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Case study: Application of Flac3D to analyse the effects of mining-induced stresses on the behavior of drawpoint pillars

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Contents

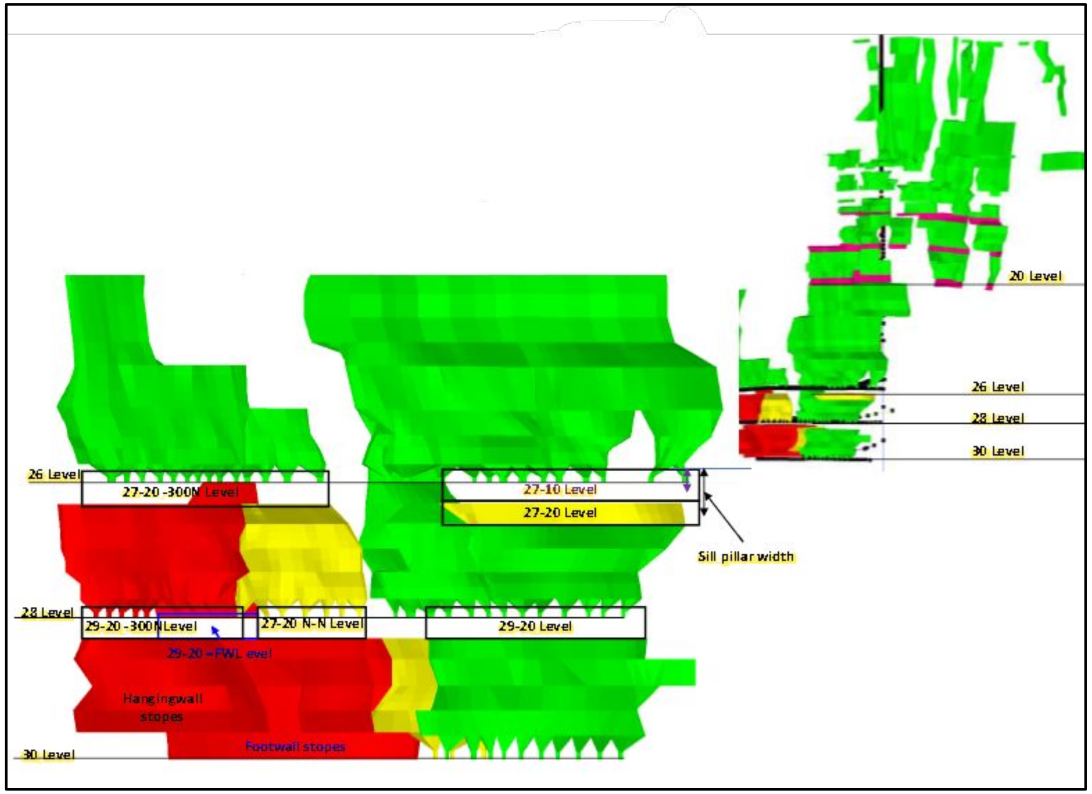
Introduction

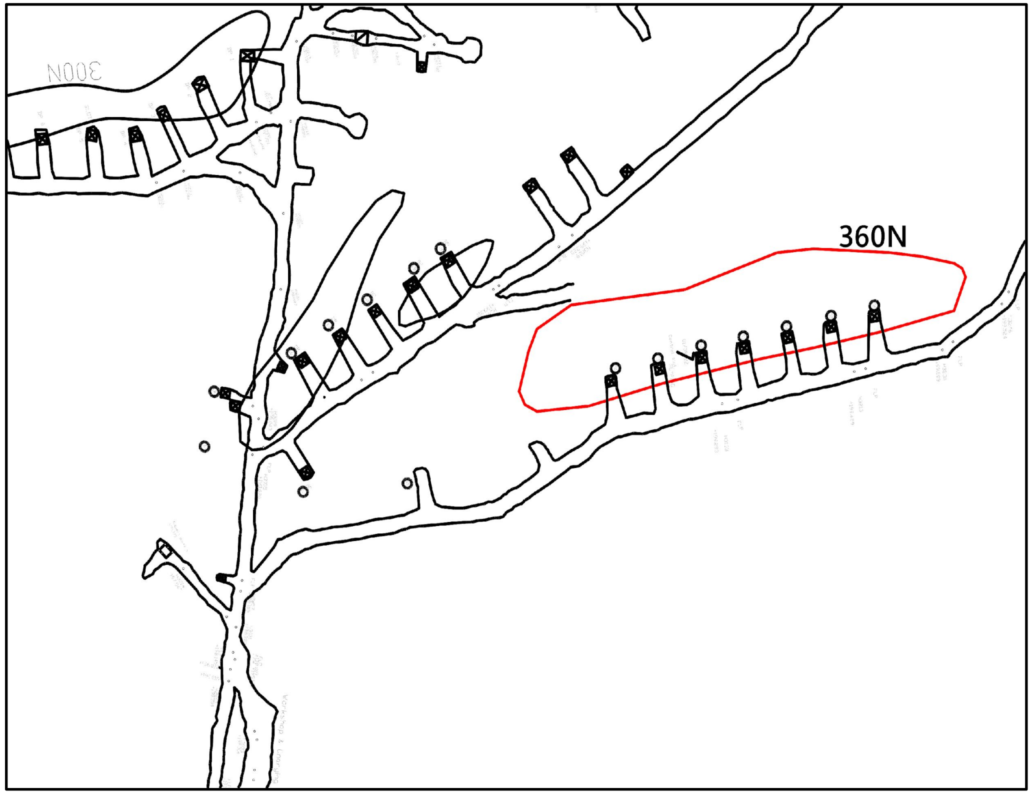
- Mine A is a gold mine located in Southern Zimbabwe
- Employs the sub-level open stoping method
- Operating in the medium depth environment
- Main production level at 1100 m below surface (30L)

PROBLEM: Drawpoint pillar instability due to a small pillar size with respect to the depth of operation

AIM: To determine an optimum pillar size for lower mining depths

Mining Overview





- 30 m wide with 105 m strike length, 80° to 86° orebody dip (360N)
- 3 m x 3 m haulage drifts and drawpoint cross cuts
- Drawpoint spacing of 10 m centre-to-centre
- No support installed in the drawpoints

Geotechnical Assessment

- Mafic tuff UCS: 180 MPa
- Laubscher's RMR: 52 to 65
- Geological Strength Index (GSI): 60 to 70
- Rock Quality Designation (RQD): 92
- Q-Rating: 1
- 3 joint sets present
- Joint spacing ranges from 0.3 m to 1.2 m
- No groundwater present in the area
- Rock mass quality classified as fair

