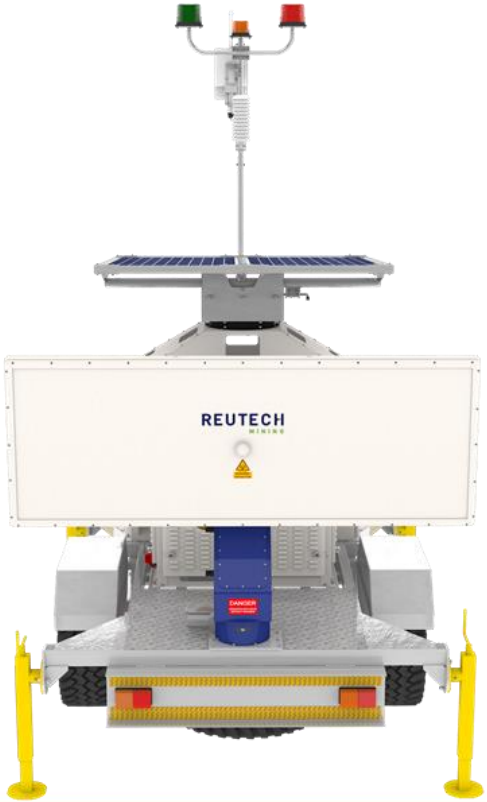
ESTABLISHING A SUCCESSFUL PIT SLOPE MONITORING DATABASE USING GROUND BASED RADARS (GBR)

SHARLA COETSEE AND PRIYANKA NARSHAI

SANIRE 2023

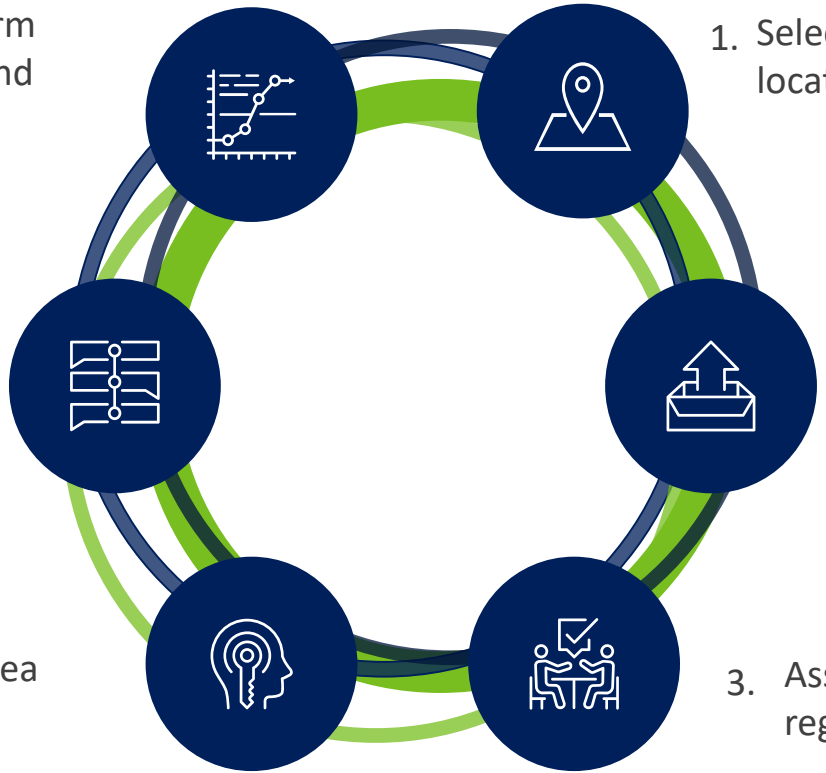
REUTECH MINING

YOU HAVE GREAT GEAR, BUT NO IDEA?



