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Transberg Method. Utilising drone photogrammetry to create near real time hazard maps and optimise slope monitoring.

Glen Guy
Encompass Mining Solutions, Brisbane, Australia
glen.guy@encompassmining.com

Mark Sjoberg
Encompass Mining Solutions, Brisbane, Australia

Abstract

In the Australian mining industry, the recent advance in rapid data collection with the use of UAV drone and LIDAR technology for the collection of mine surface data can be undertaken and provided in a usable format in only a matter of hours. This can be in the form of point cloud data or high-resolution images that can be utilised for photogrammetric imaging, defect mapping and assessment and geotechnical stability assessment of any excavated slope.

Encompass Mining have developed a method, utilising commercially available software, to provide a rapid assessment of excavated hard walls for potential kinematic or rockfall hazards. This method utilises high resolution images obtained from UAV of a subject slope and processes through evaluation software to produce a slope hazard map which can in turn identify areas with high potential rock fall hazards. Results are then used to refine mitigation measures, such as separation, hard bunding or further engineering controls that may need to be employed to reduce the risk to personnel and equipment.

This paper presents a case study of the assessment, analysis and ongoing monitoring of a structurally complex slope at an open pit operation in Australia. The employment of this method allowed quick identification of hazard zones in the operating pit and the integration of slope stability monitoring tools provided focussed monitoring and predictive analysis. By undertaking a rapid kinematic hazard assessment and identifying areas that require additional controls, the mine operations were able to optimise the mining process, minimise the downtime of equipment and keep production on schedule at a significant cost saving for the operation. This process is now routine at this mine-site as development occurs in and around the area of unstable ground and can be completed on site or remotely with the current technology.

Keywords

UAV drones, kinematic assessment, hazard mapping, rock fall, slope hazard mitigation

1 Introduction

1.1 Mining Industry Approach

Within the Australian coal mining industry, the adoption of new slope assessment technology has been stagnant with the default methodology of 2D Limit Equilibrium analysis with generic rockmass parameters producing a factor of safety, being accepted as representing slope stability. This is a simplistic and conservative assumption for a low to moderate stress, but often structurally affected, environment where kinematic instability is an inherently more dominant failure mechanism. Kinematic instability is a critical issue in mining operations, affecting both the safety and efficiency of extraction processes. It refers to the behaviour of rock masses that can result in unexpected and often catastrophic movements, such as slope failures, and rockfalls. These instabilities are influenced by various factors, including geological conditions, mining design and techniques, and external forces such as seismic activity or changes in groundwater levels. Understanding the underlying mechanisms of kinematic instability is essential for improving risk management and optimising design strategies in mining projects. As mining operations advance in complexity and scale, the need for robust models and predictive tools to anticipate and mitigate kinematic hazards has become more pronounced.

Across the mining industry for low to moderate stress open pit operations, it should be accepted that kinematic or defect driven instability is the most common form of slope failure that effect operational continuity rather than a global failure through the intact rockmass. Controlling kinematic instability can be undertaken by elimination or engineering controls which may comprise trim blasting, blast generated softwalls to break up the defect structure or changing the orientation of the pit wall strike or dip of the individual benches. All of these controls require an understanding of the defect type, orientation, persistence, spacing and surface properties to be able to effectively assess the risk of instability and quantify the hazard.

1.2 Types of Kinematic Instability

For all but very weak rock materials, the analysis of rock slope stability is fundamentally a two-part process. The first step is to analyse the structural fabric of the site to determine if the orientation of the discontinuities could result in instability of the slope under consideration (Norrish and Wyllie 1996). This determination is usually accomplished by means of stereographic analysis of the structural fabric and is often referred to as kinematic analysis (Piteau and Peckover 1978). Once it has been determined that a kinematically possible failure mode is present, the second step requires a limit-equilibrium stability analysis to compare the forces resisting failure with the forces causing failure. The ratio between these two sets of forces is termed the factor of safety (FoS).

As shown in Figure 1, most rock slope failures can be classified into one of three categories depending on the type and degree of structural control:

Planar failures are governed by a single discontinuity surface dipping out of a slope face [Figure -1(a)],

Wedge failures involve a failure mass defined by two discontinuities with a line of intersection that is inclined out of the slope face [Figure -1(b)], and

Toppling failures involve slabs or columns of rock defined by discontinuities that dip steeply into the slope face [Figure -1(c)],

Recognition of these failure types is essential to the application of appropriate analytical methods. From a rock slope design perspective, the most important characteristic of a discontinuity is its orientation, which is best defined by two parameters: dip and dip direction. Interpretation of this geologic structural data has typically required the use of stereographic projections (or stereonets) that allow the three-dimensional orientation data to be represented and analysed in two dimensions. Discontinuity planes are represented by points and lines and stereographic analyses consider only angular relationships between lines, planes, and lines and planes. This analyses does not in any way represent the position, continuity or size of the feature.

