Reviewing Laubscher's empirical method to estimate subsidence limits

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Outline

- Introduction
- A review of Laubscher's chart to estimate subsidence
- Methodology
- Data
- Results
- Conclusion

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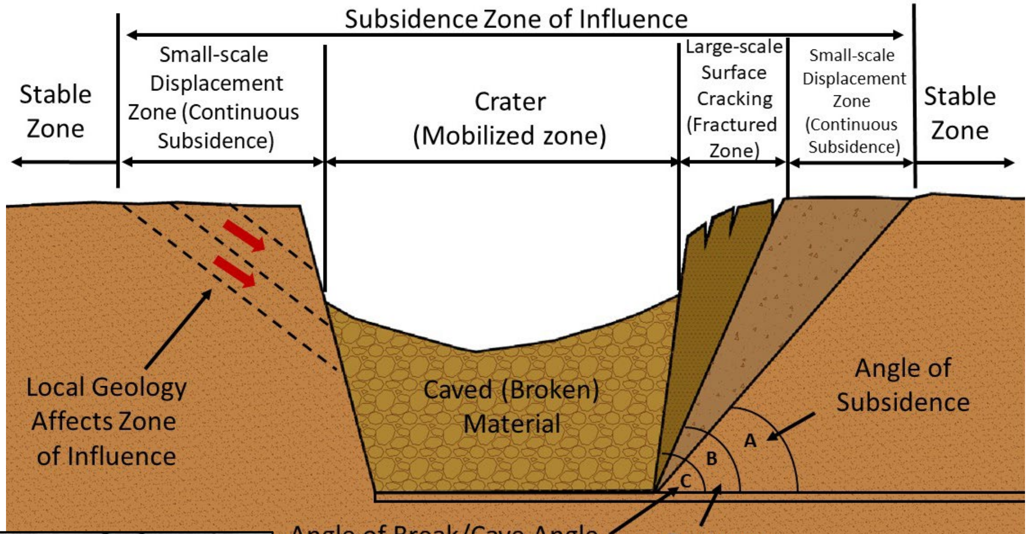
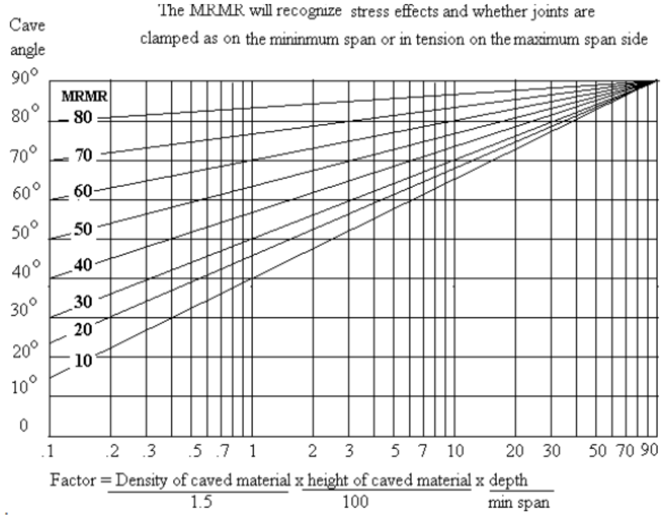
Introduction

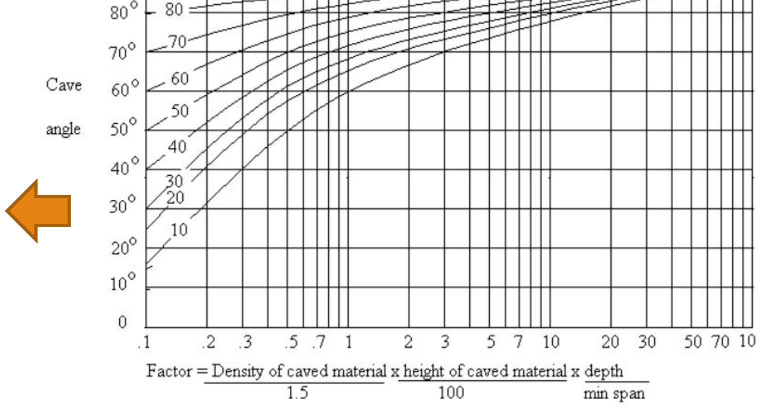


(Modified from Laubscher et al 2017)

(Eberthardt et al 2007)



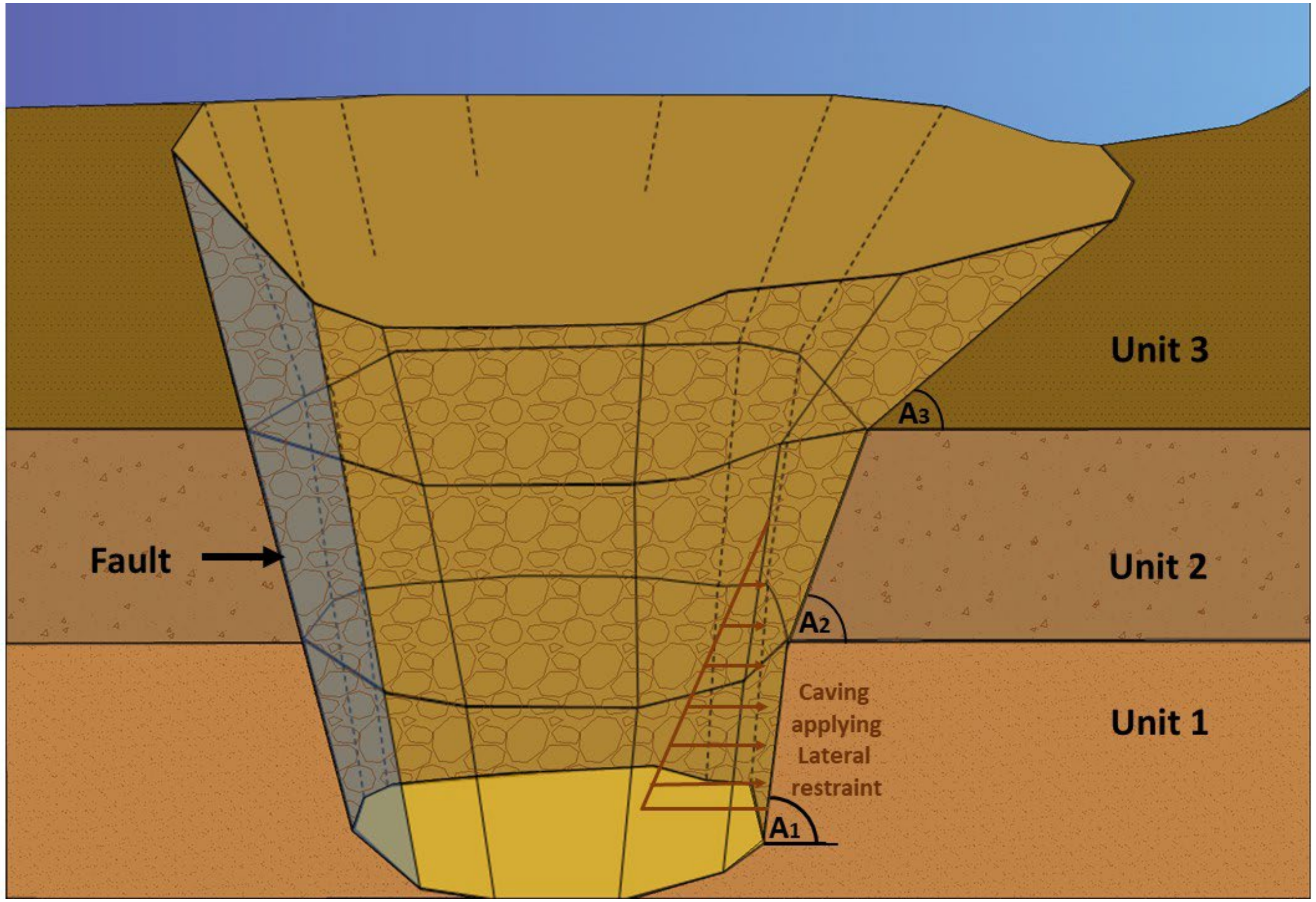
A conservative approach and should be used for siting important infrastructure such as shafts or plant.



(Laubscher 2000)

This diagram is less conservative and would be used for draw control and water inflow calculations.

Introduction



MRMR:
Unit 1 > Unit 2 > Unit 3

Cave angles:
A1 > A2 > A3

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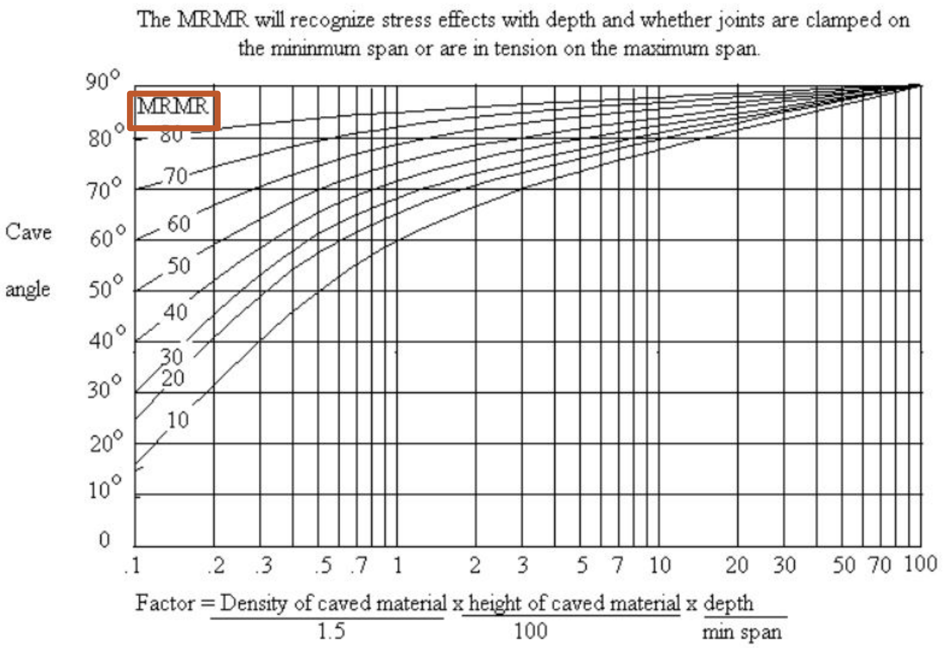
A review of Laubscher’s chart to estimate subsidence

Limitations

- **Mining Rock Mass Rating (MRMR)**



The MRMR will recognize stress effects with depth and whether joints are clamped on the mininmum span or are in tension on the maximum span.

