# Pillar Stability Assessment Methodology for Bord and Pillar Mines

SANIRE
SOUTH AFRICAN NATIONAL INSTITUTE OF ROCK ENGINEERING

*Turning Challenges Into Opportunities*

OHMS

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- In this presentation we will look at a method that was developed to conduct a pillar stability assessment for every pillar on a bord and pillar operation.

# Content

- Information received in CAD files.
- Calculate pillar dimensions.
- Assign mining height values to pillars using IDW.
- Assign rock mass classification values to pillars using IDW.
- Design parameters (FoS, W:H, e, SCF).
- Importance of underground observations in terms of pillar stability.
- Benefits of using this method.

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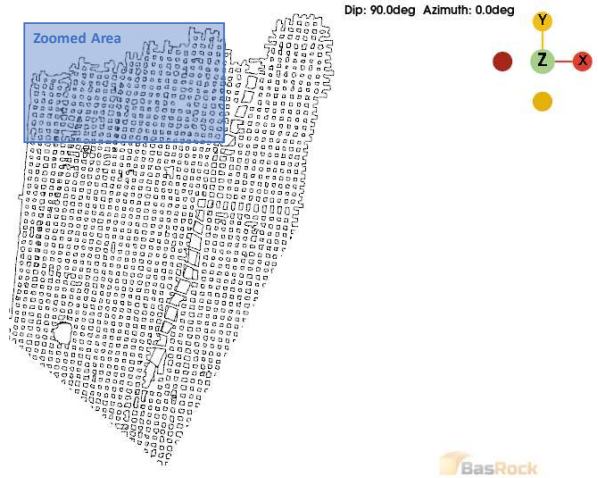
- In the content of this presentation…
- We will look at the information we receive from mine planners and how the information can be utilized in a pillar assessment.
- Next, we will calculate the pillar dimensions using the pillar geometry obtained in the CAD files.
- We will look at a method to assign mining heights to pillars using inverse distance weighting.
- If you have spatial rock mass classification data, we can also assign rock mass classification values to each pillar.
- Then we will look at Design parameters, to find or highlight potential unstable pillars.
- Importance of underground observations in terms of pillar stability.
- Benefits of using this method.

# Pillar Geometry

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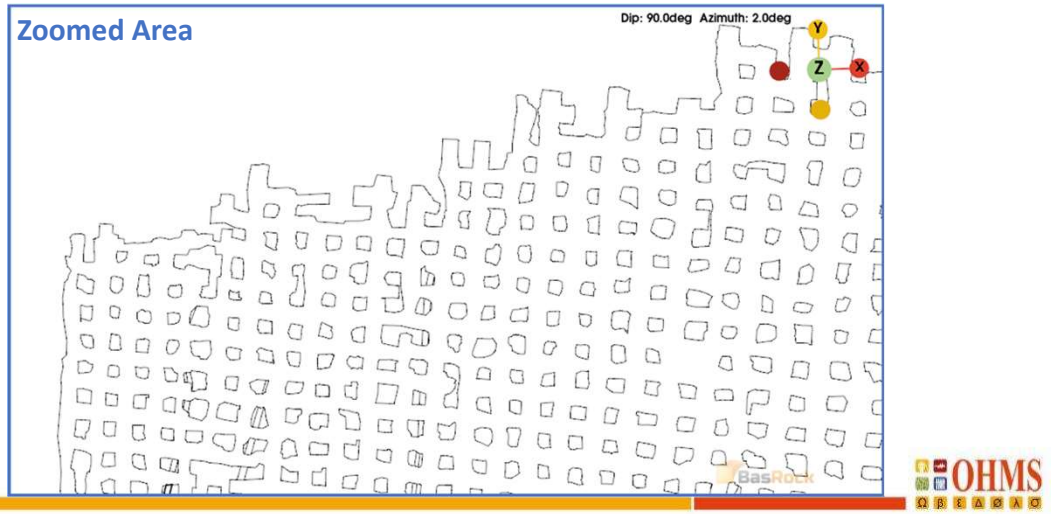
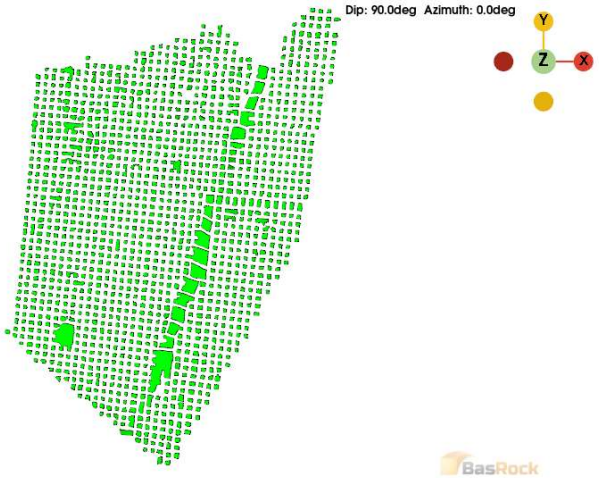
- So when we received mine plans from a mine planner, it is normally in this format.
- Where the pillar outlines are represented as polygons.
- Sometimes, these plans are not on the correct elevation.
- So to fix that, we create a surface from on-reef peg elevations and project (drape) the mine plans onto that surface.

# Pillar Geometry




- Not all pillar geometries are perfectly constructed, and some pillars need to be reconstructed.
- When you are doing a pillar stability assessment, it is important to not to alter the geometry of the polygons.
- As we need these dimensions for our pillar strength and stress estimations.

# Solid Pillars

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- Once the pillar polygons are cleaned and the polygons closed.
- Then we can convert the polygons to solid elements or faces.