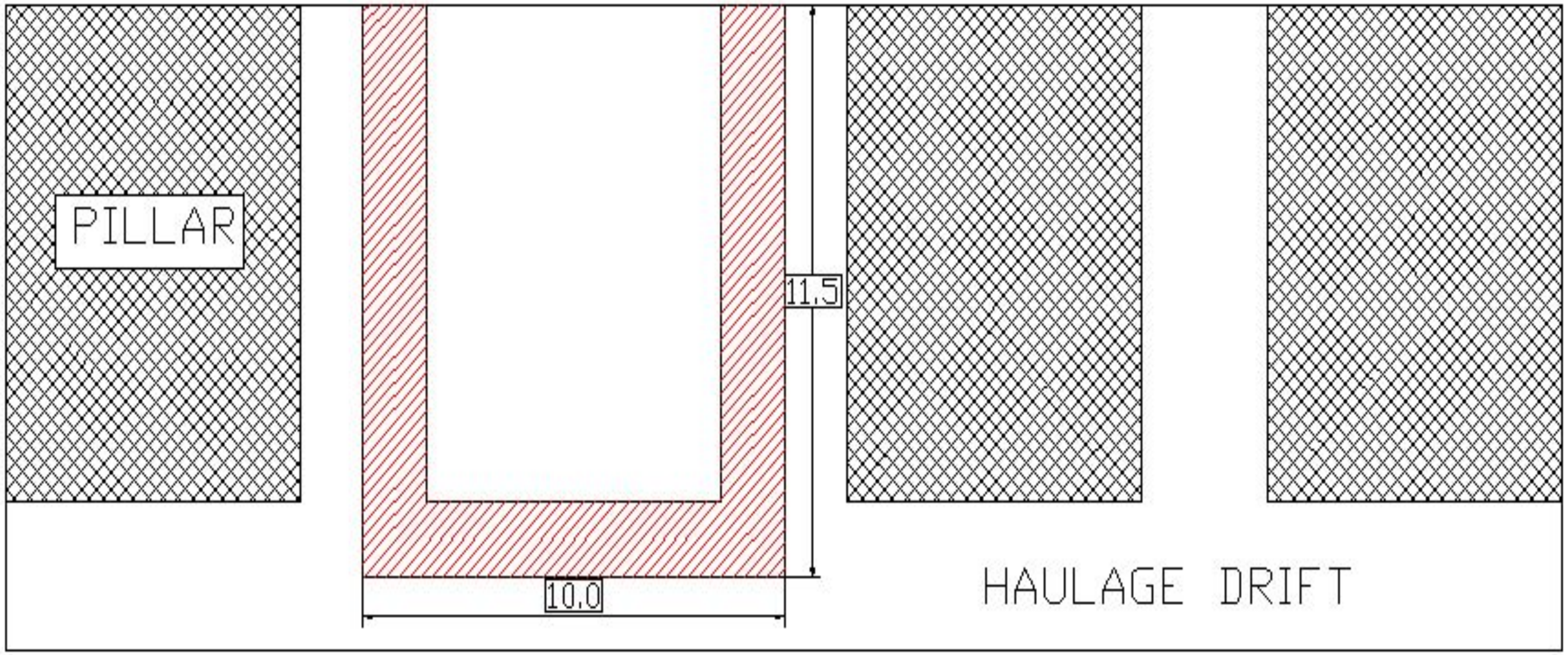
Empirical Approaches

- Hedley and Grant (1972) formula was used to determine a pillar strength of 75.8 MPa for the drawpoint pillars at 30L

$$PS = DRMS * \left(\frac{W^{0.5}}{H^{0.75}}\right)$$

- DRMS of 61 MPa
- Effective width of 8 m and a height of 3 m
- Design Factor of Safety (FoS) for pillars at mine A is 1.6
- Empirical pillar strength was used with the numerically computed average pillar stress (APS) to calculate the FoS

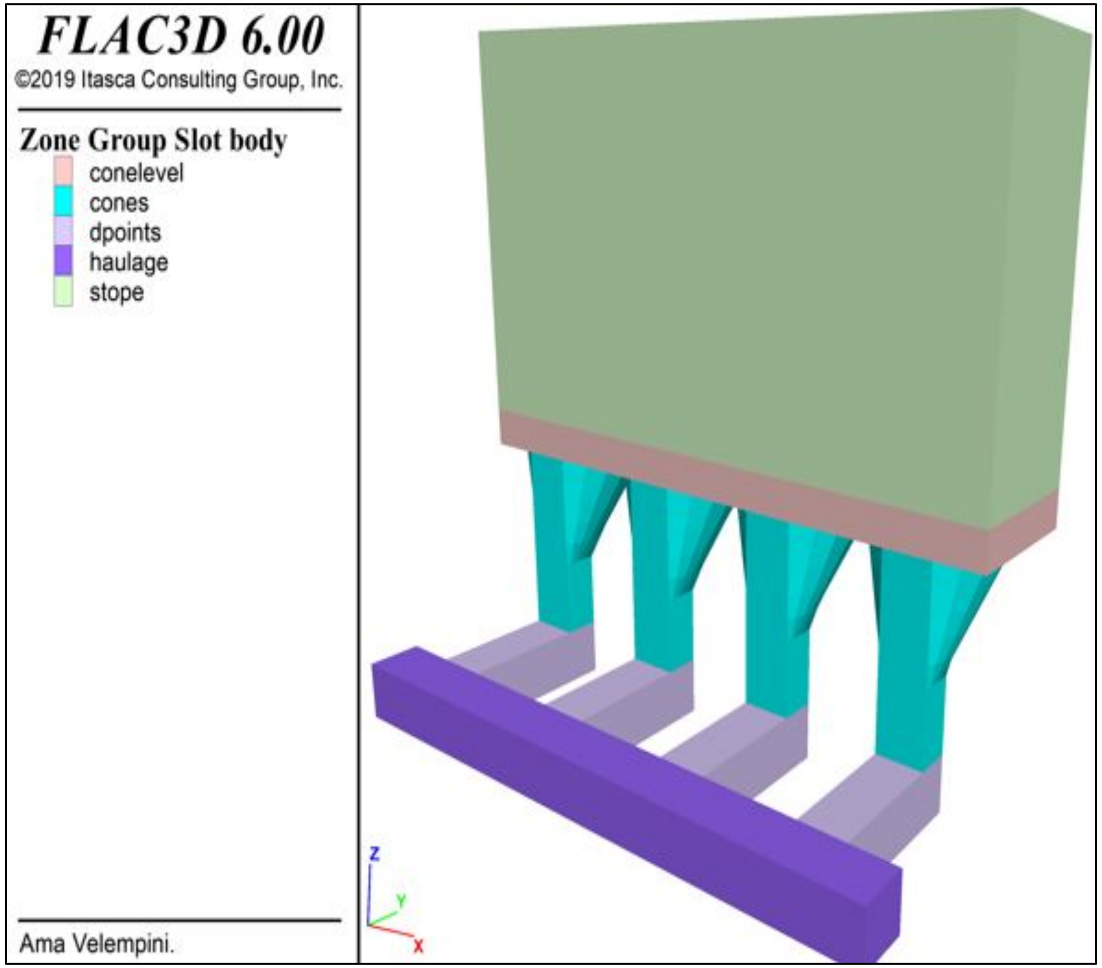
Empirical Approaches



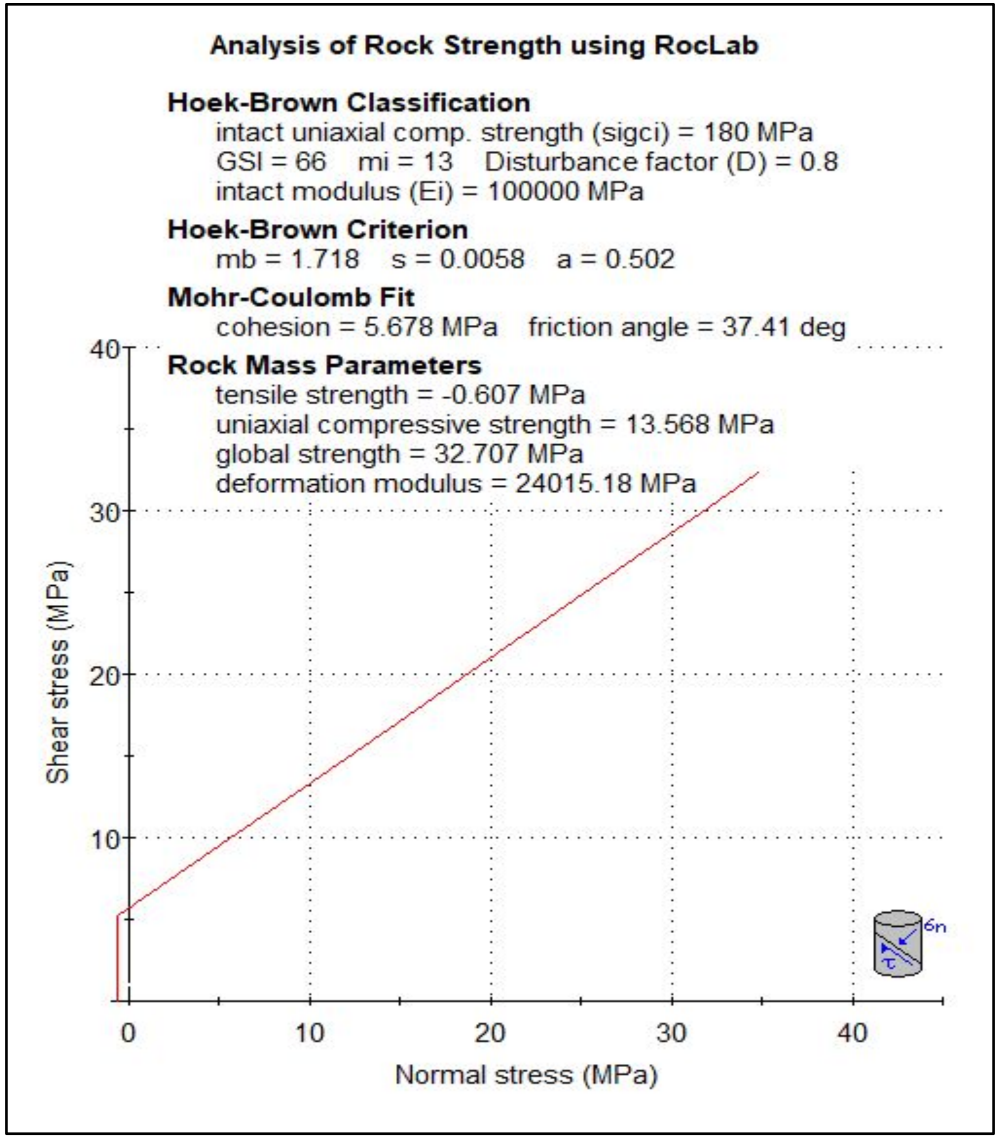
- Tributary area theory to calculate empirical APS
- $e = 1 - \left(\frac{pillar\ area}{total\ area}\right)$ $\qquad APS = \frac{pgh}{1-e}$
- Empirical APS of 50 MPa and a FoS of 1.5 before stoping operations

