The Whole Truth and Nothing but the Truth? A Case Study Comparing Analytical and Empirical Assessments Against Site Observations

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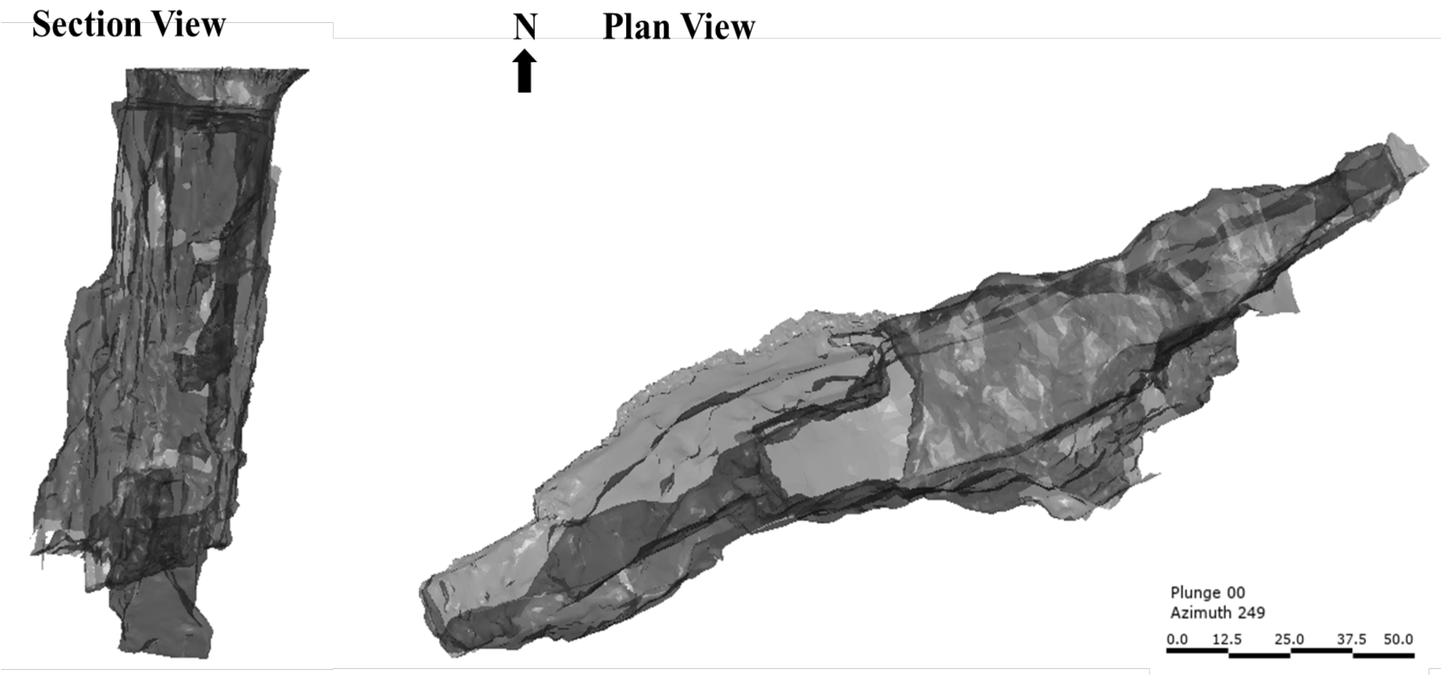
1. Introduction

- *With more than a century of mining, many historic mining operations in Canada have been abandoned*
  - *Require mine closure adhering to regulations specific to their location*
- *Mine site located in northern Canada*
  - *Interconnecting open pit and underground mining methods*
  - *Failure occurred at depth and backfill material was lost in the mine.*
  - *Pond exist where the open pit was located*
- *Geology*
  - *Greenstone belt with history of tectonic deformation, volcanic and intrusive activity*
  - *The deposit is hosted in a medium to coarse grained diorite unit*
- *Need for the study*
  - *Project is located near a community*
  - *Instabilities could have a substantial impact on the community*
  - *Focus on the stability assessments*

