20-117

GEOTECHNICAL ASSESSMENT FOR THE PURPOSE OF PARTIAL PILLAR EXTRACTION BETWEEN 2 AND 29 CROSSCUTS IN SUNSET MAINS

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Geotechnical Assessment for the Purpose of Partial Pillar Extraction between 2 and 29 Crosscuts in Sunset Mains

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1 INTRODUCTION

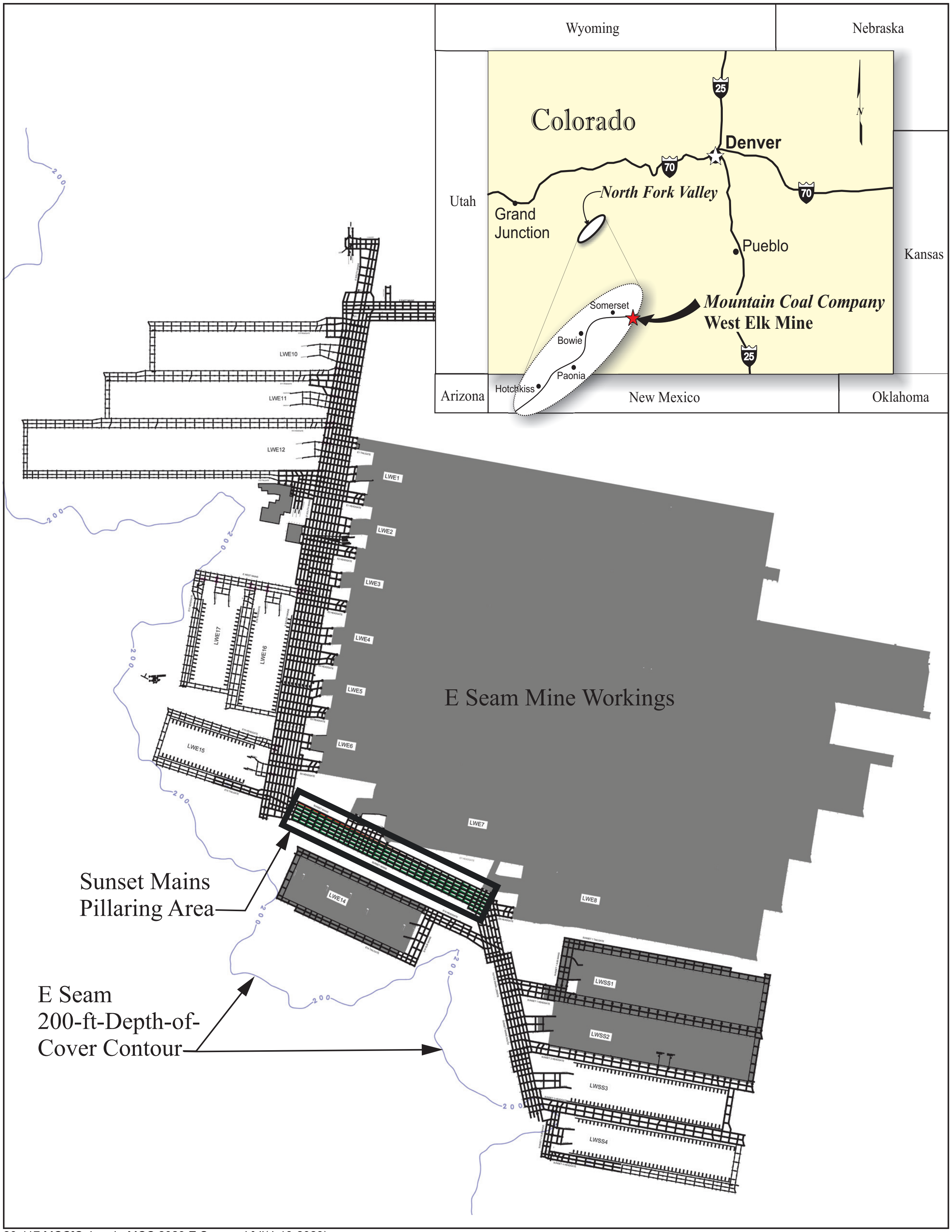
This report provides the assessment of the geotechnical parameters associated with partial secondary pillar extraction in the E Seam in Sunset Mains between crosscuts 2 and 29 (see Figure 1-1). Following discussions with Arch West Elk (West Elk Mine), a comprehensive review of the geotechnical environment, 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 mining will begin at crosscut 29.
- For the purpose of this assessment, it is assumed that pillar extraction will stop at 2 crosscut at the outby end of Sunset Mains.
- In order to maintain a bleeder system around areas of gob and to inspect inby seals, two life-of-mine roadways must remain travelable during and after pillar extraction activities.
- The mine plans to develop two additional rows of pillars along the south side of Sunset Mains between crosscuts 2 and 13, and crosscuts 16 and 29 (see Figure 1-2).
- 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.

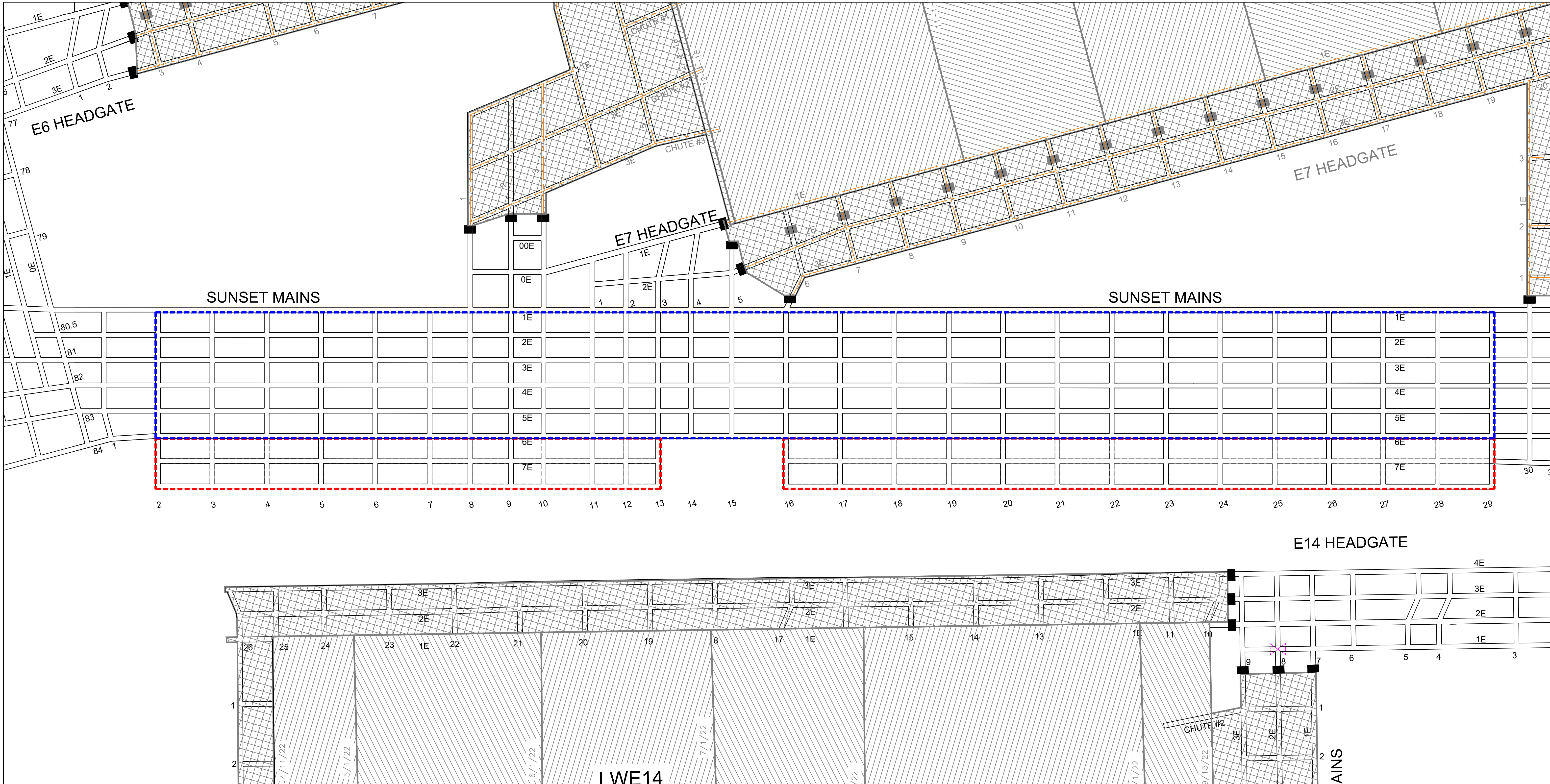
The pillar stability assessment utilized industry standard empirical pillar design formula and criteria. The numerical model program LaModel was used to assess the detailed stress environment during pillar extraction following extraction of the pillars in the panel.

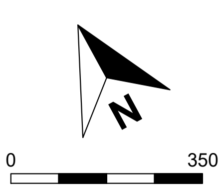
Surface subsidence modeling was carried out using the Surface Deformation Prediction System (SDPS) to estimate maximum surface displacement following pillar extraction in the panel.



20-117 MCC[Colorado-MCC 2023 E Seam.cdr]rjl(4-13-2023)

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





Legend

Pillars Inside Blue Dashed Line are Existing Development

Pillars Inside Red Dashed Line are Proposed Development

Copy of Current Mine Plan Showing Existing and Proposed Developement in Sunset Mains

ARCH West Elk

Figure 1-2

Job No.: 20-117
Scale: As Shown

Date: 4-22-2024
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20-117 MCC [SSM Extraction Proposed Modeling Sections w MBA Insert_Formatted.dwg Layout: AAI Fig 1-2]

2 Geotechnical Environment

Boreholes indicate that the immediate roof lithology (first 10 feet [ft]) of the Sunset Mains is comprised of alternating units of soft to medium hard mudstone and shale, hard siltstone, and fine-grained sandstone. Of these units, the mudstone and shale account for between 50% and 80% of the lithology. The overburden is comprised of units of coal, mudstone, shale, siltstone, and sandstone, with the majority of the lithology being dominated by the siltstone and sandstone units.

The geological structure information provided by the West Elk Mine indicates a major normal fault located to the south and trending parallel with the Sunset Mains (see Figure 2-1). The offsets for the fault are indicated to range between 36 and 70 ft. The only geological structure located within Sunset Mains is a small normal fault mapped between 20 and 23 crosscuts in entries 1E and 2E (see Figure 2-1). The throw of the fault is indicated to range between 2 and 3 ft.

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 44 and 52, which indicates weak to moderate roof competency.

The depth of cover ranges between 400 ft at the inby end of the panel to 830 ft around crosscut 19, and, from there, ranges between 600 and 700 ft outby to crosscut 1 (see Figure 2-1). Despite this wide range, most of the overburden is confined to a thickness of between 550 and 700 ft. 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 that 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 in view of the amount of surrounding longwall gob, it is anticipated that the horizontal stress will have a negligible effect on ground conditions during pillar extraction.