Numerical Modelling

- Flac3D building blocks tool was used to construct a model geometry
- Stage 1: Haulage drift and drawpoint crosscuts
- Stage 2: Cone level and open stope

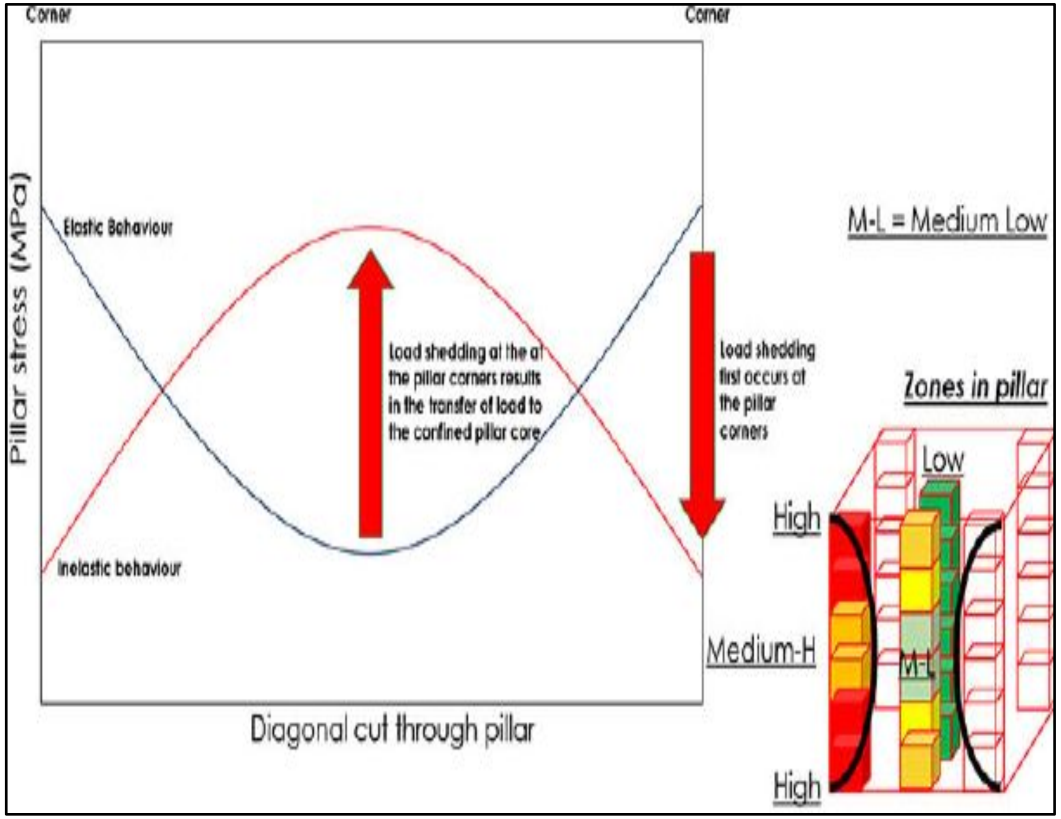


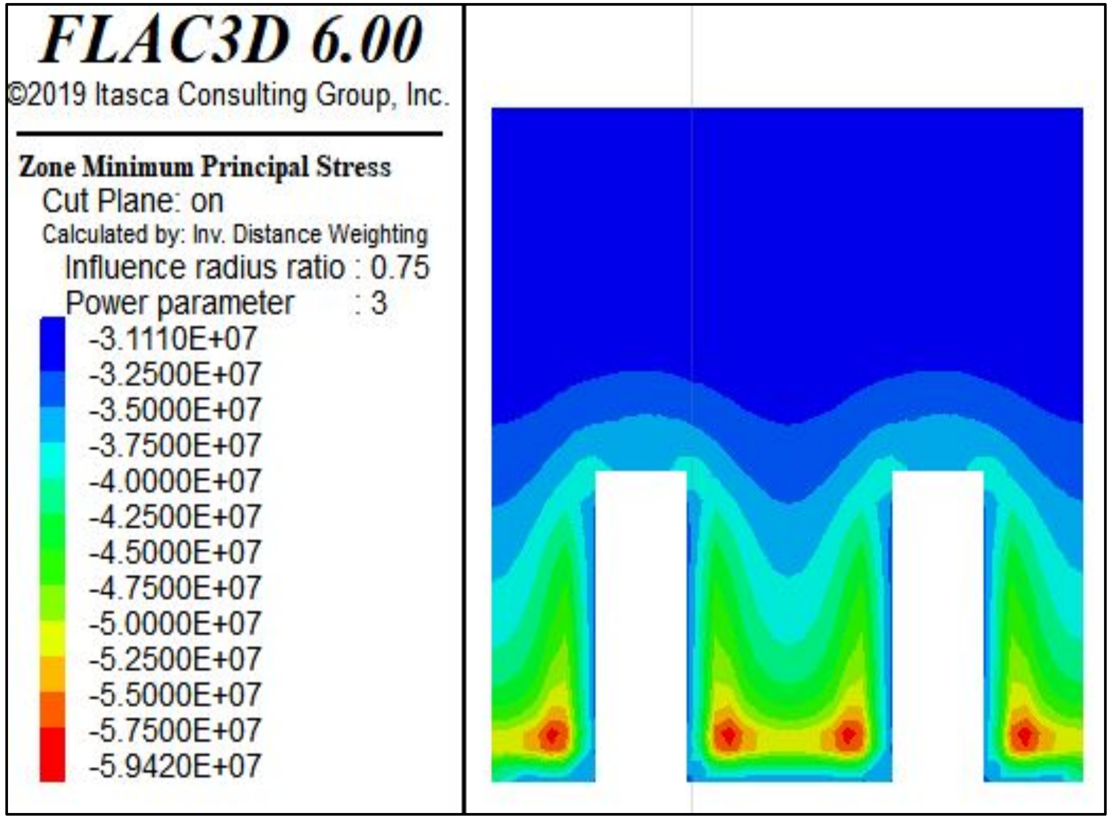
Input Data



- Rocscience Roclab software was used to determine the rock mass properties
- The Hoek-Brown constant for intact rock (mi) data was not available, therefore a sensitivity analysis was conducted
- Mi value for tuff ranges from 8 to 18 in the Roclab charts
- The Mohr-Coulomb constitutive model was used
- Density of 2750kg/m³ and Poisson's ratio of 0.25
- K-ratio of 0.78 was determined from in-situ stress measurements

