Establishment and maintenance of an effective pit slope monitoring database

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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 any 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).

Key steps utilised to establish and maintain a ground based radar database

There are a number of key, predefined steps to first establish and thereafter maintain a 'living' pit slope

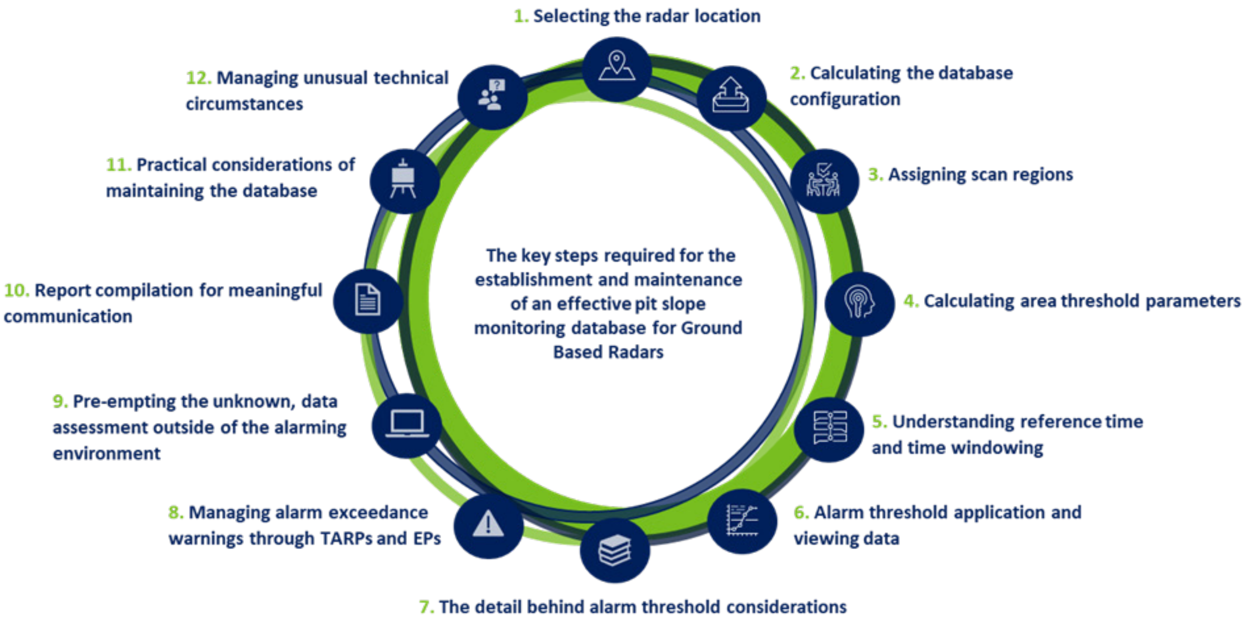

Figure 1. Key steps required for the establishment and maintenance of an effective pit slope monitoring database using GBR

monitoring database. These considerations are illustrated by means of a schematic diagram (Figure 1).

A short description of each step includes:

Step 1: Selecting the radar location

Items to be understood are the geotechnical conditions of the pit slope to be monitored, the monitoring strategy (strategic versus tactical), angle of incidence, line of sight and vector loss of movement calculations, scan envelope size (mechanical limits of the system), distance between the sensor and the pit slope (affects resultant spatial resolution), mechanical and logistical considerations (refuelling, power sources, communications network and telemetry, servicing and calibration), access to geo-refencing network, inspection for visual obstructions and housing for the system (if required).

Step 2: Calculating the database configuration

Selecting the horizontal and elevation degree step and therefore the resultant point spacing or spatial resolution, understanding the consequent temporal resolution in terms of the repeatability of the scan time.

Step 3: Assigning scan regions

Drawing the region to scan and known stable or reference regions (if applicable), applying exclusion or mask areas to mitigate false alarms, applying user areas and point locations for later assessment.

Step 4: Calculating area threshold parameters

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).

Step 5: Understanding reference time and time windowing

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. The concept of time windowing is that on a sliding scale, with shorter (to manage emergent situations/tactical monitoring such as impending collapse), medium (strategic day-to-day monitoring activities) and longer (monitoring protocols, like background monitoring, for which extended data collection is required) time windows applied.

Step 6: Alarm threshold application and viewing data

Typically, the three movement categories that alarm threshold warnings may be applied to are relative range (interchangeably called deformation or displacement), average velocity and velocity delta (acceleration or deceleration). The alarms may be either geotechnical (investigative) or critical (evacuation) level. 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.

Step 7: The detail behind alarm threshold consideration

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. There are also techniques to qualify poor data which include pure amplitude, amplitude dispersion index, cumulative flags (data point quality interrogation) and confidence (scan-to-scan coherence). 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). The vector loss of the movement component may also require alarm criteria to be sensitised if the full movement profile cannot be captured. 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.

Step 8: Managing alarm exceedance warnings through trigger action response plans (TARPs) and Evacuation Protocols (EPs)

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. 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). 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. Of great importance are pit slope evacuation 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 from a perilous area in a timeous manner.

Step 9: Pre-empting the unknown, data assessment outside of the alarming environment

Daily geotechnical assessment (down to pre-set time intervals, or continuous live monitoring) of the radar data in conjunction with other instrumentation (such as prisms, precipitation sensors, satellite based InSAR etc., if available) is imperative to pre-emptively and proactively identify potentially sinister pit slope conditions. These tasks should be undertaken hand-in-hand with visual inspection of the pit slope. 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. 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 (defined at predetermined intervals) should not be limited to recording alarm exceedance warnings, trend plot and synthetic (data) map images for the tracking of the various movement classes or instabilities. Additional information pertaining to the geotechnical conditions observed must be included, along with technically edited photographic or pictorial images of the area of interest. 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

Storage of the database (automatic back-up scripts and central server access), loading the database into a 'virtual radar' application for further assessment or back-analysis, update of the mask and 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), mitigation for multi-pathing artifacts (or any other interference artifacts) on the synthetic map (typically due to surface water), pre- and post-blast trend analysis and synthetic map assessment (for safe re-entry practices), moving the system (for blasting or new monitoring campaign etc.) and service and/or calibration planning are all par for the course of day-to-day activities and maintenance of the database.

Step 12: Managing unusual technical circumstances

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, seismic events or monitoring through support or mesh on the slope may mean that the TARP and associated alarm thresholds are revised to reflect the conditions at hand.

Whilst these steps and the theory presented in this article are by no means exhaustive, they provide some good guidance on how to actively establish and maintain data being collected in real-time for a 'living' pit slope database. Should you think we have omitted an important concept, or have any comments or recommendations, please do not hesitate to contact us. We always welcome open debate and discussion.

References

Sharon, R 2020, 'Slope performance monitoring: system design, implementation and quality assurance', in PM Dight (ed.), *Slope Stability 2020: Proceedings of the 2020 International Symposium on Slope Stability in Open Pit Mining and Civil Engineering*, Australian Centre for Geomechanics, Perth, pp. 17–38, https://doi.org/10.36487/ACG_repo/2025_0.02

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