Factor = $\frac{\text{Density of caved material}}{1.5} \times \frac{\text{height of caved material}}{100} \times \frac{\text{depth}}{\text{min span}}$

(Laubscher 2000)

MRMR adjustment factors

- Weathering
- Joint Orientation
- Blasting
- Mining Induced Stresses
- Water & Ice

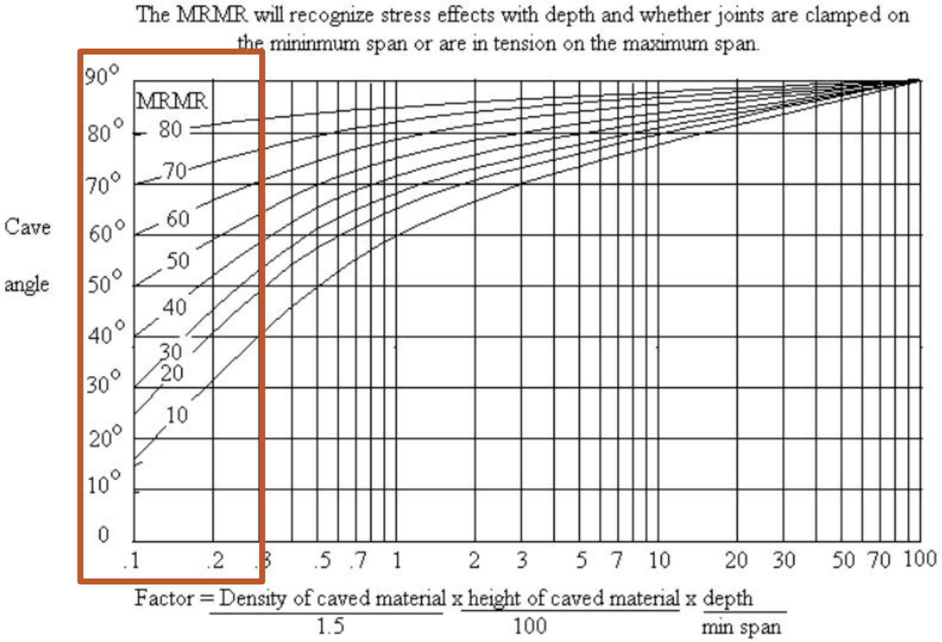
MRMR = IRMR x (adjustment factors)

IRMR: In-Situ Rock Mass Rating

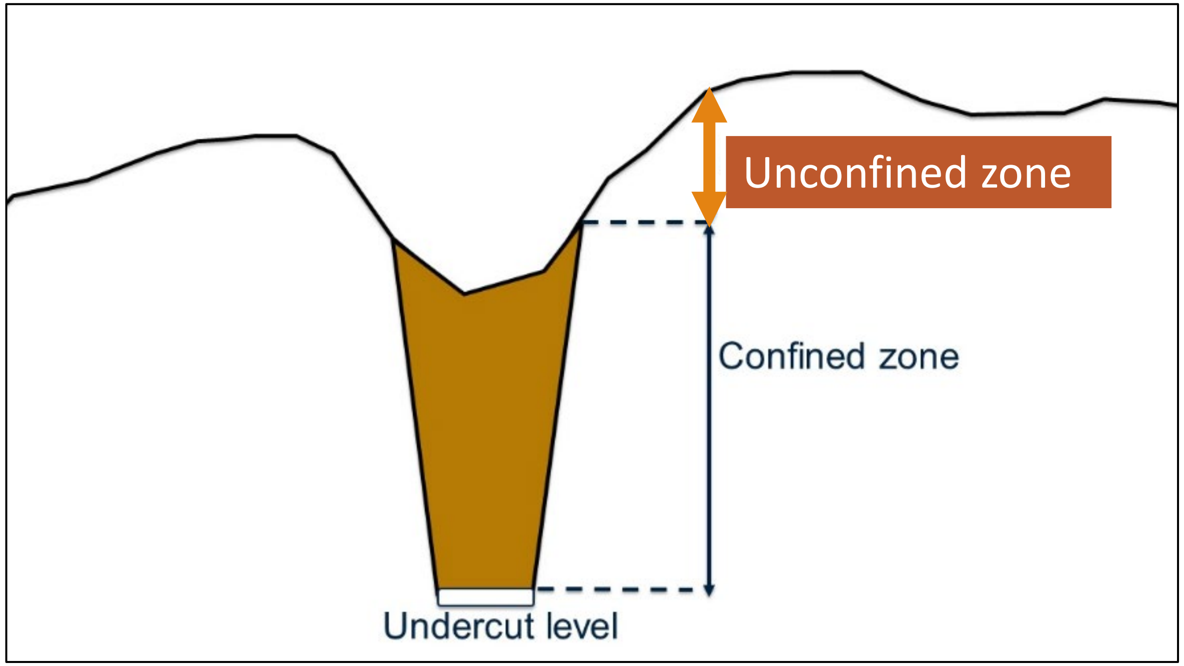
A review of Laubscher’s chart to estimate subsidence

Limitations

- MRMR
- **Unconfined Area**



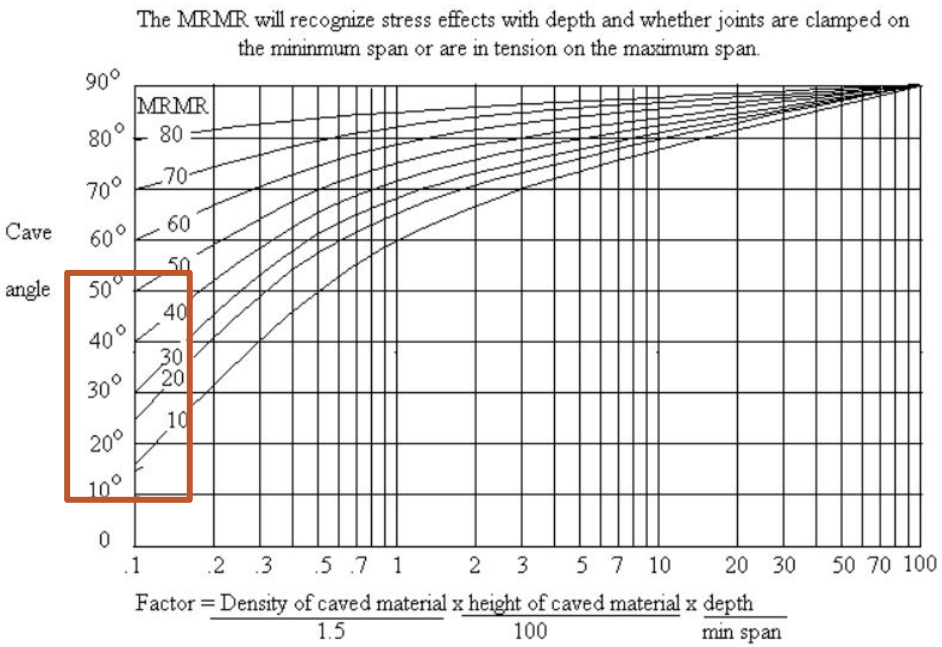
(Laubscher 2000)



A review of Laubscher’s chart to estimate subsidence

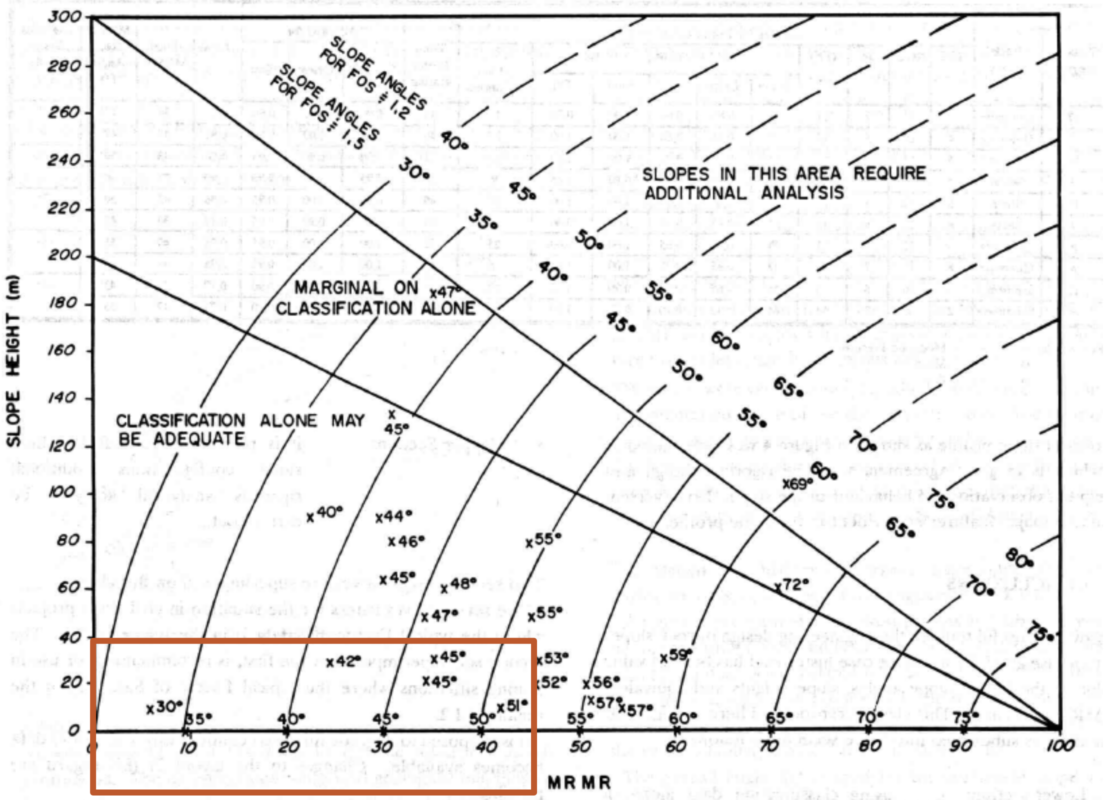
Limitations

- **MRMR**
- **Unconfined Area**



The MRMR will recognize stress effects with depth and whether joints are clamped on the mininmum span or are in tension on the maximum span.