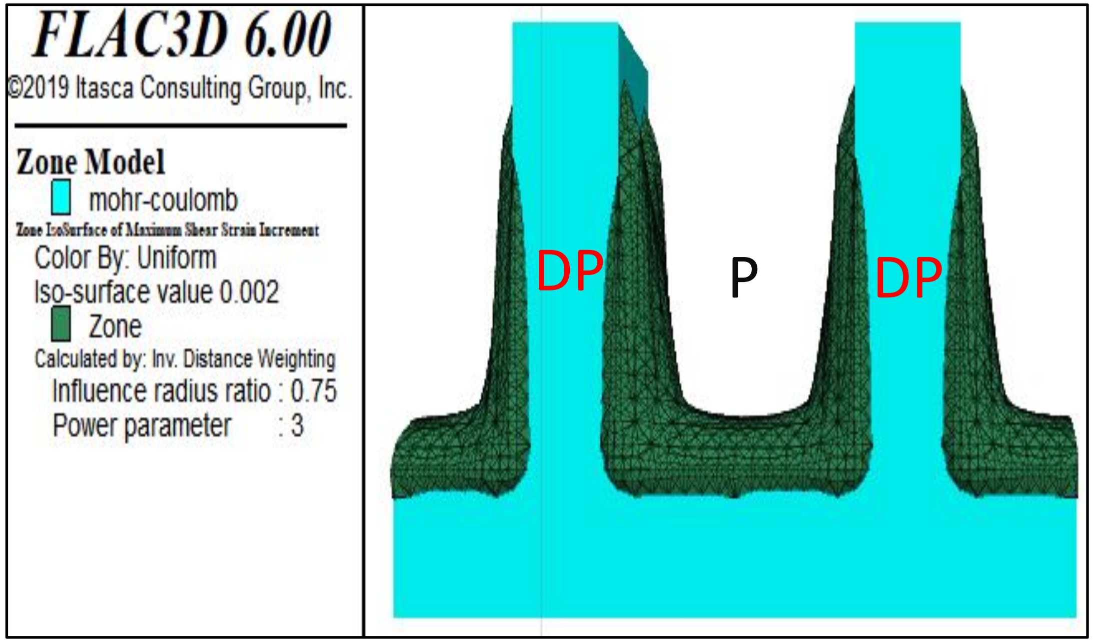
Results: Excavation Stage 1

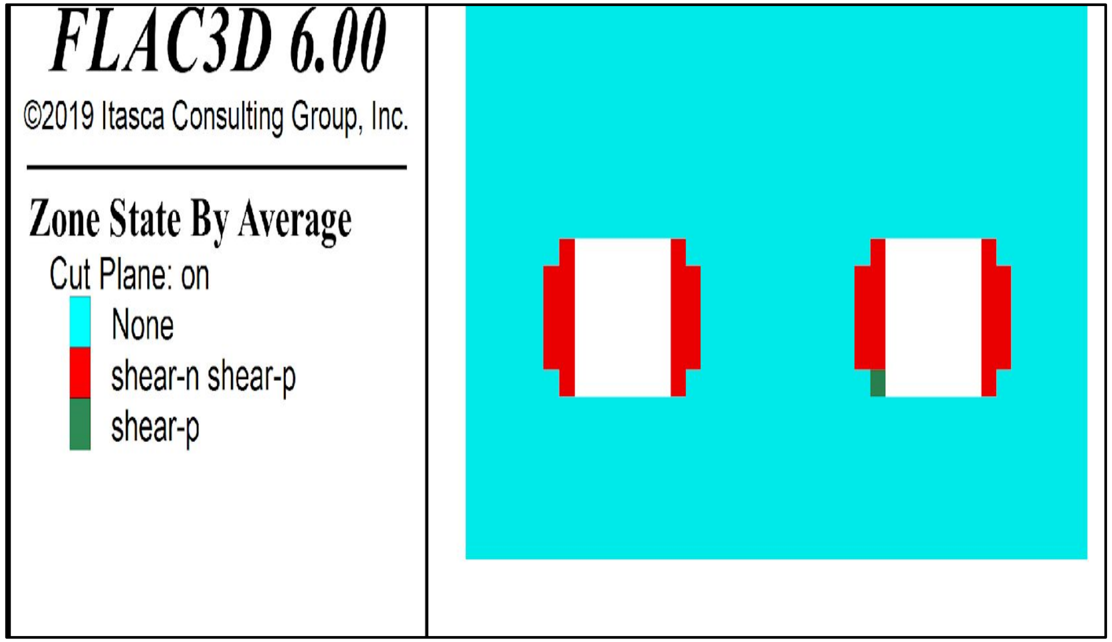




- Pillar load inversion concept (left) by K.B Lebron, et al. (2024)
- Excavation of the haulage drift and drawpoints
- APS of approximately 44 MPA and FoS of 1.7

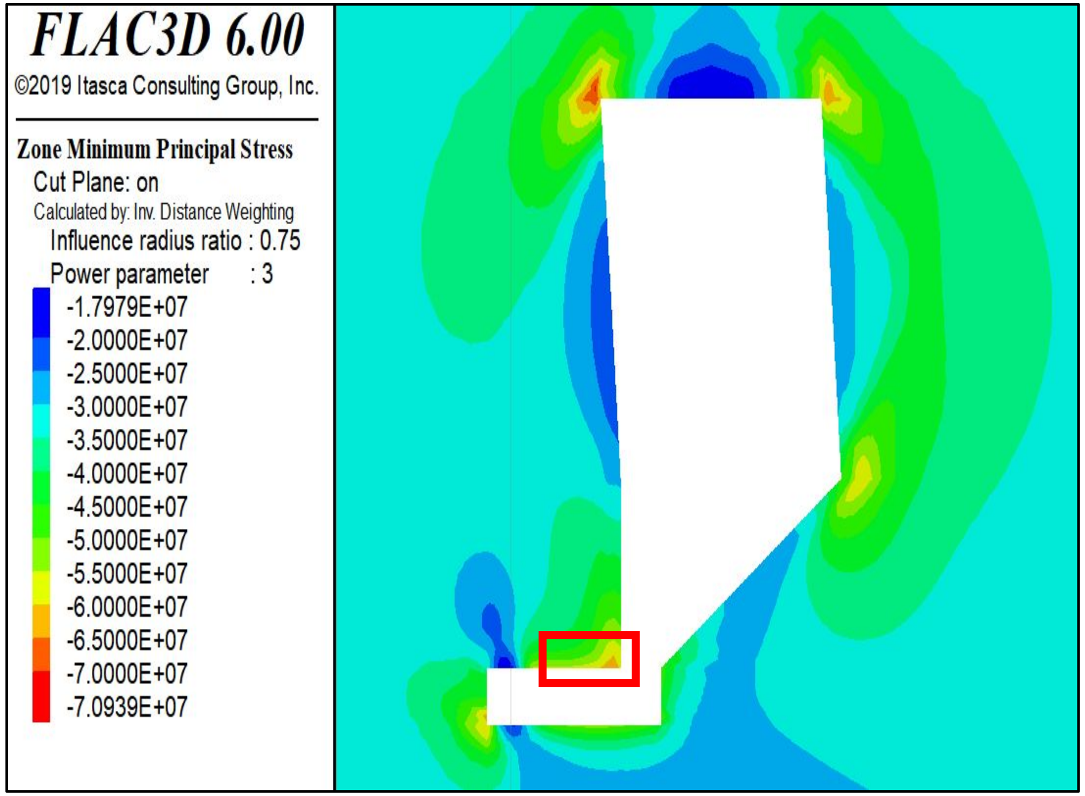
Excavation Stage 1

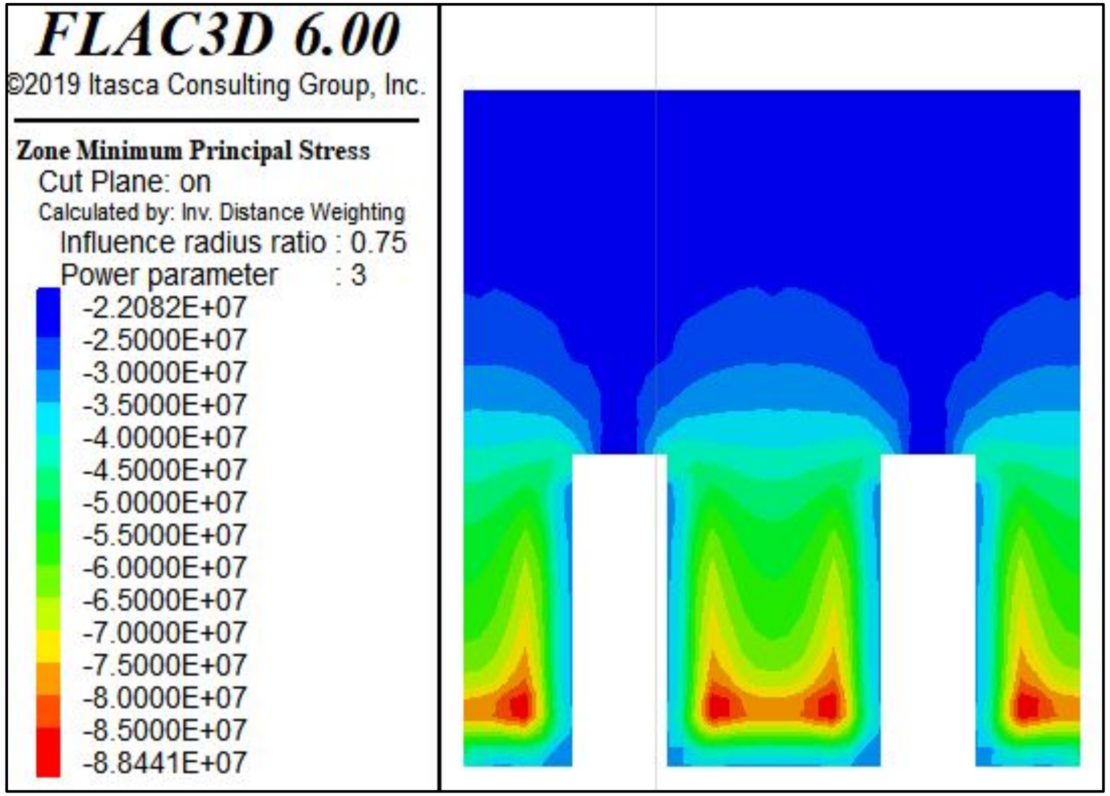




- Strain increment of 0.002 is sufficiently enough to initiate scaling
- Yielding of the pillar edges
- Depth of yield zone is approximately 1 m before stoping operations
- No yielding of the drawpoint roof