REUTECH
MINING

THESE ARE THE 6 (ISH) KEY STEPS



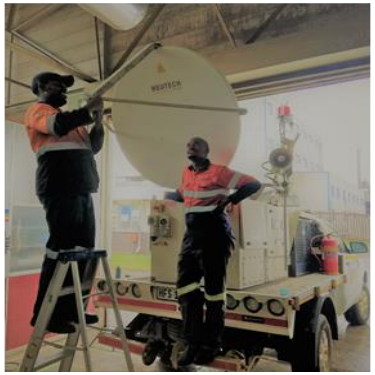
1. Selecting the radar location
2. Calculating the database configuration
3. Assigning scan regions
4. Calculating area threshold parameters
5. Measurement terminology, Understanding reference time and time windowing
6. Applying alarm thresholds and viewing data

REUTECH MINING

STEP 1: RADAR LOCATION

Before deploying the radar:

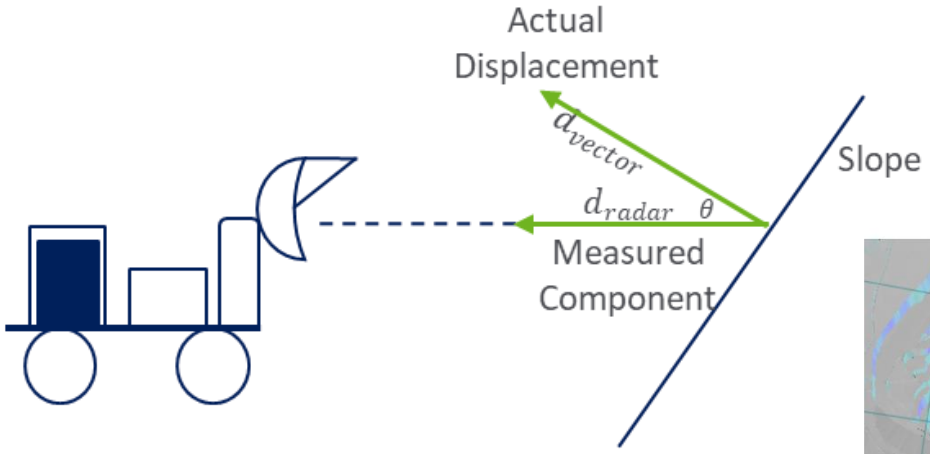
- Evaluate the geotechnical considerations comprehensively.
- Ensure mechanical considerations such as refueling truck access, external power, access to the mine LAN (network) for system updates and alarm notifications, etc are also planned for and accommodated.
- Ensure there are no obstructions such as poles, wires, buildings, etc.
- Evaluate monitoring considerations: primary/strategic (routine/long term monitoring) versus safety critical/tactical (emergent pit slope condition) monitoring?

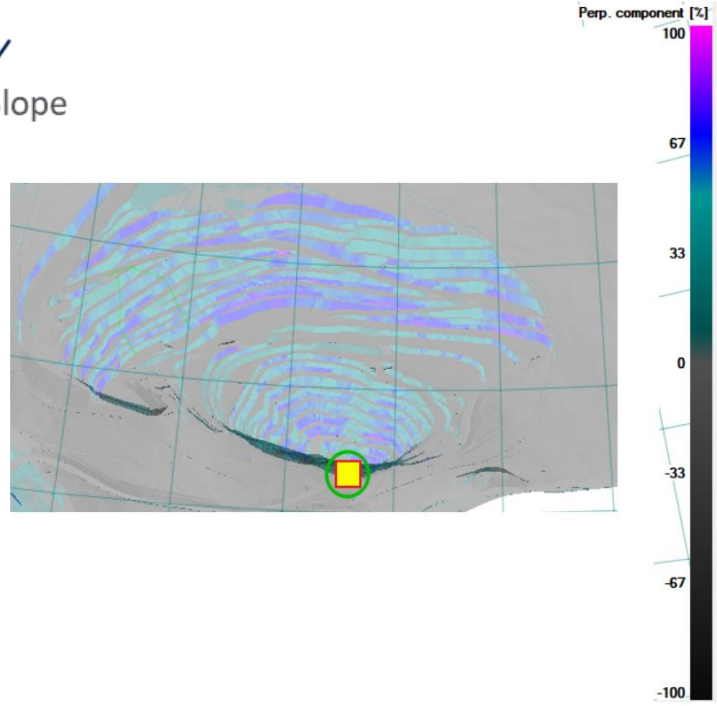


REUTECH MINING

STEP 1: RADAR LOCATION

- Confirm the radar site selection for: angle of incidence and vector loss of movement?