2. Data

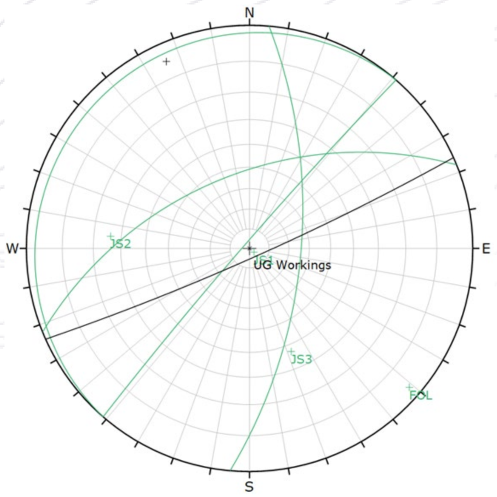
- *Available data for this site:*
  - *Collection and review of historic drawings and photographs*
  - *Review of Time Domain Reflectometry (TDR) cables installed to shallow depths in the early 1990s*
  - *A bathymetric and a 3D sonar survey of the pond and the connected flooded workings*



2. Data

- *Following the completion of the 3D sonar survey, a field programme of five drillholes was completed*
  - *Characterize the rock mass; and*
  - *Determine the discontinuity orientations surrounding the historic underground workings*

  - *On-rig logging of the oriented drill core from triple-tubed drilling provided the basis for calculation of rock mass parameters*
  - *Used for the stability assessments (RMR_{76})*



Discontinuity	Dip (°)	Dip Direction (°)
Foliation (Fol)	87	311
Joint Set 1 (J1)	03	310
Joint Set 2 (J2)	64	095
Joint Set 3 (J3)	53	338

Hole ID	Drillhole Depth (m)	TCR (%)	RQD (%)	IRS	FF/m	RMR_{76}
19-01	74.54	100	96	R4	3.2	59
19-02	107.54	99	94	R5	4.2	63
19-03B	14.69	95	74	R5	7.8	56
19-04	71.79	91	82	R5	15.6	60
19-05	12.36	100	74	R4	13.8	47

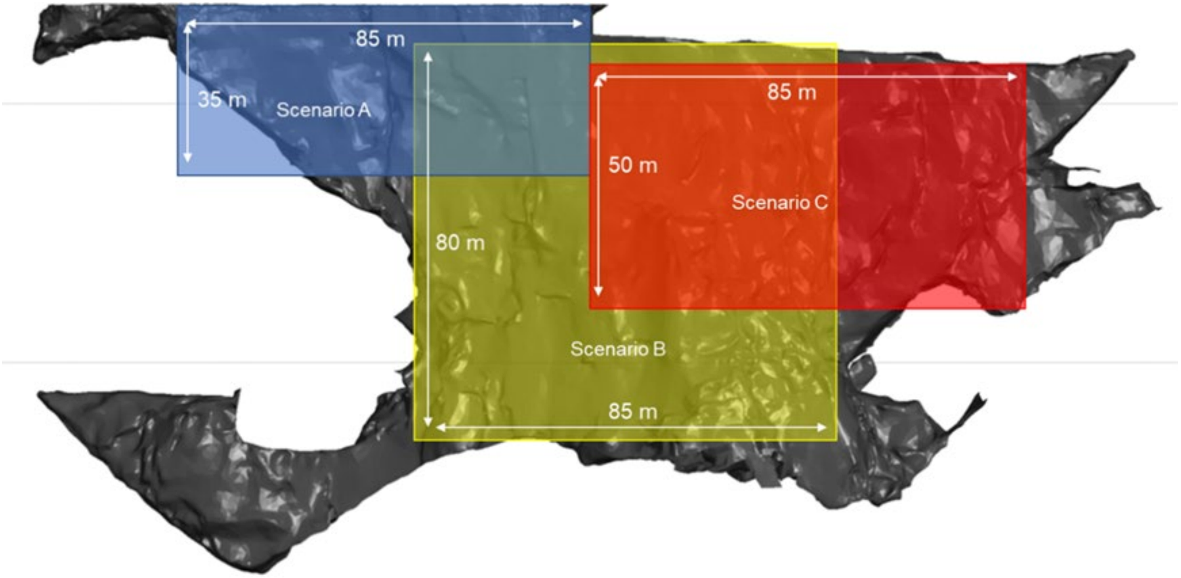
3. Stability Assessments Undertaken

- *Stability assessments completed for the site*
  - *Two analytical approaches (UnWedge & SWedge)*
    - *Assess the stability of the hanging wall and foot wall of the underground and open pit areas*
  - *Empirical approach*
    - *Assess the stability of the crown pillar*