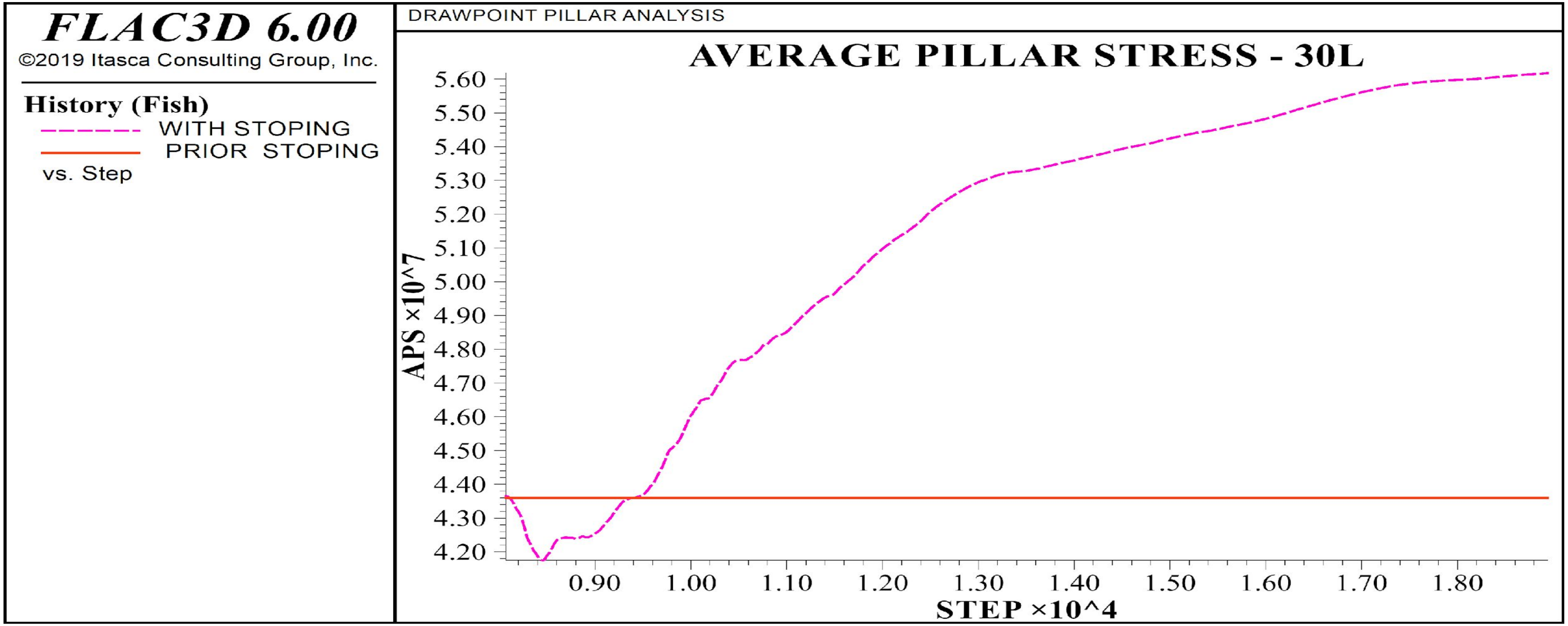
Excavation Stage 2





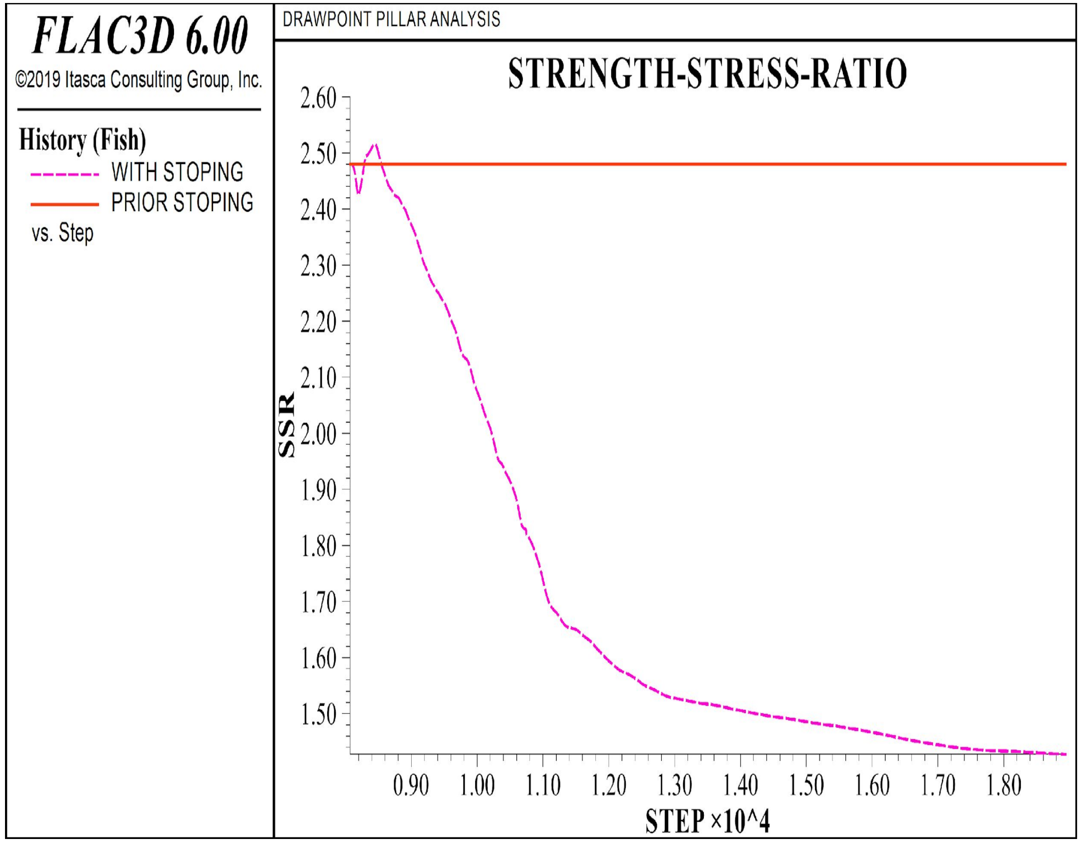
- Excavation of cone level and open stope
- High abutment stresses. Approximately 2x virgin vertical stress at the open stope corners
- Drawpoints interact with the high abutment stresses