θ	$cos(\theta)$	θ	$cos(\theta)$
0°	1.00	45°	0.71
15°	0.97	60°	0.50
30°	0.87	90°	0.00

REUTECH MINING

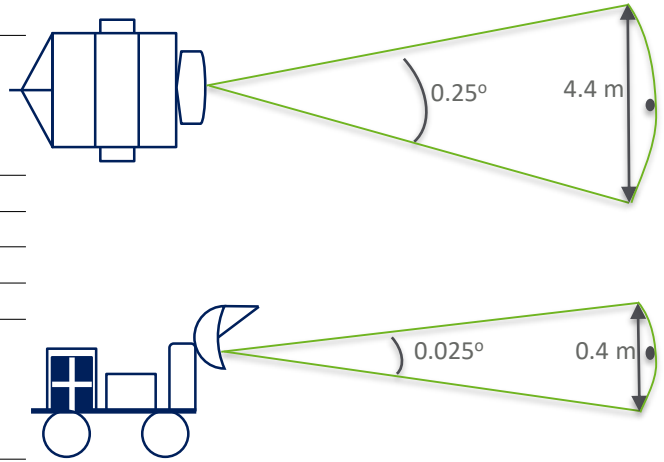
STEP 2: DATABASE CONFIGURATION

Actual degree step and resultant point spacing.

Degree step: horizontal spacing	Metres from the pit slope (m)					
	100	500	1 000	2 000	3 000	4 000
	Degree step size/point spacing (m)					
0.25°	0.4	2.2	4.4	8.7	13.1	17.5
0.33°	0.6	2.9	5.8	11.5	17.3	23.0
0.50°	0.9	4.4	8.7	17.5	26.2	34.9
0.75°	1.3	6.5	13.1	26.2	39.3	52.4

Degree step: elevation spacing	Metres from the pit slope (m)					
	100	500	1 000	2 000	3 000	4 000
	Degree step size/point spacing (m)					
0.0250°	0.1	0.2	0.4	0.9	1.3	1.7
0.0375°	0.1	0.3	0.6	1.3	2.0	2.6
0.0500°	0.1	0.4	0.9	1.7	2.6	3.5
0.0750°	0.1	0.7	1.3	2.6	3.9	5.2

Schematic visual representation.