# Solid Bords


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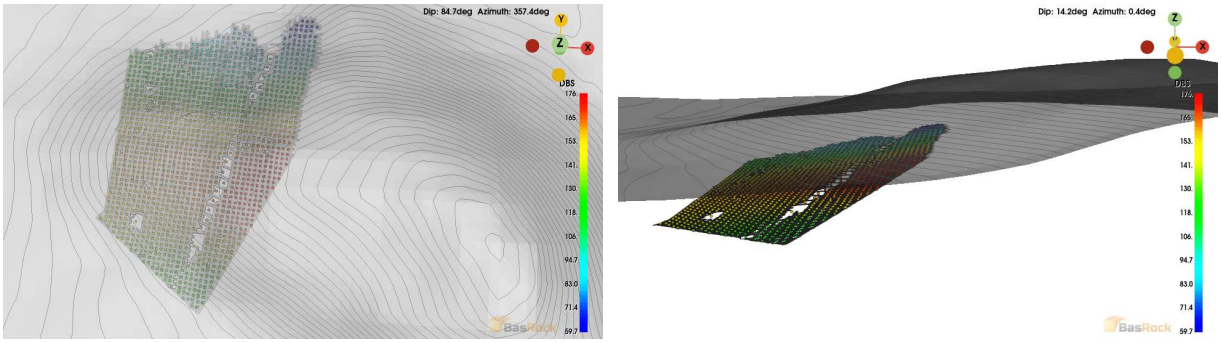
- Once I have the pillar solids, I can rapidly generate the mined out bords, representing the mine's as-mined layout.
- This can then be imported into a numerical modelling software, to calculate the pillar stresses.

# Pillar Geometry

Depth Below Surface [m]

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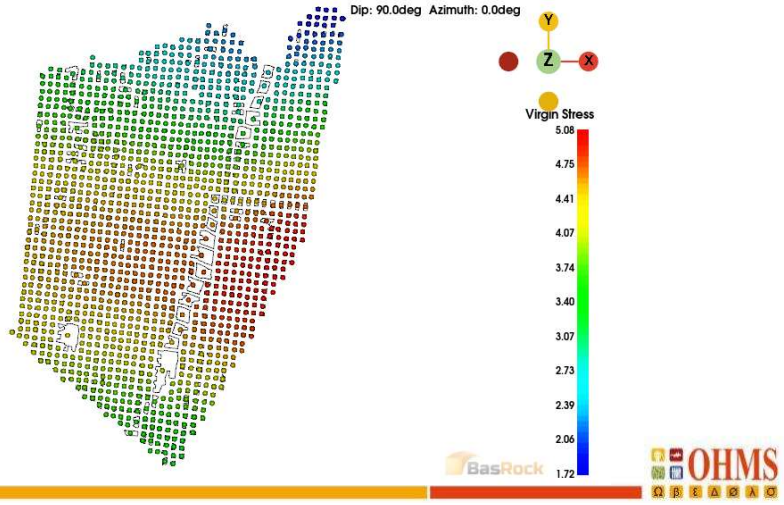
- When you have a varying (uneven) surface topography at your mine, it is important to include that into your stress estimations.
- In this example there is a small hill that peaks on the eastern side of the mine and the reef dips toward the west.
- This is a fairly shallow mine, with depth ranging from 59 to 176 mbs

# Pre-mining Stress [MPa]

$\rho gH$

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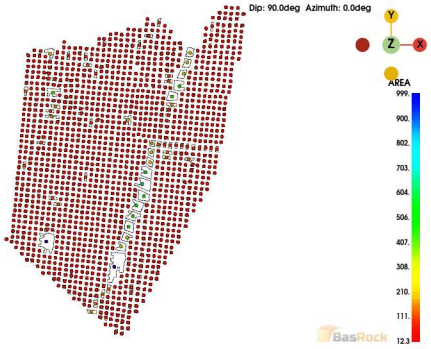
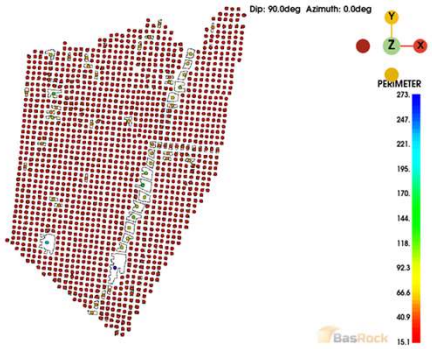
- Looking at the pre-mining stress that took into account the surface topography.

# Pillar Dimensions

**Area [m$^2$]**




**Perimeter [m]**




Area of planar polygons embedded in 3D space (Goldman, 1994)

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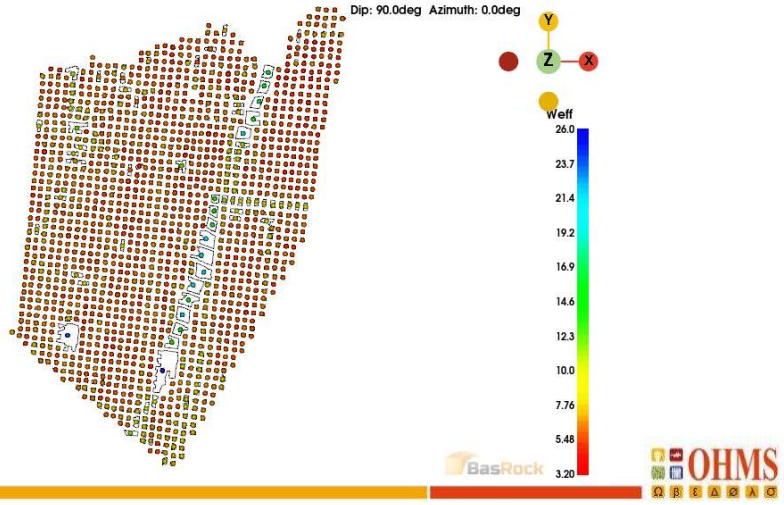
- By the use of Java Scripting, the pillar AREAS and PERIMETERS can be calculated.
- To calculate the AREA of the pillars, I used Goldman formula that is used for planar polygons embedded in 3D space.
- The formula triangulates the polygon, and then the areas of the triangles are added up.
- For the perimeter, the script calculates the length of the polygon outlines.