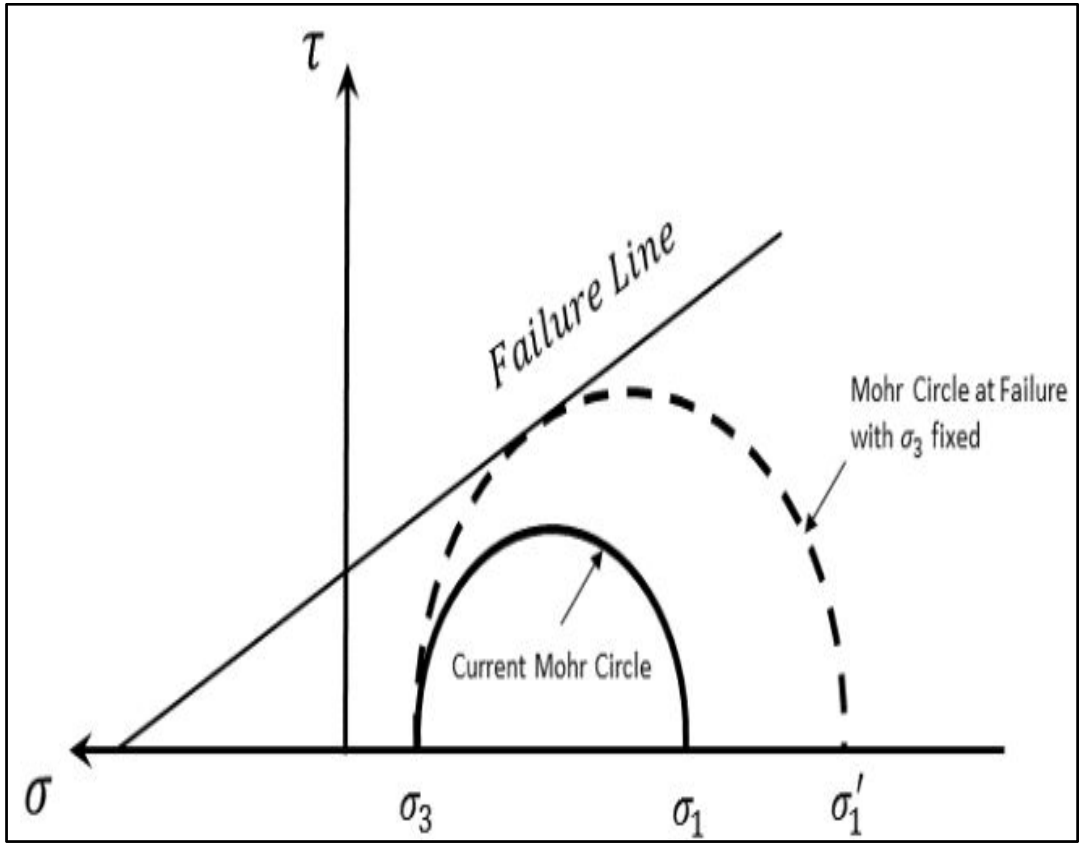
Excavation Stage 2



- Increase in APS from approximately 44 MPa to approximately 56 MPa
- Reduction in the FoS from 1.7 to 1.3

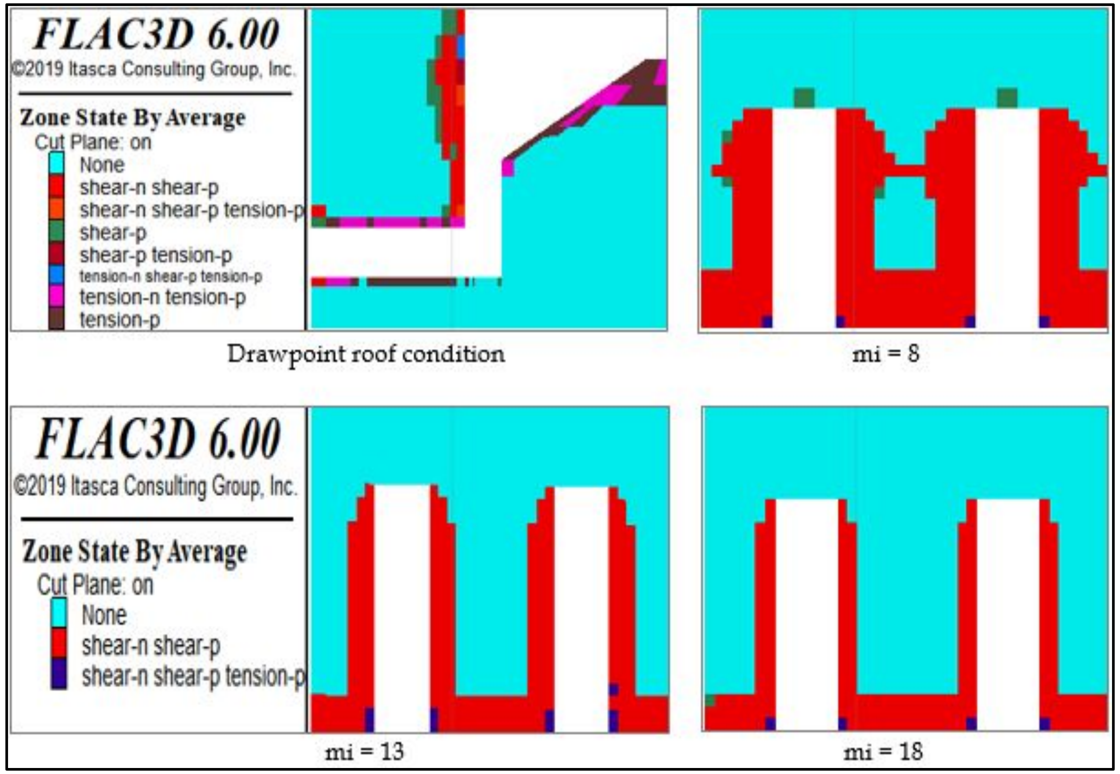
Excavation Stage 2





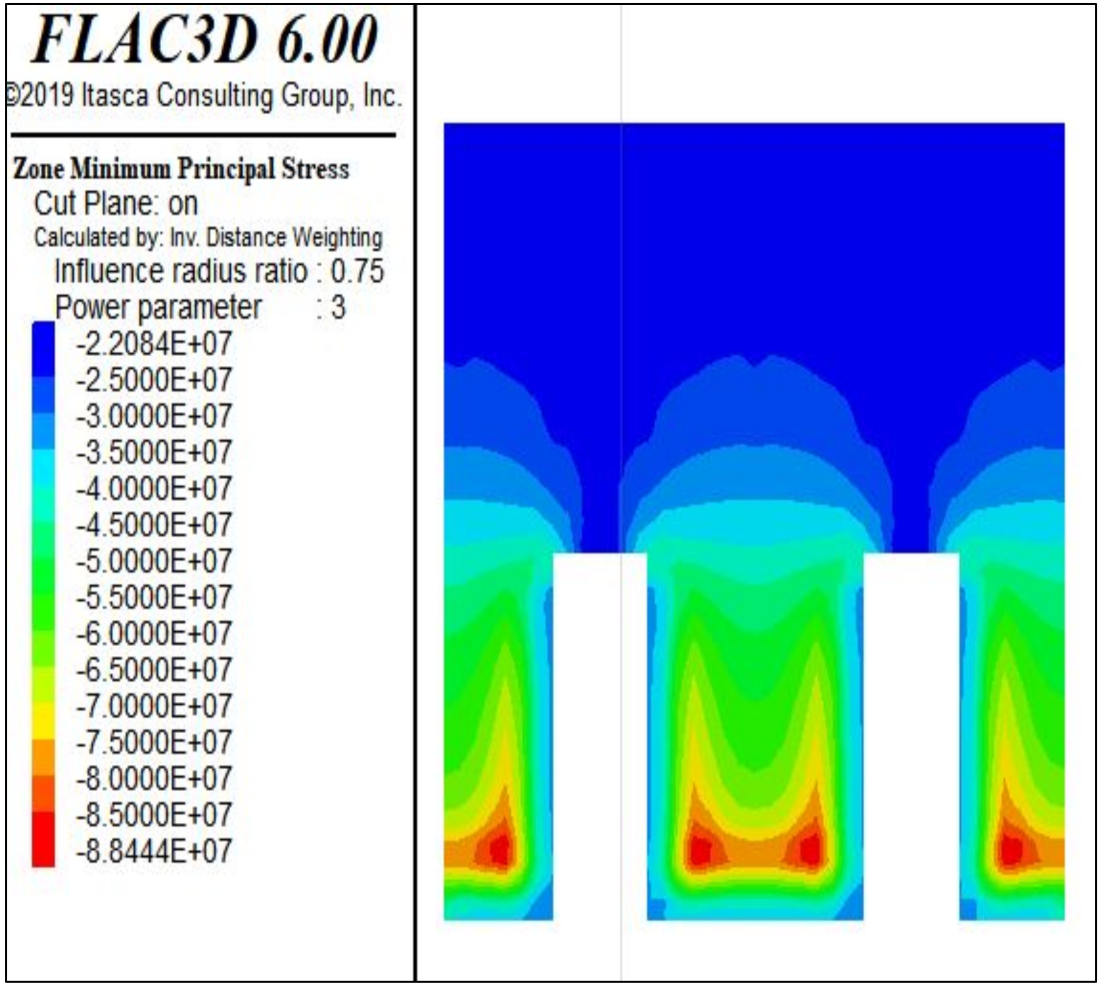
- Pillar instability following stoping operations
- $SSR = \dfrac{\sigma'_1 - \sigma_3}{\sigma_1 - \sigma_3}$