Recent advances in kinematic analytical tools have allowed for discontinuities to be represented spatially and with the ability to analyse complex geological structures and quickly identify and mitigate potential failures. Software such as Rocscience RocSlope2 provides a comprehensive 3D analysis of joint intersections in realtion to slope formations and orientation

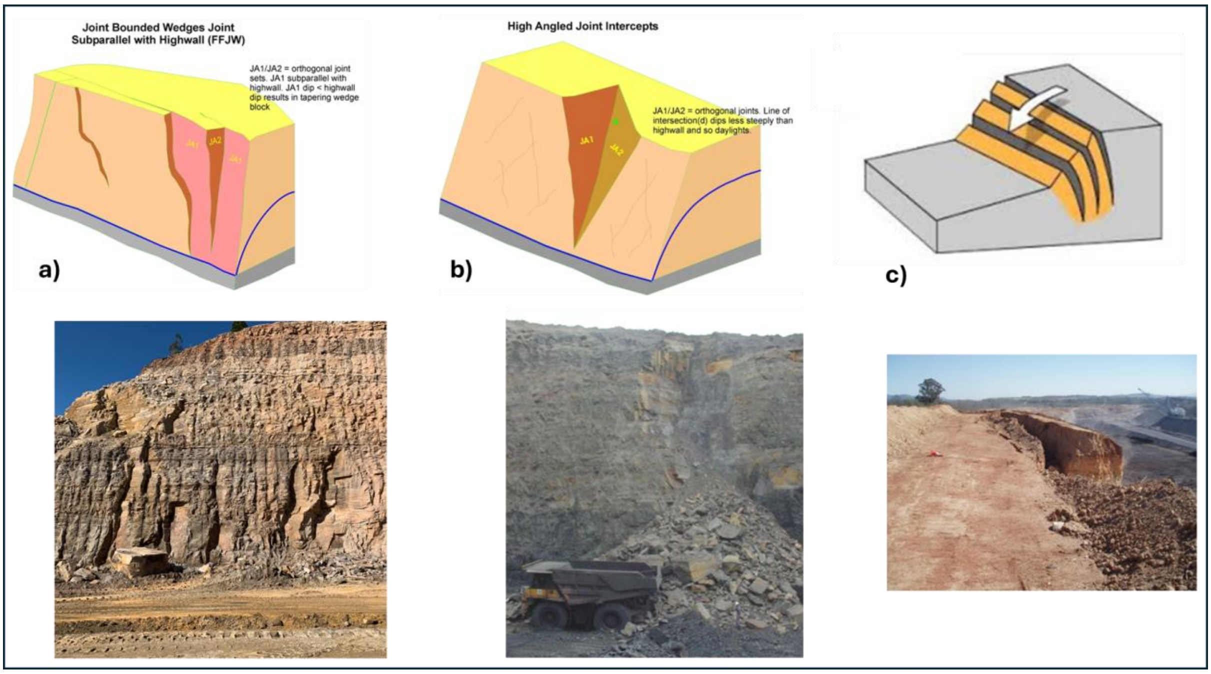

Fig. 1 Typical types of Kinematic Instability (a) Planar, b) Wedge and c) Toppling)

1.3 Rockfall Hazards

Rockfall events represent a serious hazard for people and infrastructures in surface mining operations. Activities such as blasting, bench clean-up and scaling can induce rock blocks detachment, compromising operators' and operations' safety. Rockfall events can also be affected by unpredicted structural conditions ahead of mining and variations in planned slope designs (and related geometries) upon optimisation of drill and blast operations, exposing workers, machinery, and site equipment to unpredicted risks.

As rockfall can originate during operations even in apparently stable zones, to predict an outcome a thorough understanding of rockfall kinematics in terms of trajectories, velocities, rebounds and run-out distance is required in the decision-making processes for exploitation and for the design of mitigation measures. The installation of passive mitigation measures coupled with a specific design of the pit geometry can mitigate this risk.

