In this process, alternating lifts are taken from each side of the entry into the adjacent pillars and are sufficient to extract the majority of the pillar without going beyond the supported roof (see Figure 3-2). The lifts for each pillar are initially taken next to the gob, and retreat is outby, toward the unmined pillars. No additional roof bolting is required in this process. The gob edge is controlled by a set of (two) mobile roof supports (MRS) placed on the gob side of the lift, which are kept as close as possible to the continuous miner during the removal of each sequential lift. As the removal of lifts approach the outby intersection, the continuous miner is protected by a second set of two MRS installed in the outby crosscut between the pillar being mined and the previously mined pillar in the same pillar row. Supplemental lifts can also be taken from the crosscuts into the remaining pushout stump if conditions are favorable.

In addition to the mains pillars, a combination of Christmas treeing and a single outside-lift is possible in selected areas of the gateroad and chute road pillars located outby of the seals. Coal recovery can also be extracted in the solid coal barrier pillar positioned along the outside entries.

In order to preserve the integrity of the life-of-mine roadways required for the bleeder entry and seal inspections, the neighboring pillars must remain in a long-term stable condition. The location of this travel-way is shown in Figure 3-3. In regard to the gateroad and chute road pillars, a suitable stand-off distance between the roadway and the inby extent of the pillar extraction should be implemented.

In regard to cut depths in the lifts, this assessment assumed the maximum safe reach of the continuous miner will be no more than 37 ft beyond the last row of roof bolts. The mine has indicated that this is the standard cut-out distance used for roadway development. It is also assumed that the cutting head on the continuous miner will accommodate the excavation of 11.5-ft-wide lifts.

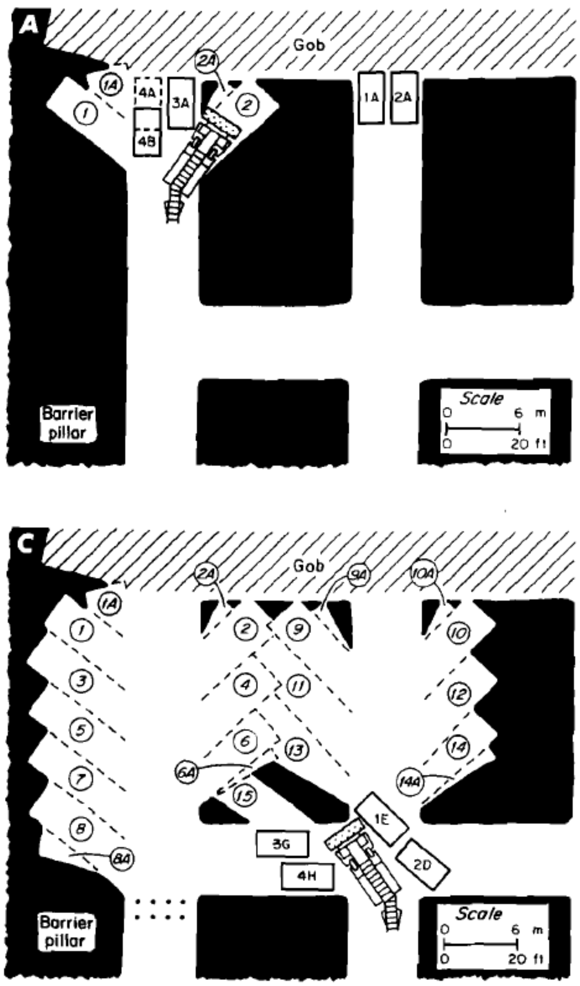
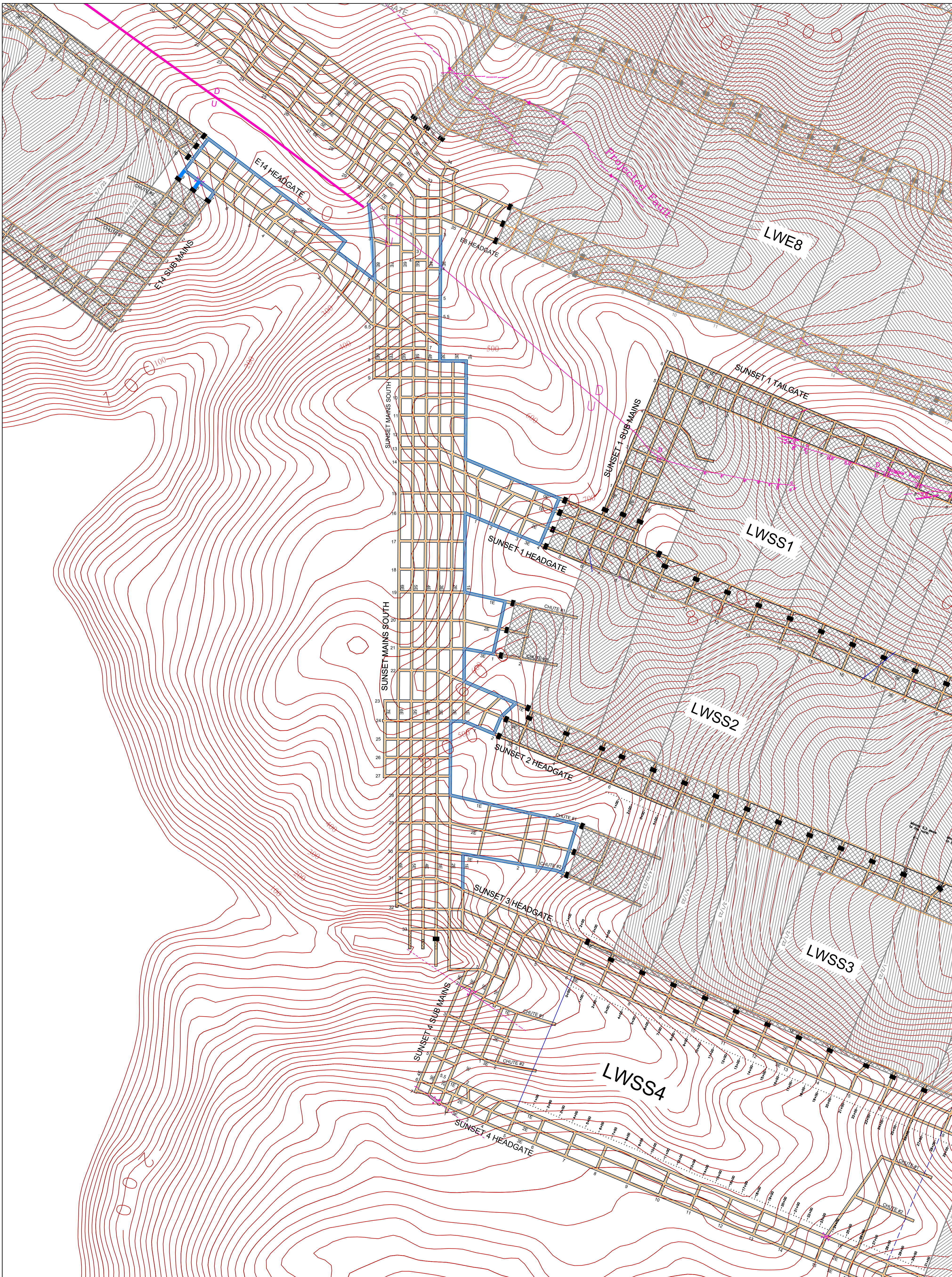


Figure 3-2. Cutting Sequence for Outside-Lift Christmas Tree Method (Mark et al. 1995)



N

0 400
Scale (ft)

Legend

480 — E Seam Depth of Cover Contour (ft) C.I. = 20 ft

Faults

Travelways Required to Remain Serviceable during and following Pillar Extraction for the Purpose of Maintaining a Bleeder System and for Seal Inspection

Previously Mined and Sealed

20-119 MCC [UGM - E Seam Mine Base Master_AAI_rjl.dwg Layout: Fig5_3-3]

Copy of Mine Plan Showing the Travelway Required to Remain Serviceable During and Following Pillar Extraction in Sunset Mains South

ARCH West Elk

Figure 3-3

Job No.: 20-119
Scale: As Shown

Date: 11-27-2023
Drawn by: RJL

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4 PILLAR STABILITY CRITERIA

4.1 Design Standards

In keeping with the pillar design standards outlined for the full extraction approach, the following has been used as a minimum baseline for the pillar extraction plans in the Sunset Mains South:

- Following extraction of the mains pillars, the remnant pillars must not remain in a load bearing condition and, as such, no more than 10 ft of coal is left in the remnant.
- For those pillars where a substantial amount of the pillar will remain after lifting (i.e., the gateroad and chute road pillars), the pillars Safety Factor (SF) must be a minimum of 1.5.
- Following pillar extraction, the pillars next to the life-of-mine roadways shown in Figure 5 must retain a minimum SF of 1.5.
- A minimum stand-off distance of 50 ft between a life-of-mine roadway and the inby extent of the pillar extraction should be applied.
- Pillar extraction will be conducted by the outside-lift Christmas tree method.
- The lifts will be a maximum of 37 ft long.

4.2 Pillar Strength Methodology

As shown in Figure 2-1, most of the existing pillars are rectangular in shape. The strength of rectangular pillars can be significantly greater than square pillars due to the greater confinement generated within them (Mark et al. 1995). On this basis, the following Mark-Bieniawski three-dimensional (3D) formula will be used to calculate the strength of the pillars:

$$\sigma_p = S_i \left[0.64 + 0.54\left(\frac{w}{h}\right) - 0.18\left(\frac{w^2}{hl}\right)\right] \qquad \text{(Eqn. 4-1)}$$

where
σ_p = pillar strength (pounds per square inch [psi])
S_i = in-situ coal strength (taken as 900 psi)
w = *pillar width (ft)*
l = *pillar length (ft)*
h = *pillar height (ft)*

4.3 Pillar Loading for Development Conditions

As the width of the pillar extraction panels in Sunset Mains South will be less than the overburden thickness (*H*), full Tributary Area loading has been assumed (see Figure 4-1). Tributary Area loading assumes that the pillar carries its proportional share of the full overburden load up to the surface and can be defined as follows:

$$T = \frac{(w_p+w_r)(l_p+w_y)\rho gH}{w_p l_p} \qquad \text{(Eqn. 4-2)}$$

where T = pillar stress (psi)
w_p = pillar width (ft)
l_p = pillar length (ft)
w_r = roadway width ft)
H = overburden depth (ft)
ρ = density of rock (taken as 162 pounds per cubic foot [pcf])

4.4 Pillar Abutment Loading for Retreat Conditions

The abutment load during pillar extraction is related to the redistribution of load away from the pillar extraction gob onto the neighboring pillar. For panels which behave in a critical and supercritical manner (as in this case), the stress (*A*) resulting from the superimposed abutment load can be defined as follows (see Figure 4-2):

$$A = \frac{pg[H^2(l_\rho+w_r)\tan\Phi]}{2(w_\rho\, l_\rho)} \qquad \text{(Eqn. 4-3)}$$

where A = abutment stress (psi)
l_p = pillar length (ft)
w_r = roadway width (ft)
H = overburden thickness (ft)
ρ = density of rock (pcf)
ϕ = abutment angle (º)

In regard to the abutment angle used in this assessment, monitoring data collected in the United States of America (USA) and Australia (CGS 1998) indicates that in supercritical panels (such as this case), it is reasonable to assume an angle of 21º. In the case of the E Seam, an abutment angle of 21º is regarded as a reasonably conservative “default abutment angle,” considering the amount of thick sandstone units located in the overburden, which have the ability to span and redistribute load away from the neighboring pillars.