(Laubscher 2000)

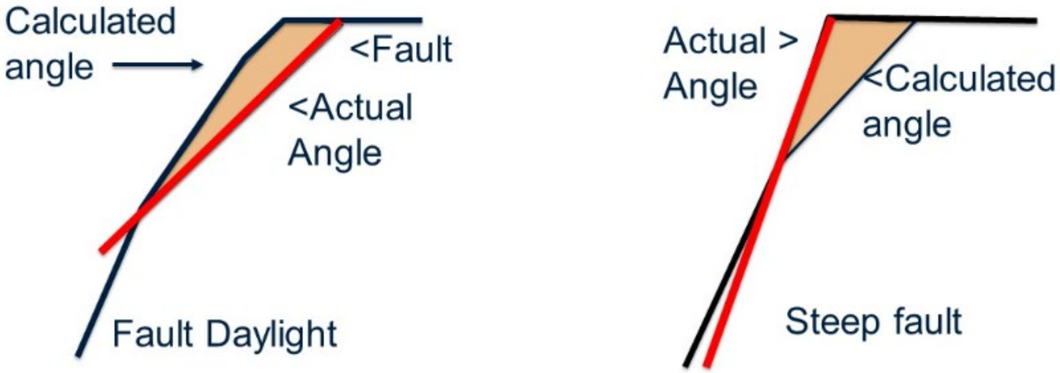


(Haines & Tebrugge 1991)

A review of Laubscher’s chart to estimate subsidence

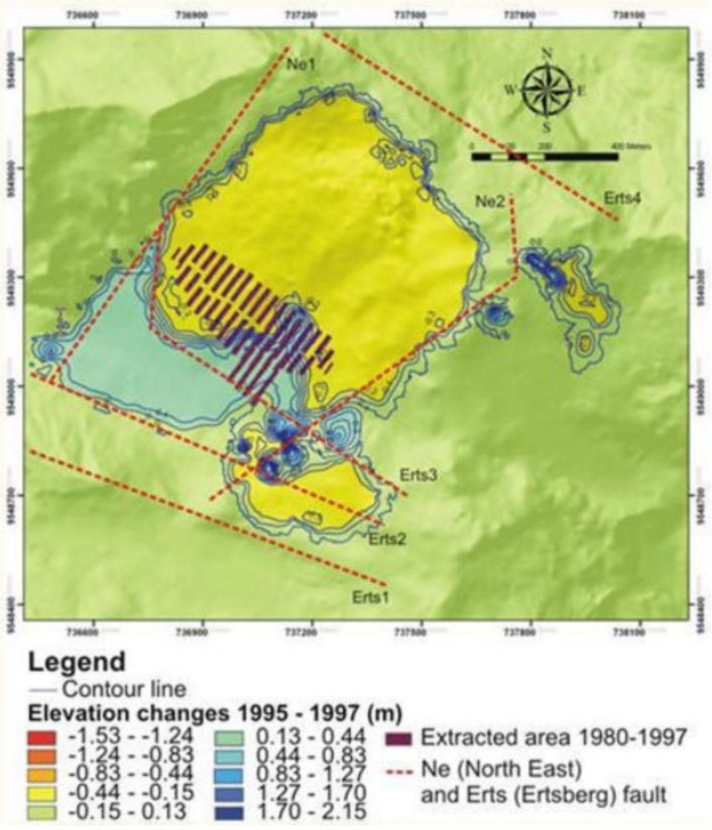
Limitations

- MRMR
- Unconfined Area
- **Structures**



(Modified from Laubscher 2000)

Grasberg



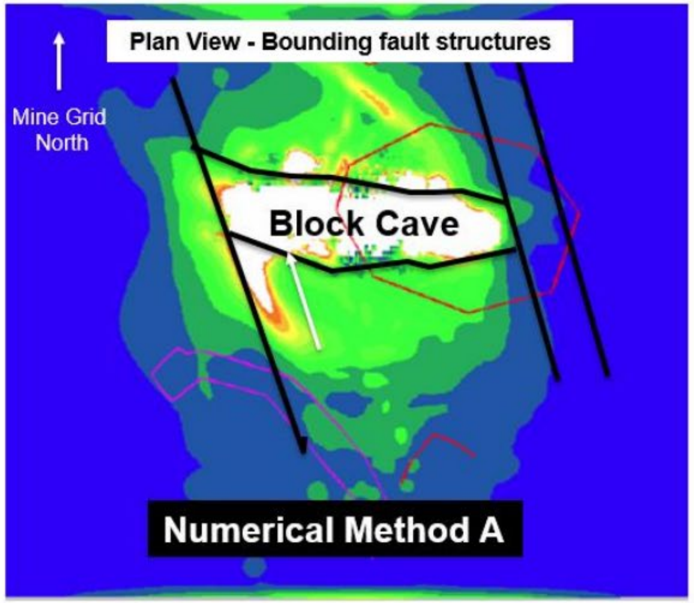
(Esaki et al 2009)

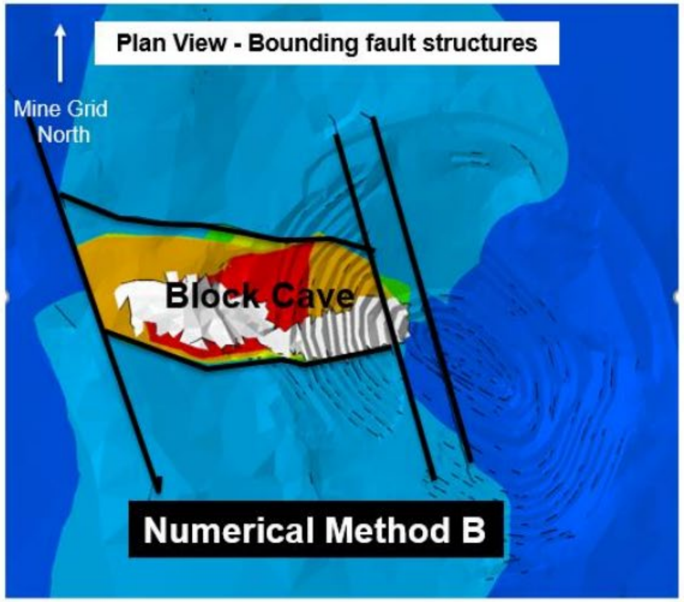
A review of Laubscher’s chart to estimate subsidence

Limitations

- MRMR
- Unconfined Area
- **Structures**

New Afton





(Davies et al 2018)

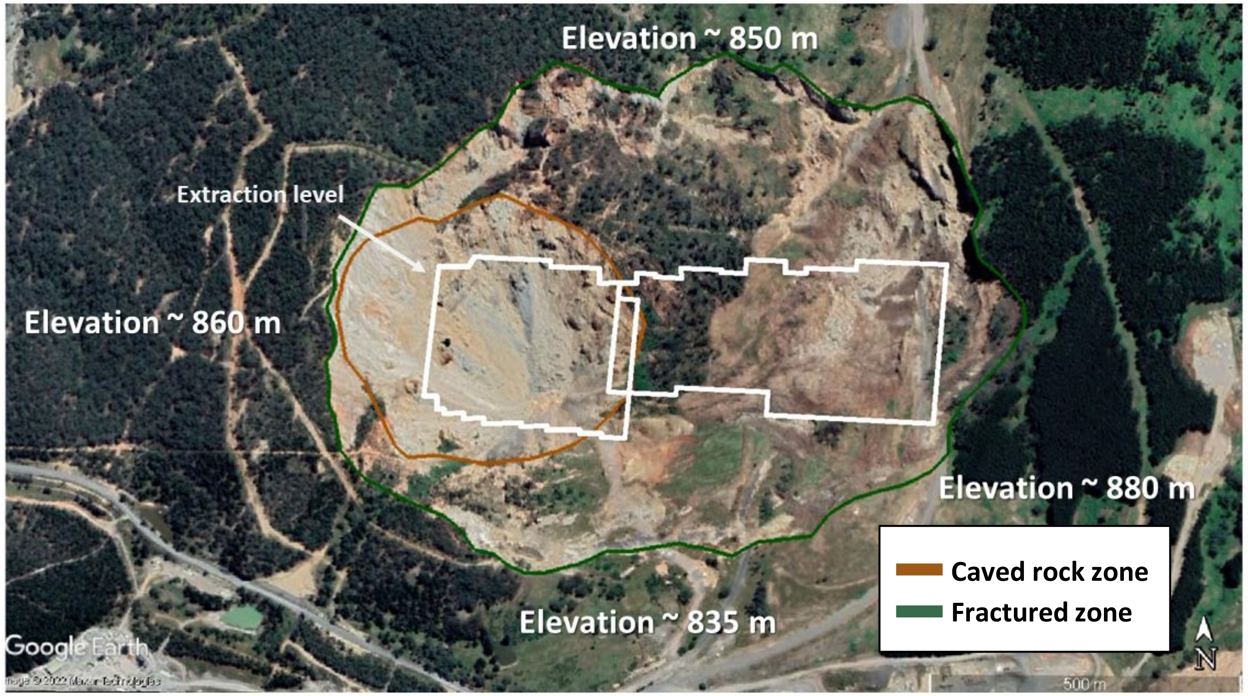
Model *Both models allowed* ***the major fault structures to dominate the subsidence behaviour***

Learning *The major bounding fault structures were large weak-faulted shear zones and* ***they did not constrain or control cave propagation..***