2 Transberg Method Process

With the recent advances in rapid and accurate topographical data collection with the use of UAV drones and LIDAR technology the collection of as mined surface data can be undertaken and provided in a usable format in only a matter of hours. In response to this Encompass Mining have developed a process, termed the Transberg Method, utilising commercially available software, to provide mining clients with a timely and precise assessment of excavated hard walls for potential kinematic instability or rockfall hazards.

This method (outlined in Figure 2) comprises;

Firstly, obtaining high resolution images from UAV of a subject slope via several passes to obtain images at sufficient overlap and photographic angles to develop a spatial image with depth,

Data is then processed through photogrammetry evaluation software, Shapemetrix to produce a 3D image where discontinuities can be mapped to capture type, Dip, Dip Direction, location (Easting, Northing and Elevation) and continuity. Defect sets can then be determined by clustering in a Stereonet then displayed spatially on the generated surface.

Output files from Shapemetrix are then imported in Rocsciences Rocslope3 to undertake a 3D kinematic assessment and identify potential planar, wedge or toppling failure areas. This can be undertaken by adjusting the mapped joint continuity to reflect the overall joint continuity determined. Results are displayed as removable blocks with a potential volume and factor of safety (FoS).

Results from Rocslope3 can then be refined to identify areas with a FoS close to 1.0 which may reflect potential kinematic failures and the resulting rockfall hazards. Rock fall may be directly associated a kinematic event or residual material following an event. Outputs are in the form of a spatial heat map that can overlain over an existing slope surface.

Key areas from the heat map are then identified to be assessed for rockfall run-out using the 3D slope profile and importing surfaces into Rocscience Rockfall 3D software. Key input parameters such as rock size and slope coefficients can be derived from observations made in pit or from analysing the 3D image for existing rock fall events and trajectories. Rockfall analysis can be used to look at run out distances and derive containment bund effectiveness and other mitigation techniques.

The results are then used to produce a slope hazard map in which high potential rock fall hazard zones are identified. Results are then used to refine mitigation measures, such as separation, hard bunding or further engineering control that may need to be employed to reduce the risk to personnel and equipment.

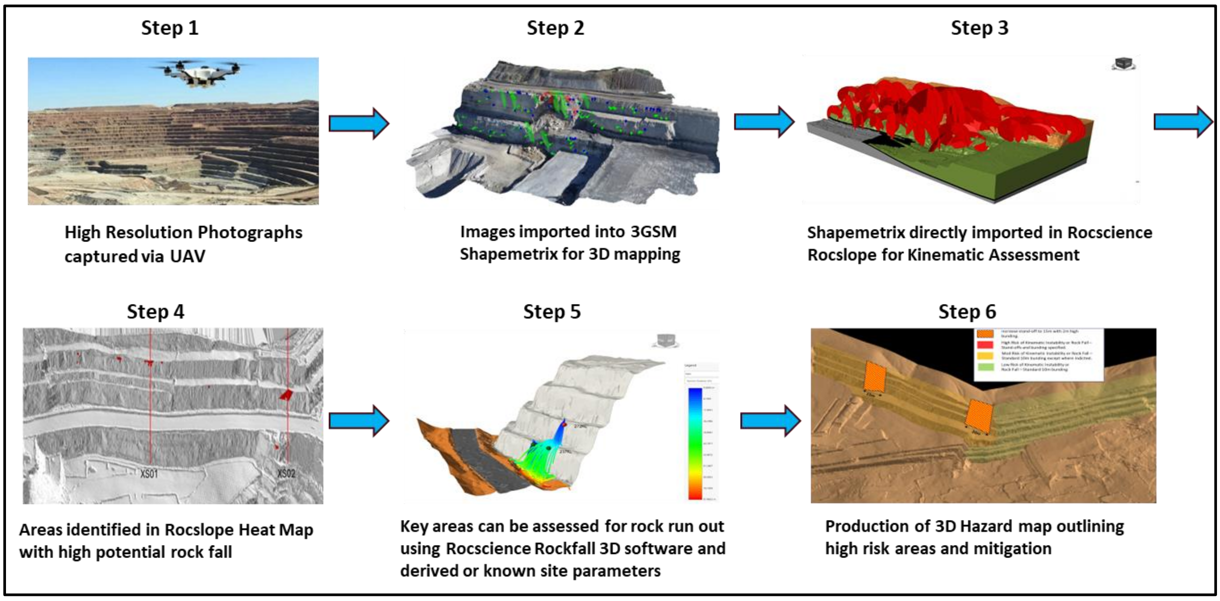

Fig. 2 Six Steps developed for the Transberg Method.