The distance to which the resulting abutment load will be redistributed away from the failed overburden onto neighboring pillars and/or barriers (*D*) can be estimated using the following equation presented by Peng and Chiang (1984):

$$D = 9.3\sqrt{H} \qquad \text{(Eqn. 4-4)}$$

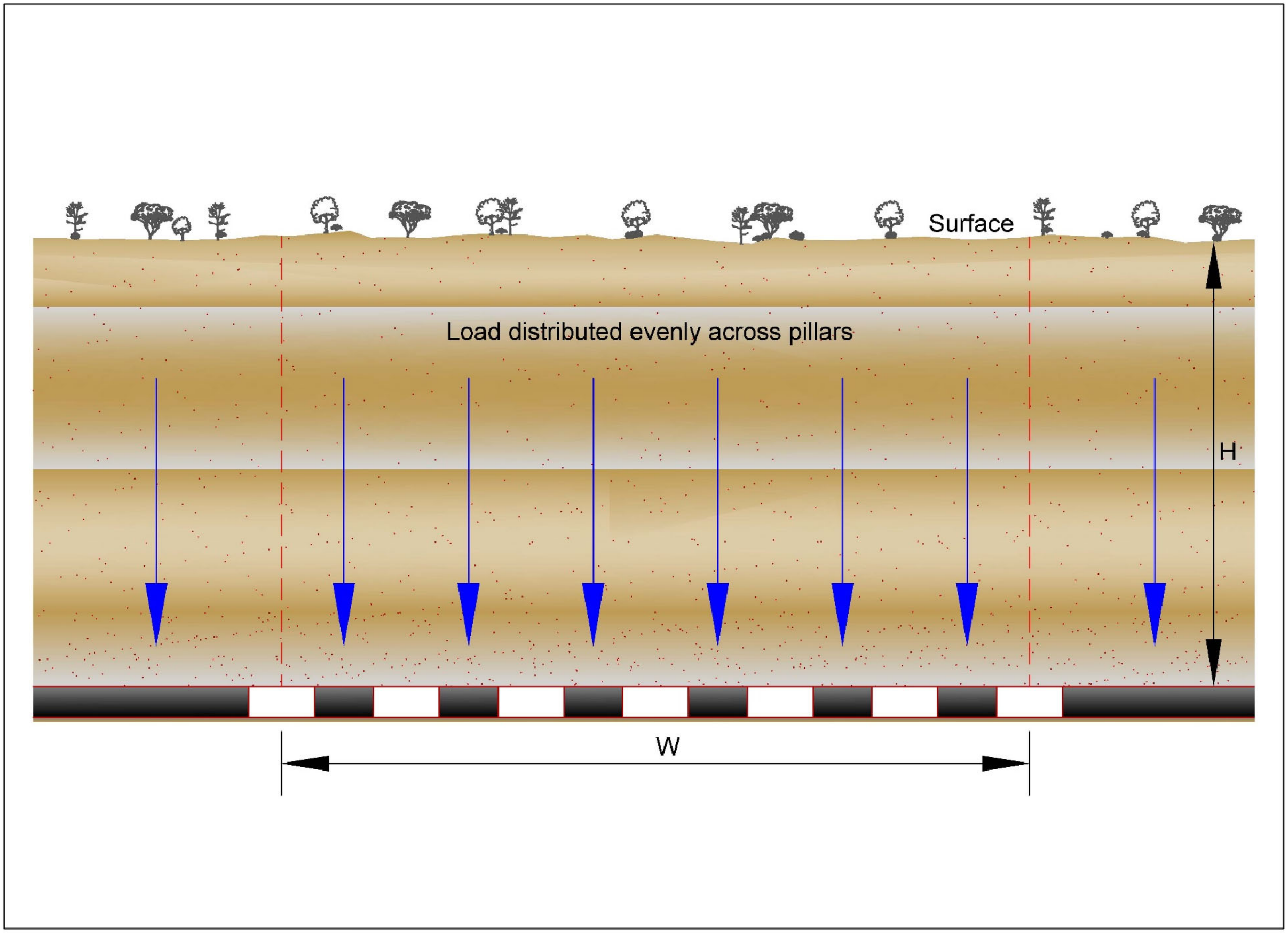
Furthermore, the proportion of the abutment load (R) that is applied to neighboring pillars and/or barriers for a single front-abutment loading scenario is calculated using the equation presented by Mark (1990):

$$R = 1 - \left[\frac{D-(w_p+w_r)}{D}\right]^3 \quad \text{(Eqn. 4-5)}$$

The remnant portion of the abutment load (i.e., $1 - R$) is applied along the remaining length of the abutment load distribution. A schematic of the abutment load distribution model used in this assessment is shown in Figure 4-3.

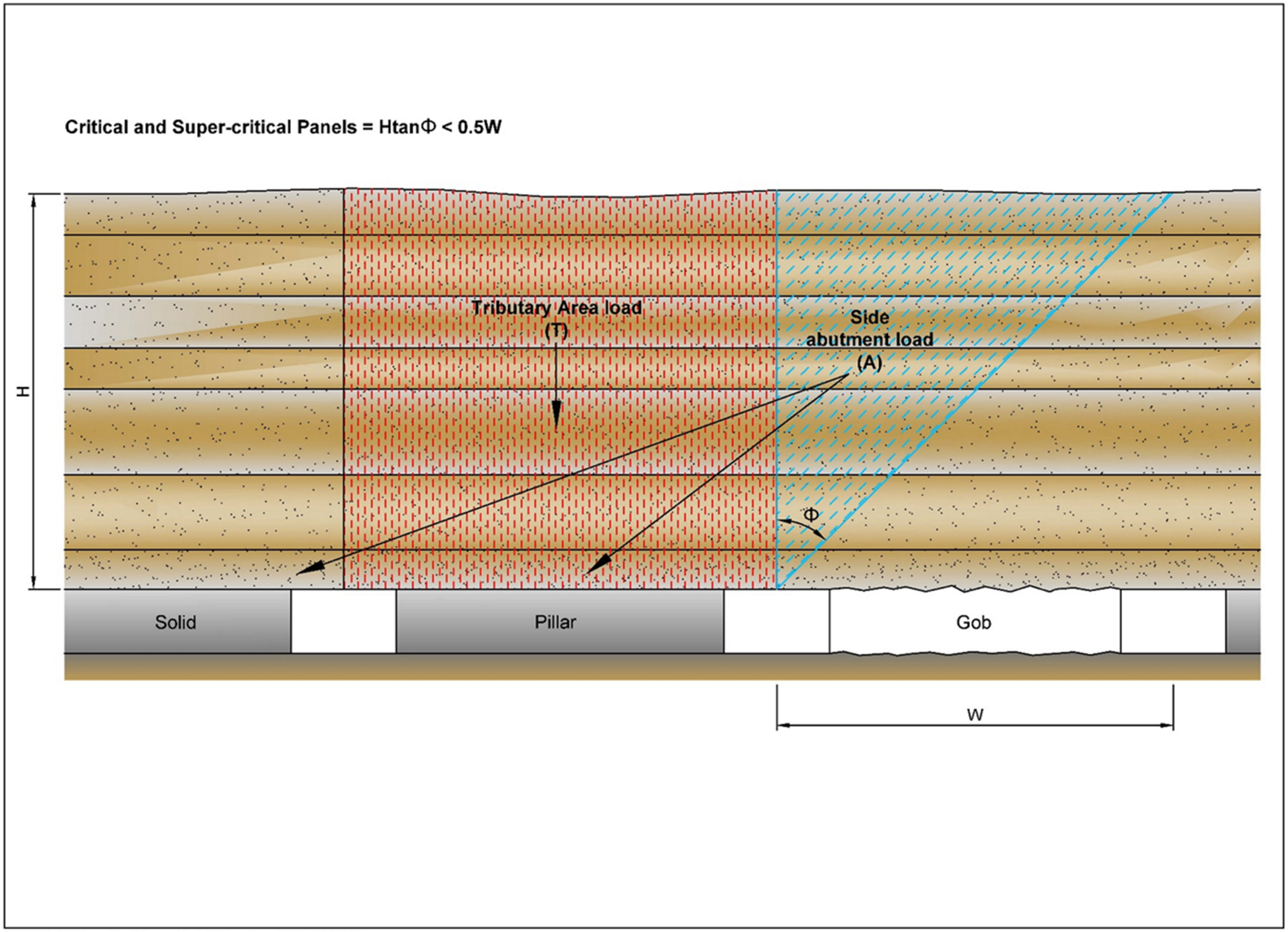
4.5 Condition of Existing Pillars in Sunset Mains South

The condition of the existing pillars in the Sunset Mains South has been assessed utilizing the above empirical methodologies. The pillar extraction areas have been divided up into seven separate zones as shown in Figure 4-4. These zones will be used to assess pillar loading conditions during simulated pillar extraction. The range of input parameters used for the assessment in each zone are summarized in Table 4-1.



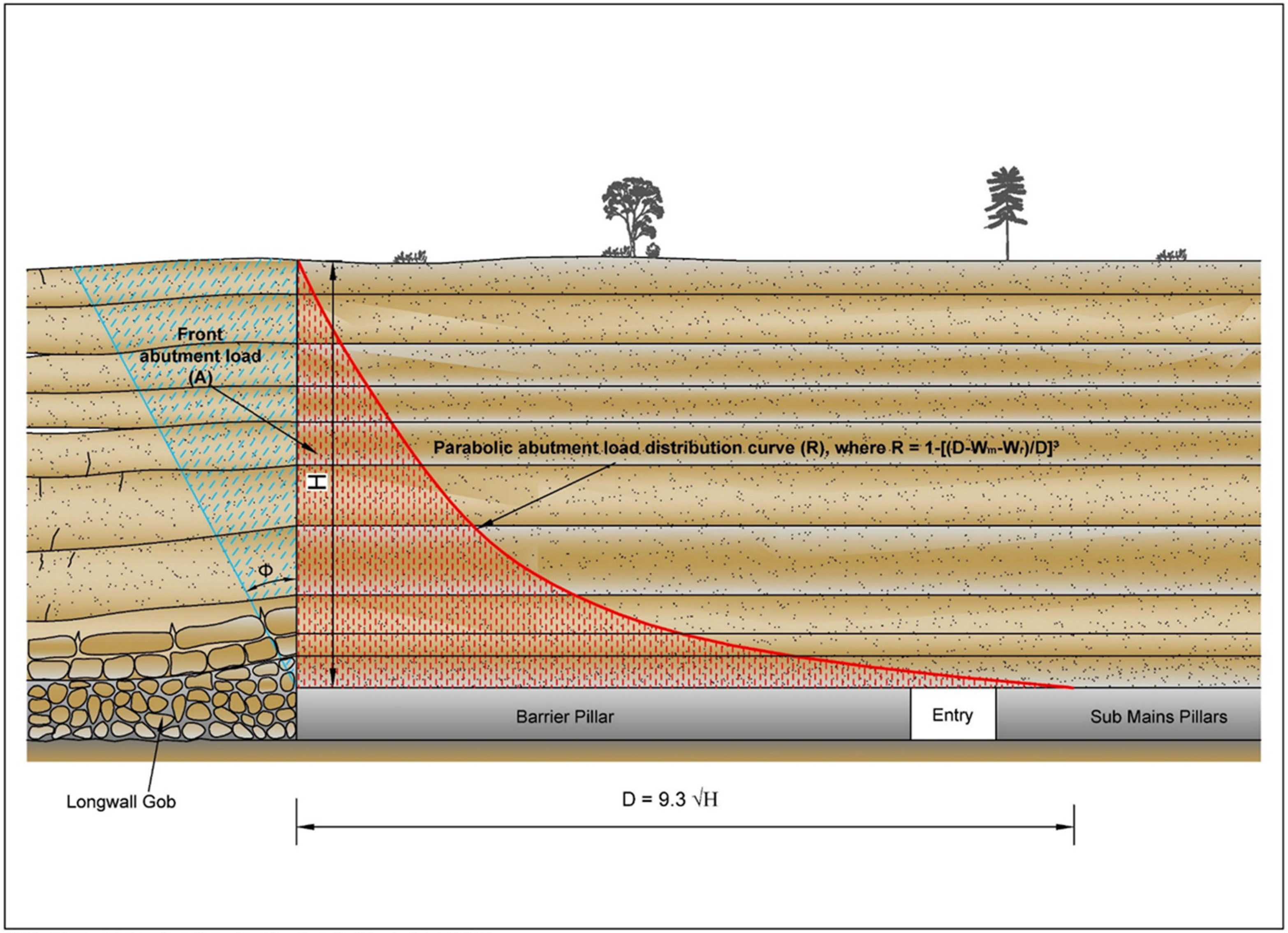
20-108 MCC[Tributary Area Loading During Dev.dwg]RS_rjl(2-7-2022)

