# Establishment and Maintenance of a Successful Pit Slope Monitoring Database

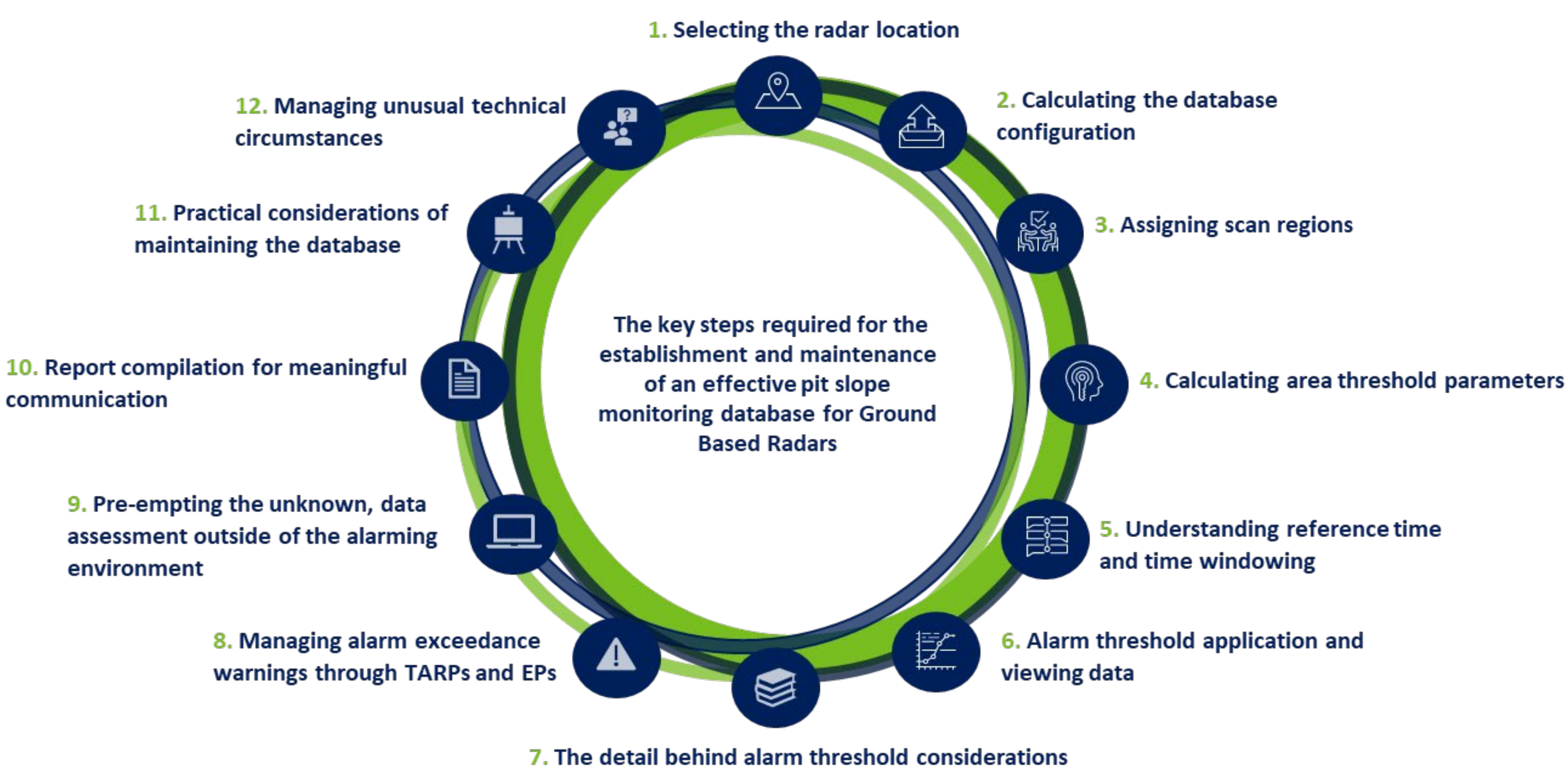
Slope performance monitoring is integral for ensuring safe operational conditions during mining activities, and for gauging the efficacy of the slope design applied. There are a number of sensors that contribute to a slope monitoring program, for which the focus herein is ground-based and real aperture radars (GBR, RAR) and specifically, the establishment and maintenance of databases/datasets captured by this type of equipment.