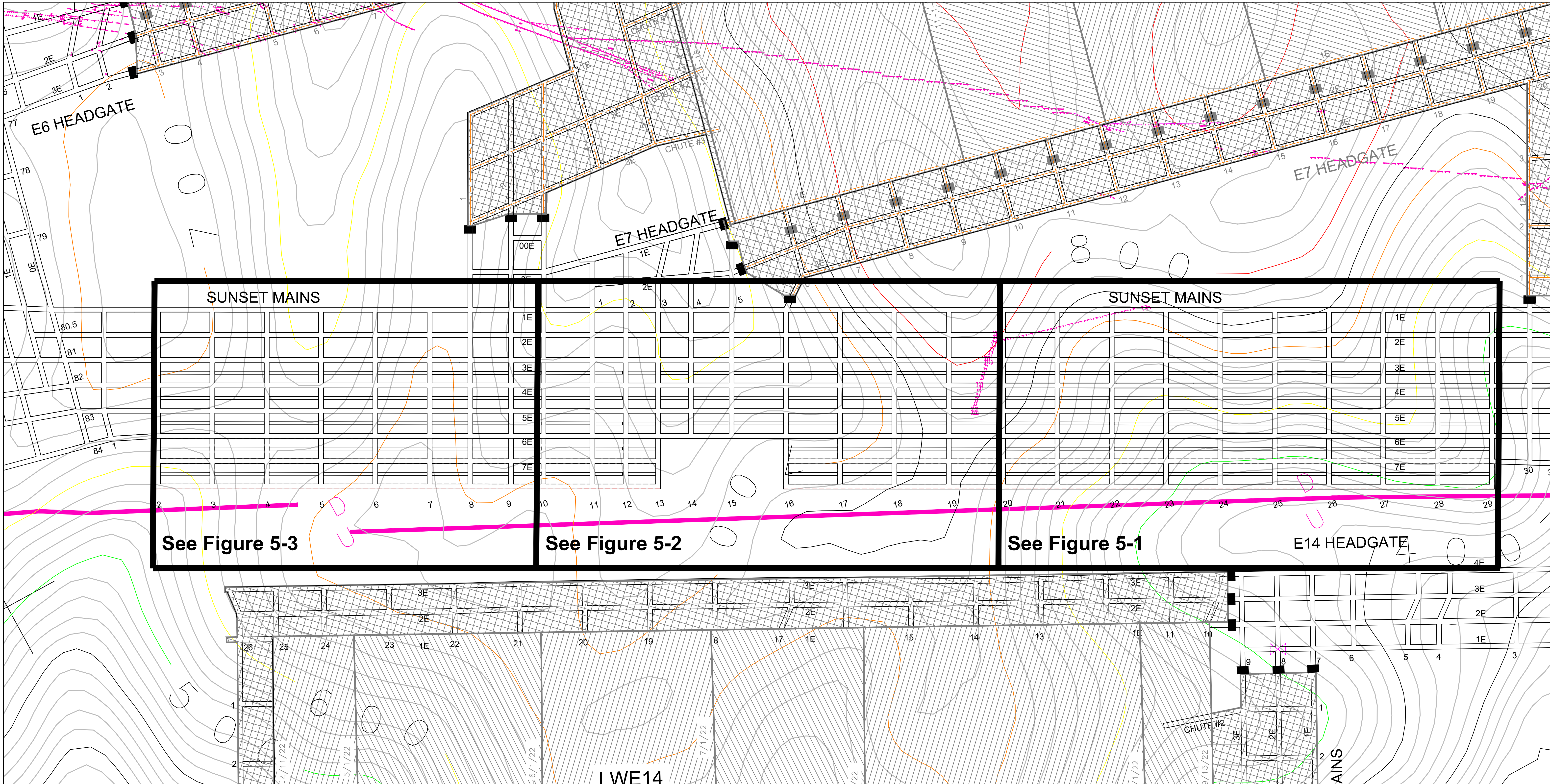
As shown in Figure 2-1, the pillars in Sunset Mains are surrounded by previously extracted longwall gob to the north and south of the panel. The gob from LW E14 extraction will be located more than 524 ft from the nearest pillars following the proposed development, while the gob from LW E7 extraction is located 300 ft away from its nearest point. Measured relationships between depth of cover and the lateral extent of abutment loading indicate that the pillars in Sunset Mains are located a sufficient distance away from the gobs to be considered outside the reach of the abutment loads. 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):

$$D = 9.3\sqrt{H}$$

This relationship suggests that any measurable abutment loads from LW E14 and LW E7 will be limited to a lateral extent of 250 and 270 ft, respectively.

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, the mine has indicated that the roadways were typically supported with a four to five ⅞-inch, Grade 75 partially encapsulated bolts every 5 ft. To date, there does not appear to have been any major roof falls in the travelways, which suggests that the installed roof support density was sufficient for the purpose of maintaining roof stability. It is assumed that the planned development in the panel will utilize a similar roof support density.



Legend

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

Faults

Previously Mined and Sealed

0 350
Scale (ft)

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

ARCH West Elk

Figure 2-1

Job No.: 20-117
Scale: As Shown

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20-117 MCC [SSM Extraction Proposed Modeling Sections w MBA Insert_Formatted.dwg Layout: AAI Fig 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).

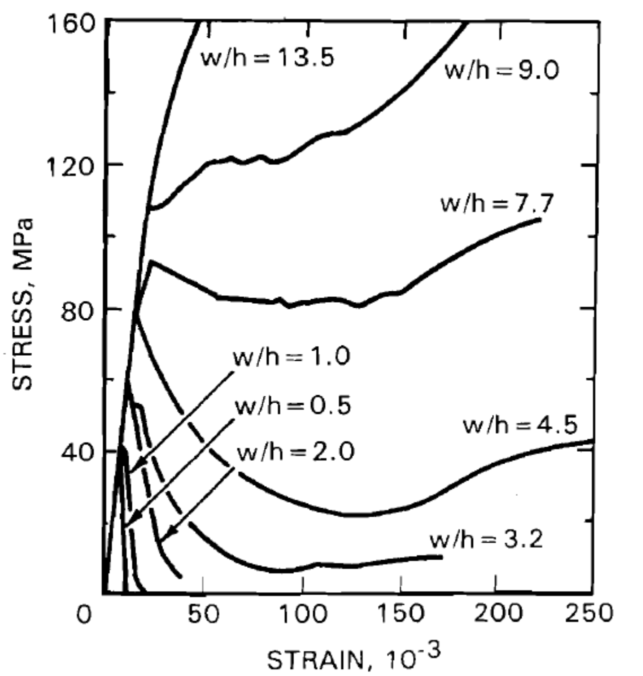


Figure 3-1. Complete Stress-Strain Curves for Indian Coal Specimens Showing Increasing Residual Strength with Increasing w/h Ratio (Das 1986)

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, 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 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 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 the travel-ways is shown in Figure 3-3.

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 ribline. 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 12.5-ft-wide lifts.

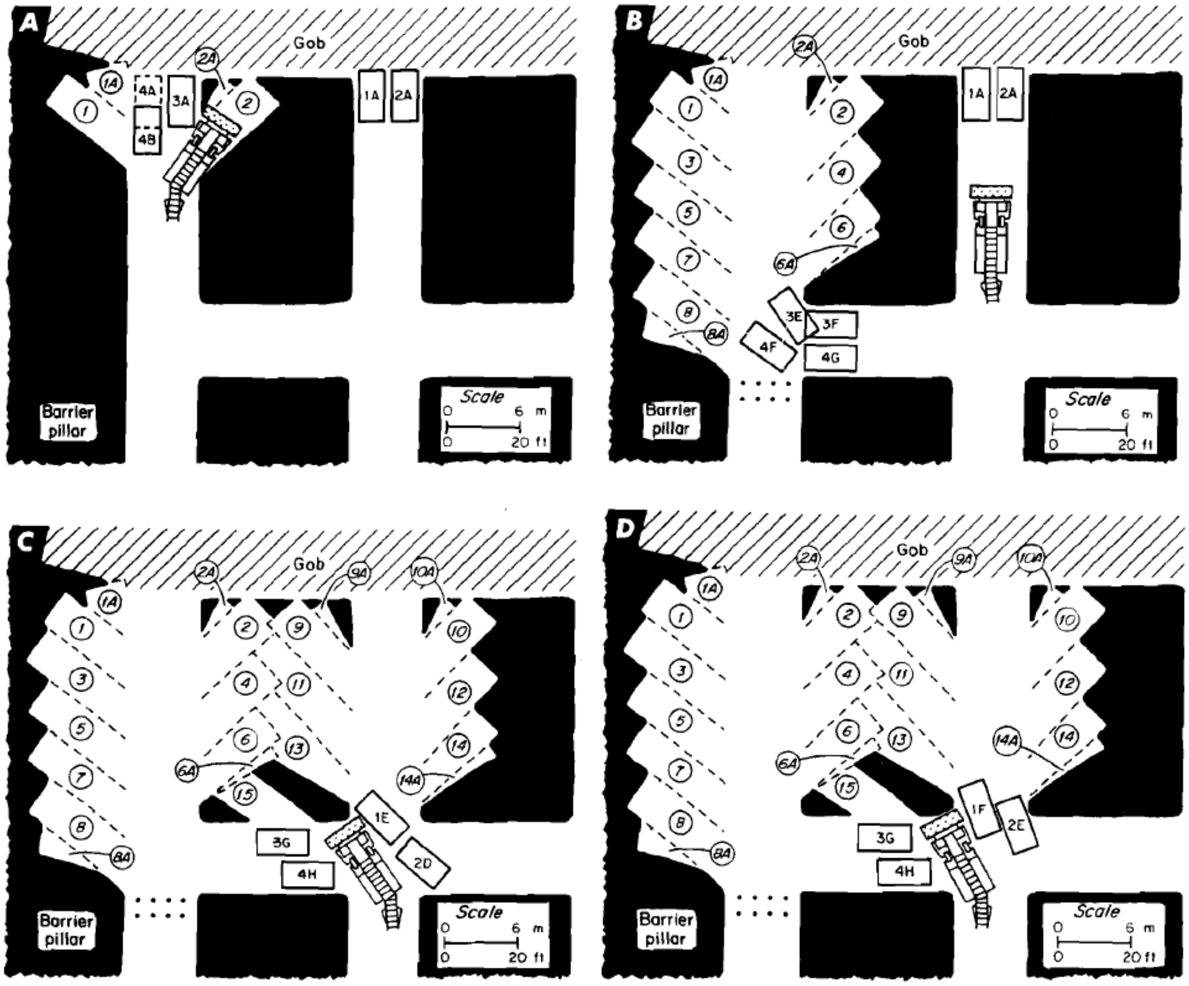
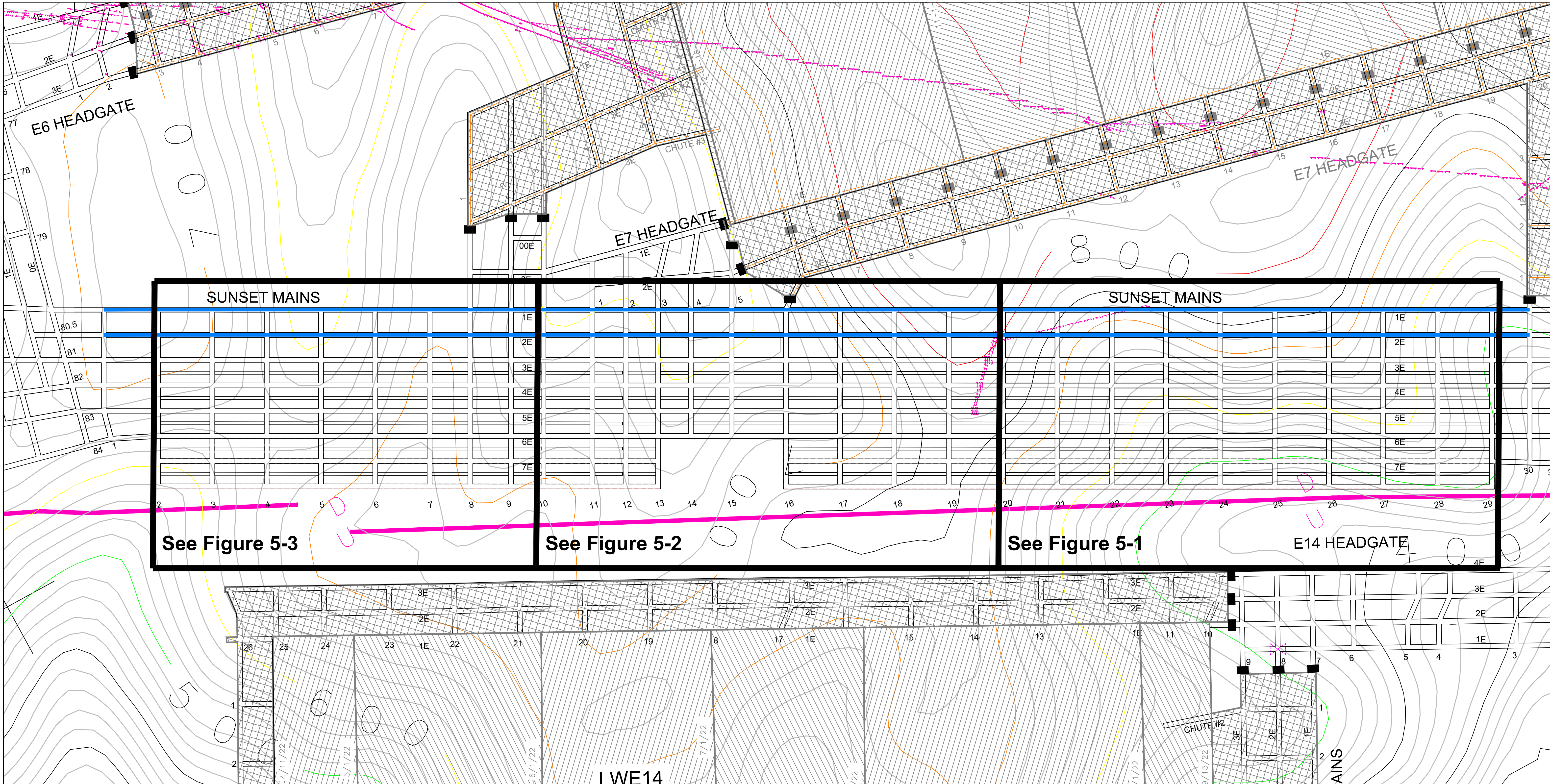


Figure 3-2. Cutting Sequence for Outside-Lift Christmas Tree Method (Mark et al. 1995)



N

0 350
Scale (ft)