Figure 4-1. Schematic Illustration of the Tributary Area Loading Concept during Development



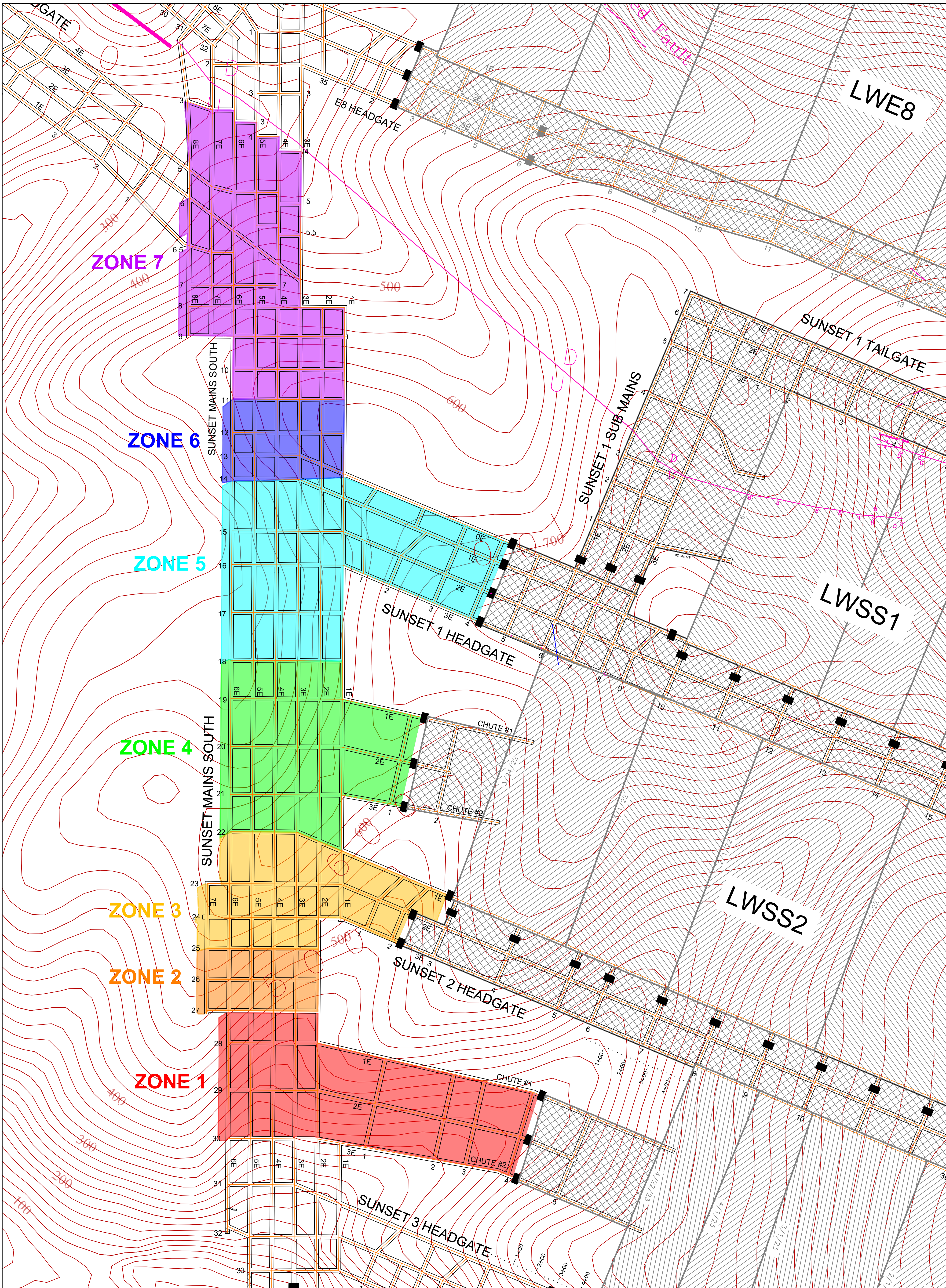
20-108 MCC[Schematic of Super-critical Abutment Loads]RS_rjl(2-1-2022)

Figure 4-2. Schematic Illustration of Critical and Supercritical Abutment Loading Concept



20-108 MCC[Inferred Redistribution in Abutment Load Away from a Goaf Edge.dwg]RS_rjl(2-1-2022)

Figure 4-3. Schematic Illustration of Inferred Redistribution in Abutment Load away from a Gob Edge



Legend

480 E Seam Depth of Cover Contour (ft)
C.I. = 20 ft

Faults

Previously Mined and Sealed

Geotechnical Zones used for the Pillar Extraction Assessment in Sunset Mains South

ARCH West Elk

Figure 4-4

Job No.: 20-119
Scale: As Shown

Date: 11-27-2023
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20-119 MCC [UGM - E Seam Mine Base Master_AAI_rjl.dwg Layout: Fig9_4-4]

Table 4-1. Input Parameters Used for the Existing Pillars in Sunset Mains South

Pillar	Roadway Height (ft)	Roadway Width (ft)	Depth of Cover (ft)	Solid Pillar Length (ft)	Solid Pillar Width (ft)	Panel Width (ft)
Zone 1	10	18	350-460	115.6-180	75	450
Zone 2	10	18	450–560	115.6	75	422
Zone 3	10	18	530-630	112-199	75	422
Zone 4	10	18	600-680	137.6-182	75	422
Zone 5	10	18	300-690	122.5-198.8	75	422
Zone 6	10	18	620-640	75-121.8	75	422
Zone 7	10	18	450-610	75-313.2	72-75	422

The results of the assessment for each zone indicate that all existing pillars have a w/h ratio of 7.2 to 7.5 and the SFs range between 2.7 and 5.5. The results are summarized in Table 4-2.

Table 4-2. Summary of the Stability for the Existing Pillars in Sunset Mains South

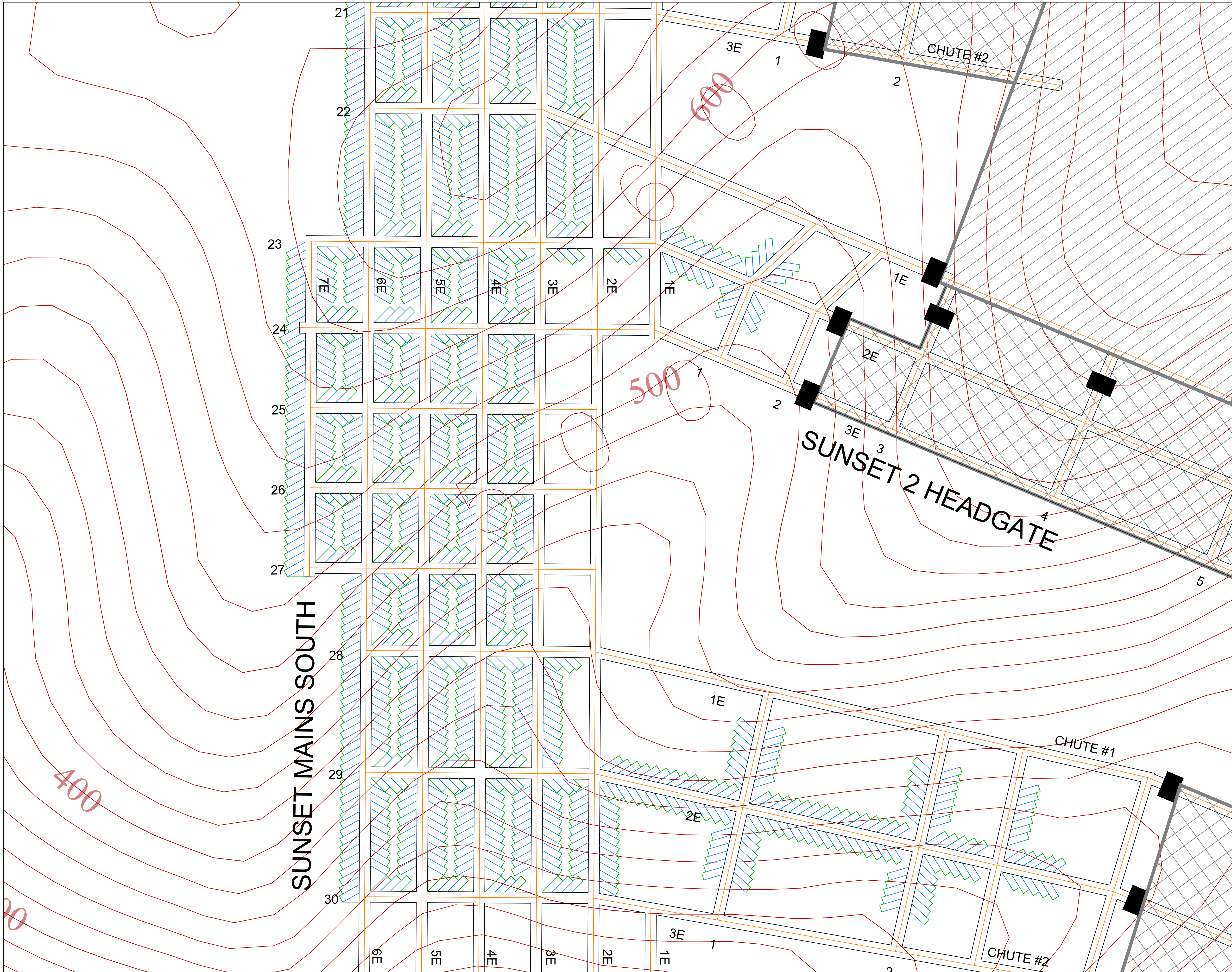
Pillar	w/h Ratio	Pillar Strength (psi)	Tributary Area Load (psi)	Safety Factor (SF)
Zone 1	7.5	3,433–3,715	537-742	4.6–6.9
Zone 2	7.5	3,433	725-903	3.8–4.7
Zone 3	7.5	3,407-3,763	955-1,008	3.4-3.9
Zone 4	7.5	3,559-3,720	920-1,069	3.3-4.0
Zone 5	7.5	3,477-3,762	935-1,088	3.2-4.0
Zone 6	7.5	3,006-3,473	993-1,107	2.7-3.5
Zone 7	7.2-7.5	2,955-3,930	738-994	3.3-5.3

5 PROPOSED PILLAR EXTRACTION PLANS

Based on the design standards stipulated in Section 4.1, the proposed pillar extraction plans are shown in Figures 5-1 to 5-4. For the purpose of assessing pillar stability during pillar extraction, the panel has been divided into seven separate zones. The zones were chosen to effectively assess the stability of the mains pillars when subjected to the retreating abutment load. The empirical assessment indicates that in all zones, the last line of pillars ahead of the retreating gob attain a SF of >1.4 under front abutment loading. These SFs are considered acceptable for the purpose of pillar extraction retreat. The results of the assessment are summarized in Table 5-1.