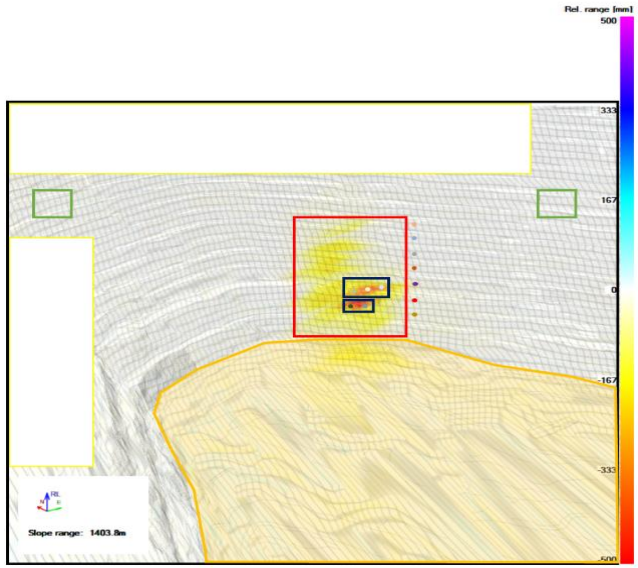


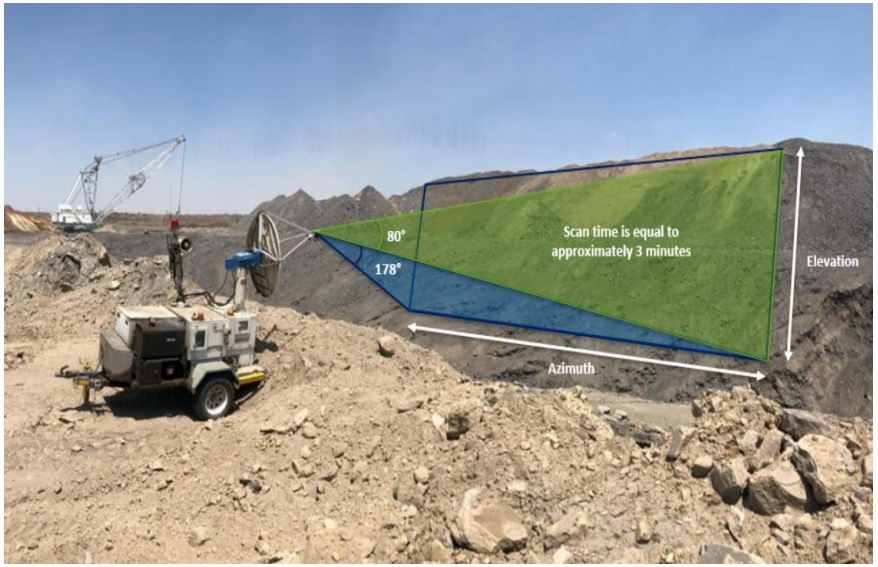
- The resultant point spacing is a function of the distance between the sensor and the pit slope.
- The point spacing may also change dependent on the shape and geometry of the pit slope, as the distance will vary.

REUTECH MINING

STEP 3: ASSIGNING SCAN REGIONS

Multiple normal regions may be applied based on the specific atmospheric conditions experienced on that portion of the pit slope.



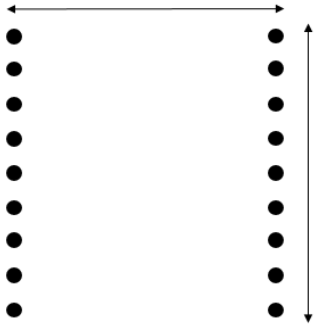


REUTECH MINING

STEP 4: SELECTING AREA THRESHOLD PARAMETERS

The horizontal point spacing is 4.4 m.

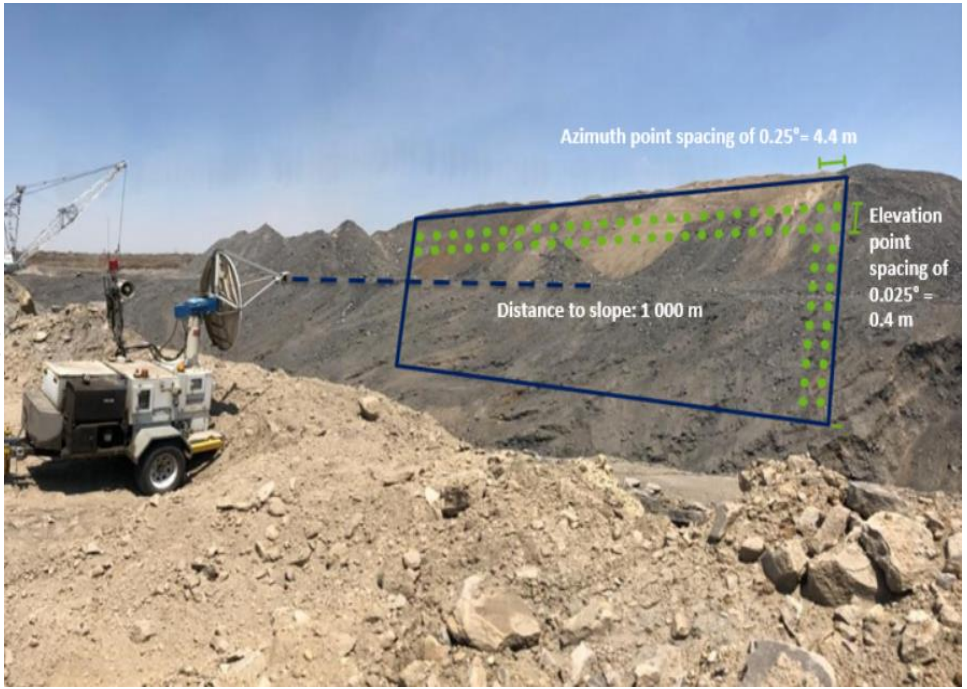
2 points are selected. The space between each of the points, in this case 1, is utilised for the full horizontal distance.