Legend

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

Faults

Previously Mined and Sealed

Travelway

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

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Figure 3-3

Job No.: 20-117
Scale: As Shown

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20-117 MCC [SSM Extraction Proposed Modeling Sections w MBA Insert_Formatted.dwg Layout: AAI Fig 3-3]

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:

- Following extraction of the mains pillars (including the newly formed 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.
- Following pillar extraction, the pillars next to the life-of-mine roadways shown in Figure 3-3 must retain a minimum SF of 1.5.
- 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 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:

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

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):

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

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 (°)

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 21°. In the case of the E Seam, an abutment angle of 21° 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):

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

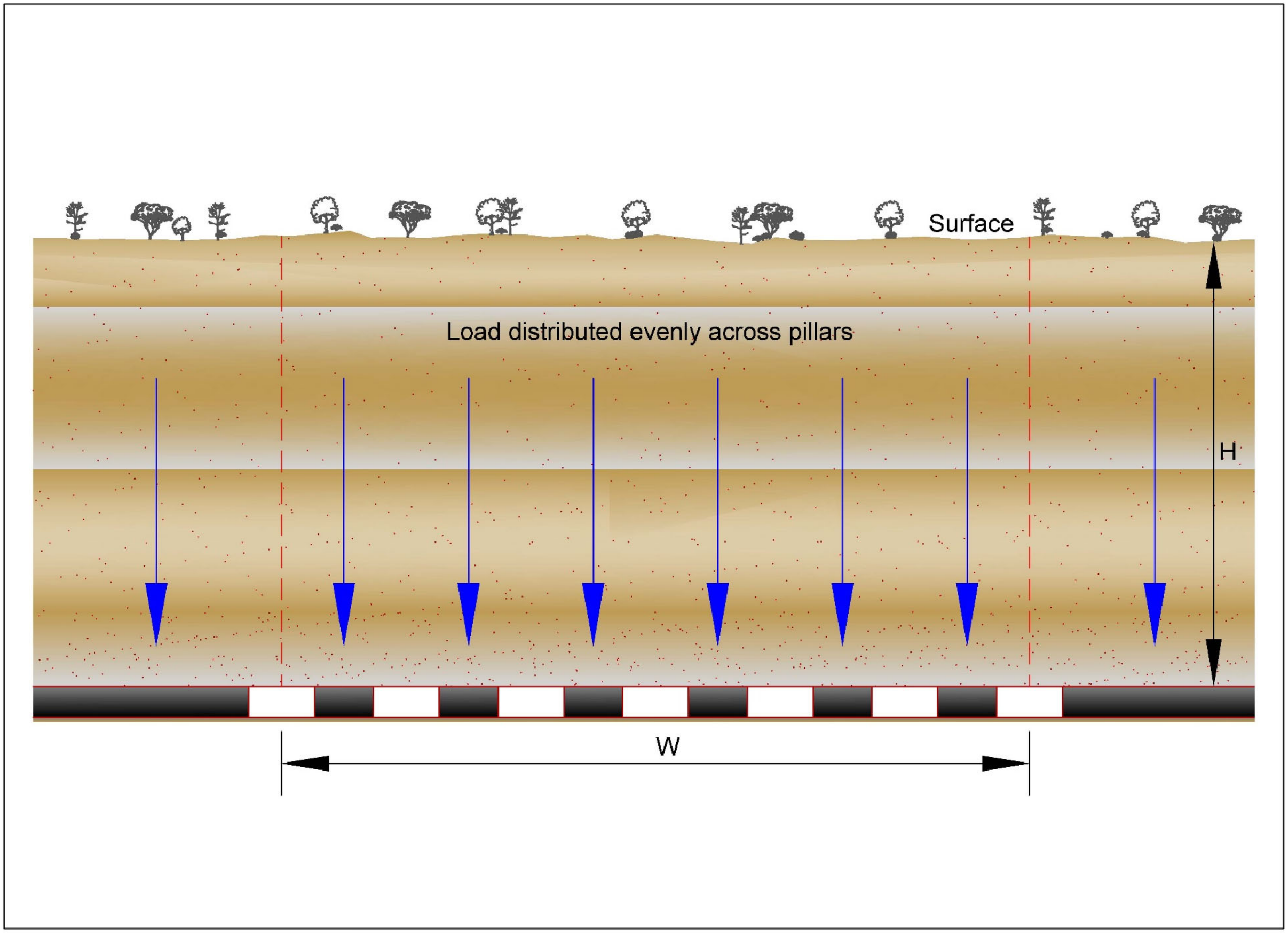
Furthermore, the proportion of the abutment load (R) that is applied to neighboring pillars and/or barriers for a single front-abutment loading scenario is calculated using the equation presented by Mark (1990):

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

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.

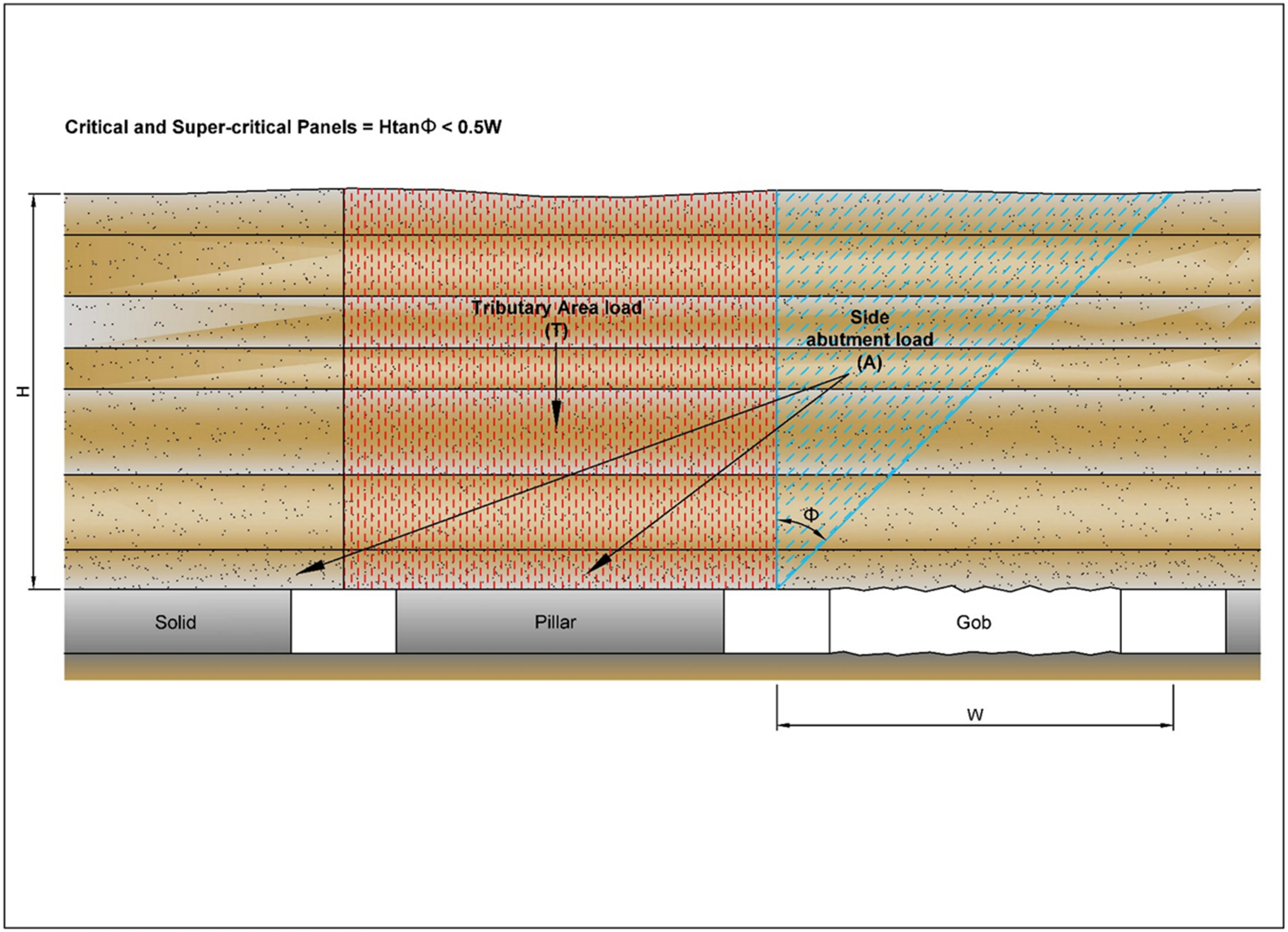
4.5 Condition of Existing Pillars in Sunset Mains

The condition of the existing pillars in the Sunset Mains has been assessed utilizing the above empirical methodologies. The pillar extraction areas have been divided up into six 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.



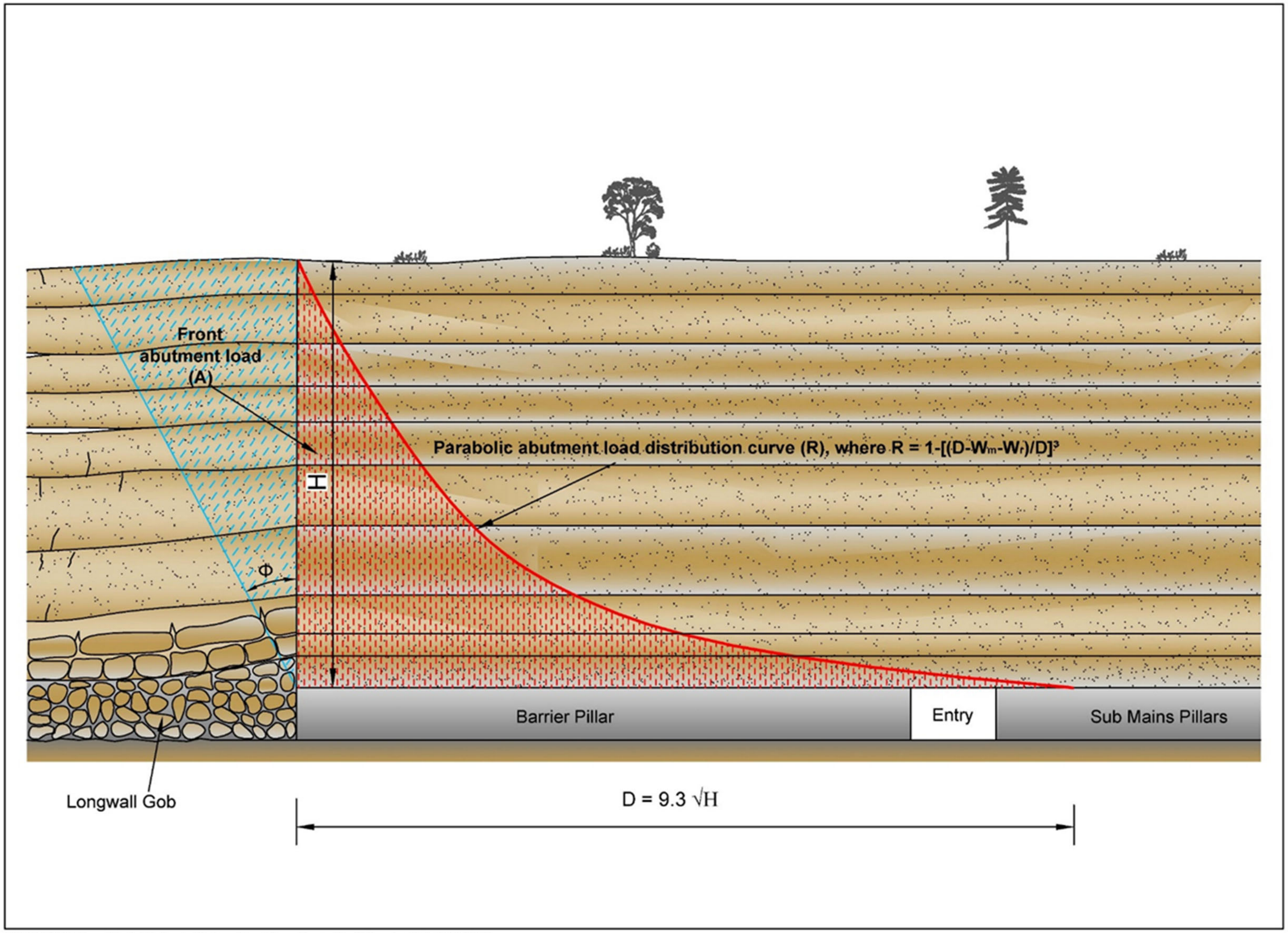
20-108 MCC[Tributary Area Loading During Dev.dwg]RS_rjl(2-7-2022)