Table 5-1. Summary of the Stability for the Pillars in Sunset Mains South During Retreat

Pillar Line	Proportion of Abutment Load (R)	Pillar Strength (psi)	Abutment Load (psi)	Safety Factor (SF)
Zone 1	96%	3,407	1,422	2.4
Zone 2	93%	3,407	1,980	1.7
Zone 3	96%	3,559	2,282	1.6
Zone 4	99%	3,720	2,542	1.5
Zone 5	81%	3,116	2,231	1.4
Zone 6	90%	3,369	2,162	1.6
Zone 7	100%	3,659	1,765	2.1



N

0 150
Scale (ft)

Legend

480 E Seam Depth of Cover Contour (ft) C.I. = 20 ft

Faults

Previously Mined and Sealed

Pillar with Planned Extraction Cuts

Sunset Mains South
Pillar Extraction Plan
Crosscut 21 to Crosscut 30

ARCH West Elk

Figure 5-1

Job No.: 20-119
Scale: As Shown

Date: 11-27-2023
Drawn by: MBA/RJL

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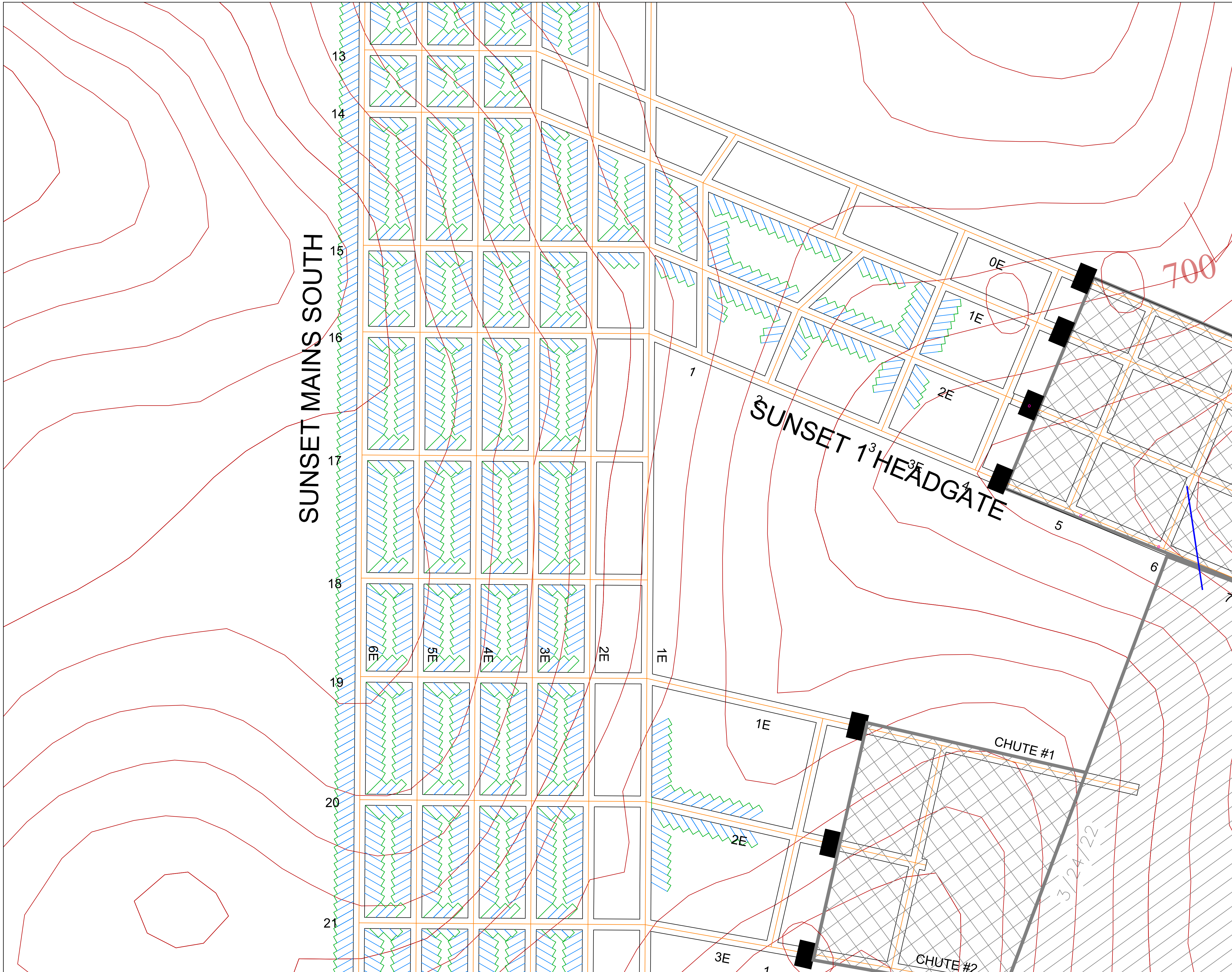
20-119 MCC [UGM - E Seam Mine Base Master_AAI_rjl.dwg Layout: Fig10_5-1]



Sunset Mains South
Pillar Extraction Plan
Crosscut 13 to Crosscut 21

ARCH West Elk

Figure 5-2

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Scale: As Shown

Date: 11-27-2023
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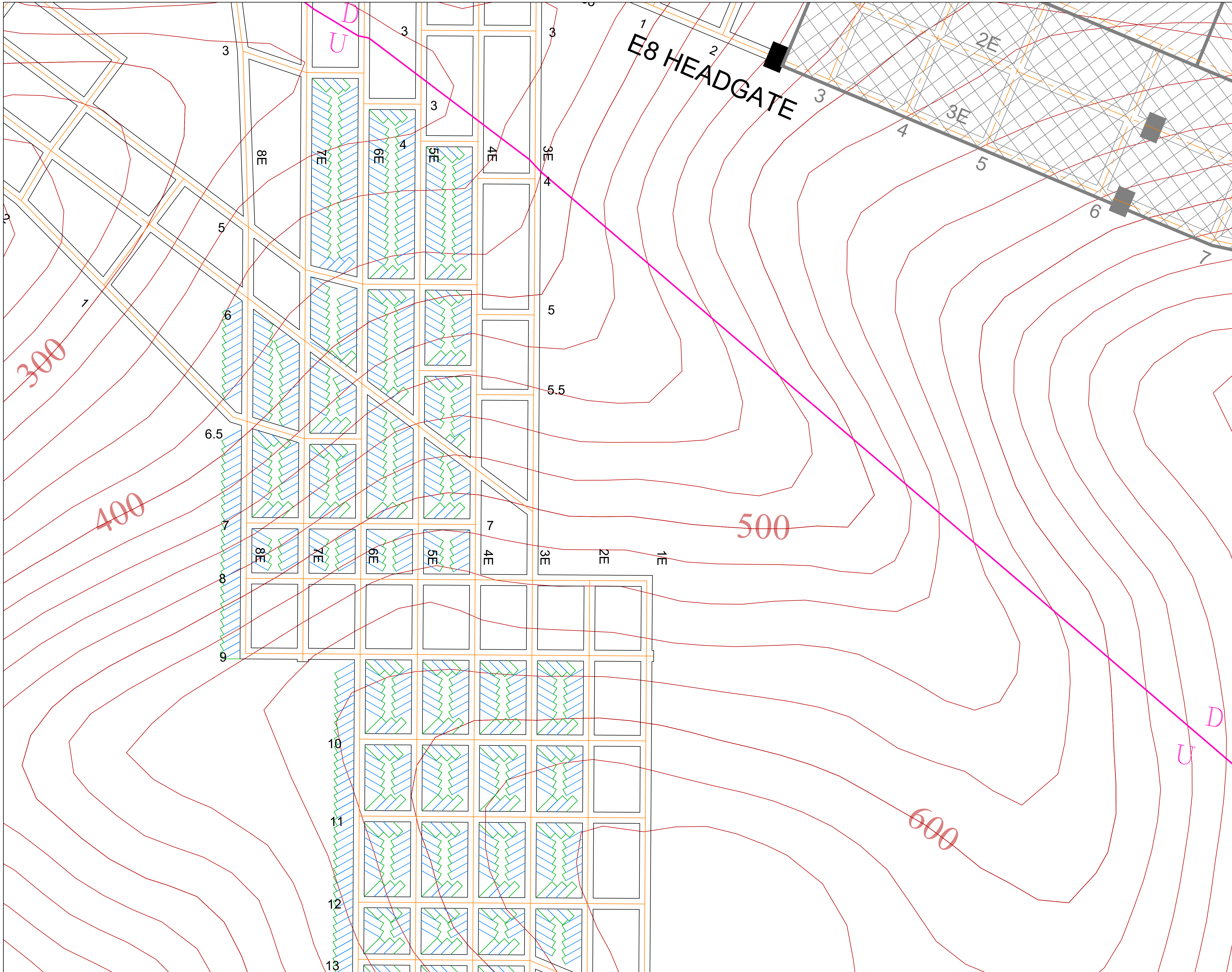

N

0 150
Scale (ft)

Legend

480 E Seam Depth of Cover Contour (ft) C.I. = 20 ft

Faults

Previously Mined and Sealed

Pillar with Planned Extraction Cuts

Sunset Mains South
Pillar Extraction Plan
Crosscut 3 to Crosscut 13

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Figure 5-3

Job No.: 20-119
Scale: As Shown

Date: 11-27-2023
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20-119 MCC [UGM - E Seam Mine Base Master_AAI_rjl.dwg Layout: Fig12_5-3]

6 NUMERICAL MODELING

Numerical modeling has been utilized in this assessment for the following two purposes: (1) to confirm the results of the empirical pillar stability assessment and (2) to estimate the maximum vertical surface subsidence following pillar extraction in the mains. The following sections provide the details of the modeling assessments.