The vertical point spacing is 0.4 m.

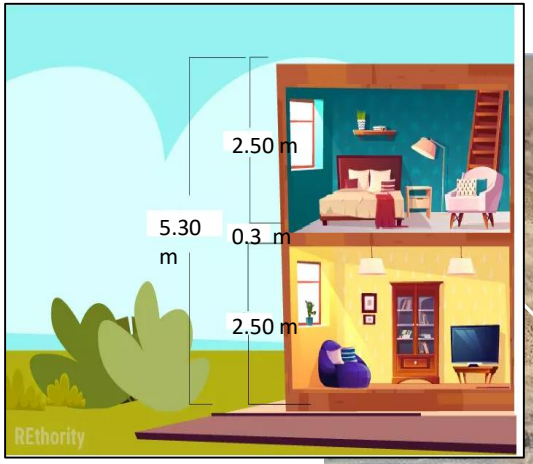
11 points are selected. The space between each of the points, in this case 10, is utilised for the full horizontal distance.

Area threshold = (4.4 m x (2-1 points)) x (0.4 m x (11-1)) points))
Area threshold = (4.4 m x 1 points) x (0.4 m x 10 Points)
Area threshold = 4.4 m x 4.0 m
Area threshold = 17.6 m^2



REUTECH MINING

STEP 4: SELECTING AREA THRESHOLD PARAMETERS



REUTECH MINING

STEP 5: MEASUREMENT TERMINOLOGY

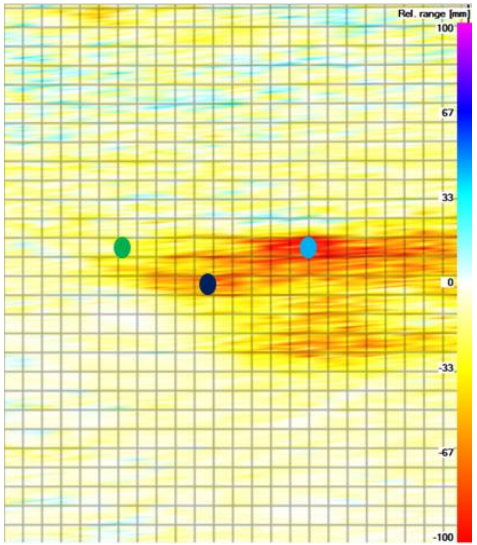
- Relative range is the total accumulated movement between the scan at the reference time or beginning of the database and the last scan.
- Average velocity is calculated by dividing the total accumulated movement since the reference time or the beginning of the database by the allocated time window.
- Velocity delta is effectively a measure of acceleration or deceleration over the specified time window.