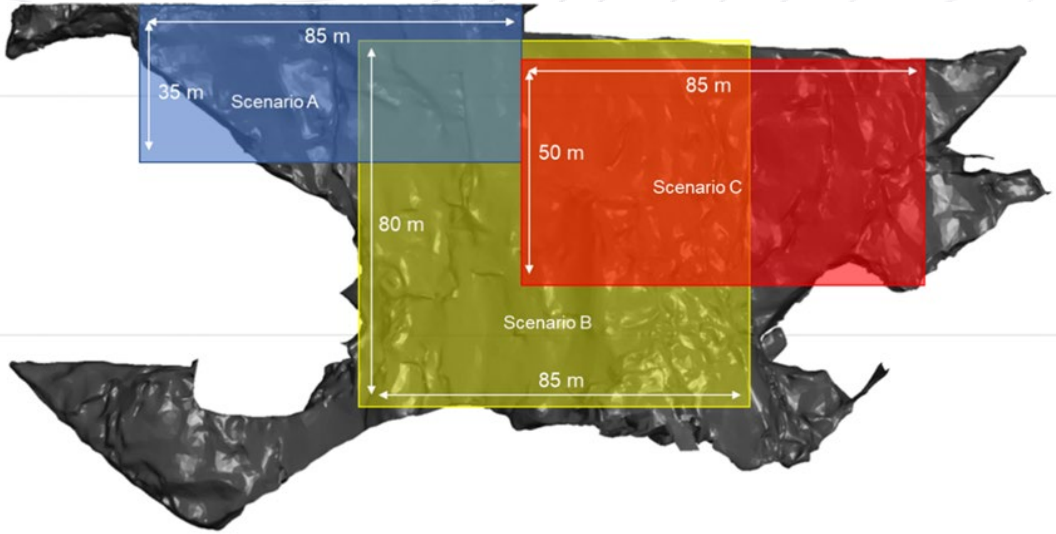
  - *Stability assessments were completed for the open pit portion of this excavation, but these assessments will not be discussed in this presentation*

3.1.1 Unwedge Analysis

- *Unwedge version 5 (Rocscience, 2019)*
  - *Three scenarios were assessed to evaluate potential blocks forming in the project site hanging wall and footwall*
  - *Assessment considered major joint orientations*
- *Joint Properties*
  - *Modified using the by Barton and Bandis (1990) approach to better consider joint persistence and the impact of rock bridges*
  - *Conservative 90% persistence was used*