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



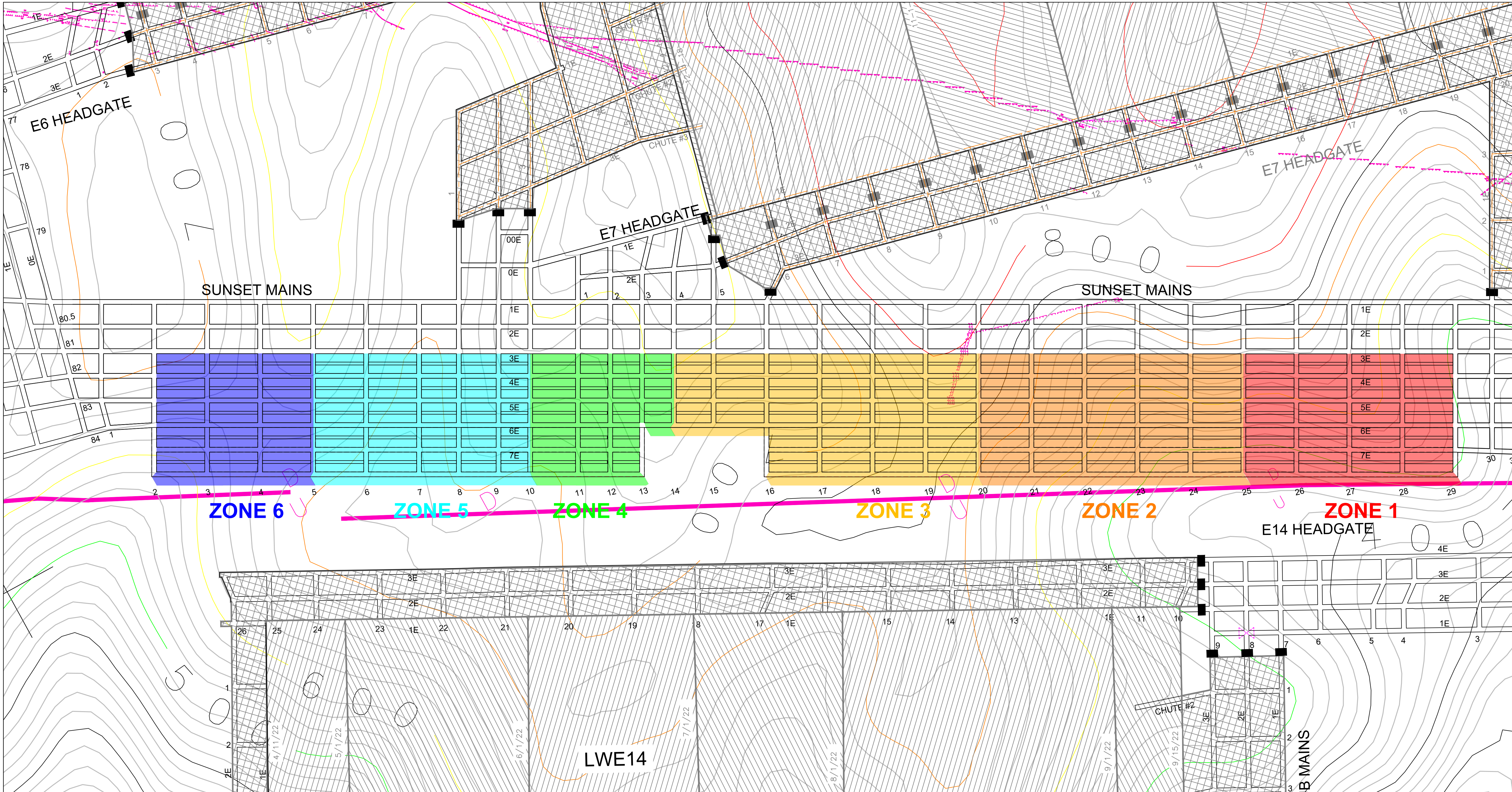
20-108 MCC[Schematic of Super-critical Abutment Loads]RS_rjl(2-1-2022)

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



N

0 350
Scale (ft)

Legend

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

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Figure 4-4

Job No.: 20-117
Scale: As Shown

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20-117 MCC [SSM Extraction Proposed Modeling Sections w MBA Insert_Formatted.dwg Layout: AAI Fig 4-4]

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

Extraction Zone	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	520 - 730	182	75	669
Zone 2	10	18	480 - 780	182	75	669
Zone 3	10	18	730 - 830	182	75	669
Zone 4	10	18	700	102 - 162	75	669
Zone 5	10	18	609 - 720	101.6 - 182	75	669
Zone 6	10	18	700	182	75	669

The results of the assessment for each zone indicate that all existing pillars have a w/h ratio of 7.5 and the SFs range between 2.9 and 5.1. The results are summarized in Table 4-2.

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

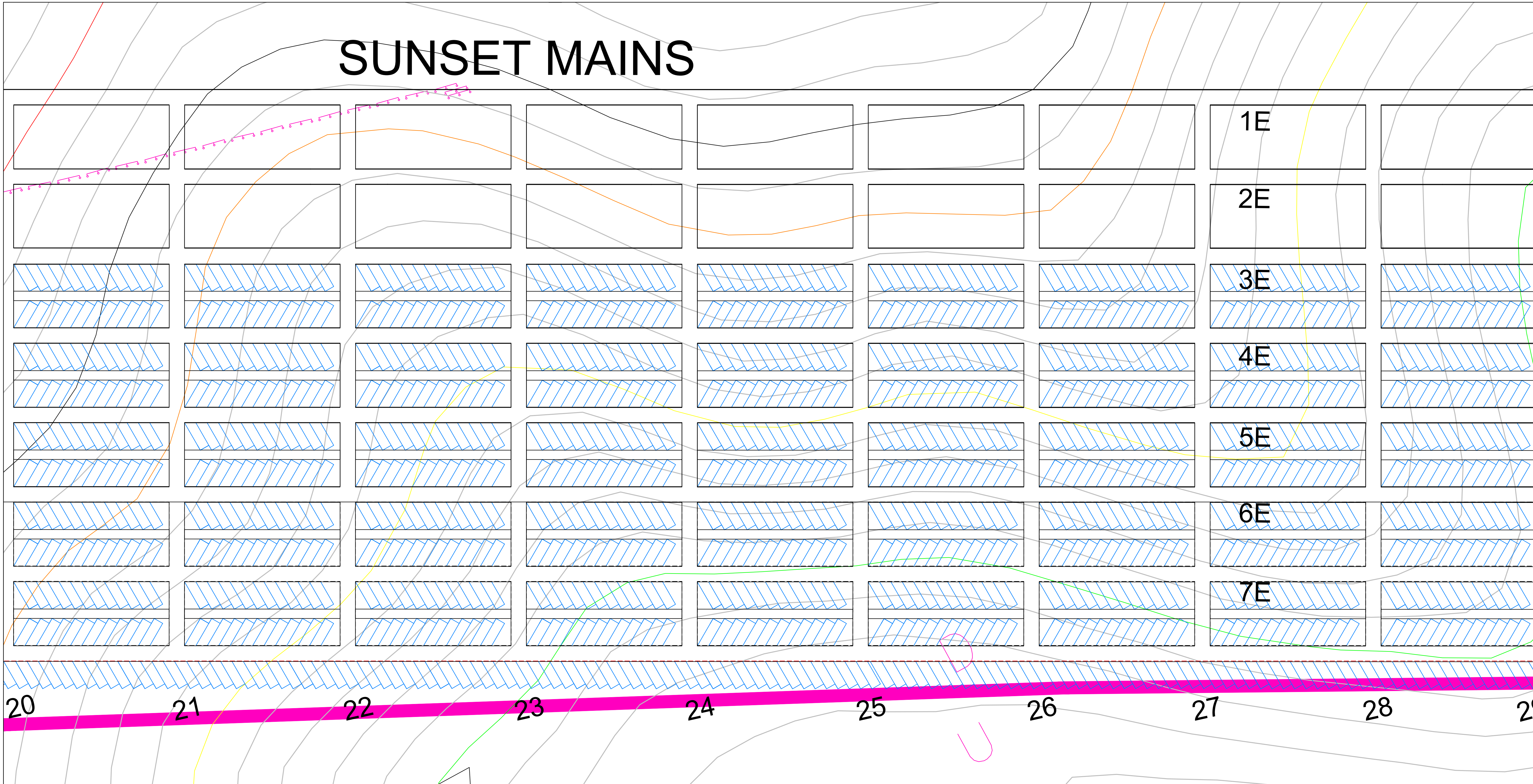
Extraction Zone	w/h Ratio	Pillar Strength (psi)	Tributary Area Load (psi)	Safety Factor (SF)
Zone 1	7.5	3,720	797 - 1,119	3.3 - 4.7
Zone 2	7.5	3,720	736 - 1,196	3.1 - 5.1
Zone 3	7.5	3,720	1,119 - 1,196	3.1 - 3.3
Zone 4	7.5	3,328 - 3,659	930 - 1,100	3.0 - 3.9
Zone 5	7.5	3,324 - 3,720	935 - 1,133	2.9 - 4.0
Zone 6	7.5	3,720	920 - 1,058	3.5 - 4.0

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 six 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 >1.5 under front abutment loading. The only exceptions to this are (1) the 3E to 4E pillar between 19 and 20 crosscuts in Zone 3, and (2) the 7E to 8E pillar between 12 and 13 crosscuts in Zone 4, where both pillars attain a SF of 1.4. Because these pillars are close to the minimum standard (i.e., SF of 1.5), they have been further assessed in the numerical modeling section. All other pillars 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 During Retreat

Extraction Zone	Proportion of Abutment Load (R)	Pillar Strength (psi)	Abutment Load (psi)	Safety Factor (SF)
Zone 1	77% - 88%	3720.00	705 - 1,066	1.8 - 2.5
Zone 2	74% - 84%	3720.00	613 - 1,311	1.5 - 2.8
Zone 3	74% - 75%	3720.00	1,258 - 1,390	1.4 - 1.6
Zone 4	76% - 80%	3,328 - 3,659	1,141 - 1,524	1.5 - 2.0
Zone 5	76% - 79%	3,324 - 3,720	1,179 - 1,649	1.4 - 2.0
Zone 6	76% - 79%	3720.00	1,141 - 1,507	1.7 - 2.0



N

0 110
Scale (ft)

Legend

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

Faults

Previously Mined and Sealed

Pillar with Planned Extraction Cuts

Sunset Mains
Pillar Extraction Plan
Crosscut 20 to Crosscut 29

ARCH West Elk

Figure 5-1

Job No.: 20-117
Scale: As Shown

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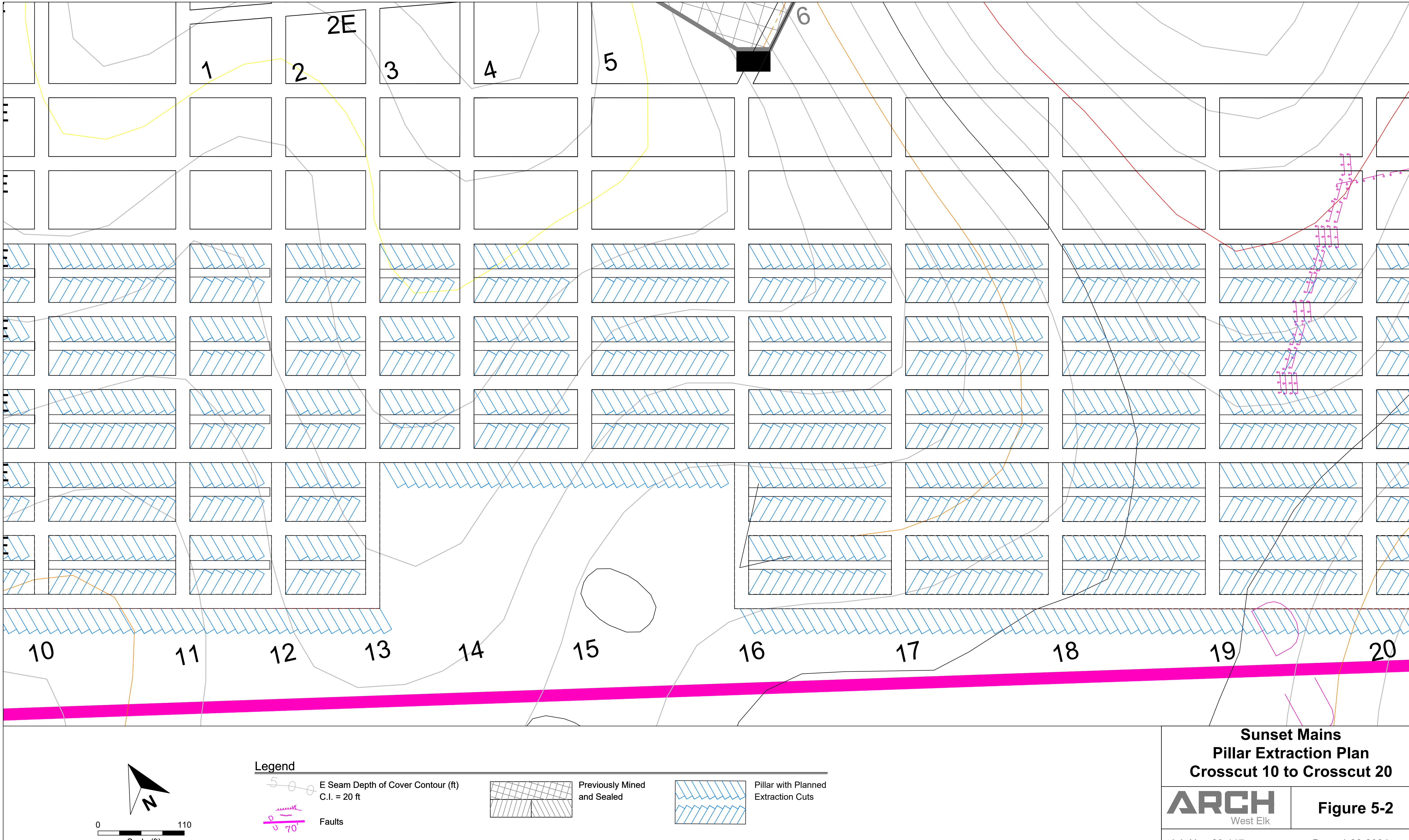
20-117 MCC [SSM Extraction Proposed Modeling Sections w MBA Insert_Formatted.dwg Layout: AAI Fig 5-1]