# Pillar Dimensions

Effective Width [m]

$$\text{Weff} = \frac{4 \times Area}{Perimeter}$$

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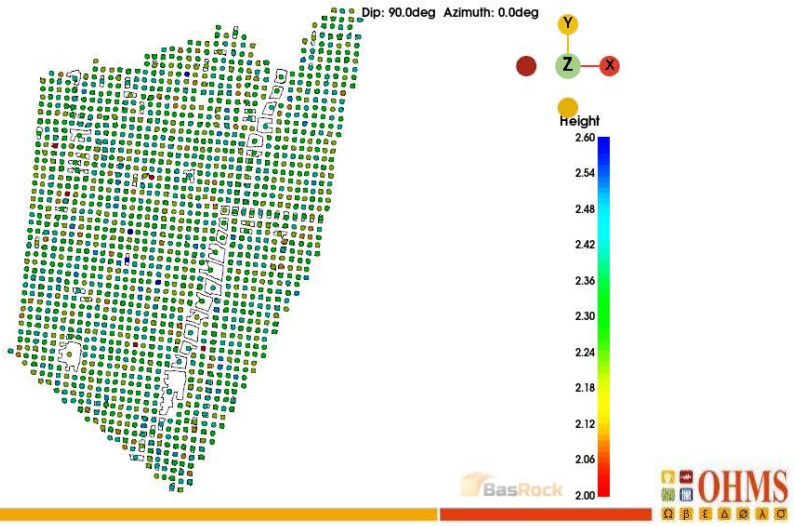
- Once we have the area and the perimeter, we can calculate the effective width.

# Pillar Dimensions

Height [m]

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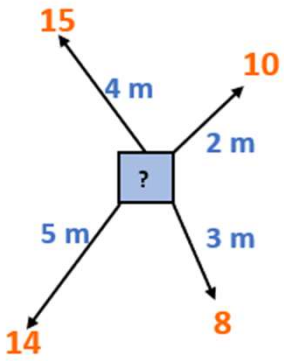
- The next important parameter for pillar strength estimation is the mining height.
- Not all pillars have mining heights surveys done next to them.
- Therefore, I use a IDW Algorithm to assign mining height.

# Inverse Distance Weighting (IDW)




| Height [m] | Distance [m] | $\frac{1}{d}$ | Weight | Weighted Value |
|---|---|---|---|---|
| 15 | 4.0 | 0.25 | 0.19 | 2.9 |
| 10 | 2.0 | 0.50 | 0.39 | 3.9 |
| 8 | 3.0 | 0.33 | 0.26 | 2.1 |
| 14 | 5.0 | 0.20 | 0.16 | 2.2 |
| | | 1.28 | 1 | **11.1** |

$$Each\ Weight = \frac{\frac{1}{d}}{sum\ of\ all\ \frac{1}{d}}$$

$$Each\ Weighted\ Value = Value \times Weight$$

$$Weighted\ Average = sum\ of\ all\ Weighted\ Values$$

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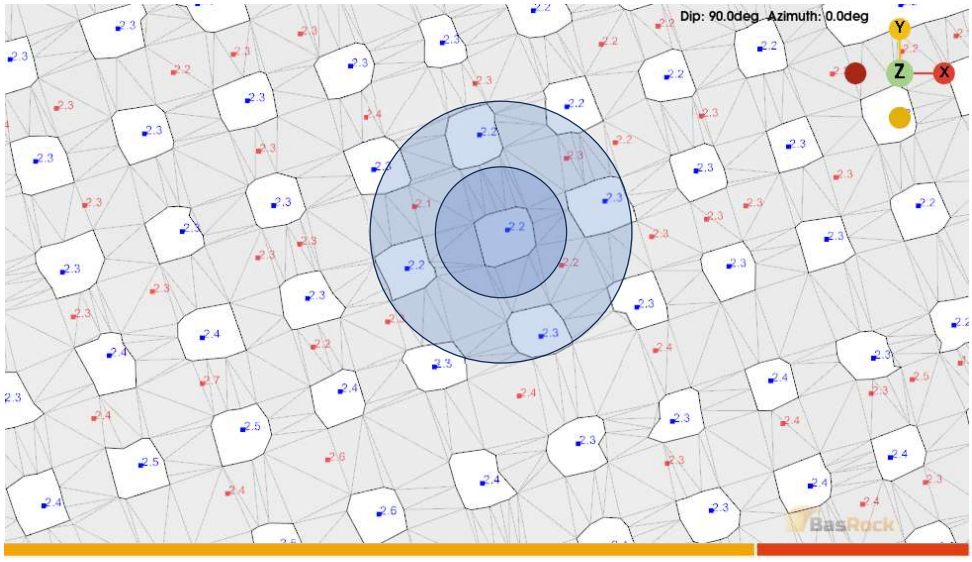
- Lets assume the blue block is our pillar.
- The orange values are our surveyed mining heights and locations.
- The blue values are the distance from the center of the pillar.
- Weighted average is 11.1.

# Inverse Distance Weighting Algorithm

Mining Height

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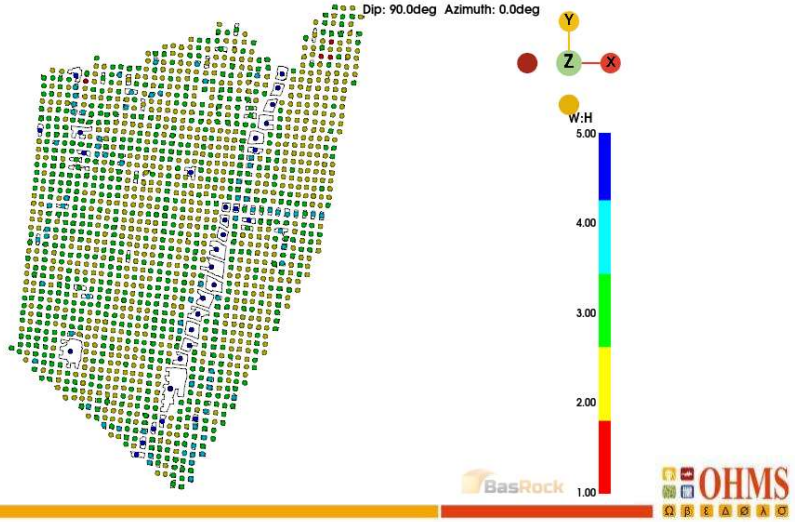
- The red values are the surveyed heights, and the blue values are the assign values using the IDW algorithm.
- The algorithm wants a search radius (1x bord length) and a minimum number (2) of values to calculated the weighted average.
- If there is not enough values in the search radius, then the search radius is increased.
- The increments by which the radius is increased can be controlled. Smaller increments, will result in more accurate pillar heights.
- The number of iterations is recorded for each pillar, as this indicates how reliable the data is.
- One can also set it up the algorithm so that after 3 iterations, it will use the design height.