3 Previous Comparable Methods

3.1 Data Collection

Prior to data collection via UAV drones kinematic mapping was undertaken predominantly via terrestrial photography or capturing a point cloud by mine survey equipment scanning an exposed wall. These methods were timing consuming due to setting up of equipment or fixing survey points to render images to and distracted from other operational duties of mine personnel. Continuity of mapping was never maintained, and data was collected ad hoc and databases were often years out of date compared to the state of mining. This would often lead to misinterpretation if the rock mass defects had altered dip or direction either under or over estimating instability.

3.2 Data Processing

Defect data processing and kinematic instability potential has been typically undertaken using a Stereonet where clusters of defects are identified and then assessed for their likelihood of resulting in instability from wedge, planar or toppling type failure. These are often grouped with no consideration of spacing, continuity or location with regard to other defects. Although the output provides an indicative likelihood, compared to the dataset size, it can often under or over estimate the occurrence. The development of 3D kinematic models has enabled an assessment of the interaction of individual defects rather than clusters or sets.

4 Case Study

4.1 Setting

This section presents a case study implementing the Transberg Method that was undertaken at an open cut coal operation in central New South Wales, Australia. The operation is located in the north-eastern margins of the Gunnedah Basin area of New South Wales (NSW), approximately 13 kilometres north-east of the township of Boggabri and 290 kilometres north-west of Sydney.

Open pit coal mining at the site is undertaken through a strip-mining configuration using truck and shovel equipment to extract overburden/interburden and coal, the former disposed of using ex-pit and in-pit waste rock dumps. Loaders and trucks are utilised to extract ROM coal reserves which are subsequently stockpiled, crushed and screened on site before being transported by road to the Gunnedah CHPP for washing and blending for sale.

The operation mines multiple coal seams within the Maules Creek sub-basin of the Gunnedah Coalfield. Target coal seams span between Braymont and Nagero with numerous seams comprising of multiple plies and varying interburden and parting thicknesses.

The advancing highwall and residual end wall are formed within in situ coal measures rock which comprise Permian age sedimentary units such as sandstone, siltstone, mudstone and conglomerate of 20 – 50 MPa in strength. Minor fault and joint structures mapped on site generally trend in an east-west or north-west to south-east direction. Normal faults observed within the pit extents typically exhibit throws of less than 2 m and dip steeply to the north (dip ~70-80°). Thrust faulting observed within the pit extents exhibit throws of up to approximately 6 m and dip steeply to the north (dip ~70-80°).

4.2 Transberg Method Implementation

The subject operation was experiencing regular small to moderate sized kinematic and rockfall events that were impacting operations particularly around activities such as drilling or blast hole loading that are required to be undertaken close to the slope face and often out of a vehicle. In addition, a large kinematic failure event had reduced a major haul road to a single lane restricting mine traffic flow. Discontinuity data collection and usage had been historically inconsistent at the operation with often only the major structures mapped.

4.2.1 Data Collection

A campaign of discontinuity mapping was implemented across the site by an initial UAV drone photography of the exposed highwalls and endwalls. This comprised two passes of the drone over every slope to capture images at a 90° and 45° angle. To capture the approximately 5 kilometres of exposed pit slope was about 2 hours of drone flight time.

Georeferenced images were then imported into Shapemetrix photogrammetry mapping software to develop a 3D mesh of the pit slope surfaces. An initial pass of defect identification was undertaken for the exposed faces. The output is shown below in Figure 3.