Sunset Mains
Pillar Extraction Plan
Crosscut 10 to Crosscut 20

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Figure 5-2

Job No.: 20-117
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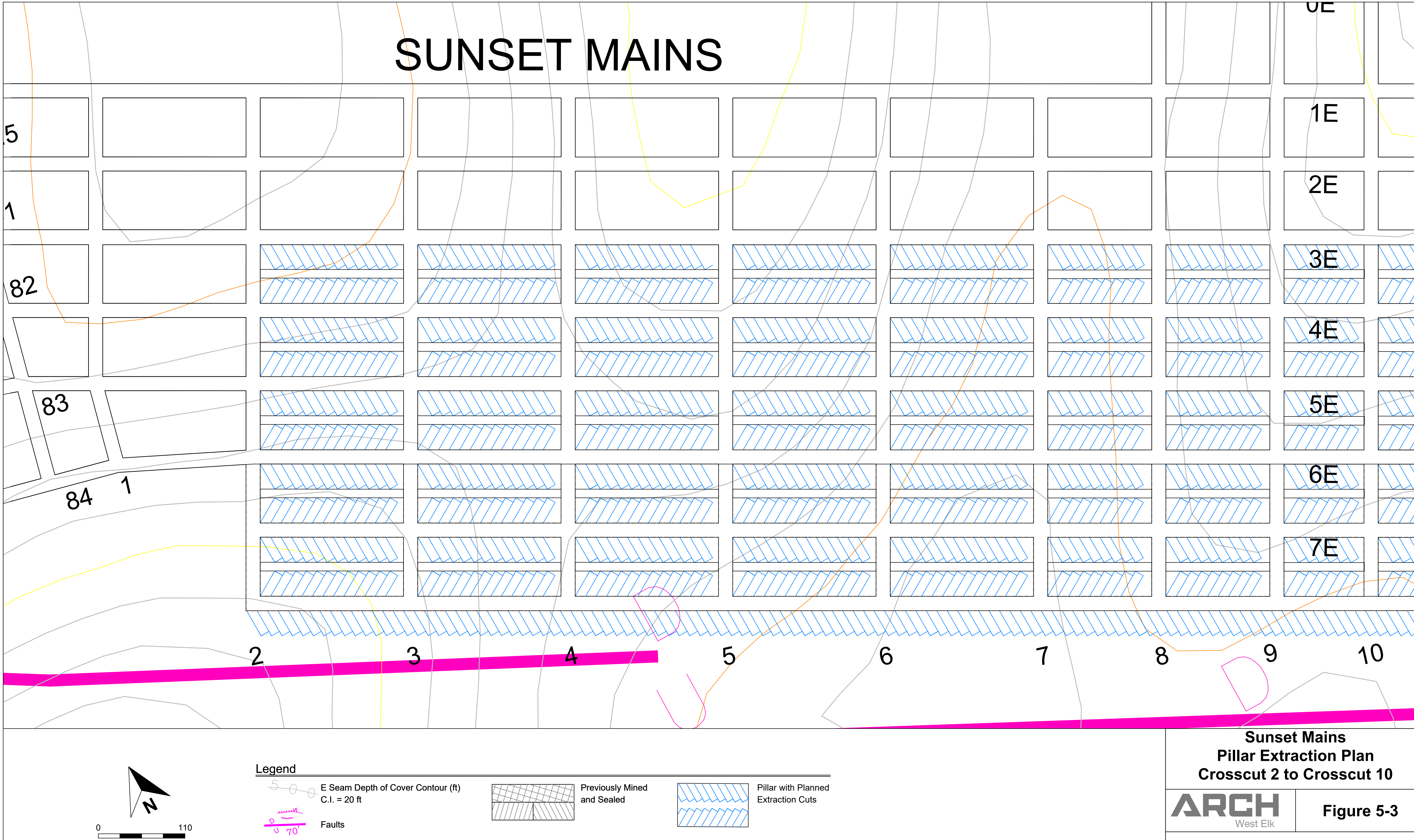
20-117 MCC [SSM Extraction Proposed Modeling Sections w MBA Insert_Formatted.dwg Layout: AAI Fig 5-2]



Sunset Mains
Pillar Extraction Plan
Crosscut 2 to Crosscut 10

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Figure 5-3

Job No.: 20-117
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20-117 MCC [SSM Extraction Proposed Modeling Sections w MBA Insert_Formatted.dwg Layout: AAI Fig 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 partial pillar extraction shown in Figures 5-1 to 5-4. For the modeling scenarios, the six 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
In-situ Coal Strength (psi)	1,180
Young's Modulus of Coal (psi)	477,000
Poisson's Ratio of Coal	0.34
Elastic Modulus of Rock Mass (psi)	1,840,000
Poisson's Ratio of Rock Mass	0.22
Lamination Thickness (ft)	160
Initial Gob Stiffness (psi)	100
Final Gob Stiffness (psi)	283,925

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 2,400 and 3,600 psi.
- The neighboring life-of-mine pillar is subjected to a side abutment load.
- The SFs of the last line of pillars all exceed 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 2 (see Figure 6-2)

- The last line of pillars is subjected to a maximum abutment load of between 2,800 and 3,600 psi.
- The neighboring life-of-mine pillar is subjected to a side abutment load.
- 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 range between 2.0 and 3.0.

Zone 3 (see Figure 6-3)

- The last line of pillars is subjected to a maximum abutment load of between 2,400 and 3,200 psi.
- The neighboring life-of-mine pillar is subjected to a side abutment load.
- The SFs of the last line of pillars range between 2.5 and 4.0.
- The 3E to 4E pillar between 19 and 20 crosscuts attains a SF of 1.5.
- 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 range between 1.5 and 2.0.

Zone 4 (see Figure 6-4)

- The last line of pillars is subjected to a maximum abutment load of between 3,200 and 4,000 psi.
- The neighboring life-of-mine pillar is subjected to a side abutment load.
- The SFs of the last line of pillars range between 2.0 and 2.5.
- The 7E to 8E pillar between 12 and 13 crosscuts attains a SF of 2.0.
- 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 range between 2.0 and 2.5.

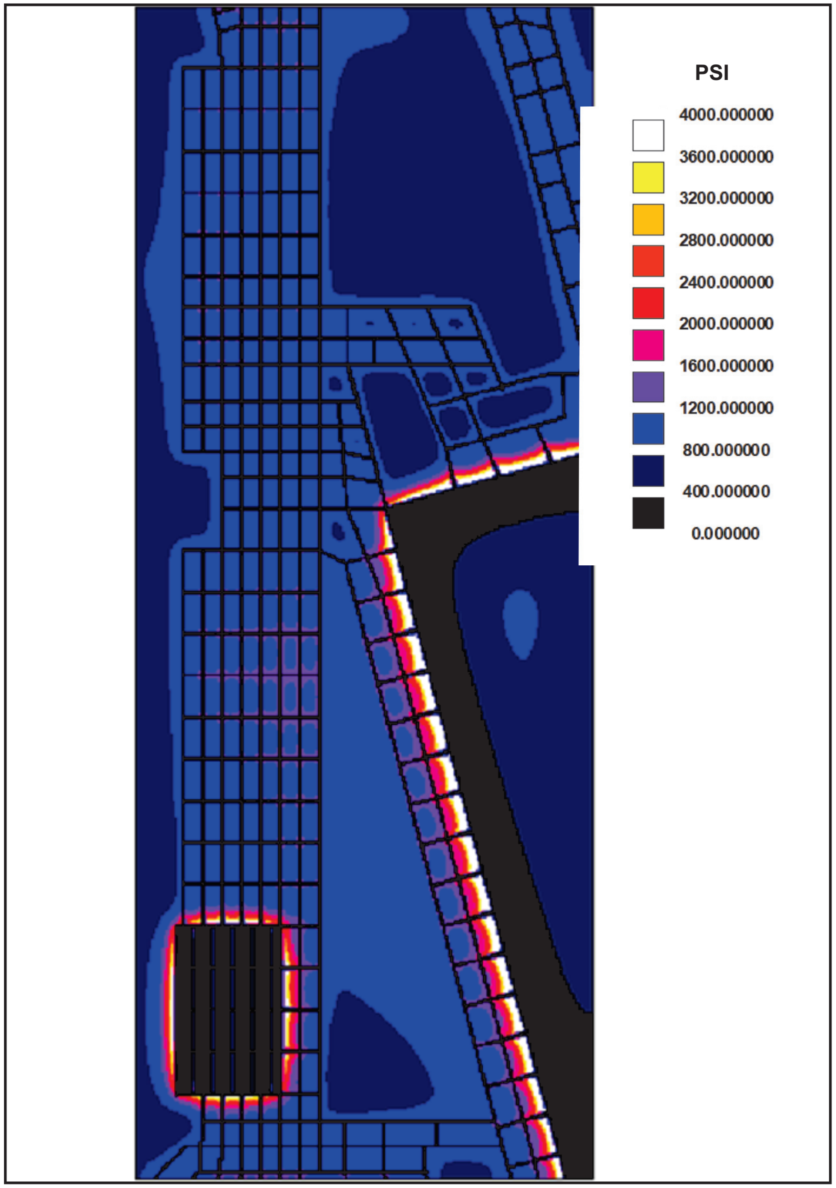
Zone 5 (see Figure 6-5)

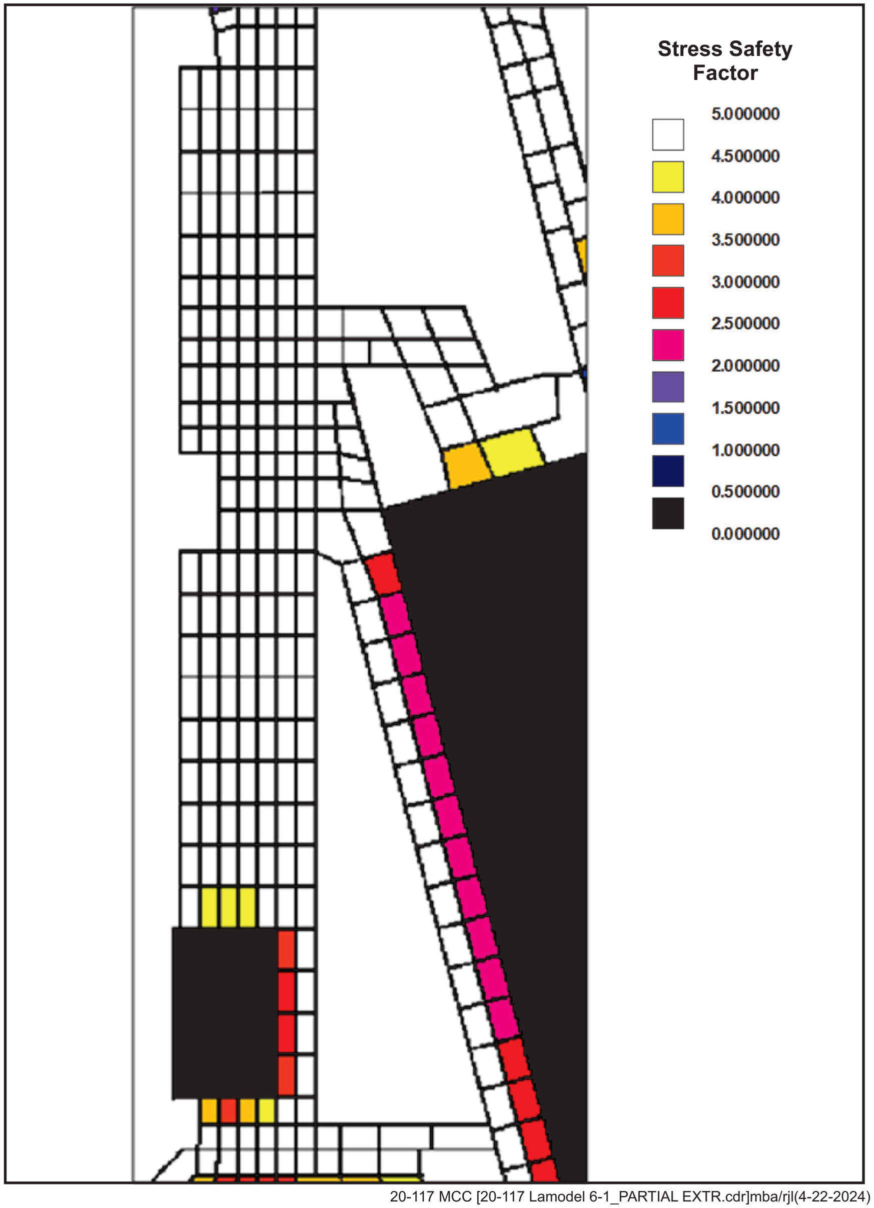
- The last line of pillars is subjected to a maximum abutment load of between 3,200 and 4,000 psi.
- The neighboring life-of-mine pillar is subjected to a side abutment load.
- The SFs of the last line of pillars range between 3.5 and 4.5.
- The SFs suggest the remnant pillars in the mains are not load bearing structures.
- The SFs of the pillars next to the life-of-mine roadway range between 1.5 and 2.5.