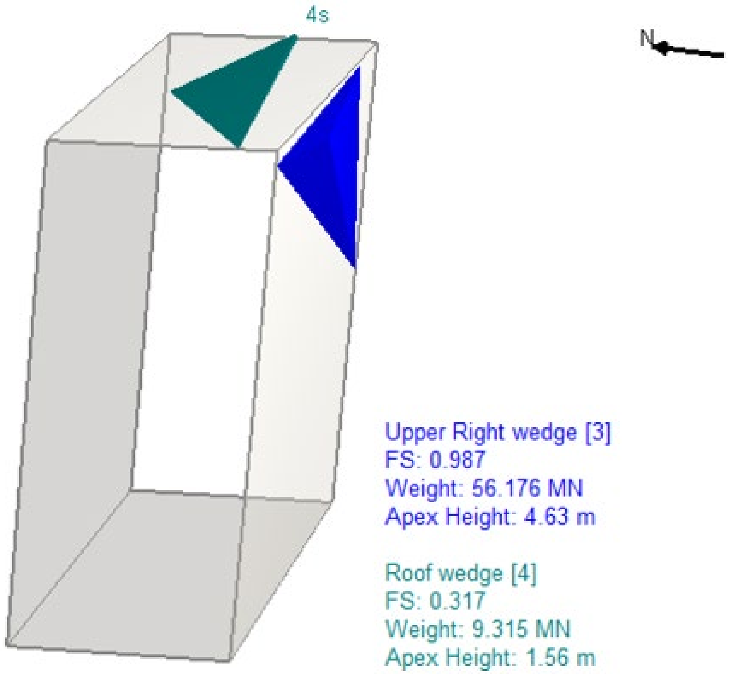
3.1.1 Unwedge Results

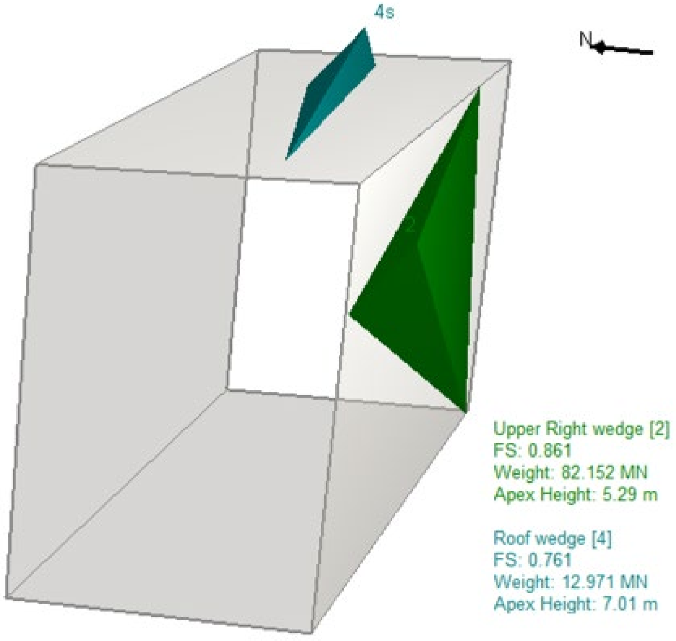


- *Scenario A*
  - *No unstable wedges were present along the hanging wall, foot wall and sidewall of the open pit pond*

- *Scenario B*

Scenario C



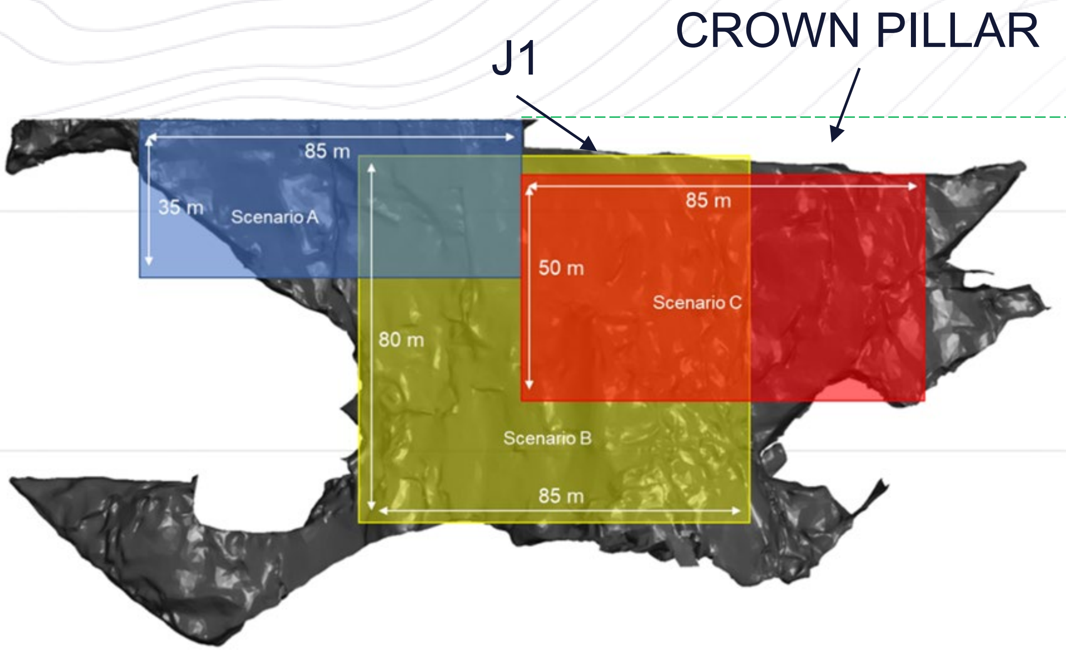


3.1.2 Swedge Analysis and Results

- *Swedge code (Rocscience, 2020)*
  - *Evaluate the geometry and stability of surface wedges in rock slopes*
  - *The combinations and probabilistic analysis were used to assess the wedge stability of the open pit pond*
- *Potentially unstable wedges along the footwall*

Scenario	PWP and Seismic Forces	Joint combination	Wedge Height	Break back distance from the crest	FoS	PoF (%)
	Hanging Wall					
Open pit pond	No	Fol and JS2b	15 m	8 m	> 5	0
Open pit pond	Yes	Fol and JS2b	15 m	8 m	> 5	0
	Foot Wall					
Open pit pond	No	Fol and JS2a	45 m	5 m	> 5	0
Open pit pond	Yes	JS2a and JS3b	45 m	17 m	0	90