A review of Laubscher's chart to estimate subsidence

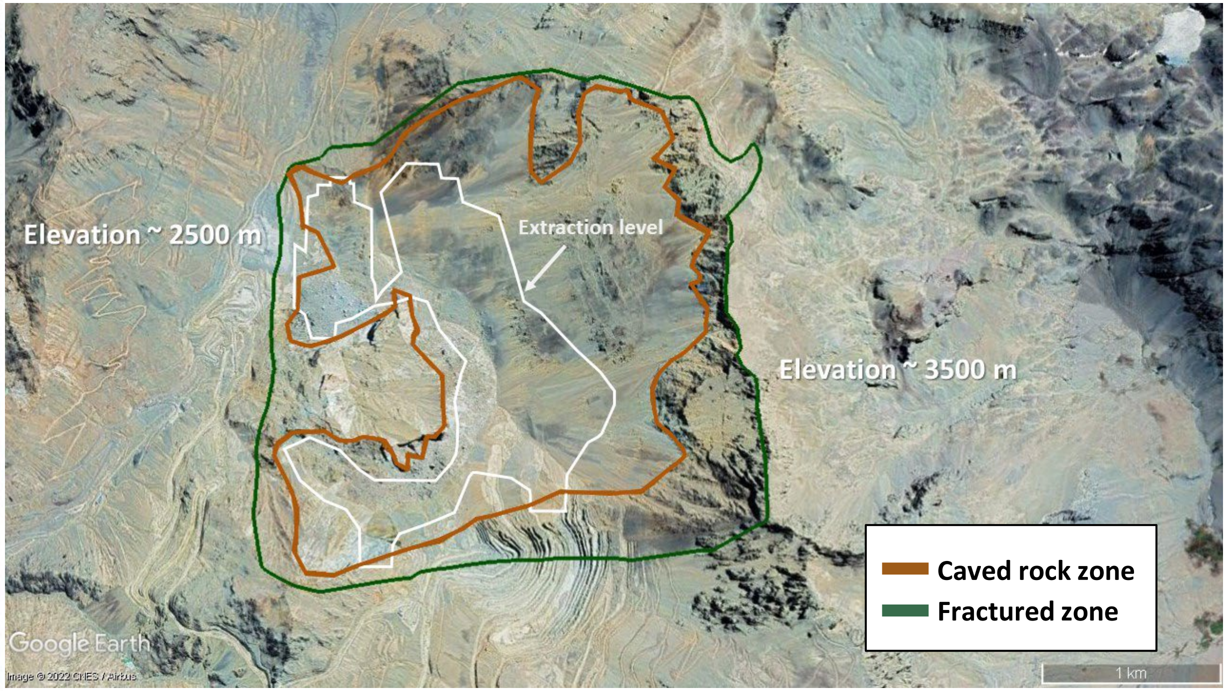
Limitations: **Topography**

Flat Topography- *Cadia East*



(Modified from Wilson 2003; Castro et al 2018)

Irregular Topography – *El Teniente*

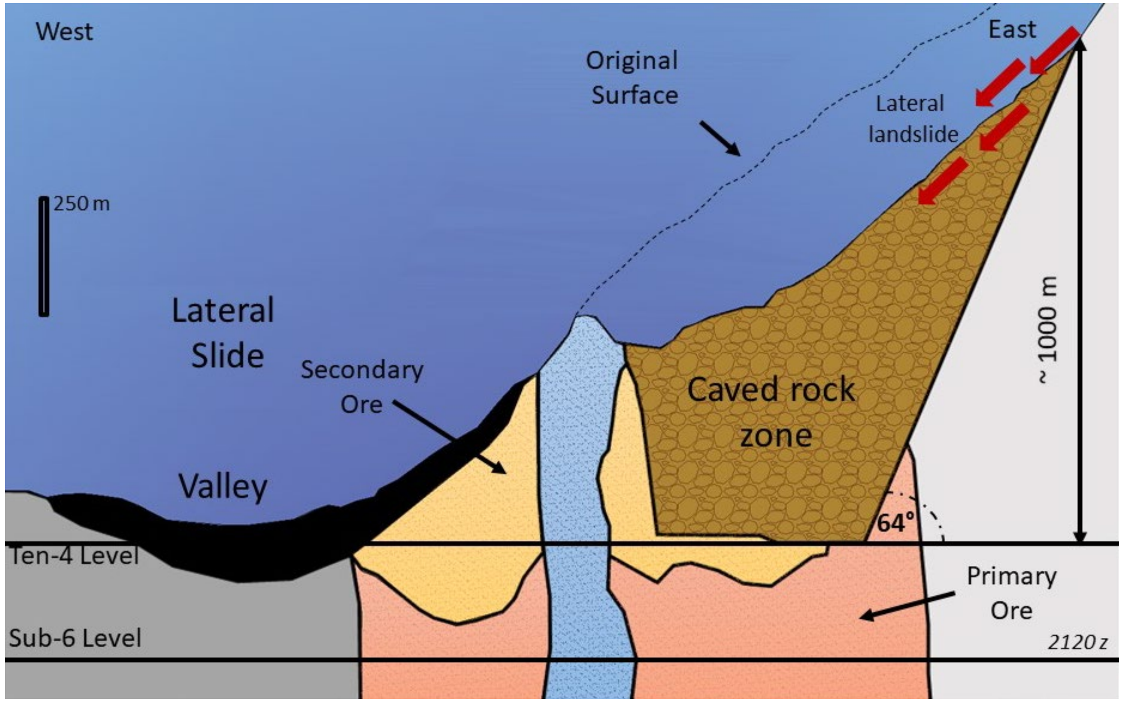


(Modified from Farloni et al 2018)

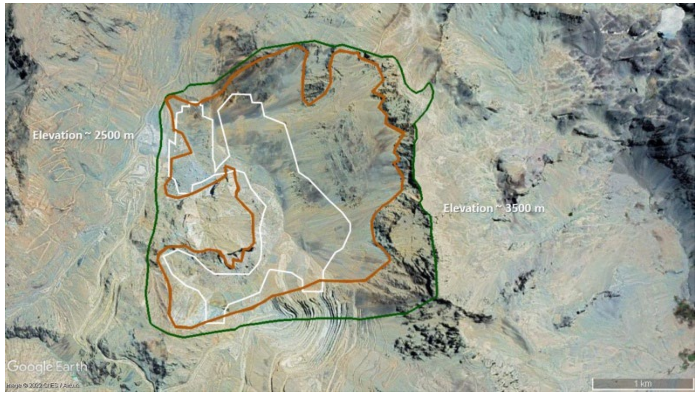
A review of Laubscher's chart to estimate subsidence

Limitations: **Topography**

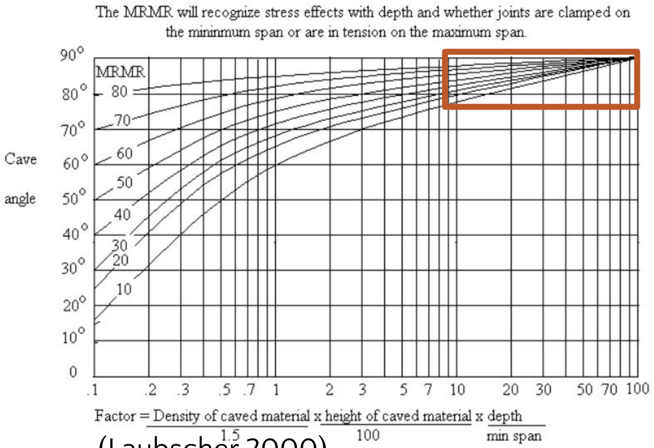
Irregular Topography – *El Teniente*



(Modified from Brzovic 2010)



(Modified from Farloni et al 2018)

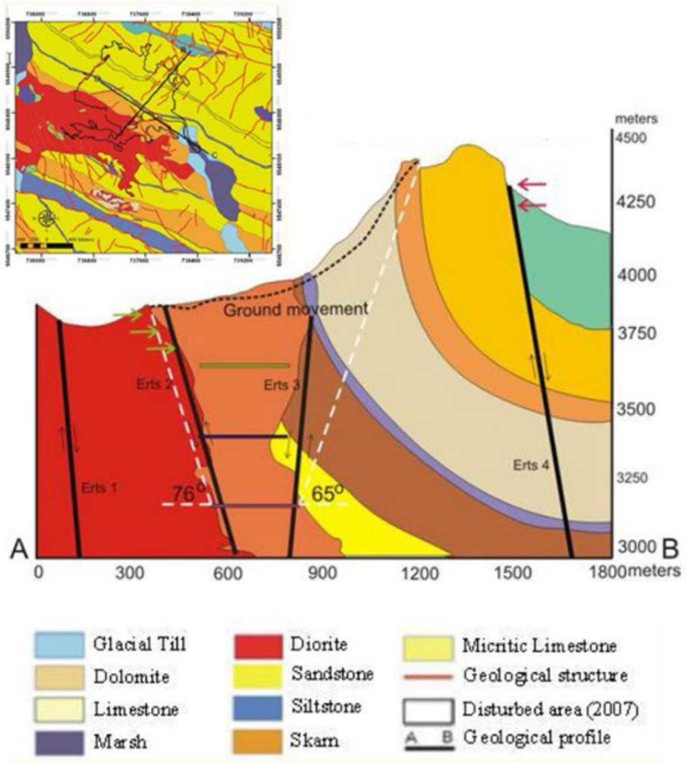


(Laubscher 2000)

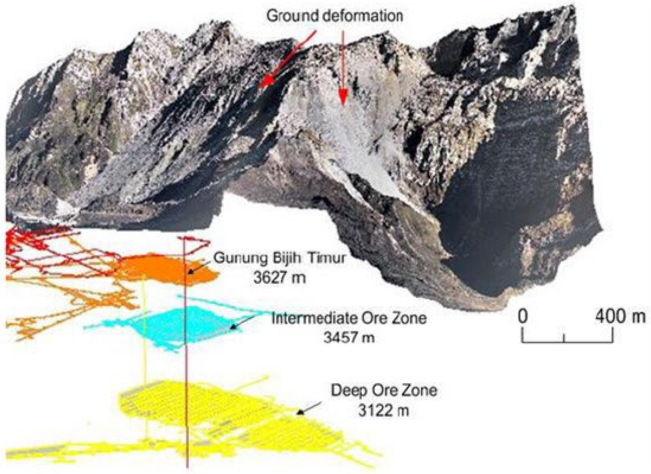
A review of Laubscher’s chart to estimate subsidence