# Pillar Dimensions

## Width to Height Ratio

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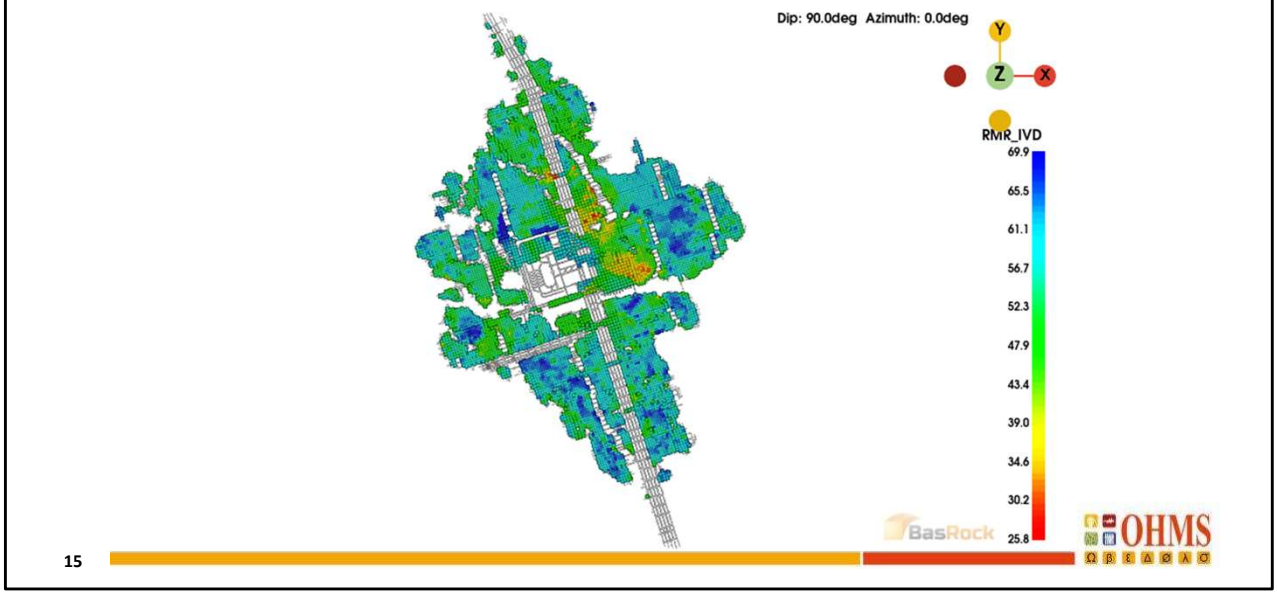
- The width-to-height (w/h) ratios of non-yield pillars are usually in the range 2 to 5.
- W:H is a design parameters we can use to monitor mining discipline by comparing to the mine design.
- So, if we categorize our pillar according to W:H, it will highlight slender or oversized pillars.

# Rock Mass Classifications




- At this B&P operation they had spatial rock mass classification data.
- The same IDW algorithm could be used to assign RMC values to each pillar.
- These values can be used as input into the Rock Mass Strength or DRMS estimates.

# Ground Control Districts


The following DRMS values are currently used:

- DRMS Class C: 54 MPa to 58 MPa
- DRMS Class D: 34 MPa to 38 MPa

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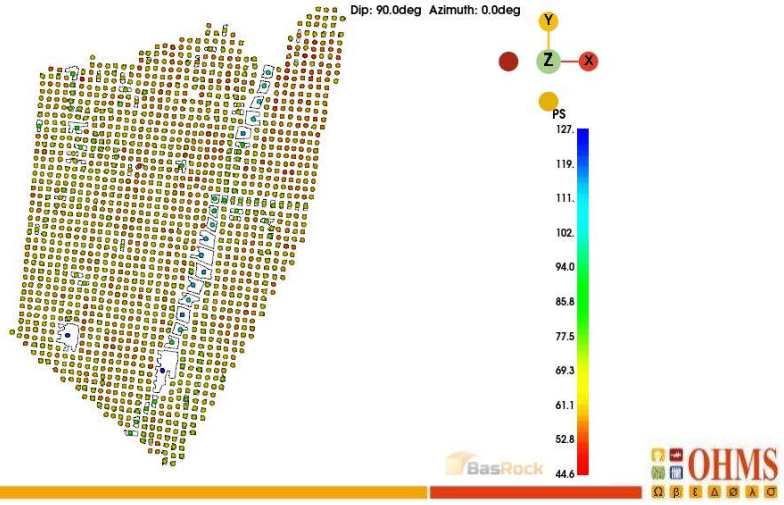
- At this B&P operation they divined GCDs based on DRMS.
- So, I could assign DRMS values to pillars, based on the GCD polygons.
- To be conservative we used the lower bound values.