Whilst directly applicable to Reutech Mining's movement and surveying radars (MSR), these steps are also valid for other service providers, and the theory and checklists can be adjusted to cater for mining GBR systems.

The maintenance of these databases are the foundation for obtaining reliable and accurate radar monitoring data. A number of alarm exceedance warnings may be applied in order to provide advance warning of pit slope conditions which may be indicative of both anticipated deformation and the forewarning of unexpected and unforeseen events. 'It is these events that can have serious implications in terms of loss of life, serious injury or disruption to mining activities' (Sharon & Eberhardt 2020). The onus is on us as geotechnical practitioners to ensure that we are not unaware, nor caught off-guard, and that we are well equipped and prepared to manage such eventualities.

Whilst having employed various sensors to collect data, the instrumentation (and its collected data) must be well understood. The intrinsic parameters regarding range, resolution, accuracy, precision, conformance, robustness and reliability are best described as being 'synonymous with ensuring confidence in data, poor quality or inaccurate data can be misleading and may be worse than having no data at all.' (Sharon 2020).

One must also be cognisant of the fundamental principles of the alarming capability and assessment tools provided via the software interface, which is typically under continuous development/improvement by the radar service provider (this entails both the physical interface itself and the code which deals directly with the management of the interpretation of measured interferometric phase and the removal of refractive index (RI) which is representative of atmospheric conditions).




**References**
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Sharon, R & Eberhardt, E 2020, Guidelines for Slope Performance Monitoring, CSIRO Publishing, Clayton.

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# Establishment of a Successful Pit Slope Monitoring Database

## STEP 1: SELECTING THE RADAR LOCATION

**Geotechnical considerations**

Geology, structure, rock mass and hydrogeology per geotechnical or monitoring domain.

**Monitoring Strategy: Primary/Strategic or Tactical/Safety Critical**

This may change the resolution selected for the database (may impact scan time) and the point spacing of the synthetic map (which will affect the area threshold size selected).

**Measurable movement variables for which alarms may be applied**

Be cognisant of what type of movement variables will be utilised in order to monitor the slope, such as Relative Range (RR), Average Velocity (AV) and Velocity Delta (VD).

**Site selection considerations**

Obvious visual obstructions, line of sight (for vector loss of movement) and angle of incidence (perpendicularity component).

**Geo-referencing**

Ensure that there are adequate referenced survey points for which to geo-reference the system .

**Mechanical and logistical considerations:**

Access, refuelling, power source, communications network and telemetry, servicing and calibration and housing.

Temperature kits (insulation or cooling equipment) for extreme environments may also be retrofitted to the system in order to provide protection to the mechanical components and ensure the system operates optimally.

## STEP 2: CALCULATING THE DATABASE CONFIGURATION

**Defining the resolution of the database**

Select the horizontal and vertical resolution in degrees (º).

**Understanding the resultant point spacing**

This is a function of the selected resolution and the distance between the sensor and the pit slope.

The further the pit slope, the larger the point spacing.

The point spacing may also change dependent on the shape and geometry of the pit slope, as the distance will vary.

**Temporal resolution**

The amount of time required for the system to sample and resample the phase offset for a full scan of the region/s selected. Three principal reasons that scan time is so important are :

1. To extend the maximum measurable velocity as much as possible to avoid phase ambiguity.
2. To ensure the sampling rate is greater than the acceleration phase, or deformation may not be detected.
3. High-frequency monitoring data aids failure forecasting by identifying acceleration. In addition, accurate time of failure predictions require constant re-evaluation as new data becomes available.

## STEP 3: ASSIGNING SCAN REGIONS

**Select the overall scan region**

Ensure that the scan envelope size and the mechanical limits of the system are taken into consideration. T

he larger the scan region, the longer the scan time.

**Known stable or reference regions (green)**

May also be applied to each normal region (typically between two and three). When using this technique, the system will automatically correct for atmospheric contribution experienced in that specific normal region only.

This area can be selected based on the geotechnical model and understanding of the stability model, previous monitoring data and historic and current prism data.

**High Threat or Special Area (red)**

Areas which can be monitored with independent alarm thresholds.

**Exclusion (yellow)**

Used to exclude parts of normal regions, e.g. areas with ramps, machinery or vegetation can be excluded. No data is collected where this region is applied).

**Masked (orange)**

Data is stored for this region, however, the region will not trigger any stability alerts.

**User (dark blue)**

Used to view movement trends for a small part of a normal or high threat/ special area region.