6.1 Pillar Stability Analysis

To confirm the empirical pillar results, Agapito performed a seven-step LaModel analysis for the pillar extraction shown in Figures 6-1 to 6-7. For the modeling scenarios, the seven zones shown in Figure 4-4 were modeled for stress redistribution during the proposed pillar extraction retreat. These zones were selected to show the highest anticipated stress conditions during retreat.

LaModel is a nonlinear, boundary-element, displacement-discontinuity code for estimating stress, displacement, and yielding in tabular deposits such as coal. It can handle in-seam materials based on both linear and nonlinear mechanical (stress-strain) behaviors. The program performs an iterative procedure to solve a set of equations representing the stress-strain state of each element in a grid, emulating the mine geometry until a steady-state equilibrium is reached. Following an MSHA-recommended confined core approach to pillar strength, element properties are arranged so that the weakest elements are adjacent to the mine opening, with element strengths increasing into the solid coal. Strain-softening elements with increasing peak and residual strengths are employed to approximate elastic-plastic behaviors observed in pillars and provide close agreement with classical empirical pillar design methods.

The model input parameters were based on a previous calibration undertaken at the mine from in-mine instrumentation results (Agapito 2011). The calibration study, based on E Seam instrumentation, resulted in the LaModel input parameters shown in Table 6-1. It was concluded that a 1,180 psi in-situ coal strength was appropriately conservative for the E Seam, although the true in-situ strength may be higher.

Table 6-1. LAMODEL Parameters from Instrumentation Calibration

Parameter	Value
Mining height (ft)	10.0
In-situ coal strength, (psi)	1,180
Young's Modulus (E) (coal) (psi)	477,000
Poisson's ratio (ν) (coal)	0.34
Elastic Modulus (E) (rock mass) (psi)	1,840,000
Poisson's ratio (ν) (rock mass)	0.22
Lamination thickness (ft)	160
Gob stiffness (initial/final) (psi)	35,000/350,000

The results of the numerical modeling for the selected mining areas are summarized as follows:

Zone 1 (see Figure 6-1)

- The last line of pillars is subjected to a maximum abutment load of between 2,000 and 3,600 psi.
- The lack of any significant vertical stress imparted onto the life-of-mine roadways.
- The SFs of the last line of pillars all exceed 4.5.
- The SFs suggest the remnant pillars in the mains are not load bearing structures.
- The SFs of the pillars next to the life-of-mine roadway exceed 1.5.
- The SFs of the LW SS3 chute road pillars exceed 4.5.

Zone 2 (see Figure 6-2)

- The last line of pillars is subjected to a maximum abutment load of between 2,000 and 4,000 psi.
- The lack of any significant vertical stress imparted onto the life-of-mine roadways.
- The SFs of the last line of pillars range between 3.5 and 4.0.
- The SFs suggest the remnant pillars in the mains are not load bearing structures.
- The SFs of the pillars next to the life-of-mine roadway exceed 2.5.

Zone 3 (see Figure 6-3)

- The last line of pillars is subjected to a maximum abutment load of between 2,800 and 4,000 psi.
- The lack of any significant vertical stress imparted onto the life-of-mine roadways.
- The SFs of the last line of pillars range between 3.5 and 4.0.
- The SFs suggest the remnant pillars in the mains are not load bearing structures.
- The SFs of the pillars next to the life-of-mine roadway exceed 2.0.
- The SFs of the LW SS2 Headgate pillars exceed 4.0.

Zone 4 (see Figure 6-4)

- The last line of pillars is subjected to a maximum abutment load of between 2,400 and 4,000 psi.
- The lack of any significant vertical stress imparted onto the life-of-mine roadways.
- The SFs of the last line of pillars all exceed 4.5.
- The SFs suggest the remnant pillars in the mains are not load bearing structures.
- The SFs of the pillars next to the life-of-mine roadway exceed 2.0.

- The SFs of the LW SS2 chute road pillars exceed 4.5.

Zone 5 (see Figure 6-5)

- The last line of pillars is subjected to a maximum abutment load of between 3,200 and 4,000 psi.
- The lack of any significant vertical stress imparted onto the life-of-mine roadways.
- The SFs of the last line of pillars range between 2.0 and 3.0.
- The SFs suggest the remnant pillars in the mains are not load bearing structures.
- The SFs of the pillars next to the life-of-mine roadway exceed 1.5.
- The SFs of the LW SS1 Headgate pillars exceed 1.5.

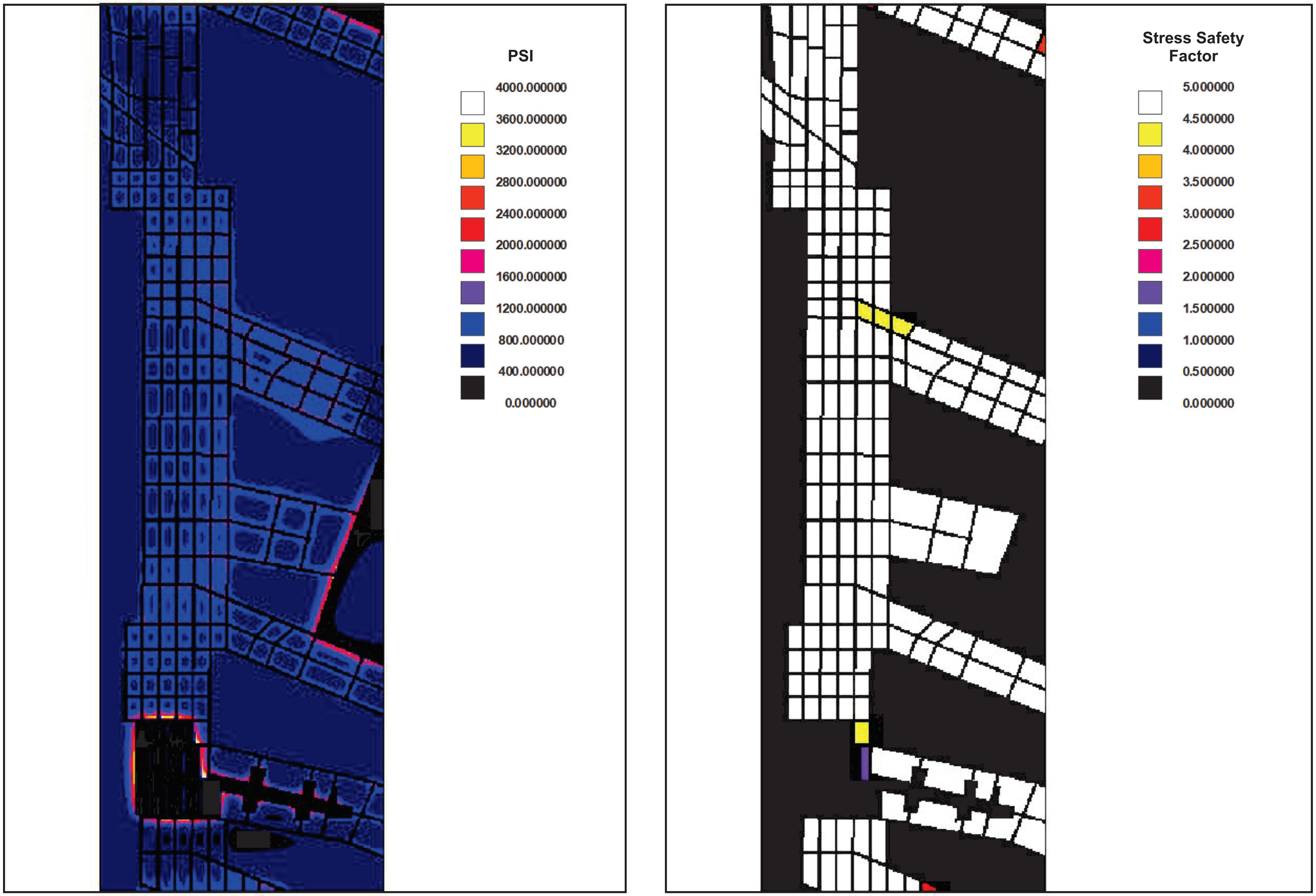
Zone 6 (see Figure 6-6)

- The last line of pillars is subjected to a maximum abutment load of between 3,200 and 4,000 psi.
- The lack of any significant vertical stress imparted onto the life-of-mine roadways.
- The SFs of the last line of pillars range between 3.0 and 3.5.
- The SFs suggest the remnant pillars in the mains are not load bearing structures.
- The SFs of the pillars next to the life-of-mine roadway exceed 1.5.

Zone 7 (see Figure 6-7)

- The last line of pillars is subjected to a maximum abutment load of between 1,600 and 2,400 psi.
- The lack of any significant vertical stress imparted onto the life-of-mine roadways.
- The SFs of the last line of pillars all exceed 4.5.
- The SFs suggest the remnant pillars in the mains are not load bearing structures.
- The SFs of the pillars next to the life-of-mine roadway exceed 3.5.

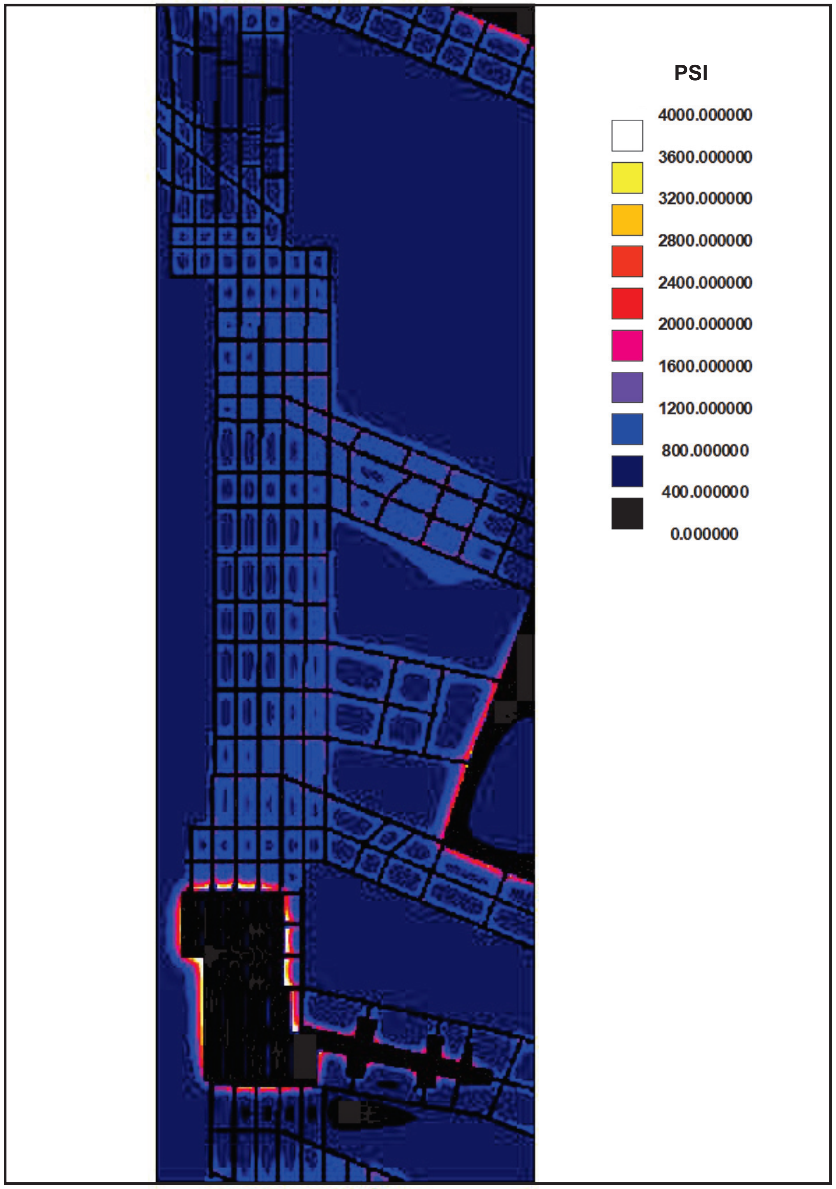
In summary, the modeling indicates that most of the abutment load is constrained to the last line of pillars and the SFs range between 2.0 and 4.5. Following extraction, the remnant pillars in the mains fail and are no longer load bearing structures. The proposed extraction plan isolates the life-of-mine roadway from any significant abutment loads, resulting in neighbouring pillar SFs in excess of 1.5. In essence, the numerical modeling outcomes support the results of the empirical assessment.