<u>Limitations: </u>Topography

Irregular Topography – *Grasberg*



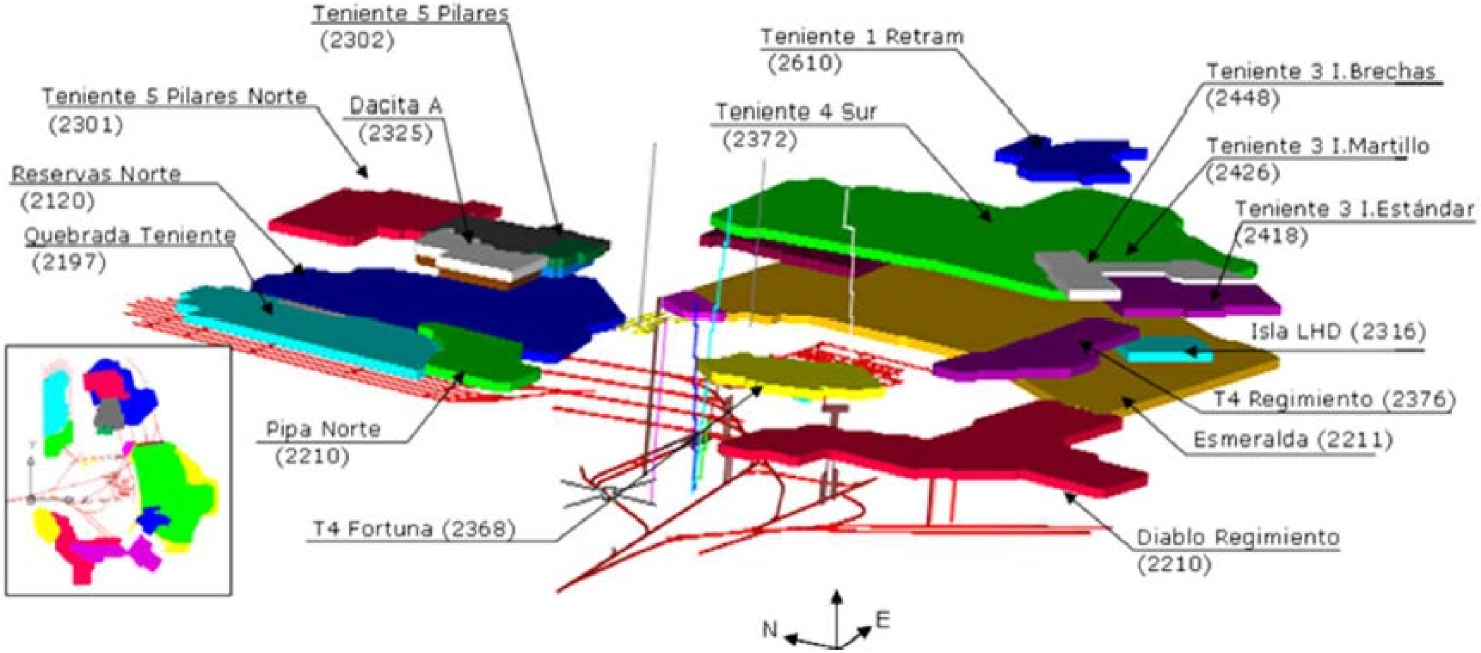
(Esaki et al 2009)



A review of Laubscher’s chart to estimate subsidence

Limitations

- MRMR
- Unconfined Area
- Structures
- Topography
- **Mining Sequence**



(Oyarce 2017)

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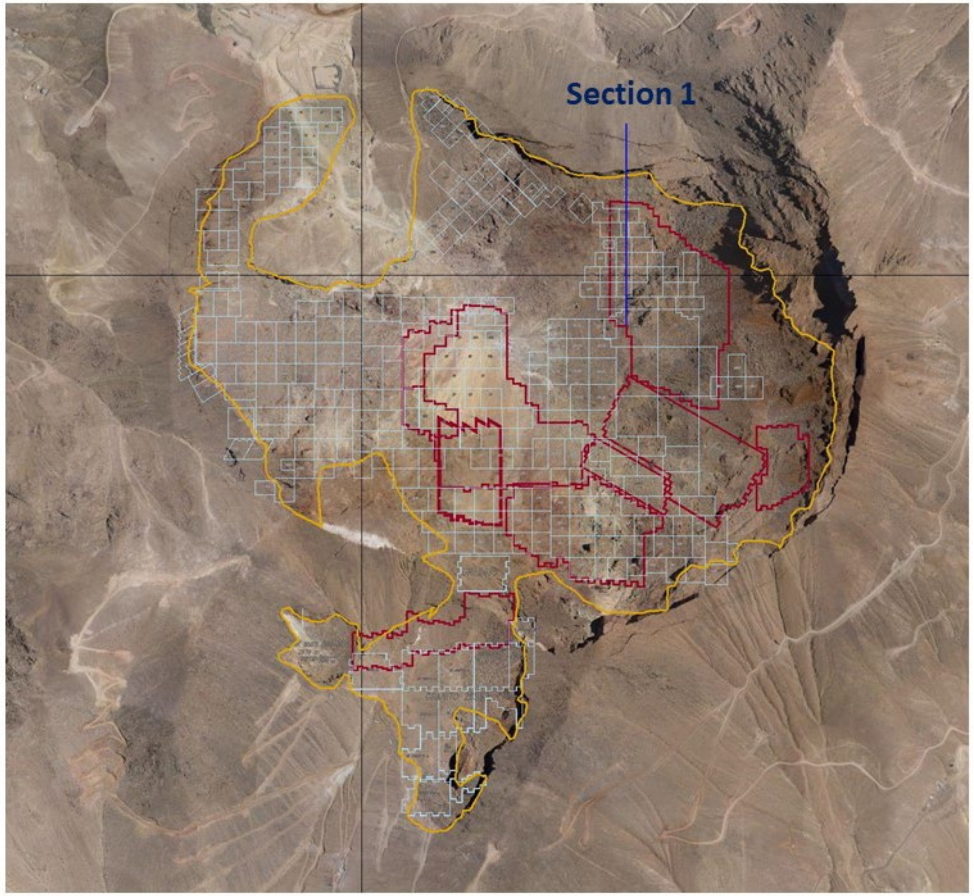
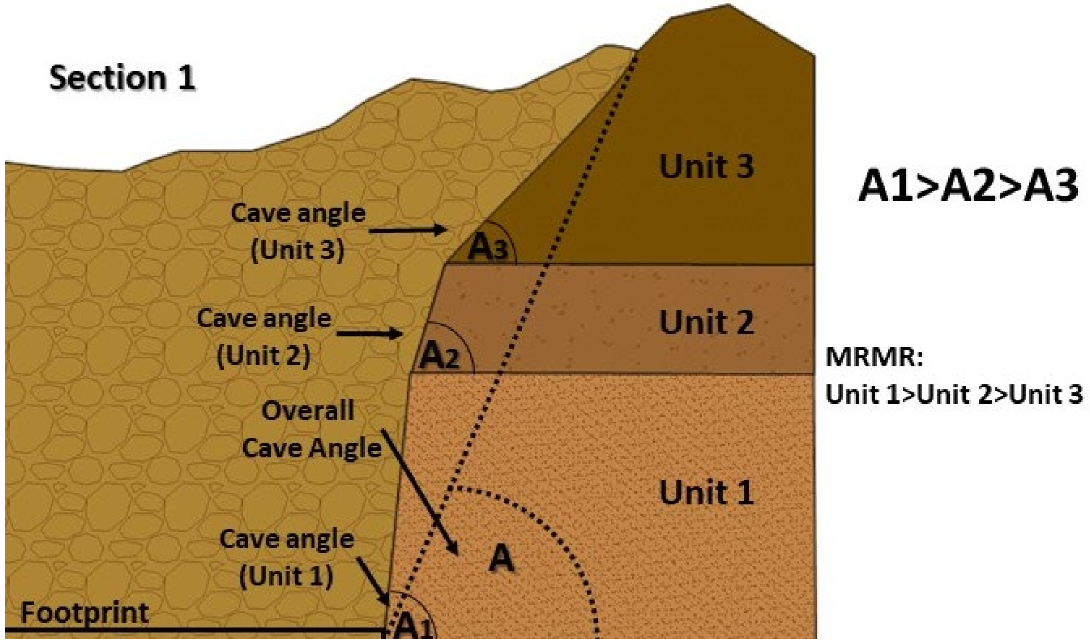
Methodology

- Information from “new” cave operations (after late 1990s)
- Interviewing experts in the field
- Comparing prediction made using Laubscher’s method and actual subsidence envelope dimensions

Methodology



(Modified from Contreras 2016)