REUTECH MINING

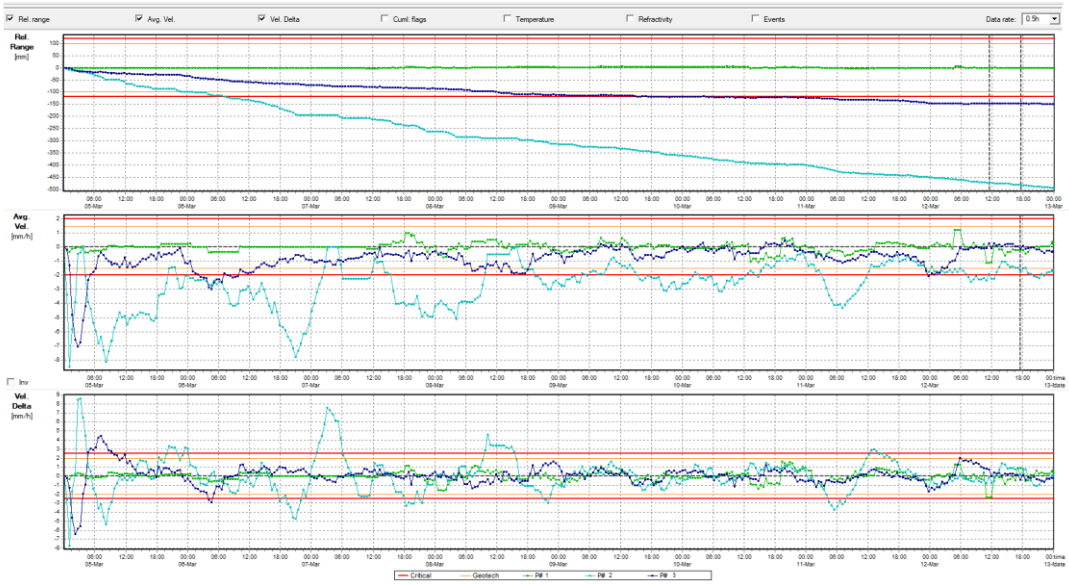
STEP 5: MEASUREMENT TERMINOLOGY

Direction of movement depends on the sensor or radar used. For our systems negative (distance is decreasing) movement is towards the radar and positive movement is away from the radar as the distance between radar and the pit slope is increasing.

- Geotechnical alarm - ideally a precursory alarm set for a lower value of movement.
- Critical alarm - a second alarm which is set at a larger threshold value of movement.

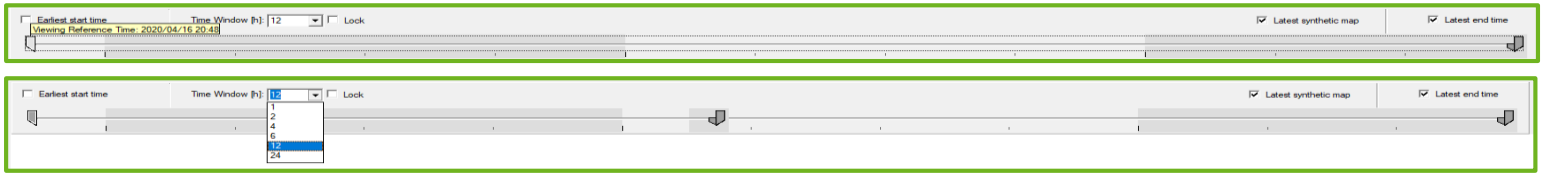


Relative Range (100 mm scale)



REUTECH MINING

STEP 5: REFERENCE TIME AND TIME WINDOWING

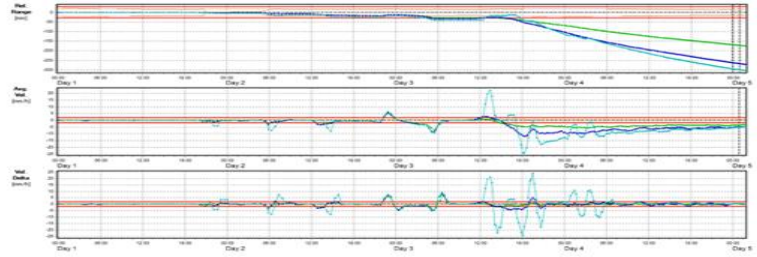


- The reference time denotes a predetermined date and time for which the value of the measurements are set at 0.
- The reference time may be: the start of the database, a strategic review period of time or a selected point in time leading up to an event for which only that data is assessed.
- Time windows of 1, 2, 4, 6, 12 and 24 hours can be applied.
- Based on the time window selected, the difference in measurement of the relative range between the latest scan and the scan at the onset of the time window is divided by the time window value.
- Remember that resetting the reference time also resets the time window calculations.