20-119 MCC [Lamodel_Zone1_Full Extr_12-26-23.cdr]mba/rjl(12-26-2023)

Vertical Stress **Pillar Safety Factor**

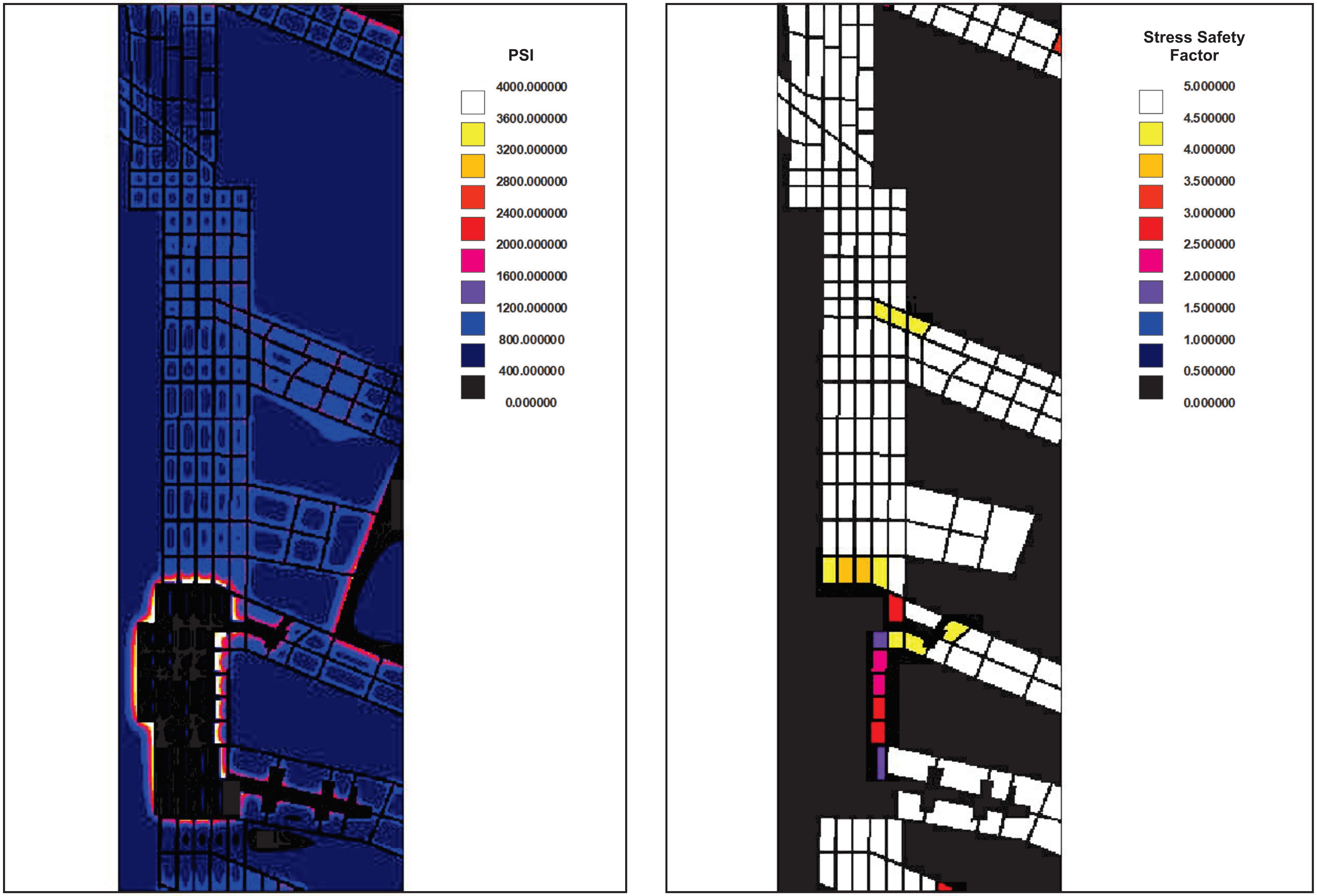
Figure 6-1. Lamodel Results for Zone 1 in Sunset Mains South



Vertical Stress

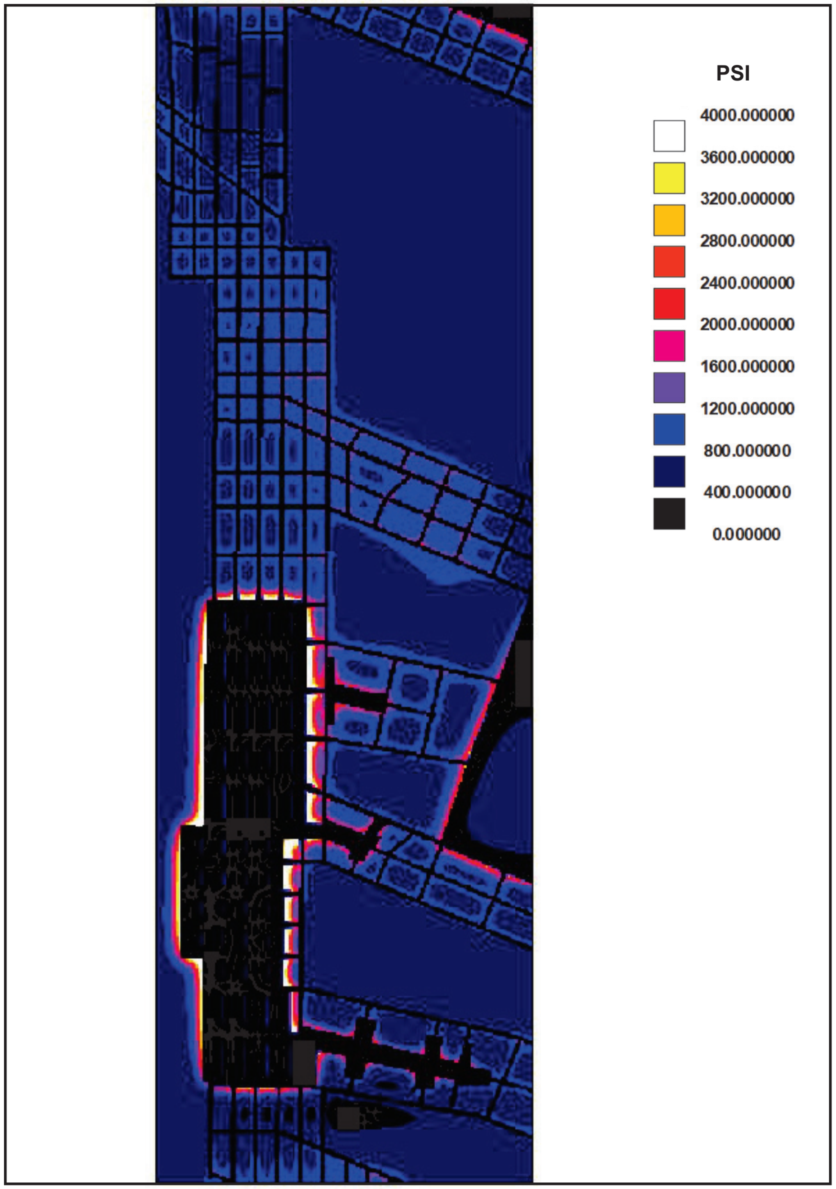
Pillar Safety Factor

Figure 6-2. Lamodel Results for Zone 2 in Sunset Mains South



Vertical Stress **Pillar Safety Factor**

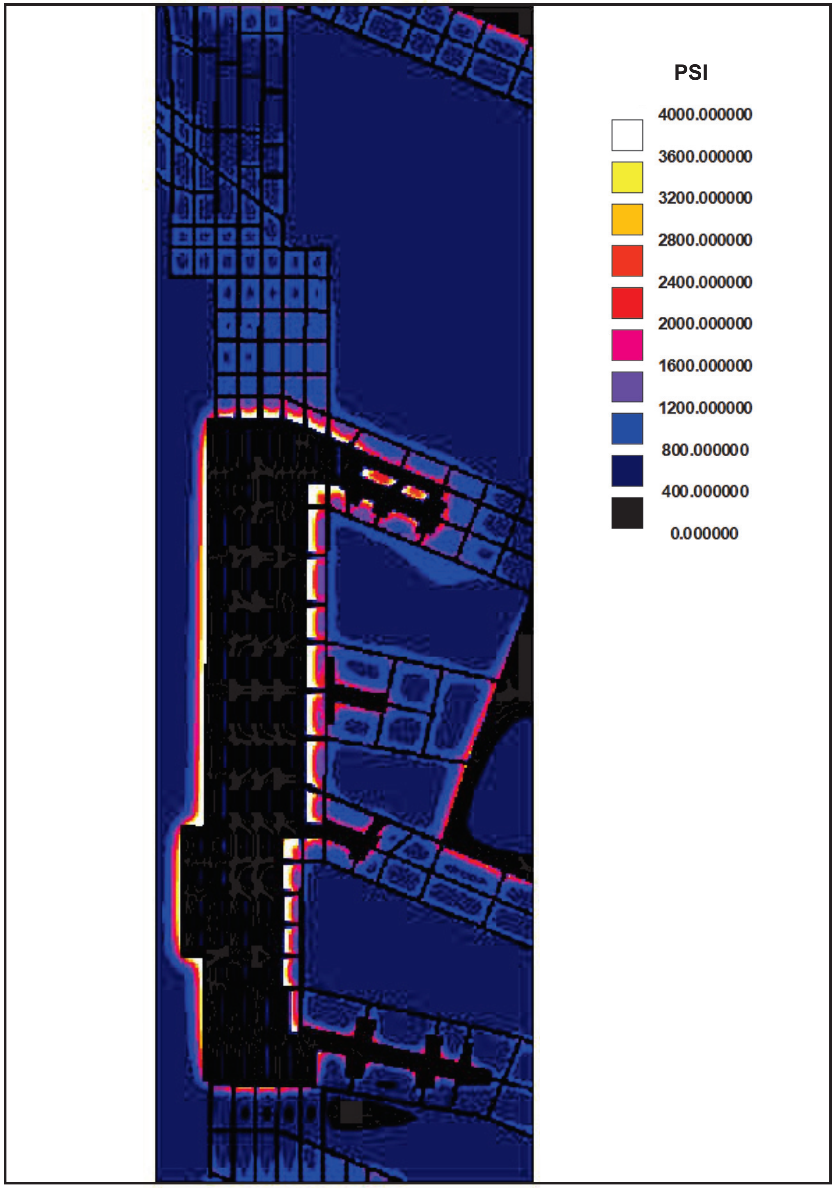
Figure 6-3. Lamodel Results for Zone 3 in Sunset Mains South