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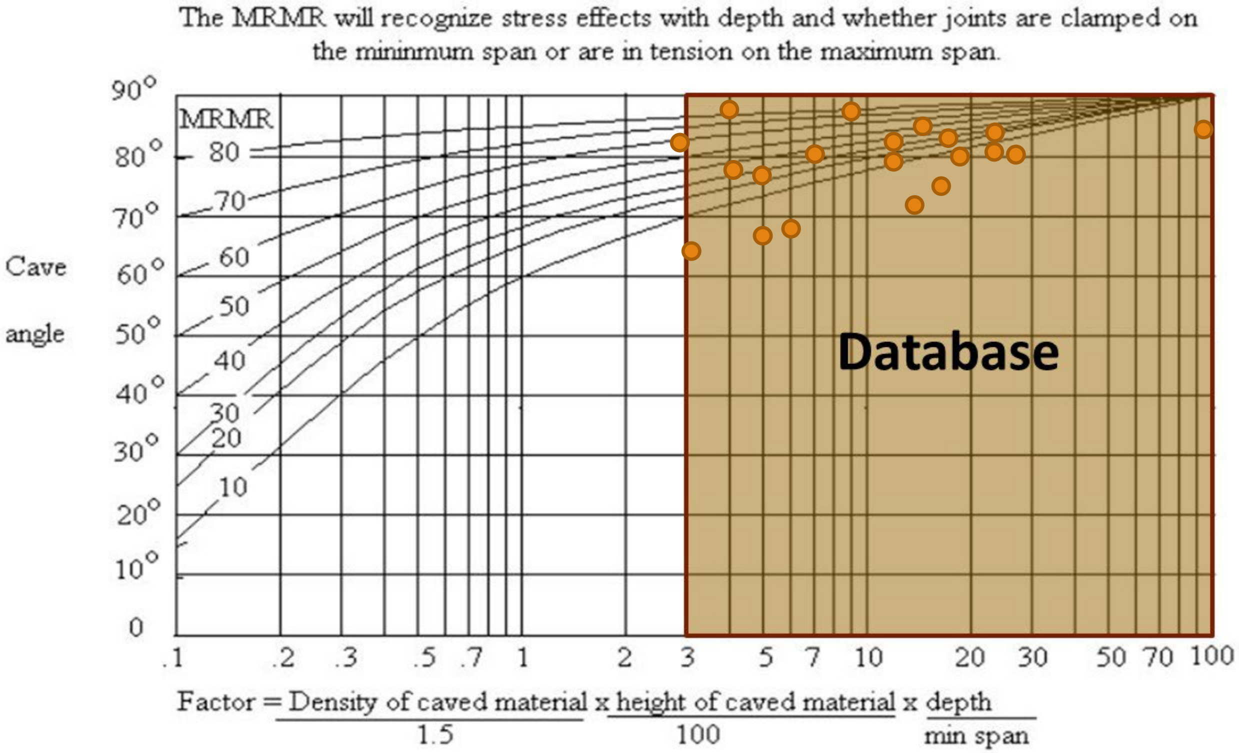
Data



- The main database used for this investigation corresponds to eight cave mines
- Most are in their last years of operation
- Deeper, larger production and low-grade ore characteristics

The predicted overall cave angle is calculated using the weighted percentage of the MRMRs intervals.

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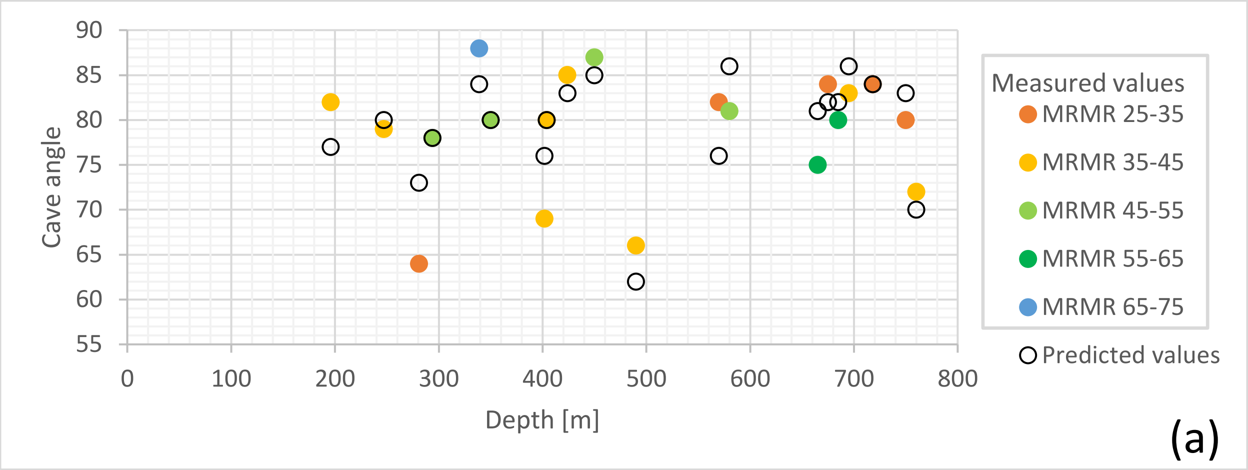
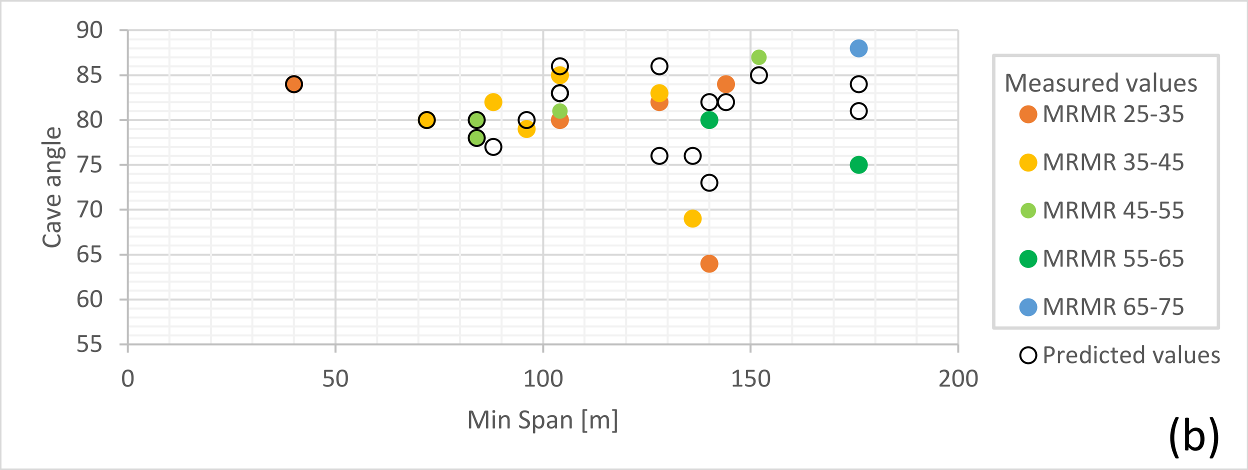
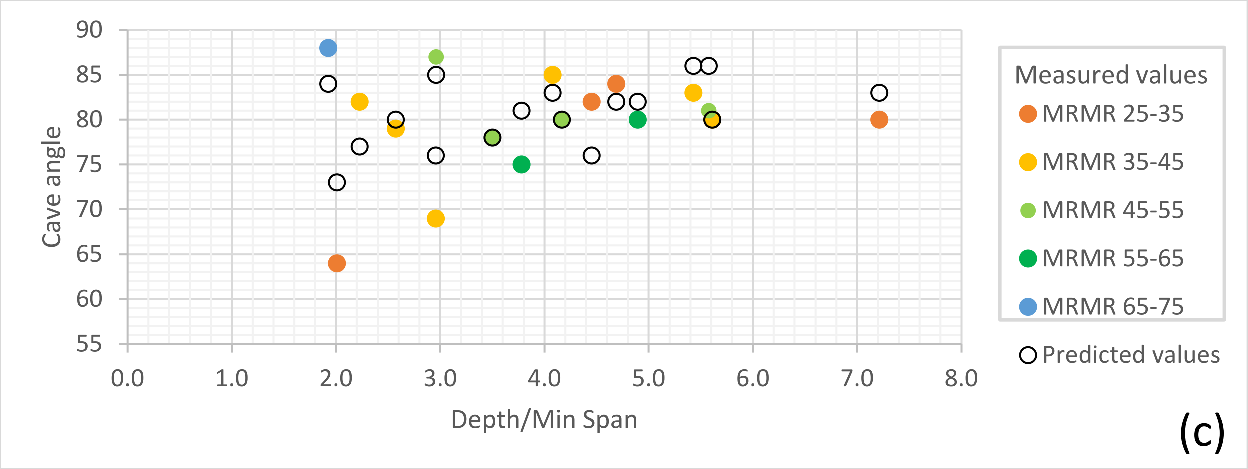
Results


90
85
80
75
70
65
60
55
Cave angle
0
100
200
300
400
500
600
700
800
Depth [m]
Measured values
MRMR 25-35
MRMR 35-45
MRMR 45-55
MRMR 55-65
MRMR 65-75
Predicted values

(a)

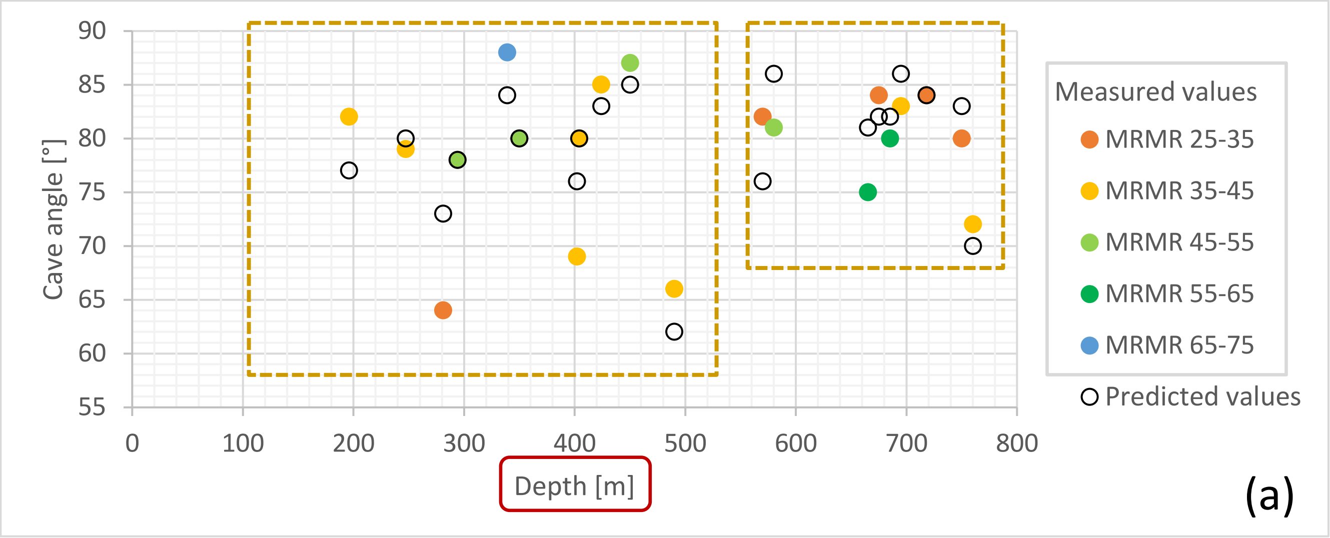

90
85
80
75
70
65
60
55
Cave angle
0
50
100
150
200
Min Span [m]
Measured values
MRMR 25-35
MRMR 35-45
MRMR 45-55
MRMR 55-65
MRMR 65-75
Predicted values