Zone 6 (see Figure 6-6)

- The last line of pillars is subjected to a maximum abutment load of between 2,800 and 3,200 psi.
- The neighboring life-of-mine pillar is subjected to a side abutment load.
- The SFs of the last line of pillars range between 3.5 and 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 range between 2.0 and 2.5.

In summary, the modeling indicates that most of the abutment load is constrained to the inby half of 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 roadways 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.

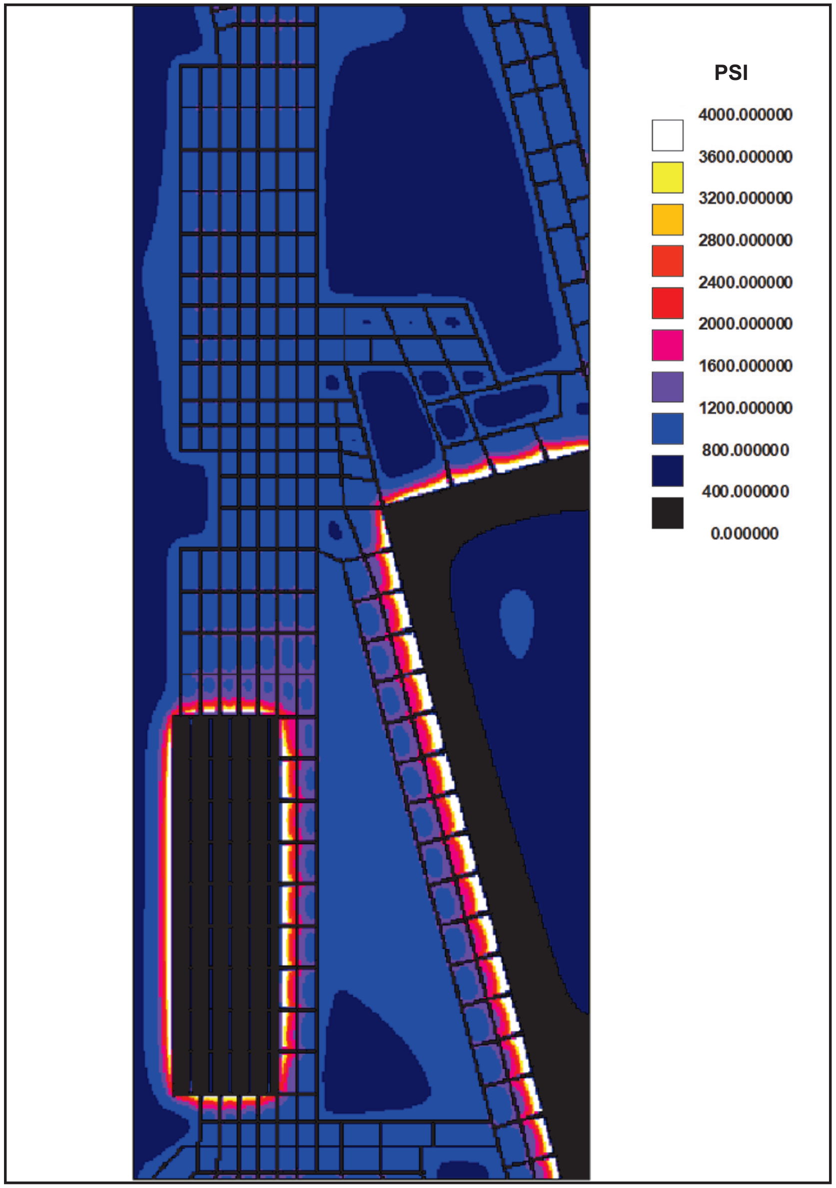


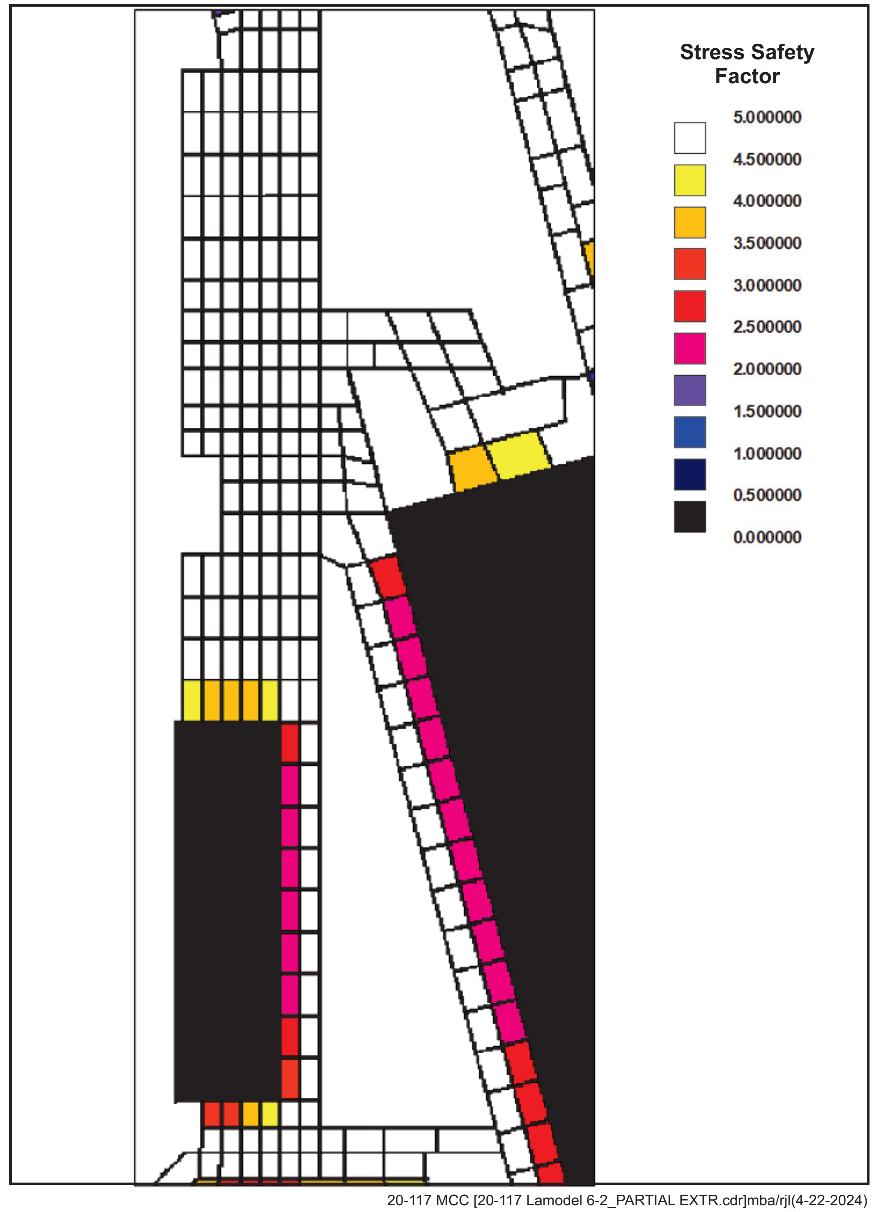


Vertical Stress

Pillar Safety Factor

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

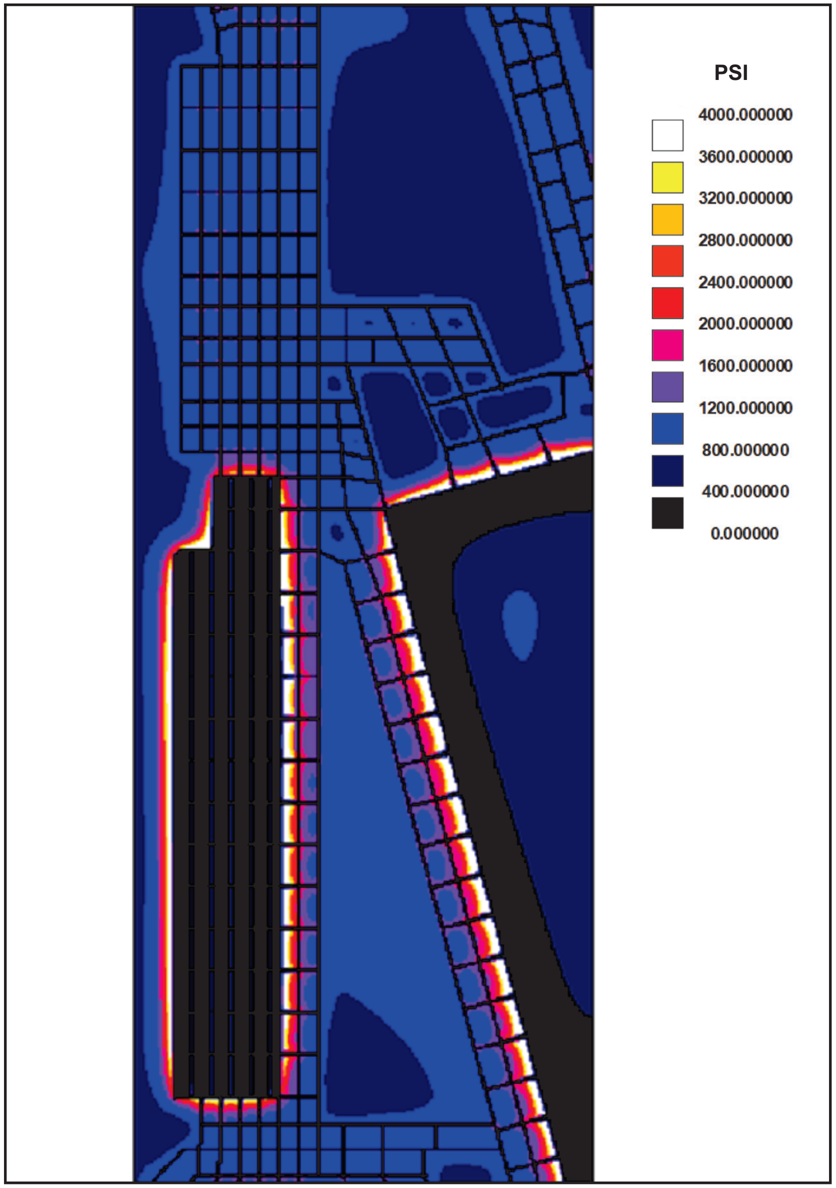


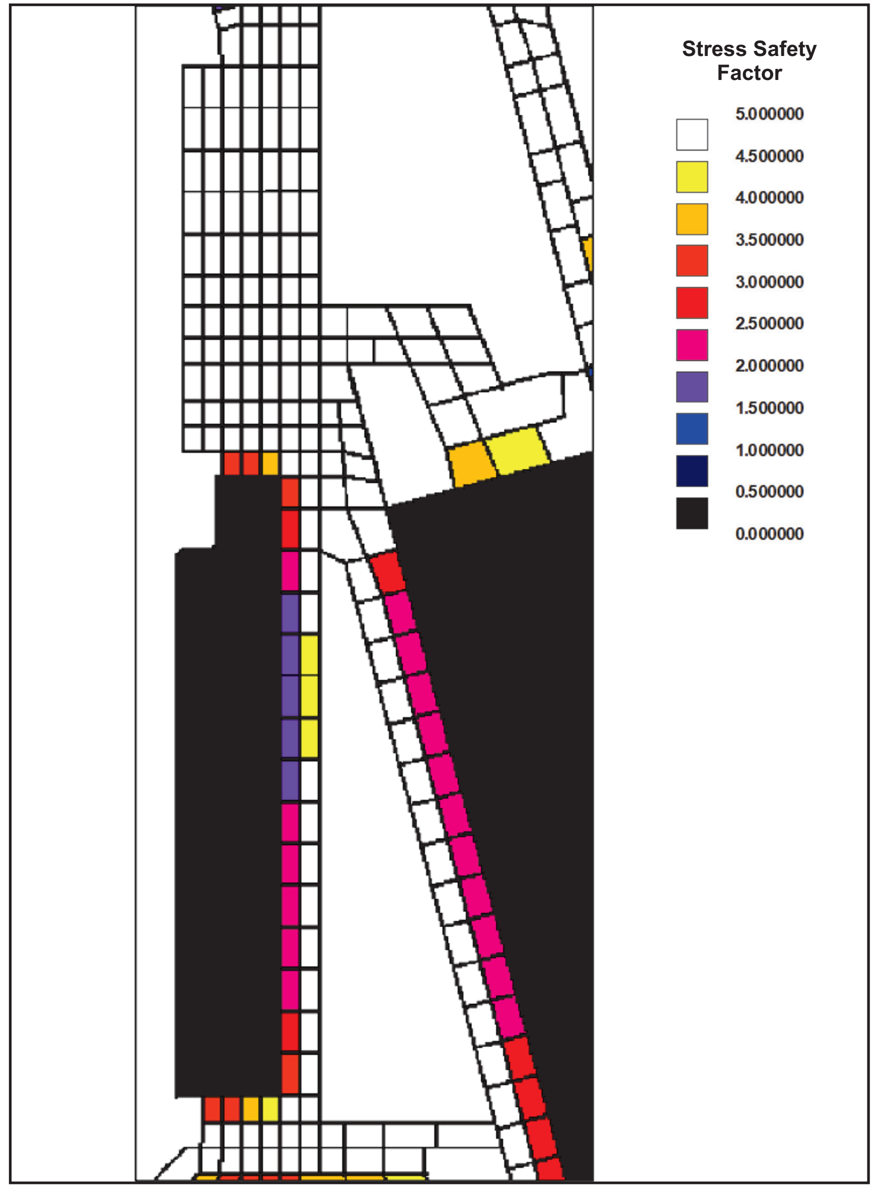


Vertical Stress

Pillar Safety Factor

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

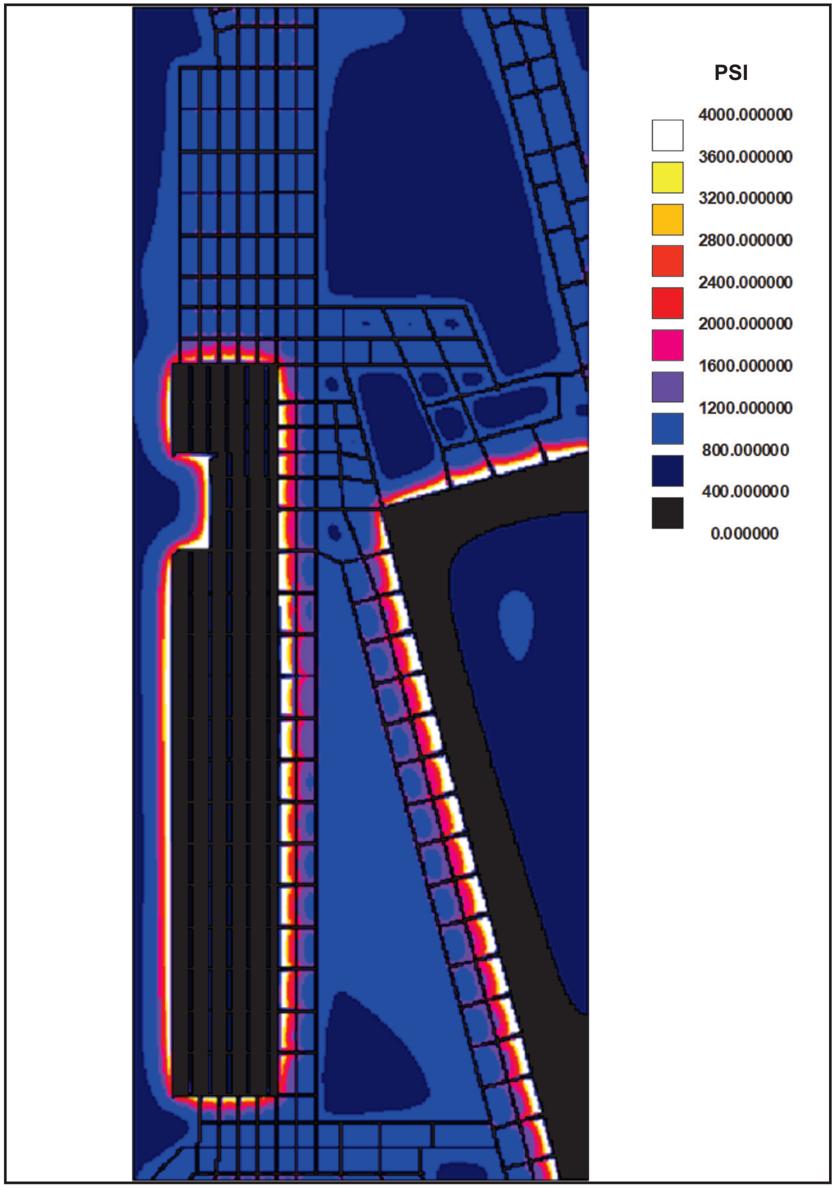


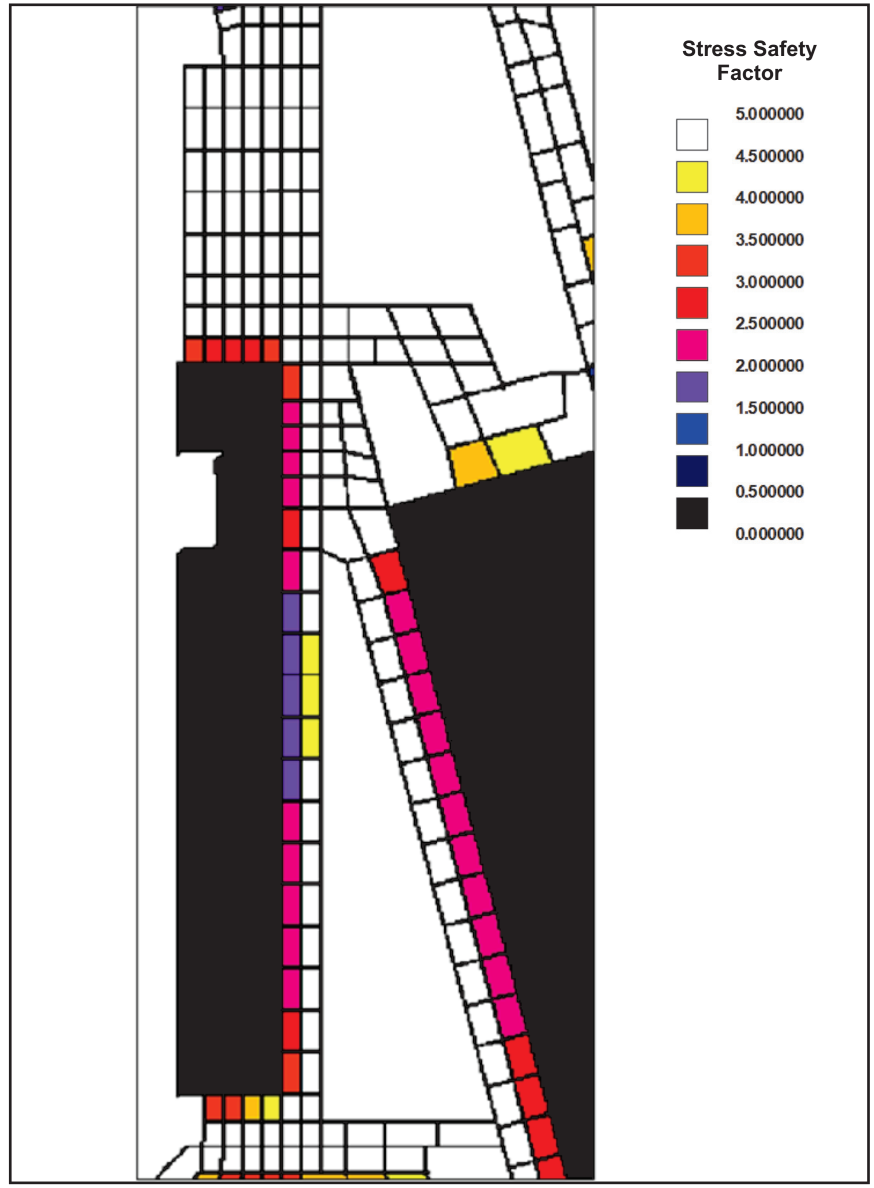


20-117 MCC [20-117 Lamodel 6-3_PARTIAL EXTR.cdr]mba/rjl(4-22-2024)