# Pillar Strength [MPa]

$$PS = K \frac{w^{\alpha}}{h^{\beta}}$$

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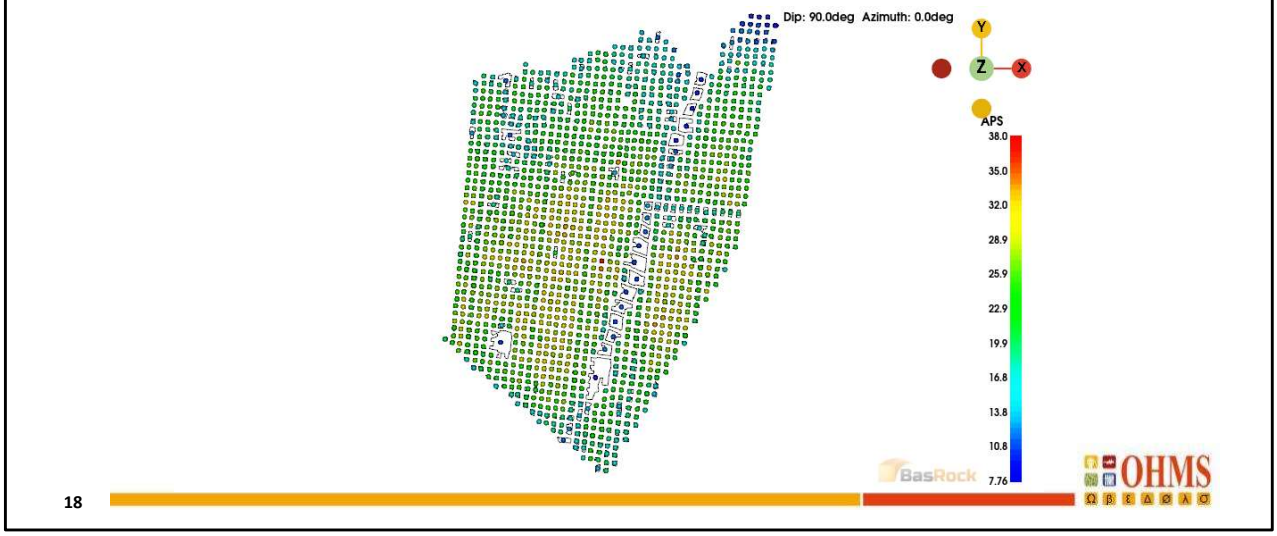
Once we have the width, height and RMS for all pillars, we can estimate the pillar strength.
Using any of the industry formulas:
Hedley&Grant
Stacy&Page
Platmine Formula. Watson's (Mer or UG2).
Lunder&Pakalnus

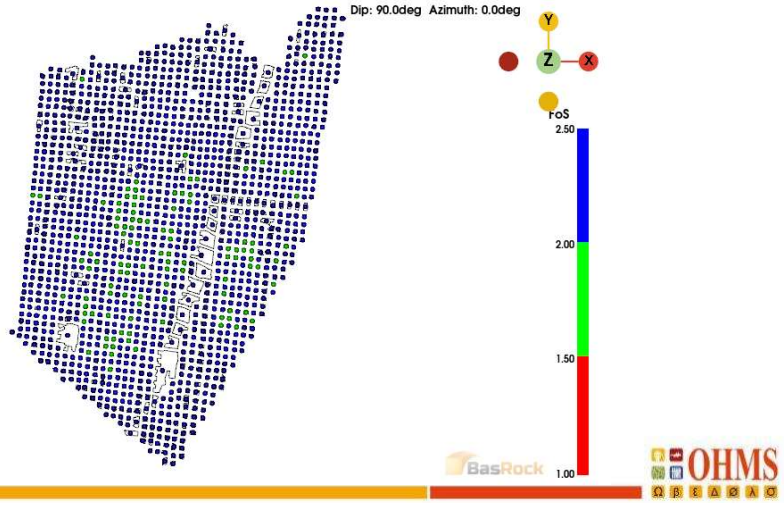
# Pillar Stress [MPa]




- The pillar stress is obtained from numerical modelling.
- In most cases we utilize Map3D, but results from any modelling software can be used.
- Map3D has outperformed some of the other software packages in terms of model size and run times.

# Factor of Safety (FoS)

$$\text{FoS} = \frac{PS}{APS}$$

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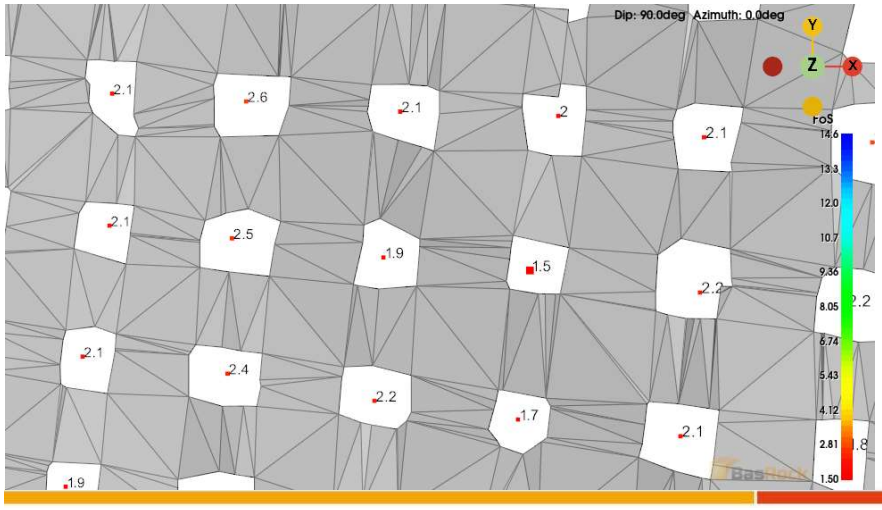
- We categorize our pillar according to the FoS.
- That will highlight where potential unstable pillars are located.
- Because most bord and pillar mines are designed on stable non-yield pillars, no FoS is less than 1.5.

# Factor of Safety (FoS)

Pillar with Lowest FoS




DBS = 162 m
A = 22.7 m$^2$
P = 18.7 m
Weff = 4.9 m
H = 2.2 m
W:H = 2.2

APS = 38 MPa
PS = 55 MPa
FoS = 1.5
SCF = 7.2
e = 0.86

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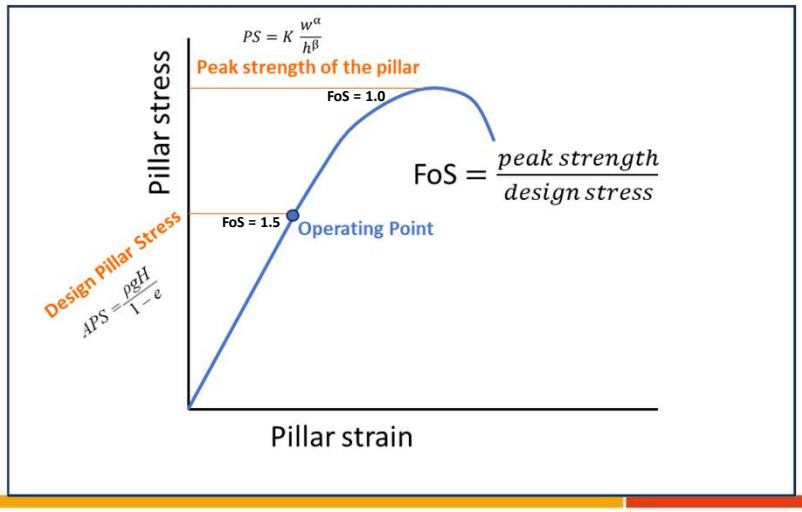
# Design of Non-Yield Pillars