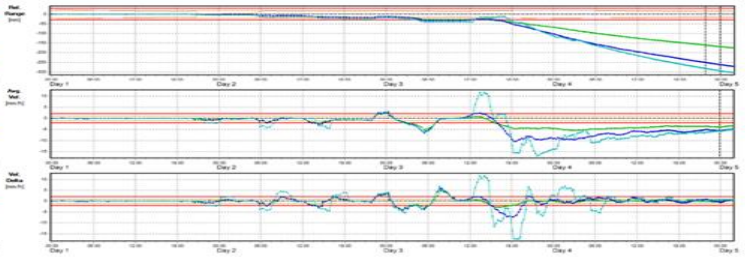
REUTECH MINING

STEP 5: REFERENCE TIME AND TIME WINDOWING

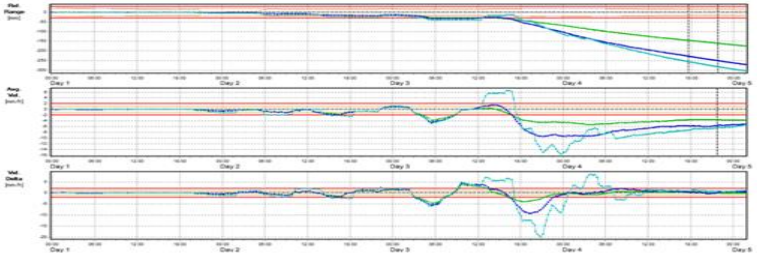
1 hour time window



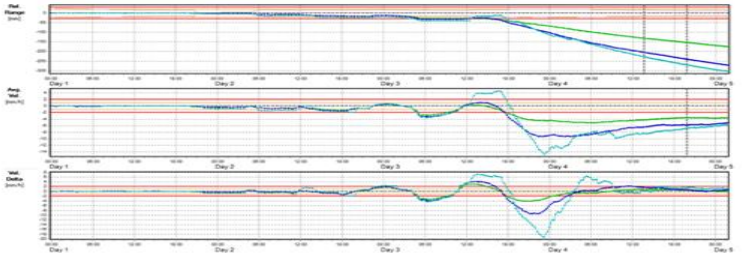
2 hour time window



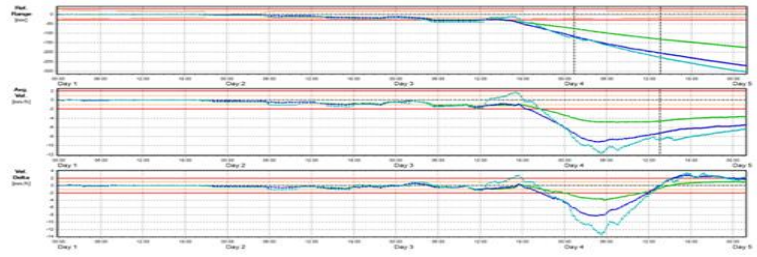
4 hour time window



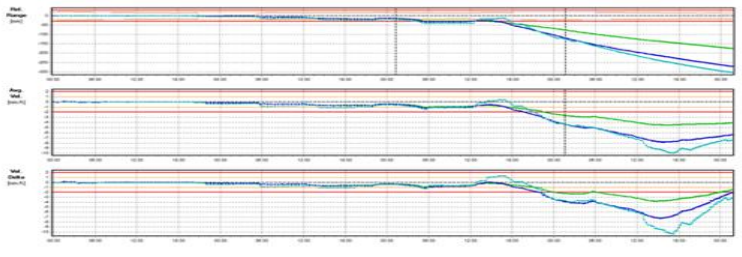
6 hour time window



12 hour time window



24 hour time window



REUTECH MINING

STEP 6: APPLYING ALARM THRESHOLDS

Alarm thresholds may be applied utilising the following techniques:

- Empirical approach.
- Database approach.
- Back-analysis approach.
- Comparative approach.
- Iterative approach of adjusting thresholds over time, narrowing of thresholds as more data is collected.

		Area		Relative Range [mm]		Average Velocity [mm/h]		Velocity Delta [mm/h]		
Region	Level	Width	Height	Approach	Recede	Approach	Recede	Approach	Recede	Time Win [h]
Normal # 0	Geotech	4	11	40.0	40.0	1.00	1.00	1.40	1.40	6
	Critical	4	11	50.0	50.0	2.00	2.00	1.80	1.80	6
High threat # 0	Geotech	2	6	20.0	20.0	0.50	0.50	0.80	0.80	2
	Critical	2	6	30.0	30.0	1.00	1.00	1.20	1.20	2

REUTECH MINING

STEP 6: APPLYING ALARM THRESHOLDS – TARP

Trigger

This is based on pre-set criteria pertaining to the geotechnical environment, anticipated failure mode and the current movement class.