4. Empirical Crown Pillar Assessment



- *Conventional approach to assessing subsidence effects over metal mines is to use the scaled span approach*
- *Developed by Carter in 1992 and has been regularly updated by (Carter et al., 2008).*
- *Scaled Crown Span:*

$$C_S = S \times \sqrt{\left\{\frac{\gamma}{t \times (1 + S_R).(1 - 0.4 \times \cos\theta)}\right\}}$$

- *Critical Span:*

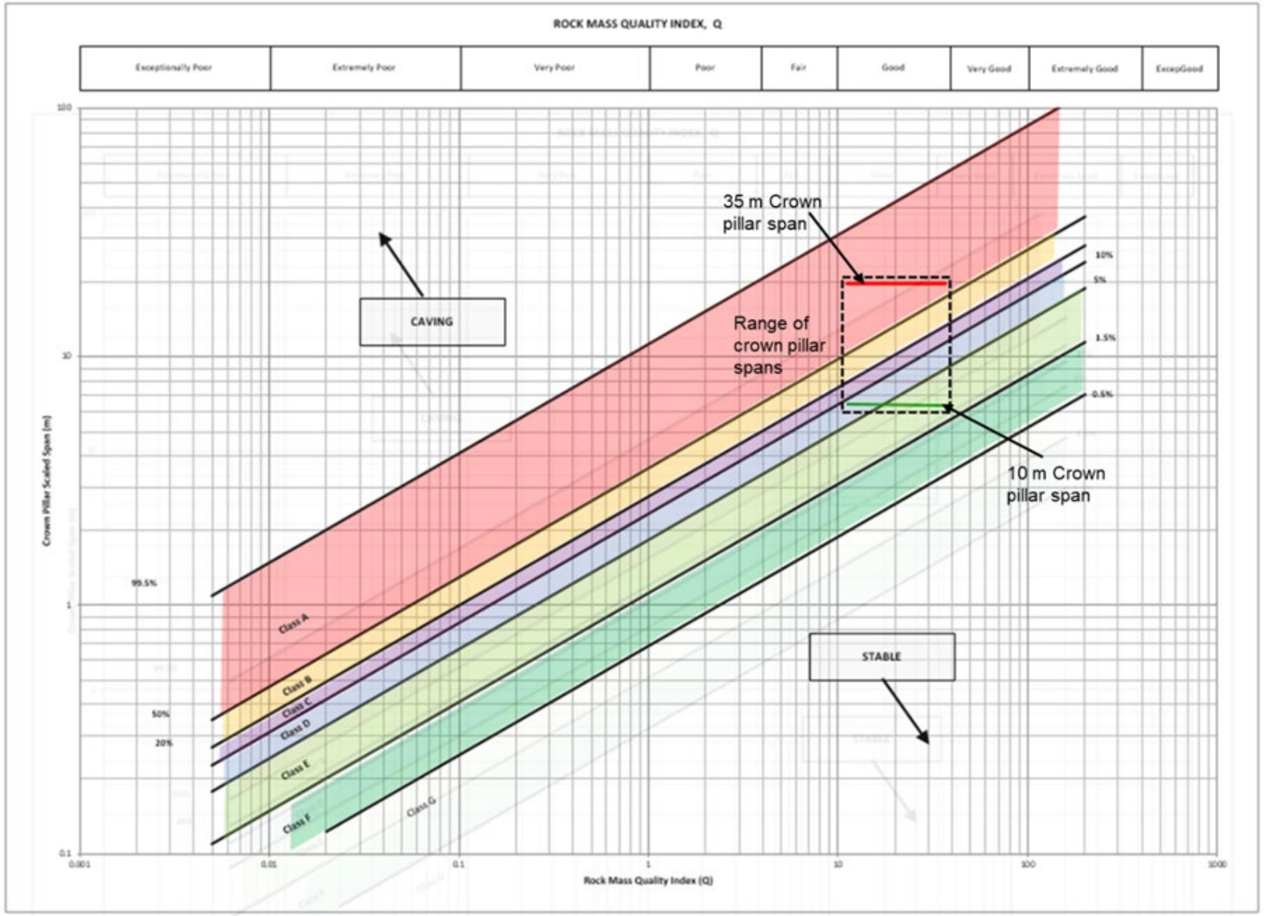
$$S_C = 3.3 \times Q^{0.43} \times sinh^{0.0016} Q$$

- *In cases where the Scaled Crown Span is less than the Critical Span, the crown pillar would be considered as stable, where this relationship is reversed the pillar would be considered unstable*