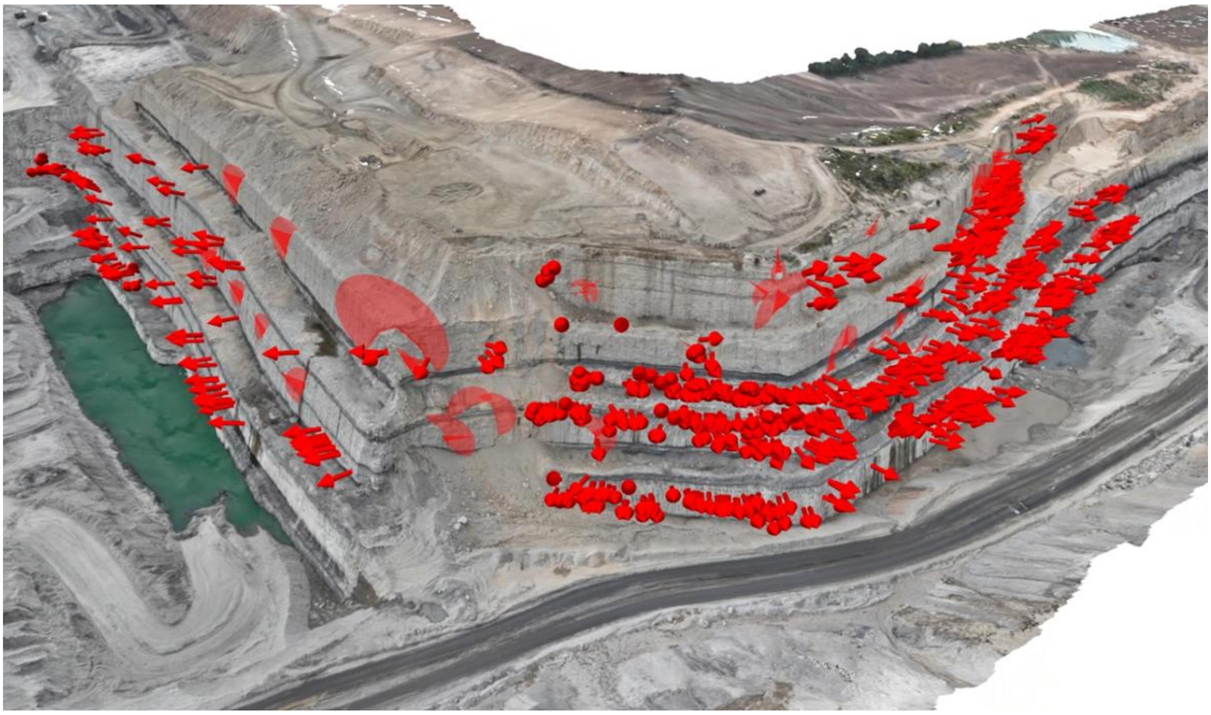

Fig. 3 3D image with mapped defect from eastern and northern highwalls.

Mapping of defects on the exposed excavated endwall and highwalls identified 813 discontinuity features. It was noted that some of these may represent the same feature but a different exposed face. In these cases, the continuity of the feature was noted. Plotting of the identified discontinuities in an equal angle, lower hemisphere stereonet showed that there were four discontinuity sets present represented by two major and two minor sets identified with some randomly orientated scattered features. These results are shown below in Figure 4 colour coded for each cluster identified.

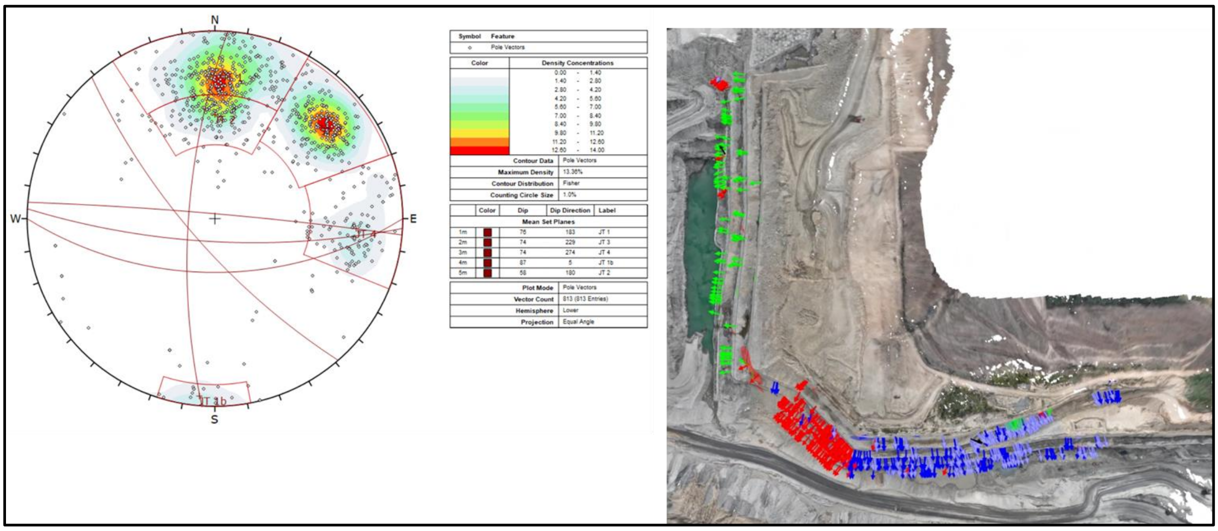

Fig. 4 3D image with mapped defect from eastern and northern highwalls.