These regions do not create alarms and are for assessment purposes only.

**Point data (colour assigned)**

Used to view the trend plots for specific selected points on the synthetic map.

## STEP 4: CALCULATING AREA THRESHOLD PARAMETERS

**What is area threshold?**

Each movement scanning database is set up according to the degree step (resolution) which defines the resultant resolution between points on the pit slope, this is also function of the distance between the sensor and the pit slope.

**Area threshold theory**

The area threshold is a selected number of points (interchangeably referred to as pixels or voxels) in both height and width for which data is assessed for alarm exceedance purposes.

The area threshold should represent the smallest instability size monitored, which is typically a bench height (or half a bench in height is a double bench).

Remember, area thresholds that are too large may not alarm as the area on average may not meet the alarm criteria of movement exceedance.

## STEP 5: UNDERSTANDING REFERENCE TIME AND TIME WINDOWING

**Reference time**

The reference time denotes a predetermined date and time for which the value of the measurements are set at/to 0, in order to manage detailed alarming criteria for a sub-set of the database.

**Time windowing theory**

The concept of time windowing is that on a sliding scale, 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.

**Time windowing: short**

Short duration time windows are more sensitive as smaller amounts of measurement data are being averaged by shorter duration of time.

They are applicable to emergent monitoring situations whereby safety critical or tactical monitoring protocols are adopted and applied. For example; excavation of higher risk areas, rehabilitation of critical areas or the monitoring of an instability.

Shorter duration time windows may be applied for the cracking and dislocation leading up to the collapse movements stages of a trigger action response plan.

**Time windowing: medium**

Medium duration time windows give a good indication of movement and alleviate multiple alarms for situations whereby monitoring protocols require alerts, however the area being monitored may not be close to an area of production or a critical area such as during primary and strategic monitoring.

Information pertaining to the triggered alarms can be collected and utilised to refine alarm settings should they need to be refined to be either more or less sensitive.

Medium duration alarm settings are also useful during the creep leading up to the onset of the cracking and dislocation stages of pit slope movement.

**Time windowing: long**

Longer duration time windows are much less sensitive as larger amounts of measurement data are being averaged by longer duration of time.

They are useful longer term monitoring protocols that may range between the elastic and the creep stages of pit slope movement.

**Time window application**

The time window is highly dependent on the geotechnical conditions and the anticipated failure mode, how the instability will progress and the site and domain specific trigger action response plan. Additional points to consider include:

- Early onset of movement versus progressive movement*3.
- Movement patterns such as linear, bi-linear, stick-slip, regressive, transitional, slow accelerating, linear accelerating and accelerating (progressive) *3.
- Note how many more times the alarm settings may be triggered based on the time window applied.

## STEP 6: ALARM THRESHOLD APPLICATION AND VIEWING DATA

**Movement categories for which alarms may be applied**

*Relative range* is the total accumulated movement between the scan at the reference time or beginning of the database and the last scan. Relative range may also be known as deformation or displacement. Relative range is not time windowed as it is an accumulated measurement of pit slope movement, this may be reported in mm, cm or inches.

*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. This is a sliding scale and may be reported in mm/hr, cm/day and in/hr.

*Velocity delta* is effectively a measure of acceleration or deceleration over the specified time window. It is reported in mm/hr, cm/day and in/hr.

**Movement convention**

The movement direction will depend on the sensor or radar being utilised and needs to be checked and communicated. For Reutech MSR systems:

*Negative* movement is towards the radar as the distance between the radar as the pit slope is decreasing.

*Positive* movement is away from the radar as the distance between radar and the pit slope is increasing.

When assessing the synthetic map, both conventions of movement should be checked and qualified, both to ascertain what is considered to be a normal instability profile, but also that of subsidence or back-break.

**Alarm levels**

The alarms may be either geotechnical (investigative) or critical (evacuation) level.

**Alarm thresholds application approaches**

*Empirical: the* use of empirical published examples.

*Database:* the assessment of current database trends.

*Back- analysis:* through the interrogation of previous monitoring history that covers an instability or regular strategic monitoring.

*Comparative*: utilising datasets from operations in similar geotechnical environments.

**Additional items to take into consideration**

Temperature which is the measure of heat at the radar unit.

Refractivity is measured in part per million (ppm) and represents the temperature, humidity and pressure recorded at the radar.