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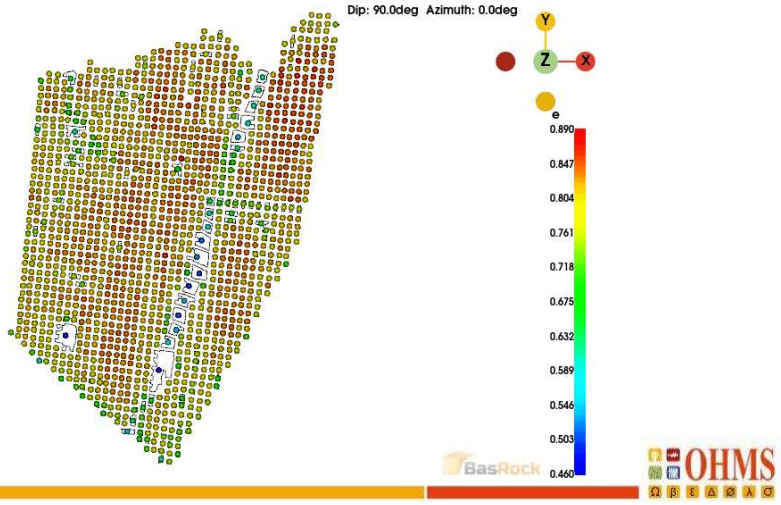
- This is a Stress Strain curve of a non-yield pillar.
- Here at the peak is the strength of the pillar and the only parameter we can control is the Width.
- And this is the Operating Point of a non-yield pillar. Where FoS is around 1.5 to 1.6.
- So, for Design Pillar Stress one can only manage the extraction ratio.
- It is important to use the correct constitutive behaviour modelling code to allow for stress redistribution when pillar start to yield and fail.

# Theoretical Extraction Ratio (e)

$$APS = \frac{\rho g H}{1 - e}$$

$$e = 1 - \frac{\rho g H}{APS}$$

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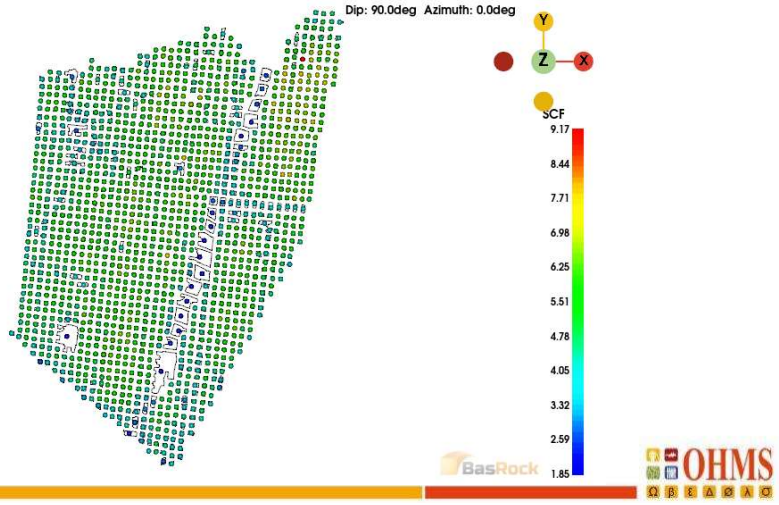
- Having the pre mining stress and the APS, a theoretical extraction ratio can be calculated.
- Note that this extraction ratio will not be exactly like we know it (mine vs unmined).
- Because we did not use Tributary Area Theory to estimate the pillar stress.
- Pillars located on the boundary of the mine will have a lower APS due to the abutment carrying some of the load.
- Also pillars next to large regional pillars will have lower APS values compared to TAT.

# Stress Concentration Factor (SCF)

$$SCF = \frac{APS}{pgH}$$

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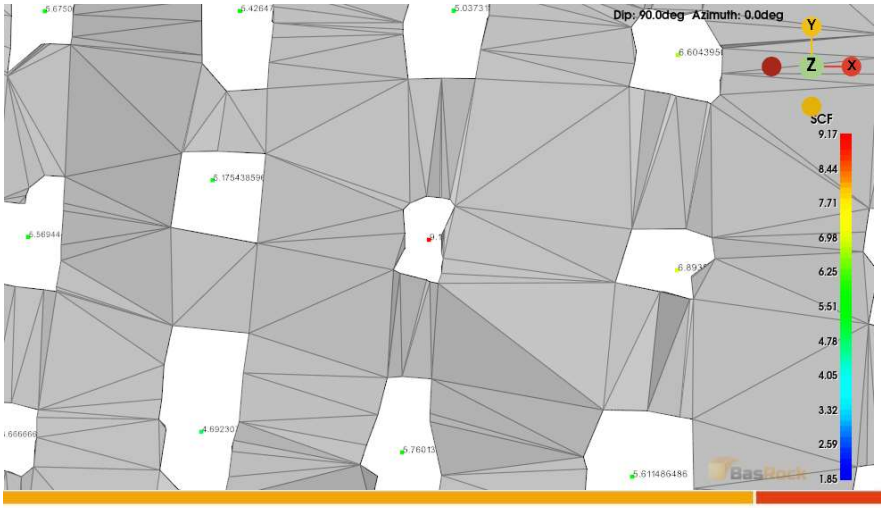
- SCF is a parameter that highlights the pillar risk.
- The parameter will highlight the rock mass that has experienced the most stress change.
- So, it indicates by how much the stress increased from pre-mining stress up to now (APS).