20-119 MCC [Lamodel_Zone 4_Full Extr_12-26-23.cdr]mba/rjl(12-26-2023)

Vertical Stress **Pillar Safety Factor**

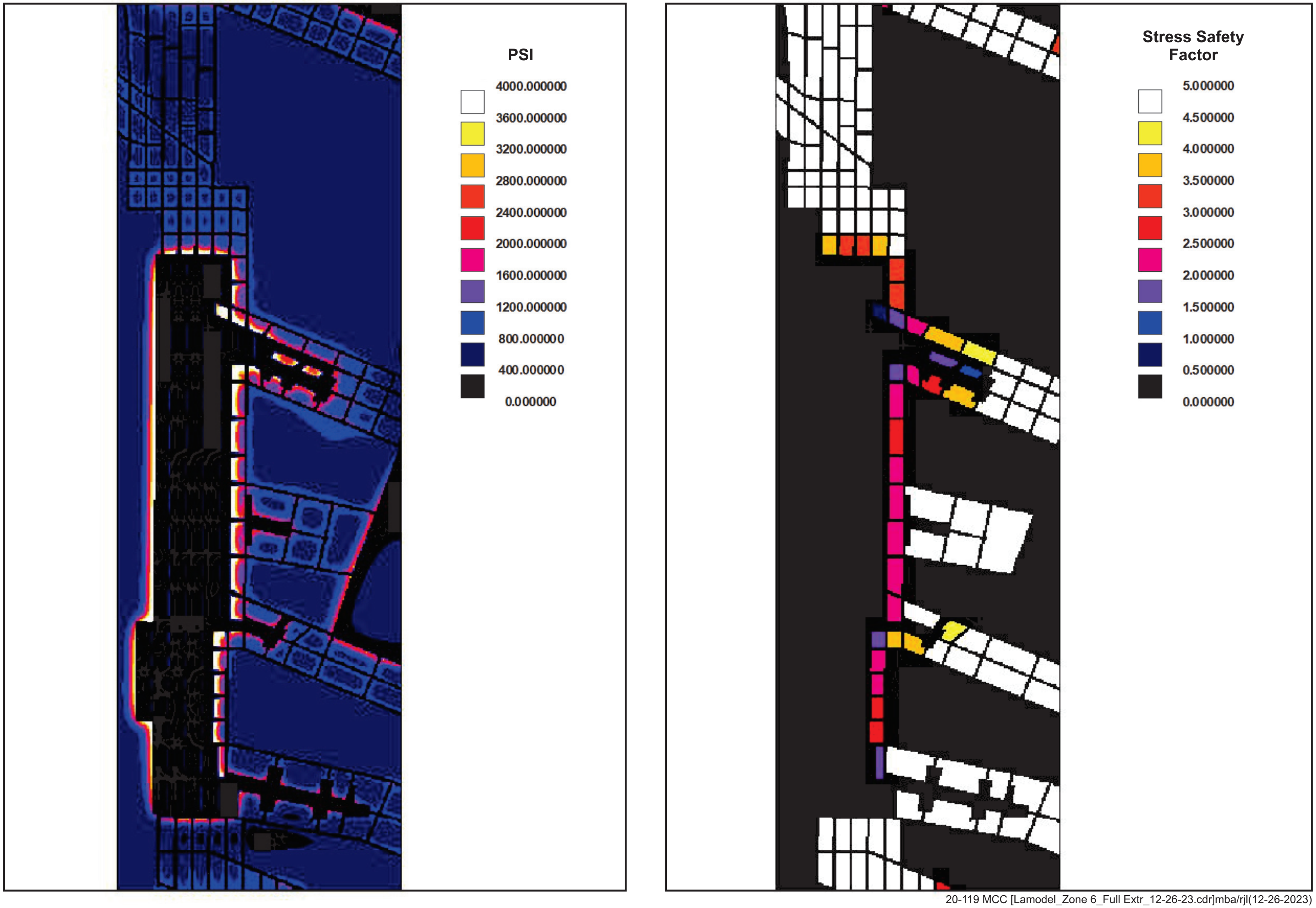
Figure 6-4. Lamodel Results for Zone 4 in Sunset Mains South