4.2.2 Discontinuity Analysis

The georeferenced mapped discontinuity data the current topographic surface together with the underlying geology surfaces and was imported into Rocscience Rocslope, the 3D kinematic assessment software. Volumes were created that represent the slope geotechnical domains. Material properties were assigned to volumes and joint surfaces were initially assumed as dry. The model developed is shown in Figure 5 with defects represented as discs sized to the features continuity.

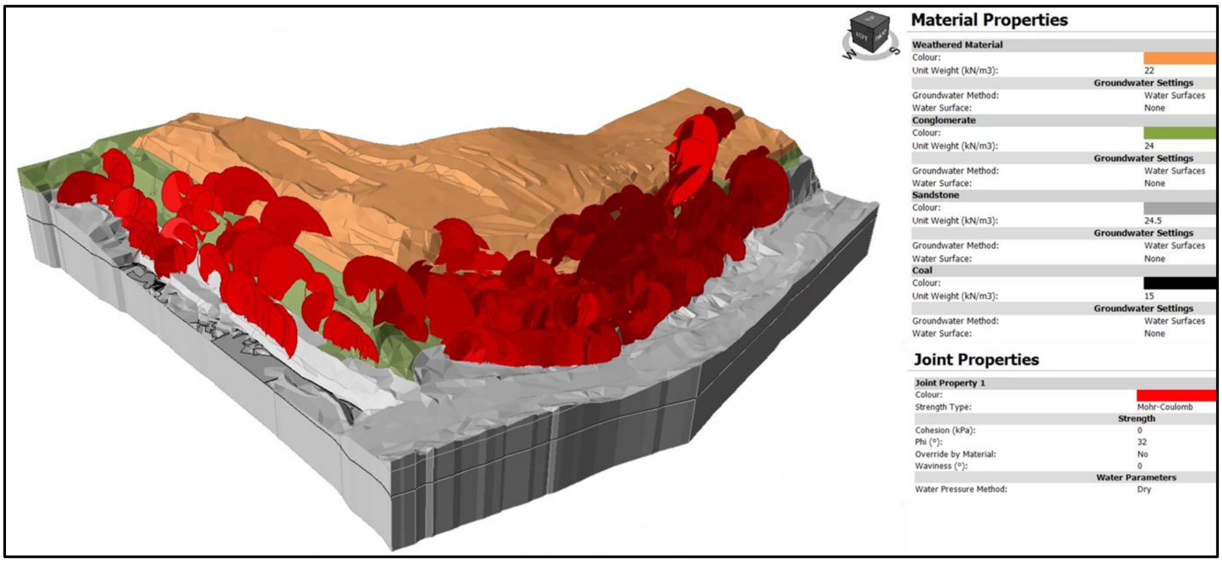

Fig. 5 Rocslope Model developed for the eastern and northern highwalls

Rockmass defect spatial location and persistence are then considered to determine if kinematically feasible blocks can develop via wedge, planar, toppling or composite (combination) style of instability. The results are then presented spatially with identified areas referred to as removable blocks with the output showing overall number of identified blocks, block sizes and whether blocks are considered stable, usually defined as FoS > 1.20. The results are presented in Table 1 with unstable blocks shown in Figure 6.

Table 1 Summary of Rocslope analysis results

Figure width [cm]	**Number**	**Block Sizes**	**Average Block size**
Stable Blocks	886	1.0 – 735m3	11.9m3
Unstable Blocks	303	1.0 – 115m30	8m3