Vertical Stress **Pillar Safety Factor**

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

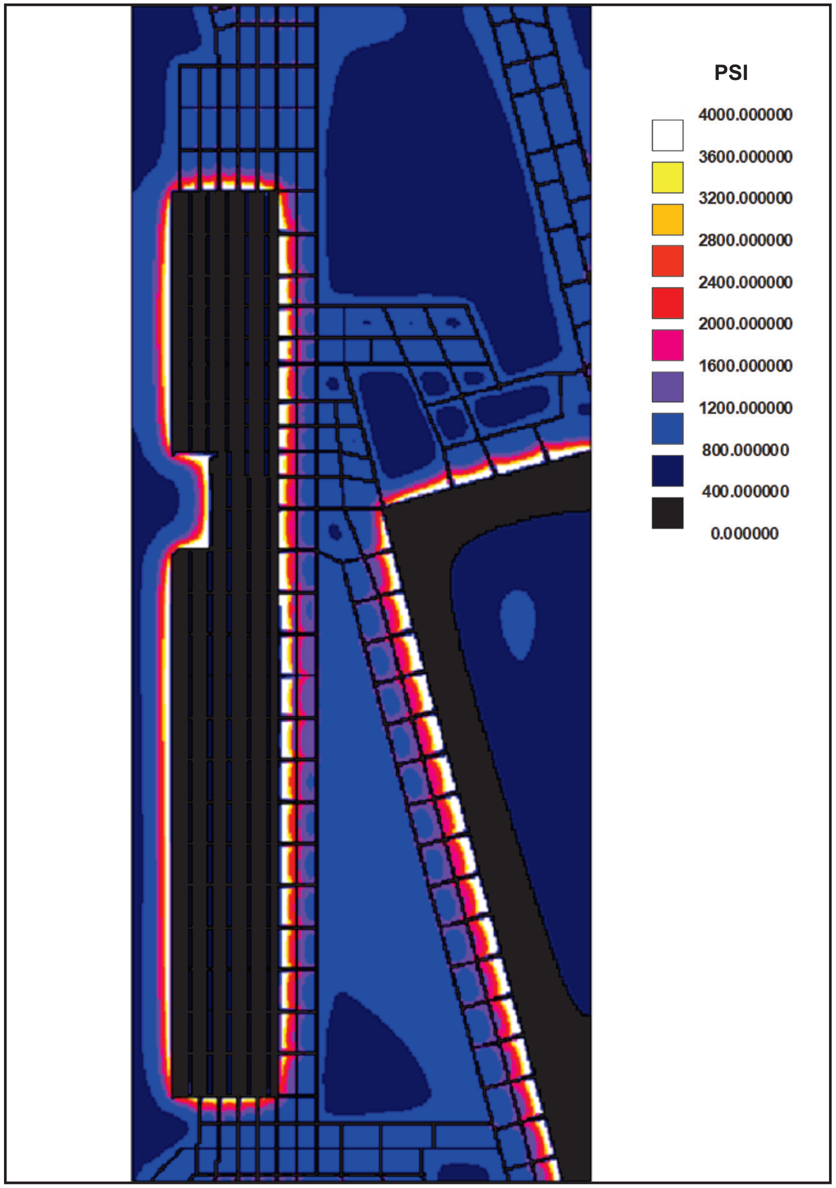


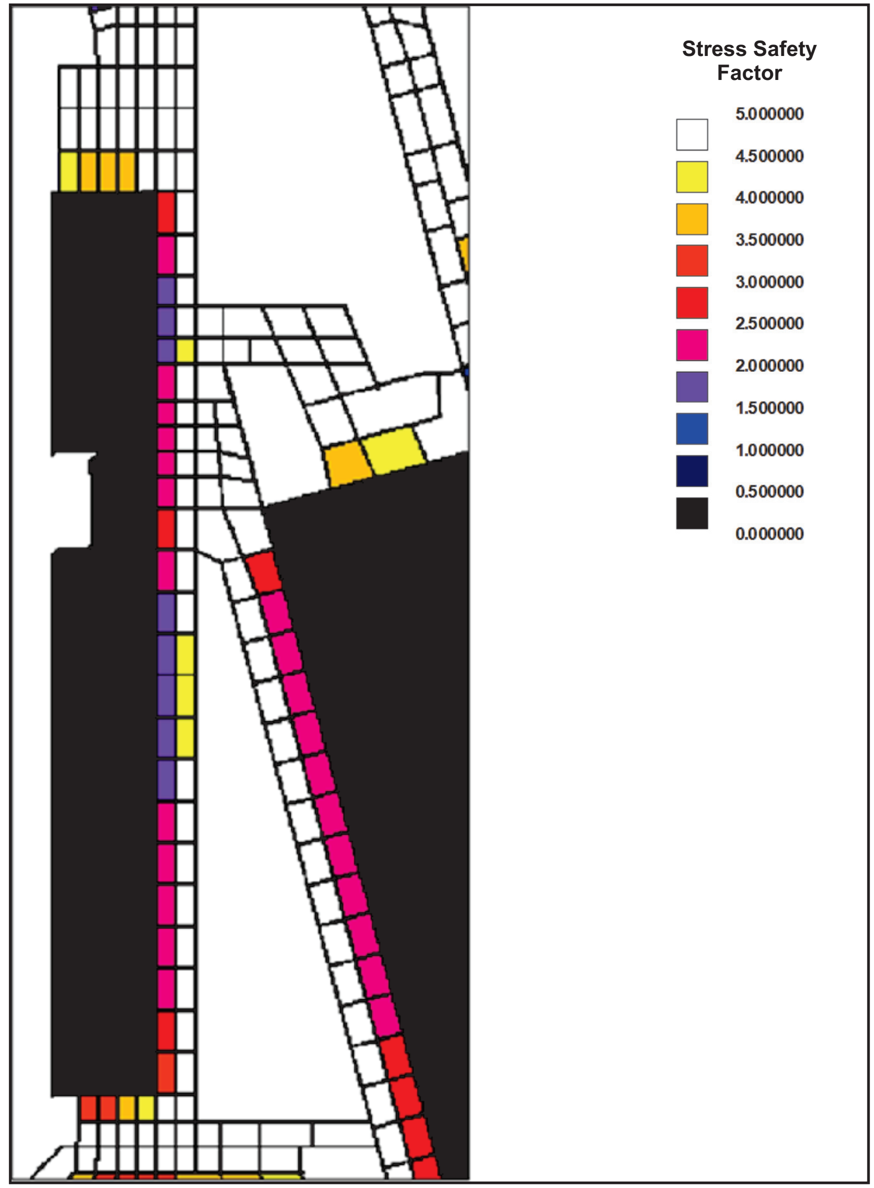


Vertical Stress

Pillar Safety Factor

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





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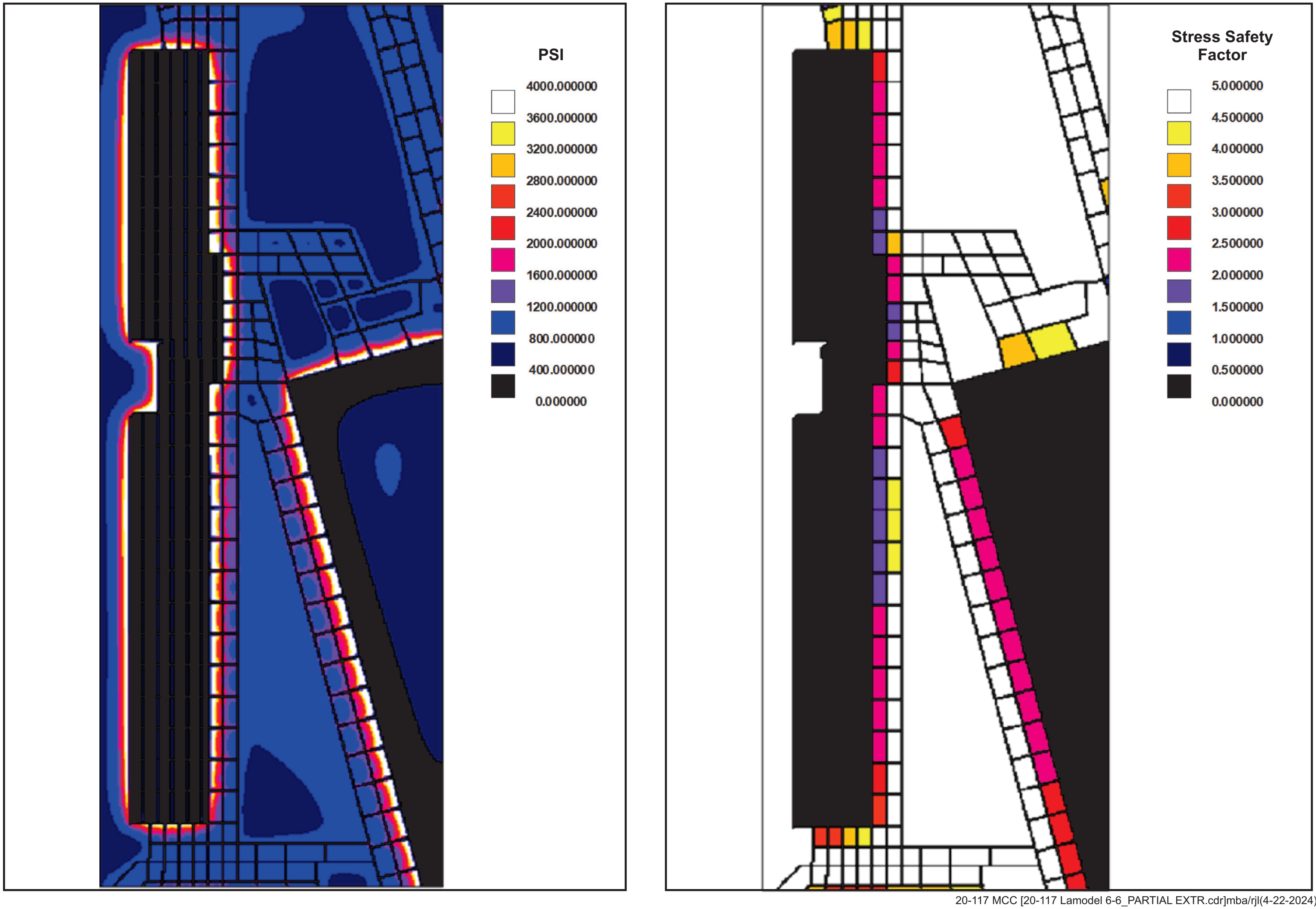
Vertical Stress **Pillar Safety Factor**

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



Vertical Stress **Pillar Safety Factor**

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

6.2 Surface Subsidence Analysis

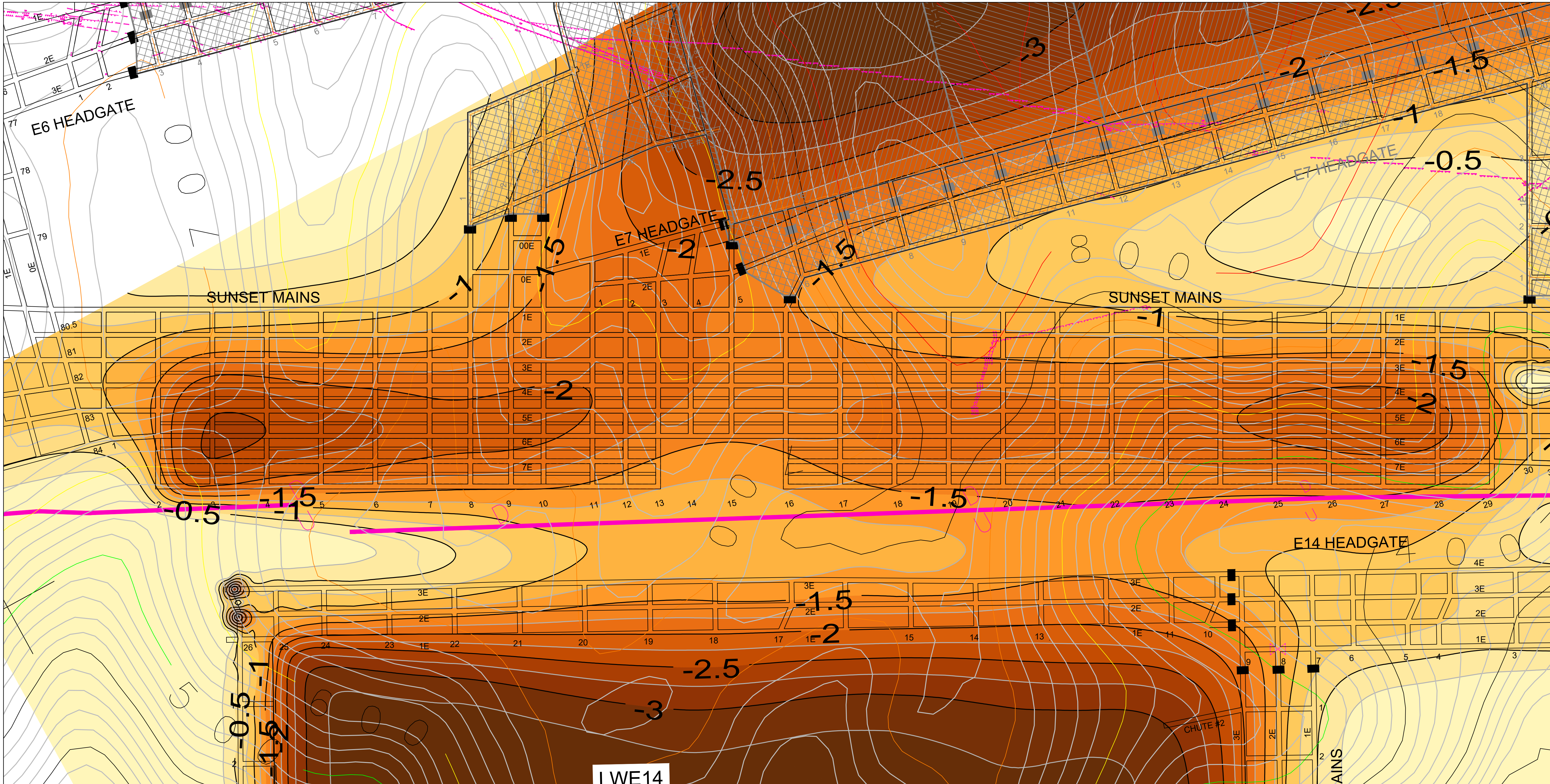
Agapito utilized the numerical modeling software program Surface Deformation Prediction System (SDPS) to assess the likely maximum surface subsidence resulting from the proposed partial pillar extraction plans. SDPS uses an integrated approach of calculating and predicting ground deformations above undermined 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 2.5 ft of vertical surface subsidence is estimated following the proposed pillar extraction (see Figure 6-7). This includes the pre-excavation subsidence, where 0.75 ft was modeled from the mains development and neighboring longwall extraction panels. In essence, the modeling indicates that a maximum of 1.75 ft of additional subsidence will occur following the proposed pillar extraction. In terms of the extent of the subsidence trough, the subsidence does not extend in any significant means beyond the footprint of the pillar extraction area.



Legend

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

Faults

Previously Mined and Sealed

Subsidence Key (ft)

-0.25 -0.50 -0.75 -1.00 -1.25 -1.50 -1.75 -2.00 -2.25 -2.50 -2.75 -3.00 -3.25 -3.50

0 350
Scale (ft)

N

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

ARCH West Elk

Figure 6-7

Job No.: 20-117
Scale: As Shown

Date: 4-22-2024
Drawn by: MBA/RJL

Agapito Associates, Inc.
ENGINEERS & GEOLOGISTS

20-117 MCC [SSM Extraction Proposed Modeling Sections w MBA Insert_Formatted.dwg Layout: AAI Fig 6-7 Sub after Extr]

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 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. On this basis, the intersections should be assessed by an appropriate mine official for the need of supplementary support prior to lifting.

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 roadways 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 pillars between crosscuts 2 and 29. 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 29.
- For the purpose of this assessment, it is assumed that pillar extraction will stop at 2 crosscut at the outby end of Sunset Mains.
- In order to maintain a bleeder system around areas of gob and to inspect inby seals, two life-of-mine roadways must remain travelable during and after pillar extraction activities.
- The mine plans to develop two additional rows of pillars along the south side of Sunset Mains between crosscuts 2 and 13, and crosscuts 16 and 29.
- 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 are suitable for full extraction using the Christmas tree method. The main 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 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 1.75 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.

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