**Synthetic map and trend plot viewing**

The synthetic (data) map and trend plots should be viewed on various scales, time windows and reference times to ensure that the movement class and profile, as well as the inhomogeneous movement of the pit slope, are understood, identified instabilities are demarcated accordingly and areas of interest are defined.

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# Maintenance of a Successful Pit Slope Monitoring Database

## STEP 7: THE DETAIL BEHIND ALARM THRESHOLD CONSIDERATIONS

**General alarm threshold considerations**

The phase ambiguity limit of the system, temporal resolution which defines the amount of phase that can be accumulated, ensuring the alarms applied are not coarser then these limits, sensitising or desensitising alarms using the area threshold and time window applications.

**Alarm configuration**

Alarms may also be 'stacked' and applied on an ascending scale (leading to collapse) or descending scale (de-escalation) depending on the type of movement being experienced/monitored.

**Qualifying poor data**

There are also techniques to qualify poor data which include pure amplitude, cumulative flags (data point quality interrogation) and confidence (scan-to-scan coherence).

This forms part of data validation and the acceptance criteria for use of the data in slope performance monitoring.

**Removal of atmospheric contribution assessment**

Temperature and RI should be assessed in collaboration with the relative range in order to understand the component of the phase that is being allocated to true pit slope movement and what levels of atmospheric contribution have been removed per interferometric scan.

Herein lies the importance of temporal resolution or scan time and the effect on alarming (the shorter the scan time the more effective the alarm).

**Vector loss of movement considerations**

The vector loss of the movement component may also require alarm criteria to be sensitised if the full movement profile cannot be captured.

**Informing alarm threshold selection through data assessment**

The assessment of empirical versus site data and the back analysis of previous instabilities will also inform alarm threshold selection per geotechnical domain and instability type.

**A note on time of failure predictions**

There are a number of techniques that may be utilised to predict time of failure, as well as warn of impending collapse such as inverse velocity, velocity ratio and specific coherence assessment. Calculating the run-out distance of the instability may also be completed.

**Preparing data export for use in other software packages**

The data collected by the GBR can be exported as a Digital Terrain Model (.dtm) and as a 3D point cloud for which movement data is assigned. This data can then be imported into third-party software packages for further specific assessment, such as Slide3 and RS3 (Roscience) for Factor of Safety (FoS) and Probability of Failure (PoF) calculation at various stages of the deformation profile.

## STEP 8: MANAGING ALARM EXCEEDANCE WARNINGS THROUGH TRIGGER ACTION RESPONSE PLANS (TARPS) AND EVACUATION PROTOCOLS (EPS)

**Trigger Action Response Plans (TARPs)**

An appropriate TARP (agreed and approved by all stakeholders) is essential in order for the operation to support the required response efforts to activated alarms and to de-escalate them depending on the trigger level, risk assessment (likelihood × consequence) and the hazard rating. The alarm is activated, as in, exceeded/triggered, not active.

**System health constraints**

It is also paramount to be cognisant, and plan for system health concerns which are reflected in the system status (loss of telemetry, low fuel, batteries depleted, specific hardware constraints, stabilisation scan mode (adverse atmospheric conditions) etc). These eventualities should be included in the TARP under their own designated alert level.

When the system is compromised, either due to mechanical or atmospheric concerns (atmospheric system stabilisation mode), note that there may be no real-time data being received from the system, therefore, no active monitoring for which there will not be alarm threshold exceedance warnings.

**Compiling situation specific TARPs**

In addition, custom TARPs may be necessary for specific instability modes (movement stages and patterns), and seasonal changes in the atmospheric environment.

These various TARPs need to be compiled with the site characteristics in mind and communicated efficaciously to all levels of the workforce.

**Evacuation Protocols (EPs)**

Of great importance are pit slope evacuation protocols/procedures, their implementation, practice, and periodic review. It is of little value to have a well-established TARP with no associated procedure to remove mining personnel and equipment from a perilous area in a timeous manner.

## STEP 9: PRE-EMPTING THE UNKNOWN, DATA ASSESSMENT OUTSIDE OF THE ALARMING ENVIRONMENT

**Assessment of radar data**

Daily geotechnical assessment (down to pre-set time intervals, or continuous live monitoring) of the radar data is imperative to pre-emptively and proactively identify potentially sinister pit slope conditions.

Checklists and sign-off procedures may be developed to assist with this task, as well for record purposes (system health, shift handover, data assessment and alarm exceedance warning receipt list).