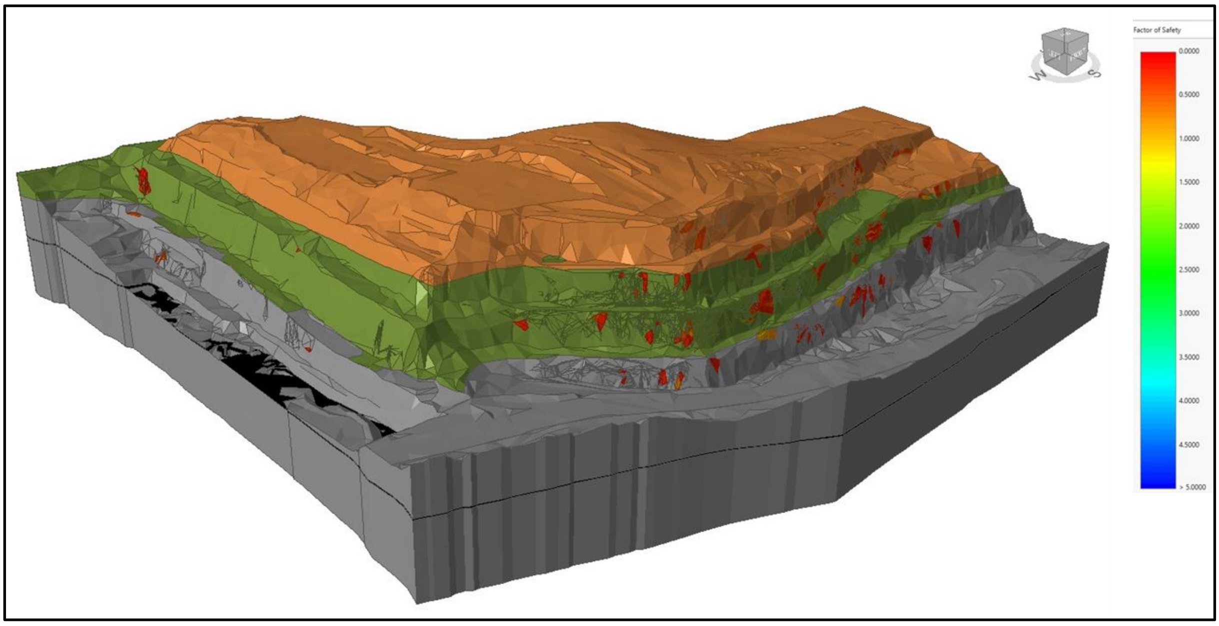

Fig. 5 Rocslope Model for the eastern and northern highwalls showing the spatial location of unstable blocks

4.2.3 Analysing the Results

The results showed that the majority of pseudo stable (or kinematically admissible) blocks were identified on the northern highwall. The results were compared to the existing or known rock fall hazards on the wall with several new areas identified as potential rock fall zones associated with existing or developing failures. The largest block (115m³) identified from the analysis was on the second bench crest above the pit floor on the northern highwall. Some smaller blocks (~25-40m³) were also identified on the same crestline. The block identified in the model output is shown in the spatial pit photo in Figure 6.

After initial feedback of the results to the operation a new Hazard Alert was raised, and an assessment of mitigation measures was undertaken. These followed the hierarchy of controls where engineering and separation controls were considered before softer controls such as monitoring.