Plan

1. Add incident to the hazard plan
2. Review the monitoring data
3. Review the trigger level
4. Review mining plans and activities

Action

1. Evaluate the trigger based on the pre-set criteria and the alarm level
2. Review the monitoring data
3. Conduct a visual and physical inspection of the slope
4. Evaluate the immediate likelihood x consequence = risk

Response

1. Inform production
2. Advise on action to be taken

Ensure that there is an evacuation procedure in place that has been communicated, tried and tested.

REUTECH MINING

CONCLUSIONS: TIPS FOR DATABASE ASSESSMENT

- Calibrate synthetic map with visual observation of the pit slope (visual inspection, images or Slope Vision Camera).
- Is the alarm caused by true or false movement e.g. actual slope movement or machinery, production, vegetation etc.
- What are the visual observation of the pit slope e.g. poor rock mass conditions etc?
- Assess trend plots for as much movement history as possible taking into cognisance the overall accumulation of relative range which may indicate more sinister movement.
- Evaluate the average velocity e.g. an increase in the speed of accumulation.
- Monitor the velocity delta e.g. rapid acceleration and deceleration patterns that may indicate the depletion of the shear strength parameters.

REUTECH MINING

REFERENCES

- Carla, T, Farina, P, Intrieri, E, Botsialas, K & Casagli, N 2017a. On the monitoring and early warning of brittle slope failures in hard rock masses: Examples from an open-pit mine. Engineering Geology. 228: 71–81.
- Carla, T, Intrieri, E, Di Traglia, F, Nolesini, T, Gigli, G & Casagli, N 2017b. Guidelines on the use of inverse velocity method as a tool for setting alarm thresholds and forecasting landslides and structure collapses. Landslides. 14:517–534.
- Cawood, F. T. & Stacey, T. R., 2006. Survey and geotechnical slope monitoring considerations. The Journal of the South African Institute of Mining and Metallurgy. 106: 495-502.
- Crosta, GB, Agliardi, F, Rivolta, C, Alberti, S & Dei Cas, L 2017. Long-term evolution and early warning strategies for complex rockslides by real-time monitoring. Landslides. 14: 1615–1632.
- Dick, GJ, Eberhardt, E, Cabrejo-Liévano, AG, Stead, D & Rose, ND 2015. Development of an early-warning time-of-failure analysis methodology for open-pit mine slopes utilizing ground-based slope stability radar monitoring data. Canadian Geotechnical Journal. 52: 515–529.
- Hoek , E., & Bray , J. W. (1981). Rock Slope Engineering. London. The Institution of Mining and Metallurgy. London.
- Rose, ND & Hungr, O 2007. Forecasting potential rock slope failure in open pit mines using the inverse-velocity method. International Journal of Rock Mechanics and Mining Sciences. 44: 308–320.
- Sharon, R., 2020. Slope performance monitoring: system design, implementation and quality assurance. Slope Stability, pp. 107-37.
- Sharon, R. & Eberhardt, E., 2020. Guidelines for Slope Performance Monitoring. Clayton: CSIRO PUBLISHING.
- Shellam, R. & Coggan, J., 2020. Analysis of velocity and acceleration trends using slope stability radar to identify failure ‘signatures’ to better inform deformation trigger action response plans. Perth, Australian Centre for Geomechanics.
- Sullivan, T. D., 2007. Hydromechanical coupling and pit slope movements. Slope Stability 2007, p. Keynote.
- Read, J., Stacey, P. (2009). Guidelines for Open Pit Slope Design. CSIRO Publishing, Collingwood.
- Wyllie, D. C., & Mah, C. W. (2004). Rock Slope Engineering Civil and Mining. London : Spon Press Taylor & Francis Group.

REUTECH MINING

+27 21 880 1150

reutechmining@reutech.co.za

www.reutechmining.com

Reutech Mining

REUTECH
MINING