**Assessing radar data in conjunction with other instrumentation/sensors**

The radar data should also be assessed in conjunction with other monitoring instrumentation/sensors (such as prisms, precipitation sensors, satellite based InSAR etc., if available).

**The importance of visual assessment of the pit slope condition**

The aforementioned tasks should be undertaken hand-in-hand with visual inspection of the pit slope.

The onus is on us, as geotechnical practitioners to ensure that we are visually calibrated with the pit slope, and that we have seen and are aware of its ever changing characteristics and behaviour.

Taking time to conduct the various visual assessment techniques adds to one's own empirical knowledge base.

**Tracking and recording of daily activities**

Other daily tasks include tracking and recording activities such as environmental conditions, blasting, seismic events, mining activities (production activities which include loading or unloading portions of the pit slope, as well as excavation at the toe) and any other noteworthy occurrence in event logs.

**Service provider assistance and third party review of monitoring data and its interpretation**

Contacting your service provider for an overview of the data, or an unbiased third-party review at pre-determined intervals is also a useful tool for qualifying and quantifying the information derived from the monitoring campaign.

## STEP 10: REPORT COMPILATION AND MEANINGFUL COMMUNICATION

**Reporting**

Reporting (defined at predetermined intervals) should include to recording alarm exceedance warnings, trend plot and synthetic (data) map images for the tracking of the various movement classes or instabilities.

**Additional information**

Additional information pertaining to the geotechnical conditions observed must be included, along with technically edited photographic or pictorial images of the area of interest.

Recommendations for the update of hazard plans, risk profiles, geotechnical and monitoring domains, mining sequencing, drill and blast activities, blast re-entry timing etc.

**Deployment Records**

Deployment records which detail the name of the system, location and database (name) as well as the contents of the database are also required as part of managing the history of the data being collected.

## STEP 11: PRACTICAL CONSIDERATIONS OF MAINTAINING THE DATABASE

**Data storage**

Storage of the database (automatic back-up scripts and central server access).

**Periodic review of database history**

Loading the database into a 'virtual radar' application for further assessment or back-analysis.

**Database management in conjunction with mining activities**

Update of the high threat/special, mask, exclusion areas and known stable regions, ensuring that benches down to the floor of the pit are monitored by adjusting the scan region (as mining progresses).

**Synthetic map artifact management**

Mitigation for multi-pathing artifacts or any other interference artifacts of the synthetic map, needs to be managed as soon as they arise on a case-by-case basis. Any interference on the synthetic map compromises the quality of the data and the ability of the system to generate representative alarm threshold exceedance warmings.

Multi-pathing and interference artifacts on the synthetic map are typically due to the presence of strong reflectors in the vicinity of the scan envelope. Surface water, dewatering infrastructure (piping on the pit slope), mesh (and bolting) and production equipment are the usual culprits.

**Pre- and post-blast slope condition assessment**

Pre- and post-blast trend analysis and synthetic map assessment for safe re-entry practices, should be undertaken per blast and defined per geotechnical and monitoring domain, for which the reaction of the pit slope to the blast (blast type dependent) should be described and recorded.

**Re-deployment procedure**

The system may be moved at periodic or predefined intervals in order to protect it from nearby blasting or a new monitoring campaign.

A system specific checklist and redeployment procedure should be developed as part of this process, for which signoff of particular elements is required.

Of particular importance is the geo-referencing of the system, and the application of custom-designed software to automatically re-align the scan regions and the three-dimensional movement data from previous deployment/s for the same database.

These practices are paramount for ensuring the longevity of the monitoring database for which enables the continued assessment of the pit slope condition.

## STEP 12: MANAGING UNUSUAL TECHNICAL CIRCUMSTANCES

**Technically challenging conditions**

In some instances, technically challenging conditions such as highly inclement weather (snow, sleet, heavy rainfall, extreme heat), freeze and thaw, as well as expansion and contraction conditions, in-pit micro-climates, thick dust storms/haze and seismic events; present the geotechnical practitioner with additional items to consider when managing TARPs, EPs and geotechnical feedback to operational activities.

**Synthetic map noise**

Monitoring through support or mesh, vegetation and blast spill material on the pit slope may mean that the region creation, TARP and associated alarm thresholds are revised to reflect the conditions at hand.

These circumstances typically introduce noise (distorted data which is known to be inaccurate) to the synthetic maps, cause false alarms, and compromise the data quality for that portion of the pit slope.


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