Stage 2: Sensitivity Analysis

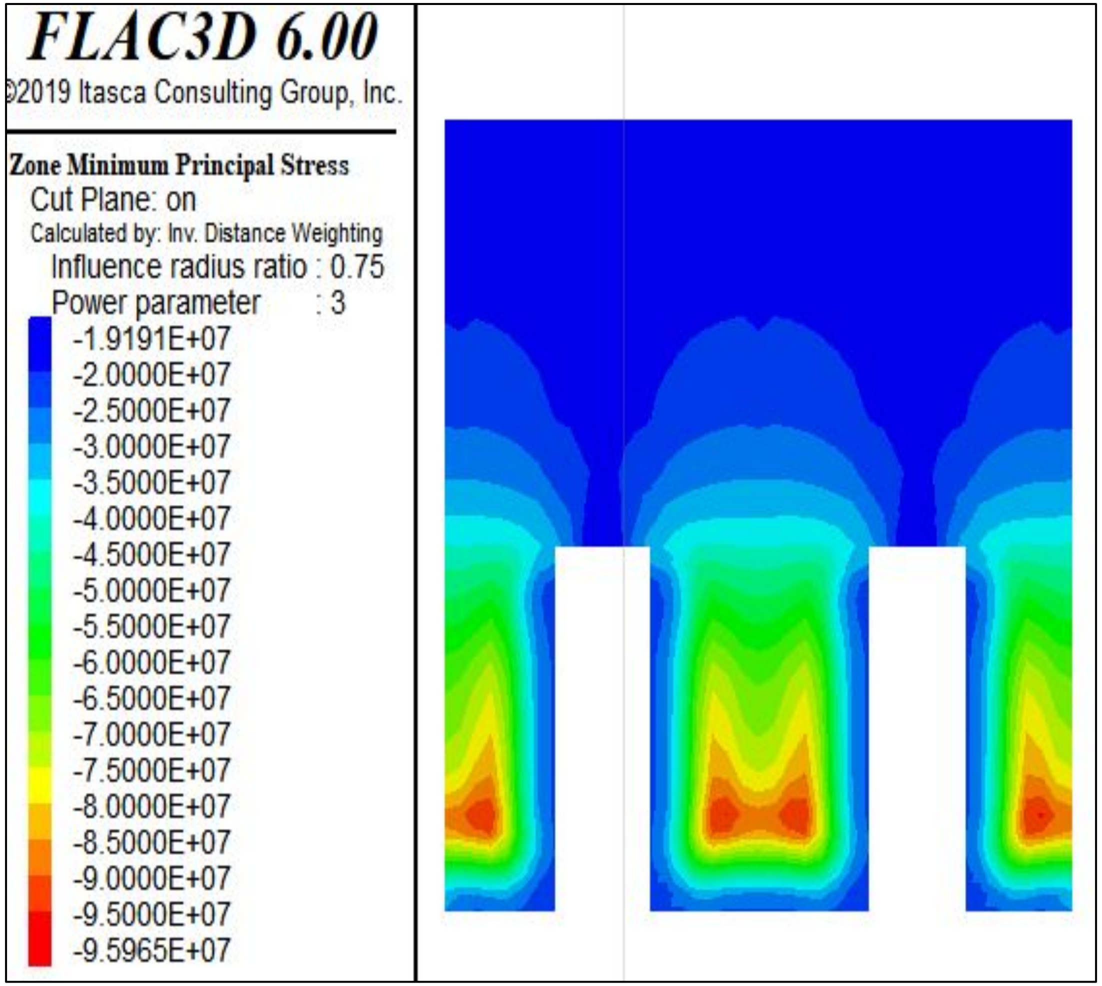


- Mi value ranges from 8 to 18 on the Roclab charts
- An increase in the yield zone depth from 1 m to 1.5 m for median mi value (13)
- Tensile failure in the drawpoint roof

Stage 2: Sensitivity Analysis



mi = 13



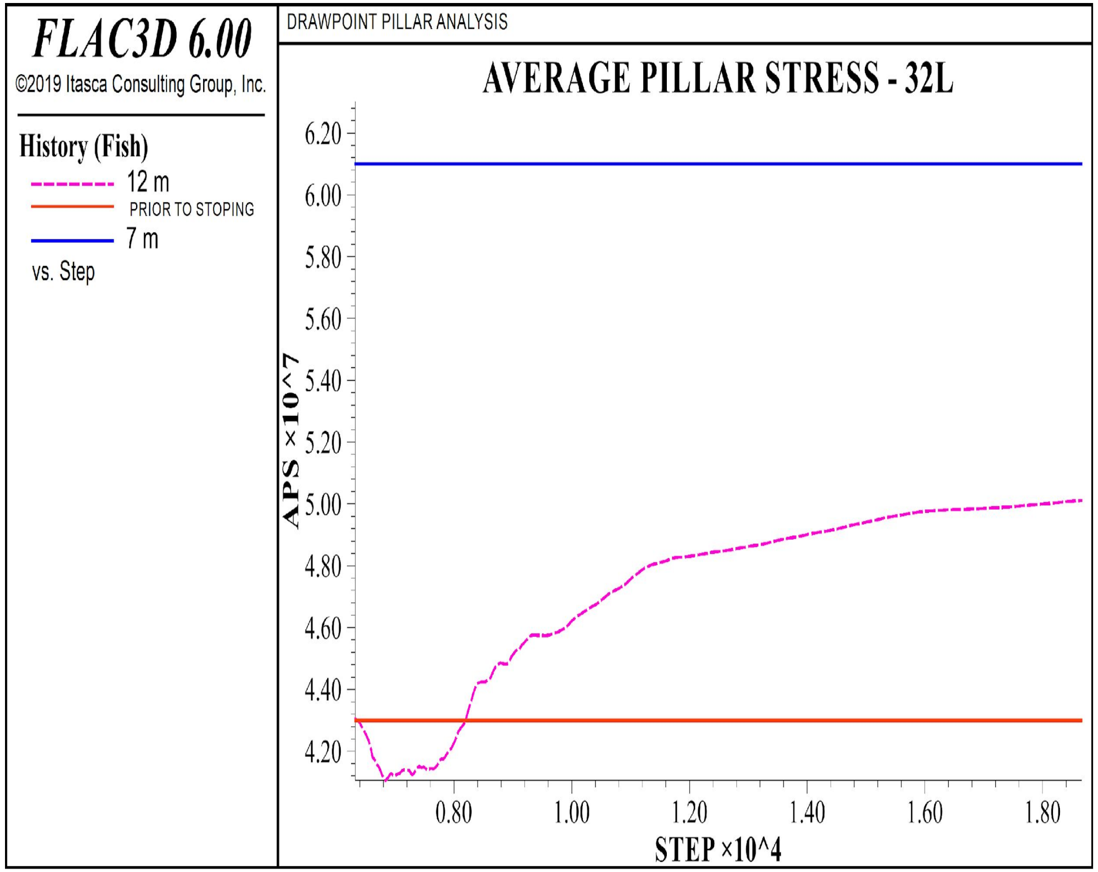
mi = 8

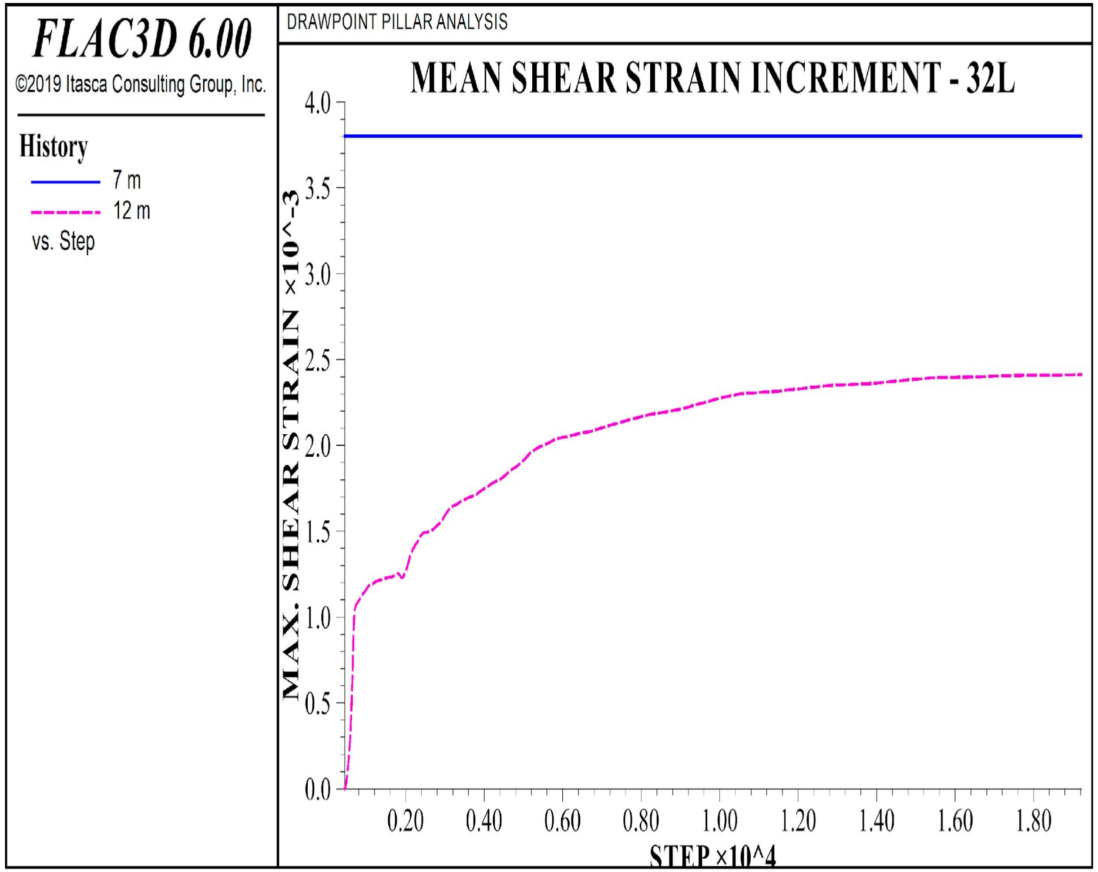
Factors of Safety

DEPTH BS (LEVEL)	DRAWPOINT PILLAR WIDTH (m)			
	7	10	12	14
1015 m (28L)	1.5	1.8	2.0	2.1
1092 m (30L)	1.3	1.6	1.8	2.0
1168 m (32L)	1.2	1.5	1.7	1.8
1245 m (34L)	1.1	1.4	1.6	1.7