# Stress Concentration Factor (SCF)

Pillar with highest SCF




DBS = 78 m
A = 12.3 $m^2$
P = 15.1 m
Weff = 3.2 m
H = 2.2 m
W:H = 1.5

APS = 26 MPa
PS = 44 MPa
FoS = 1.7
SCF = 9.1
e = 0.89

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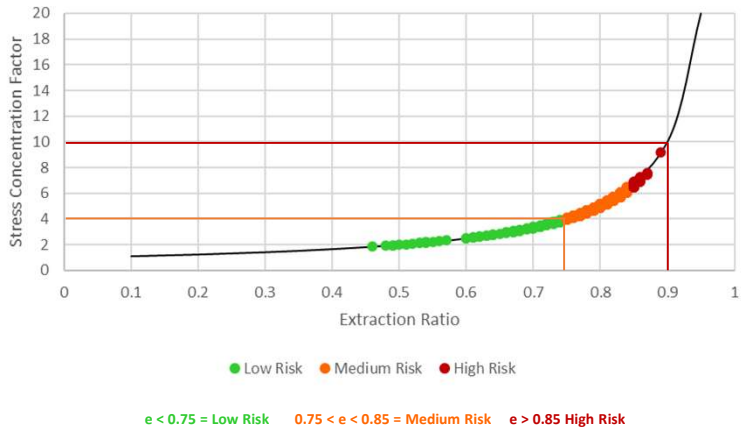
A = 12.3 m2
P = 15.1 m
H = 2.2 m
W:H = 1.5
Weff = 3.2 m

APS = 26 MPa
PS = 44 MPa
FoS = 1.7
SCF = 9.1
E = 0.89

# Relation Between Pillar Stress Level and Extraction Ratio




e < 0.75 = Low Risk  0.75 < e < 0.85 = Medium Risk  e > 0.85 High Risk

(Brady & Brown, 2004)

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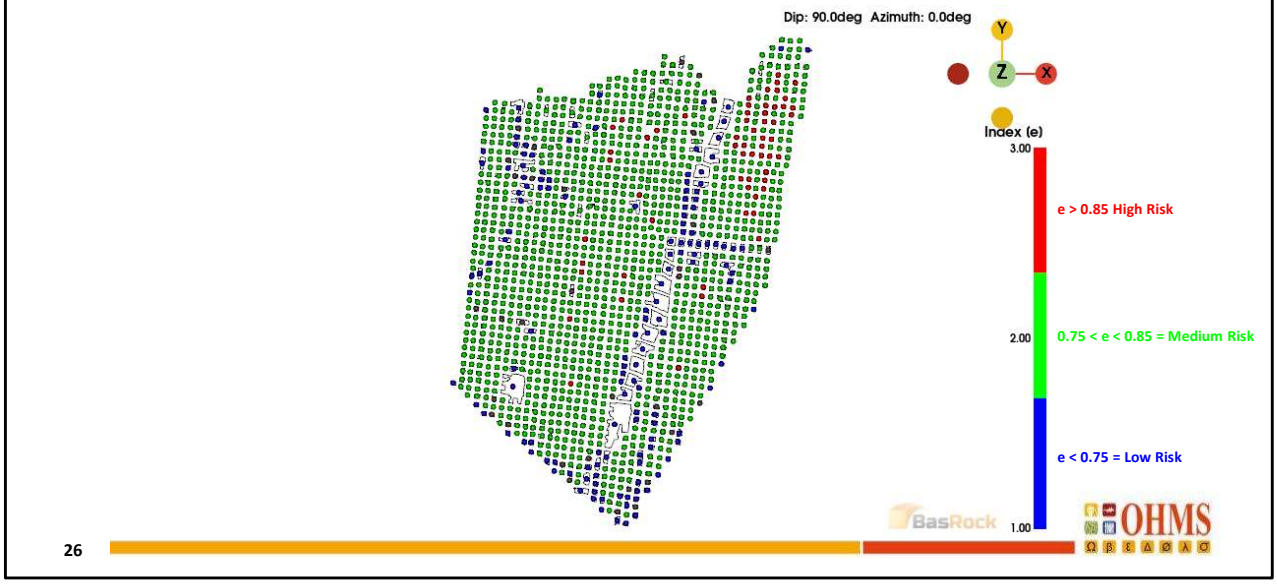
- This graph illustrates the relation between pillar stress level and extraction ratio.
- When operating at high extraction ratio, we can see a high incremental change in pillar stress level, for small change in extraction ratio.
- Think it also a nice design tool. For when deciding on what extraction ratio you want to use.
- If we choose 75% extraction ratio. Where our bords and pillars have the same dimensions.
- Then the stress level will be 4 x the pre-mining stress.  90% it will be 10 x pre-mining stress.

# Categorize Pillars

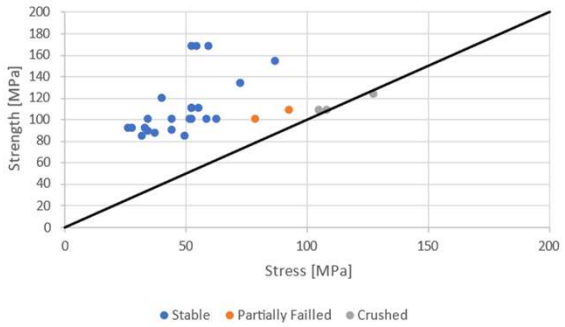
## Extraction Ratio

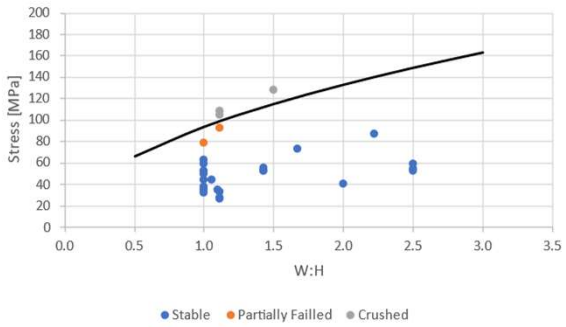



- So if we categorize our pillar according to the extraction ratio or in terms of risk.
- We can see where our potential unstable pillars are located.
- So if we want to start collecting more information in terms of pillar stability, with underground observations.
- I would go and visit the red pillars first.