Vertical Stress

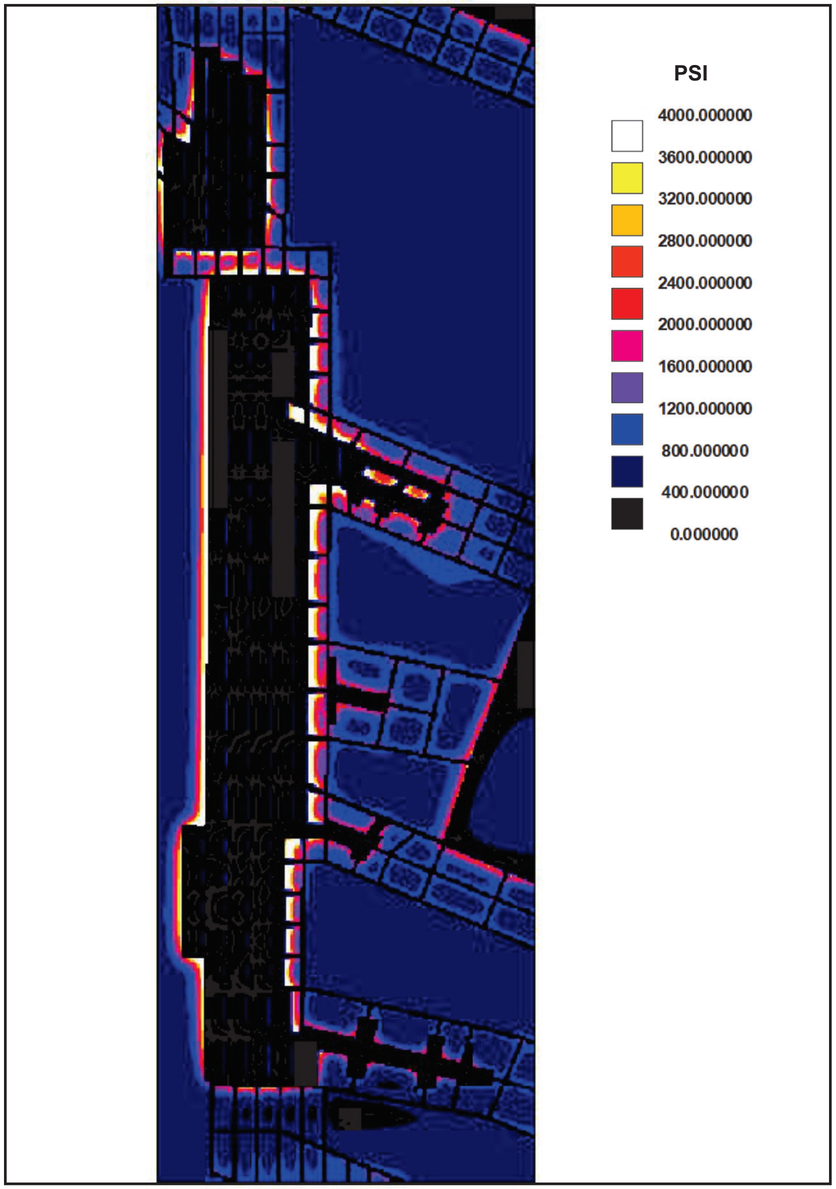
Pillar Safety Factor

Figure 6-5. Lamodel Results for Zone 5 in Sunset Mains South

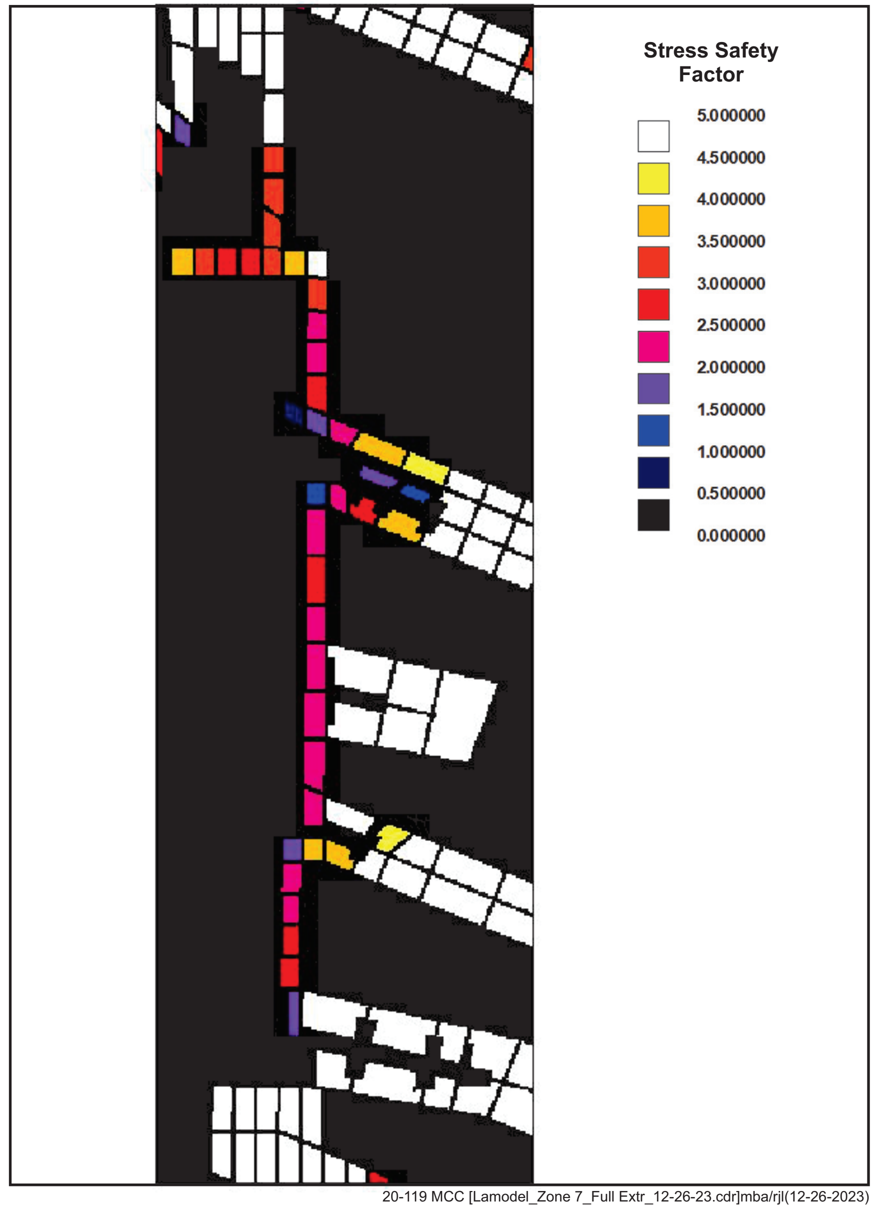


Vertical Stress **Pillar Safety Factor**

Figure 6-6. Lamodel Results for Zone 6 in Sunset Mains South



Vertical Stress



Pillar Safety Factor

Figure 6-7. Lamodel Results for Zone 7 in Sunset Mains South

6.2 Surface Subsidence Analysis

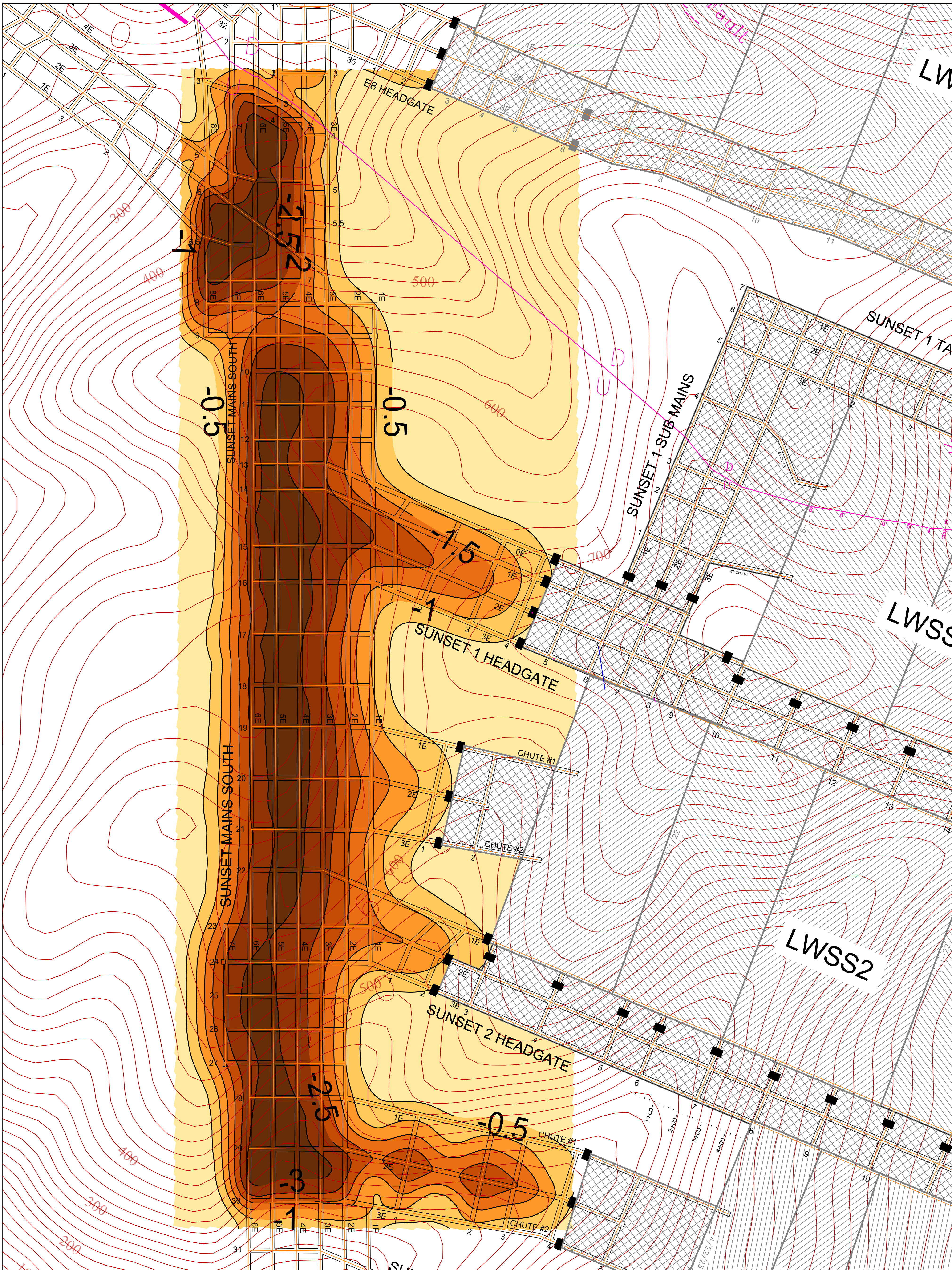
Agapito utilized the numerical modeling software program Surface Deformation Prediction System (SDPS) to assess the likely maximum surface subsidence resulting from the proposed pillar extraction plans. SDPS uses an integrated approach of calculating and predicting ground deformations above undermined areas. Based on empirical or site-specific regional parameters, the model quantifies a variety of ground deformation indices for both longwall and high extraction room-and-pillar mines, including subsidence profile, angle of draw, strain, slope, and curvature. The input parameters used in the model are summarized in Table 6-2.

Table 6-2. Input Parameters used in the SDPS Model

Location	Extraction Height (ft)	*Total Extraction (%)	Percent Hardrock (%)	Location of Subsidence Impacts
E Seam	10	100	50	Surface

Note: *total extrication includes remnant pillars

The modeling results indicate that a maximum of 3.5 ft of vertical surface subsidence is estimated following the proposed pillar extraction (see Figure 6-8). In terms of the extent of the subsidence trough, the subsidence does not extend beyond the footprint of the pillar extraction area.



Legend

480 E Seam Depth of Cover Contour (ft) C.I. = 20 ft

Faults

Downroll

Previously Mined and Sealed

N

0 450
Scale (ft)

Subsidence Key (ft)

-0.5 -1.0 -1.5 -2.0 -2.5 -3.0 -3.5

SDPS Modeling Results Showing Surface Subsidence Contours above the Proposed Pillar Extraction in Sunset Mains South

ARCH West Elk

Figure 6-8

Job No.: 20-119
Scale: As Shown

Date: 11-27-2023
Drawn by: JBW/RJL

Agapito Associates, Inc.
ENGINEERS & GEOLOGISTS

20-119 MCC [UGM - E Seam Mine Base Master_AAI_rjl.dwg Layout: FigX_6-8]

7 GROUND CONDITIONS ANTICIPATED DURING PILLAR EXTRACTION

The use of MRS enhances the safety of personnel by (1) providing a more effective ground support, (2) reducing worker exposure near the gob edge, and (3) eliminating a major cause of material handling injuries (Mark et al. 1995). Given the wide range in roof lithology, the ground conditions in Sunset Mains South are expected to be variable during lifting. In most areas, caving up to the rear of the MRS is anticipated, particularly in the areas where double lifting is utilized. General experience suggests that the highest geotechnical risk during pillar extraction when using the Christmas tree method is pushout removal and retreating up to intersections. With regard to pushout removal, the pushout should only be removed if the roof exhibits good competency and the operator is experienced in this manner. Particular attention should be given to intersections, as past experiences demonstrate that intersections, particularly 4-way intersections, are most prone to roof falls during pillar extraction.

In addition to the above, local geotechnical anomalies also require attention. Particular attention should be given to locally poor roof conditions, particularly in any joint and/or fault zones. These areas should be assessed by an appropriate mine official for the need of supplementary support prior to lifting. Poor ribs should be scaled to remove loose material prior to lifting. No extraction should be conducted from a roadway that has spalled to a width of >25 ft prior to lifting unless the area has first been inspected by an appropriate mine official and a remedial roof support strategy developed.

As mentioned previously, the gob edge is controlled by a set of two MRS placed on the gob side of the lift. The MRS should be kept as close as possible to the continuous miner during the lifts. As the lifts approach the outby intersection, another set of two MRS should be installed in the outby crosscut between the pillar being mined and the previously mined pillar in the same pillar row. In regard to the use of the MRS, the following guidance is critical in maintaining control of the gob:

- The MRS should be moved as often as possible to kept them as close as possible to the continuous miner to reduce the possibility of premature roof caving.
- When moving the MRS during pillar extraction, each MRS should be advanced no more than one-half the length of a canopy and pressurized against the roof before the second MRS canopy is lowered and trammed forward a similar distance and pressurised against the roof.
- The canopy should not be lowered more than necessary to clear roof obstructions during advancement.
- The MRS should be set against the roof with just enough force to make contact with the immediate roof.
- Lower setting pressures should be used in weak immediate roof. This is an important factor considering the amount of soft mudstone and shale logged in the immediate roof in the Sunset Mains.

In regard to the life-of-mine roadways, accepting that the modeling indicates roadways should be isolated from any large surges in vertical stress, it is nonetheless recommended that the adequacy of the existing roof support is assessed. Prior to pillar extraction, the roadways should be inspected and if any areas are deemed necessary, re-supported to an adequate level. Continued monitoring of the life-of-mine roadway during pillar extraction is necessary to confirm the roadway remains serviceable. If significant changes to the roadway are observed, modifications to the pillar extraction process should be evaluated.

8 CONCLUSION

Agapito has considered the typical pillar extraction approaches and methods best suited for the Sunset Mains South pillars between crosscuts 2 and 30. Based on the considerations listed below, the full extraction approach using the Christmas tree extraction method has been recommended.

- Pillar extraction mining will begin at crosscut 30.
- Pillar extraction will stop one crosscut outby of the BF Fault at the outby end of Sunset Mains South.
- In order to maintain a bleeder system around areas of gob and to inspect inby seals, a single life-of-mine roadway must remain travelable during and after pillar extraction activities.
- The pillars will be extracted in their current state and, as such, additional development and roof bolting should not be considered for preparation in the pillar extraction plan.
- To avoid unstable remanent pillars, the pillar extraction should aim to mine as much of the pillar as safely and practically possible.
- If a large percentage of the pillar remains following extraction, the remaining pillar should be classed as long-term stable.

Empirical and numerical assessments indicate that the pillars in Sunset Mains South are suitable for full extraction using the Christmas tree method. The mains outcomes of the assessment are as follows:

- The existing pillars are adequately sized to support the front abutment load to a satisfactory SF.
- The remnant pillars that will remain following extraction will not be capable of bearing any significant loads.
- The remaining pillars in the gateroads and chute roads will remain long-term stable with SFs in excess of 1.5.
- The pillars next to the life-of-mine roadways have been assessed as long-term stable with SFs in excess of 1.5.
- The maximum surface subsidence associated with the pillar extraction mining is estimated to be 3.5 ft.

Variable roof and rib conditions are anticipated during pillar extraction activities, and the presence of local geotechnical anomalies should be examined and evaluated. Particular attention should be given to the roof conditions prior to pushout removal and prior to retreating up to an intersection. Prior to lifting, an appropriate mine official should examine the roof and ribs and, if need be, a remedial support strategy implemented. These potential areas include locally poor roof, joint zones, faults, excessive rib spall, and/or overwide roadways.

Lastly, the gob edge should be controlled by a set of two MRS placed on the gob side of the lift. The MRS should be kept as close as possible to the continuous miner during the lifts. As the lifts approach the outby intersection, another set of two MRS should be installed in the mouth of the intersection.

9 REFERENCES

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