4.1.1 Design Guidelines

- *Input Parameters: Empirical Assessment*
  - *Using average rock mass characteristics from the field programme*
    - *As parameters specific to the crown pillar were unknown*
  - *Specific gravity: 2.91 g/cc*
  - *From the 3D sonar survey:*
    - *Dip of the ore body: 85°*
    - *Strike length of crown pillar: 104 m*
    - *Crown pillar thickness: 7 m*
    - *Crown Pillar span:10 to 35 m*

4.1.1 Crown Pillar Stability Results



Class	Probability of Failure (%)	Minimum Factor of Safety	Maximum Scaled Span, Cs (=Sc)	ESR (Barton et. al. 1974)	Design Guidelines for Pillar Acceptability/Serviceable Life of Crown Pillar				
					Expectancy	Years	Public Access	Regulatory position on closure	Operating Surveillance Required
A	50 - 100	<1	$11.31Q^{0.44}$	>5	Effectively zero	< 0.5	Forbidden	Totqally unacceptable	Ineffective
B	20 - 50	1.0	$3.58Q^{0.44}$	3.0	Very, very short-term (temporary mining purposes only; unacceptable risk of failure for temporary civil tunnel portals)	1	Forcibly prevented	Not acceptable	Continuous sophisticated monitoring
C	10 - 20	1.2	$2.74Q^{0.44}$	1.6	Very short-term (quasi-temporary stope crowns; undesirable risk of failure for temporary civil works)	2 - 5	Actively prevented	High level of concern	Continuous monitoring with instruments
D	5 - 10	1.5	$2.33Q^{0.44}$	1.4	Short-term (semi-temporary crowns, e.g. under non-sensitive mine infrastructure)	5 - 10	Prevented	Moderate level of concern	Continuous simple monitoring
E	1.5 - 5	1.8	$1.84Q^{0.44}$	1.3	Medium-term (semi-permanent crowns, possibly under structures)	15 - 20	Discouraged	Low to moderate level of concern	Conscious superficial monitoring
F	0.5 - 1.5	2.0	$1.12Q^{0.44}$	1.0	Long-term (quasi-permanent crowns, civil portals, near surface sewer tunnels)	50 - 100	Allowed	Of limited concern	Incidental superficial monitoring
G	< 0.5	>>2	$0.69Q^{0.44}$	0.8	Very long-term (permanent crowns over civil tunnels)	> 100	Free	Of no concern	None required

Cartel et al., 2008

5. Conclusions

- *5.1 Hanging Wall and Foot Wall Assessment Conclusions*
  - *3D Sonar survey*
    - *Increased confidence in stability of underground void and remaining sill pillars*
    - *Showed features underwater – boat*
    - *No extensive rubble on the floor of excavation*
    - *Suggest that hanging wall and foot wall failures were limited*
    - *Kinematically possible wedges had not formed and failed from the hanging / foot wall*

- *5.2 Crown Pillar*
    - *Scaled Scan Method,3D Sonar Survey and historical photographs*
    - *Minimal degradation of the rock forming the crown pillar*
    - *No indication of degradation*
    - *Crown pillar stood for over 90 years without failing or showing any significant degradation*
    - *At odds with the empirical assessment results*

5. Conclusions

- *Experience gained*
  - *Empirical and analytical tools used for stability assessment didn't correspond with the observed excavation stability*
  - *Highlights the importance of collecting observations of excavation performance to determine the behaviour*
  - *Observations should be considered to make appropriate engineering judgements*

6. References

- *Barton, N.R. and Bandis, S.C. (1990). Review of predictive capabilities of JRC-JCS model in engineering practice. In Rock joints, proc. Int. symp. On rock joints, Loen, Norway, (eds N. Barton and O.Stephansson), 603-610. Rotterdam: Balkema.*
- *Carter, T.G., Cottrell, B.E., Carvalho, J.L., and Steed, C.M. (2008). Logistic Regression improvements to the Scaled Span Method for dimensioning Surface Crown Pillars over civil or mining openings*
- *Rocscience Inc. (2019). Unwedge Version 5. www.rocscience.com, Toronto, Ontario, Canada*
- *Rocscience Inc. (2020). Unwedge Version 5. www.rocscience.com, Toronto, Ontario, Canada*
- *Rocscience Inc. (2020). Swedge Version 7. www.rocscience.com, Toronto, Ontario, Canada*

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