- Table presenting the FoS for several pillar sizes simulated at different mining depths
- An increase in the FoS is associated with an increase in the pillar width
- Recommended pillar width for 32L is 12 m with an FoS of 1.7 after cone level development

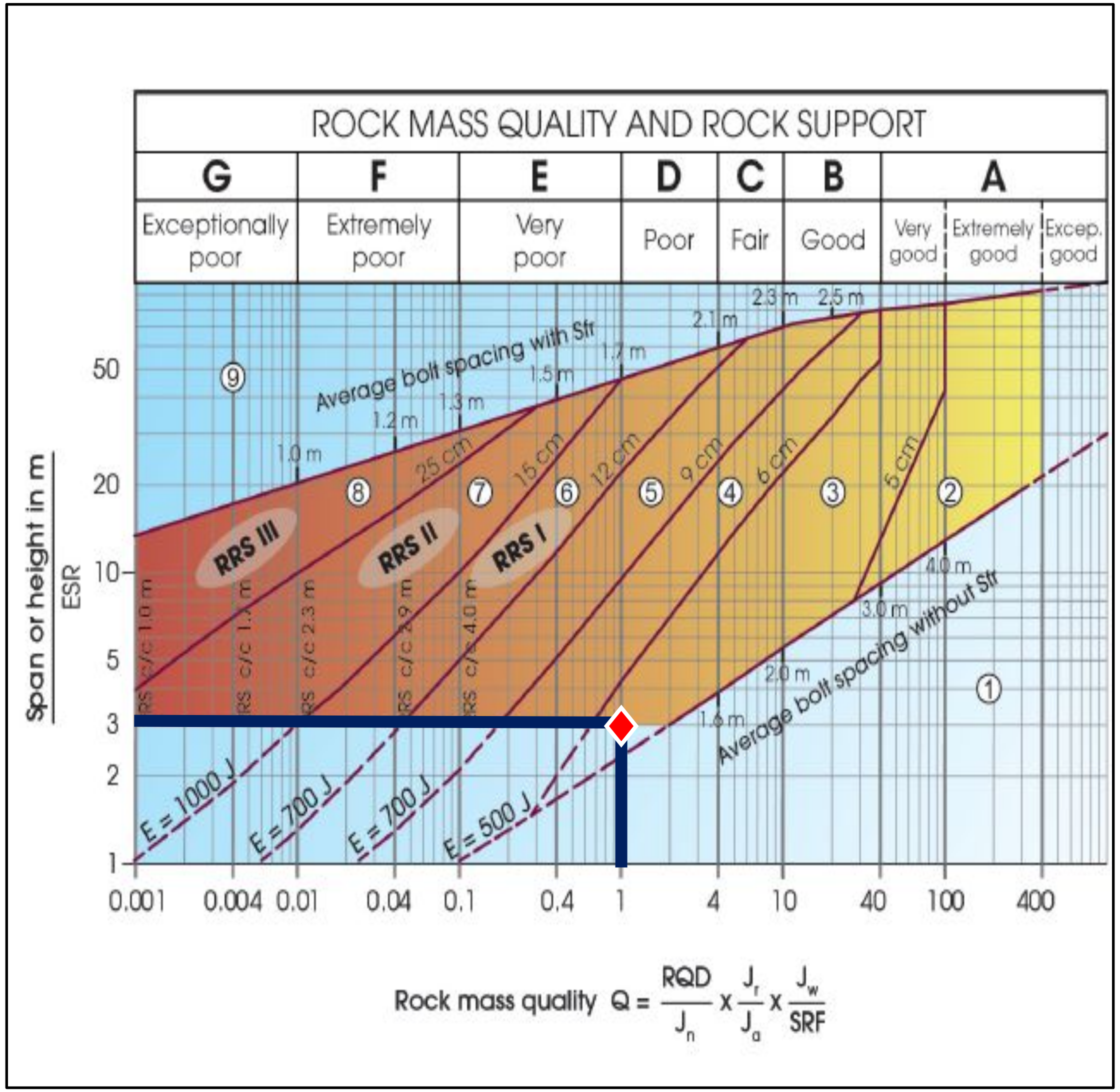
Optimum Pillar Size For 32L





- Lower APS of approximately 50 MPa vs 61 MPa
- Higher pillar strength of 89 MPa vs 76 MPa, 18% increase in strength
- 12 m pillar is approximately 1.6x stiffer than the 7 m pillar

Ground Support



- Q-rating of 1
- Span/height of 3 m and ESR of 1
- Support category 3 – systematic bolting with surface support
- Numerical modelling indicated approximately 1.5 m depth of fracturing
- 2 m long fully grouted shepherd crooks, 1 m x 1 m grid spacing
- Blast-on-mesh to retain slabs

Ground Support

SUPPORT* PRESSURE FOR DECREASING MRMR

MRMR	RMR 1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
	← Rock reinforcement—plastic deformation →									
1A										
1B										
2A										
2B	a	a								
3A	b	b	a	a						
3B	b	b	b	b	b	c				
4A	r	r	c	c	c	d	d			
4B				d	e	f	f	c+l		
5A						f/p	h+f/p	h+f/l	h+f/l	
5B							h+f/p	f/p	t	t

SUPPORT TECHNIQUES

Rock reinforcement

a	Local bolting at joint intersections
b	Bolts at 1 m spacing
c	b and straps and mesh if rock is finely jointed
d	b and mesh/steel-fibre reinforced shotcrete bolts as lateral restraint
e	d and straps in contact with or shotcreted in
f	e and cable bolts as reinforcing and lateral restraint
g	f and pinning
h	Spilling
i	Grouting

Rigid lining

j	Timber	Low deformation
k	Rigid steel sets	Low deformation
l	Massive concrete	Low deformation
m	k and concrete	Low deformation
n	Structurally reinforced concrete	

Yielding lining, repair technique, high deformation

o	Yielding steel arches
p	Yielding steel arches set in concrete or shotcrete

Fill

q	Fill

Spalling control

r	Bolts and rope-laced mesh

Rock replacement

s	Rock replaced by stronger material
t	Development avoided if possible

Conclusion

- 7 m wide pillar was deemed to be unstable with a FoS of 1.3
- Install shepherd crooks and weld mesh at 30L
- 12 m pillar width with a FoS of 1.7 was recommended for 32L
- Support to be installed during development operations at 32L

Recommendations

- Continuous barring down of the roof of the drawpoint crosscuts and haulage drift must be done as the surrounding rock mass is in the yield zone.
- Ensure adherence to production blast design in order to minimize hangups and large boulders in drawpoints.
- Take rock samples for laboratory tests to determine the mechanical properties.
- Implement pillar monitoring programs. Install multipoint borehole extensometers in some of the drawpoint pillars to monitor dilation. Use a borehole camera or a ground penetrating radar (GPR) to monitor the extent of fracturing around the drawpoints.

Acknowledgements

- Aaron Chagwedera (Rock Engineer, LKAB, Sweden)
- Zimbabwe National Institute of Rock Engineering (ZINIRE)
- Rock Mechanics Laboratory (South Africa)

References

1. Itasca Consulting Croup. 2019. FLAC3D Version 6 Manual. Minneapolis.
2. Le Bron, K. B., Gardner, L. J. & Van Zyl, J., 2024. Beyond the empirical design method: The strain criterion and the pillar load inversion concepts. *Journal of the Southern African Institute of Mining and Metallurgy,* 124(5), pp. 293–302.

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QUESTIONS?

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