# Underground Observations

## Pillar Stability




(Hedley and Grant, 1972)

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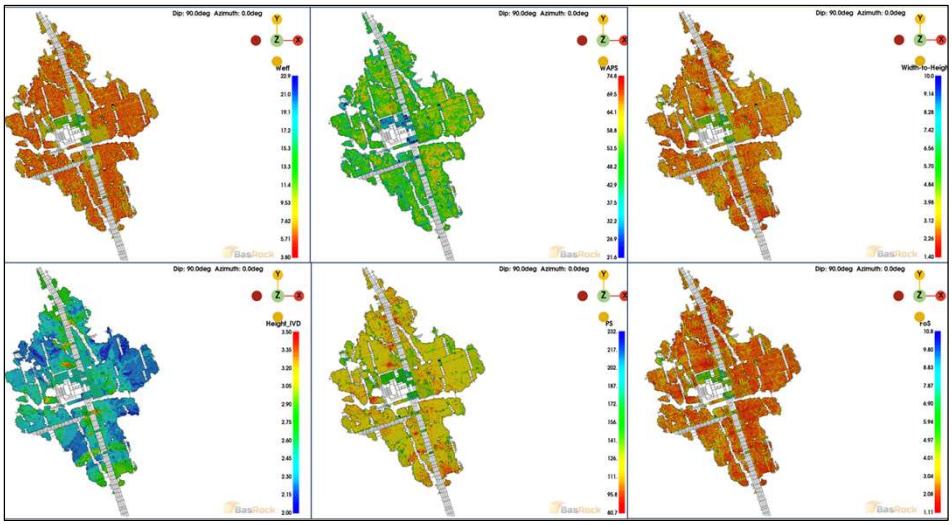
- Underground observations are used to verify the FoS.
- It is important to know the status of a pillars. stable, unstable or failed.
- The Hedley and Grant database consisted of 28 pillars of which 23 were stable, 2 partially failed, and 3 crushed pillars.
- Based on their observations, they could derive the power law formula.
- Once we have our own observations, we can start deriving our own pillar strength estimate formulas. OR see which industry formula fits our data the best.

# Case Study 1



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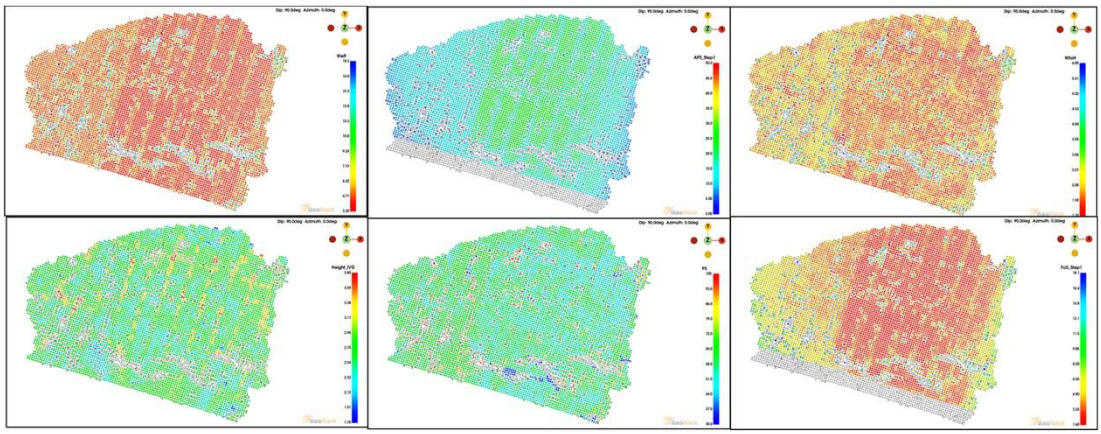
So to proof that I can do it for an entire BnP operations.
Here we assessed 8800 pillars.

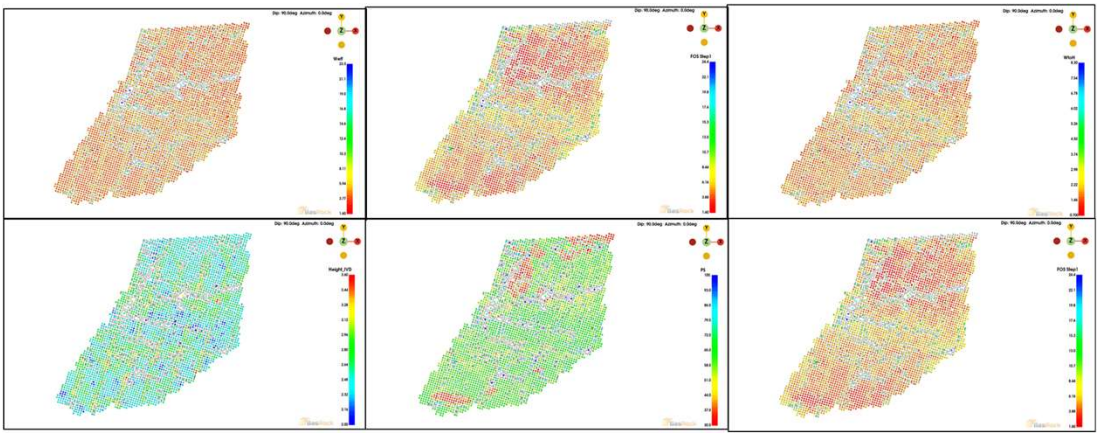
# Case Study 2 North





At this operation we assessed 6650 pillars on the northern side of the mine.

# Case Study 2 South



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and 3160 pillars on the Southern side.

# Benefits of Using this Method

- All pillar information in a single csv file that can be queried and filtered spatially.
- Compare as-mined layout to mine design and monitor mining discipline.
- Highlight potential high-risk pillars for rehabilitation or additional support.
- Highlight potential low-risk pillars for pillar reduction potential.
- Draw statistical distributions on all pillar parameters.
- Highlight areas where data gathering is needed (rock mass classifications, mining heights, status of pillars).




- All pillar information is in a single csv file that can be queried and filtered spatially.
- You can compare the as-mined layout to mine the design and monitor mining discipline.
- Highlight potential high-risk pillars for rehabilitation or additional support.
- Highlight potential low-risk pillars for pillar reduction potential.
- Draw statistical distributions on all pillar parameters.
- Highlight areas where data gathering is needed (rock mass classifications, mining heights, status of pillars).