(b)

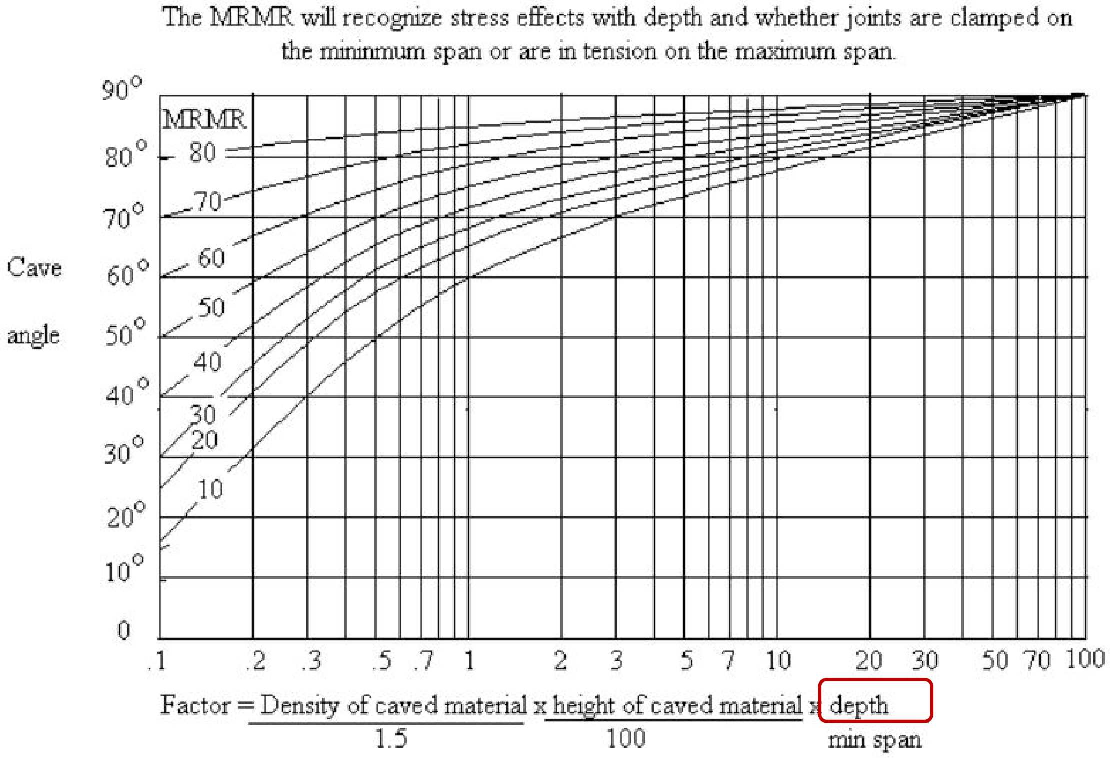

90
85
80
75
70
65
60
55
Cave angle
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
Depth/Min Span
Measured values
MRMR 25-35
MRMR 35-45
MRMR 45-55
MRMR 55-65
MRMR 65-75
Predicted values

(c)

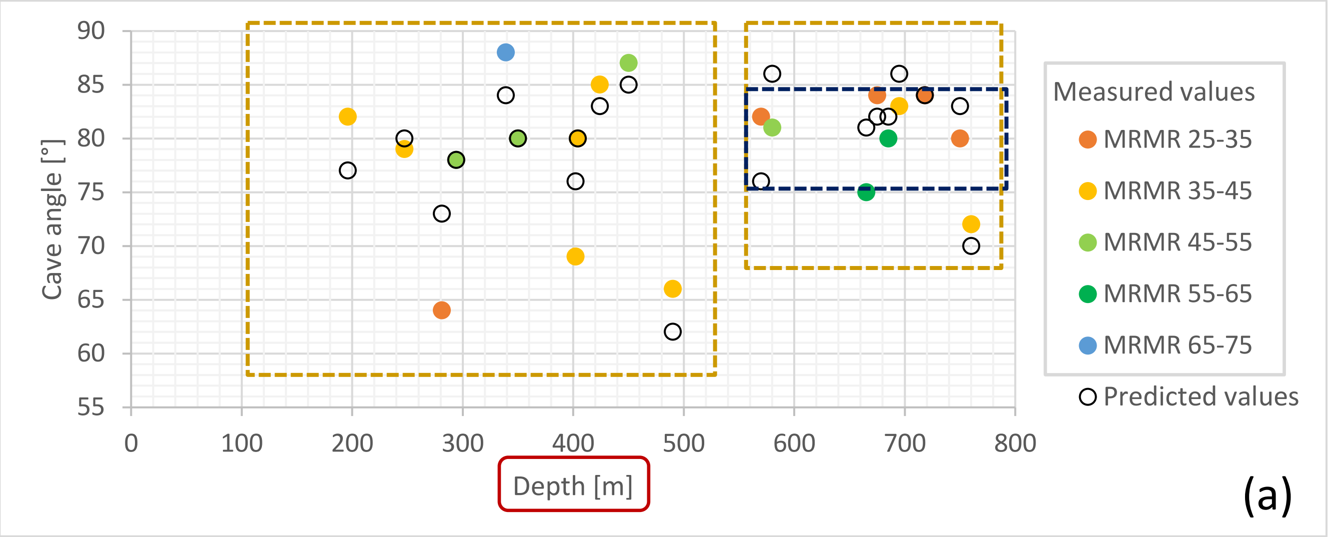
Results

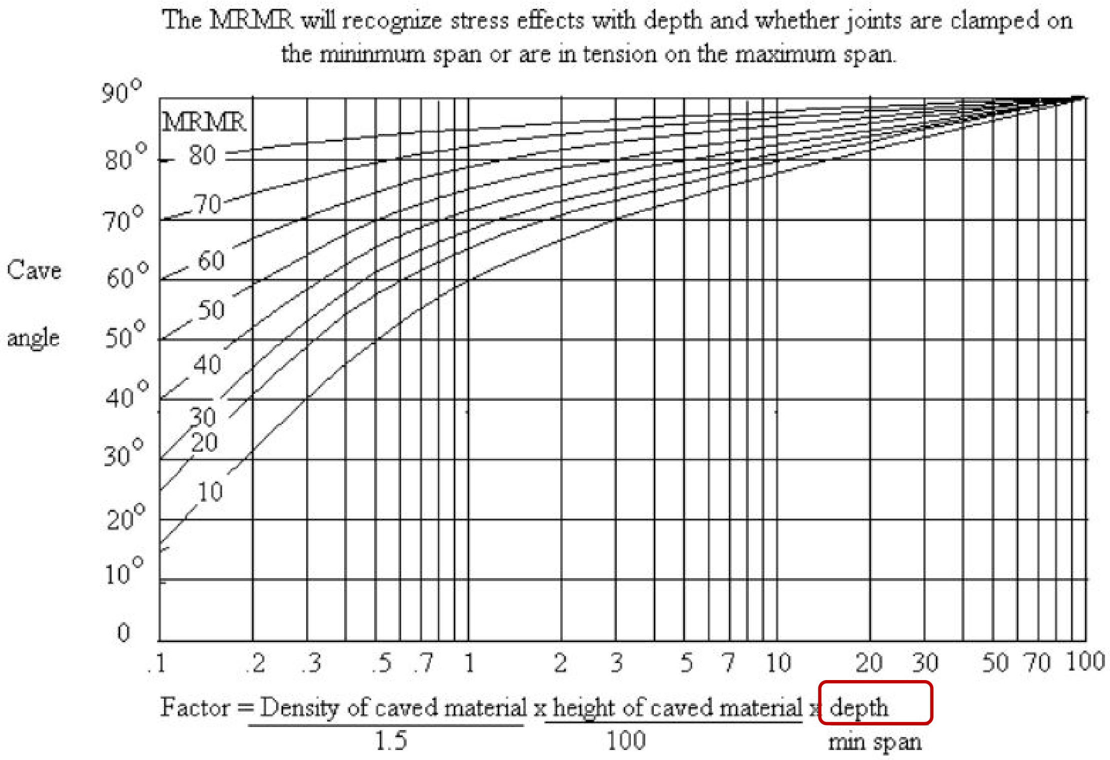

Cave angle [°]
90
85
80
75
70
65
60
55
0
100
200
300
400
500
600
700
800
Depth [m]
Measured values
● MRMR 25-35
● MRMR 35-45
● MRMR 45-55
● MRMR 55-65
● MRMR 65-75
○ Predicted values

(a)


The MRMR will recognize stress effects with depth and whether joints are clamped on the mininmum span or are in tension on the maximum span.
Cave angle
90°
80°
70°
60°
50°
40°
30°
20°
10°
0
MRMR
80
70
60
50
40
30
20
10
.1
.2
.3
.5
.7
1
2
3
5
7
10
20
30
50
70
100
Factor = Density of caved material / 1.5 x height of caved material / 100 x depth / min span

Results

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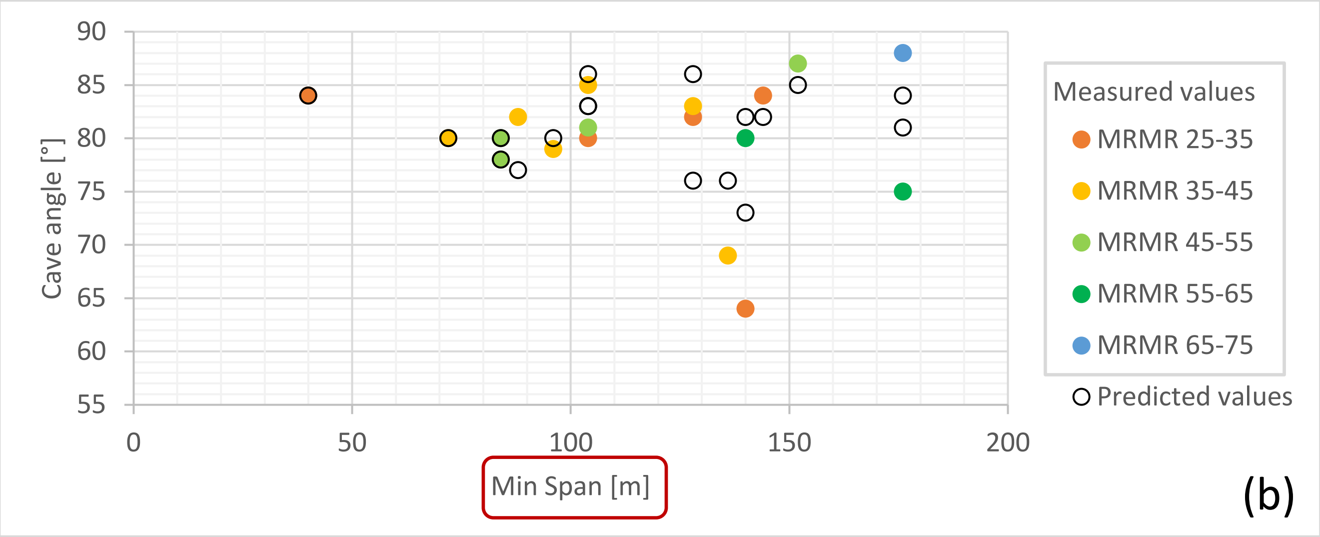
Results



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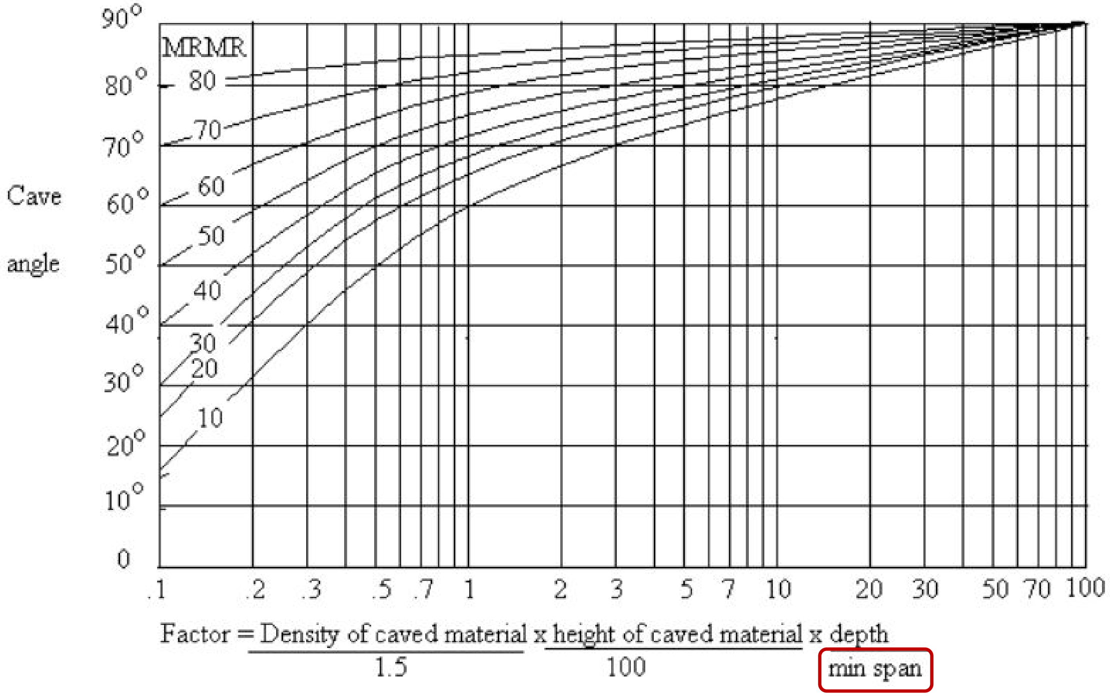
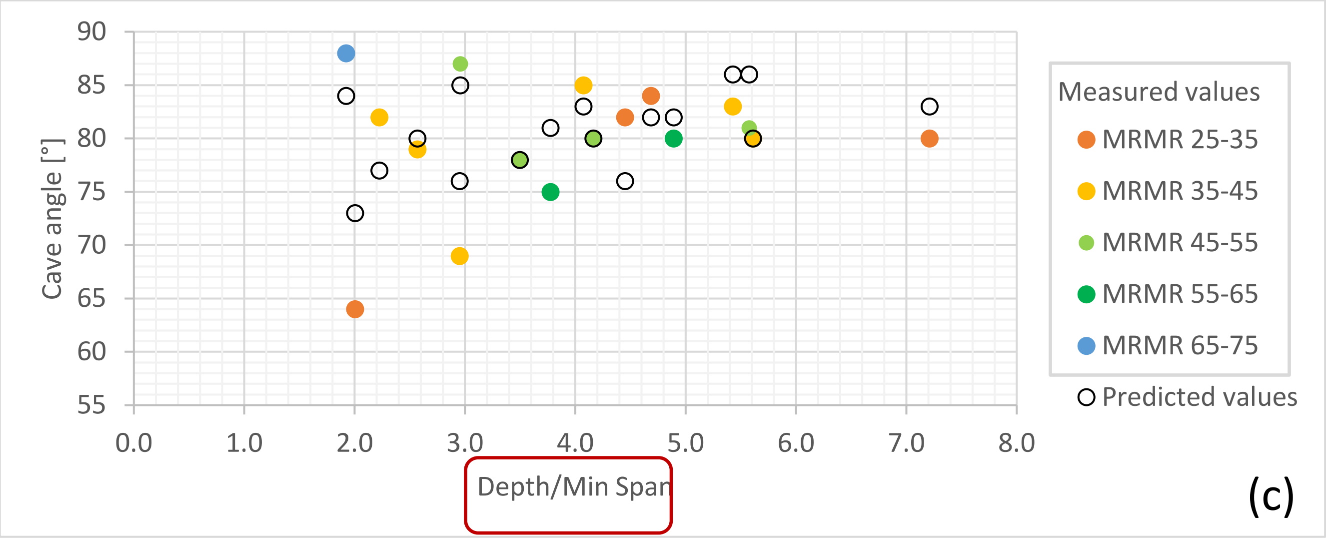
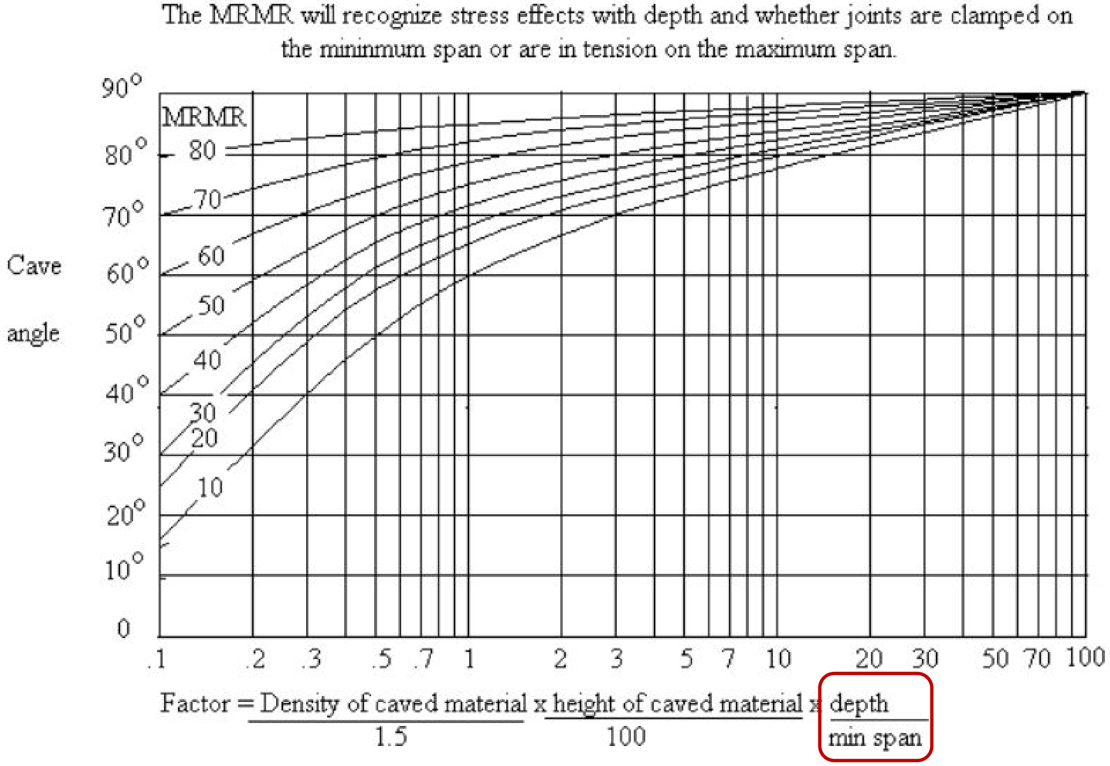


Results



(c)


The MRMR will recognize stress effects with depth and whether joints are clamped on the mininmum span or are in tension on the maximum span.

Factor = $\frac{\text{Density of caved material}}{1.5}$ x $\frac{\text{height of caved material}}{100}$ x $\frac{\text{depth}}{\text{min span}}$

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Conclusion

- Laubscher’s method, like any empirical methodology, has limitations. For that reason, it is necessary to consider and evaluate them. The limitations found and reviewed can be divided into the following categories:
  - MRMR → Expert advice is crucial to define MRMR values as well as a robust database. In addition, a future study that considers a review and update of the MRMR adjustments is recommended.
  - Unconfined area → These cases could be compared with the values given in the chart developed by Haines and Terbrugge.
  - Structures
  - Topography
  - Mining Sequence

Numerical Analysis

Conclusion

- The application of empirical methodologies is acceptable in the early stages of a caving project.

- The evaluation of new cases from recent cave mining operations showed that Laubscher’s method performs well in the prediction of cave angles(Root-mean-square deviation:4°)

- It is observed that for depths greater than 600 m the measured cave angles tend towards the same range of values (80°±4°) regardless of their geotechnical quality.

- Due to a paucity of reliable data, the Laubscher method remains only partially reviewed but may be useful as a first approximation.

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