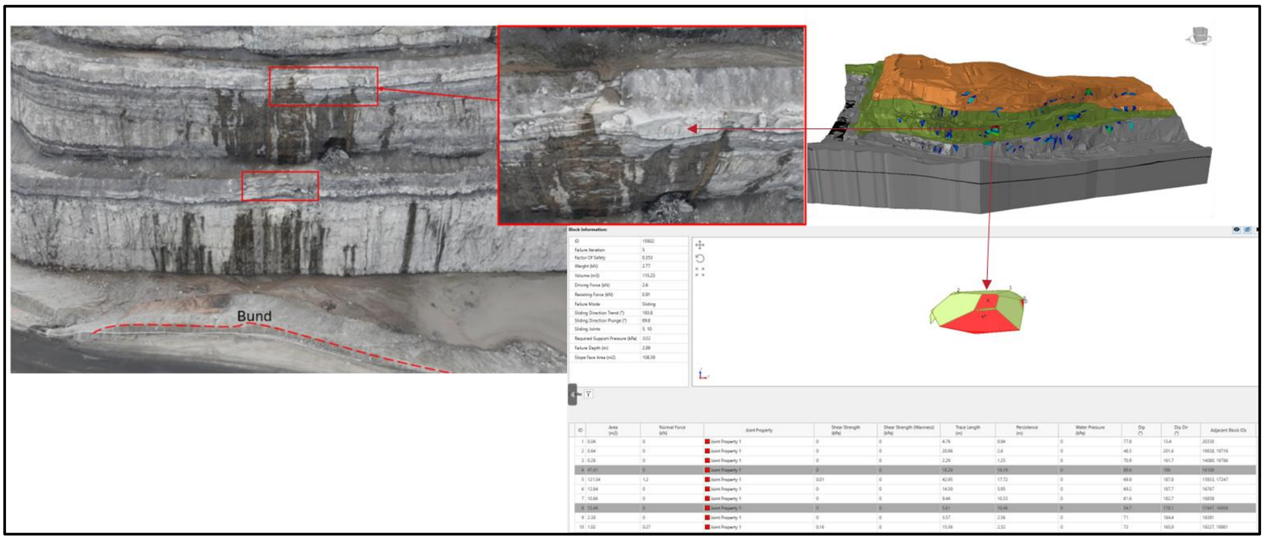

Fig. 6 Correlation of actual mined surface and Rocslope Model output

4.2.4 Establishing and Testing Mitigation Measure

Mitigation measures in the form of separation and bunding were decided as the best option given the design restriction to further engineering of the slope. Slope monitoring via visual and slope stability radar during mining activities undertaken in the area were also required as part of the risk mitigation strategy. In order to determine to optimal wall stand-off distance and bund dimensions rock fall analysis was undertaken using Rockfall 3, a 3D rockfall assessment tool.

Input parameters such as the coefficients of normal and tangential restitution which are required for meaningful rock fall analysis were able to be back analysed from areas of known rockfall identified in the original photogrammetry image where the origin, wall type, rock size and runout distances were able to be measured (Figure 7). These were also validated visually in the operation pit.

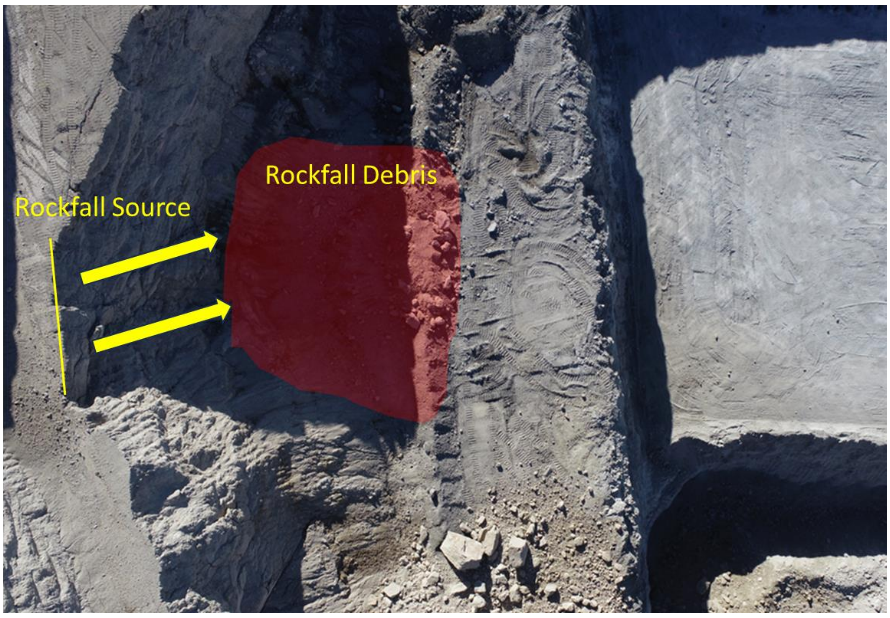

Fig. 7 Rockfall occurrence within the operation

To assess the subject area a point seeder was created at the origin crest with co-ordinates taken from Shapemetrix mapping data for the centre of the block. Rock volumes assigned to the point seeder were

115m³ correlated to the output data from Rocslope. A 20m line seeder (green) on the slope crest where some smaller rocks were identified was also utilised for the analysis. Rock volumes assigned to the line seeder were 8m³, 27m³ and 64m³.

A Rigid Body Analysis methodology was utilised using various rock shapes with 50 rocks per rock group simulated for analysis. Once the initial, unrestricted run-out distance had been calculated various rock arrestor bund distances and heights were tested in the model to establish the optimal and practical solution. The benefit of running a 3D model was to determine the lateral spread behind the bund to aid in determining the extent that the bund need across the toe of the highwall.

The heatmap presented in Figure 8 shows the runout distance from the origin in the X and Y direction. Mean runout distance is ~30m with the minimum runout distance 1m and maximum as 93m laterally. Utilising these dimensions an effective rockfall arrestor earth bund was able to be established in the area to mitigate the effects of the hazard. In addition, a slope stability radar was deployed and set up in the area to monitor the wall for deformation. A targeted scan area for the radar was able to be utilised based on the results of the kinematic hotspot map.

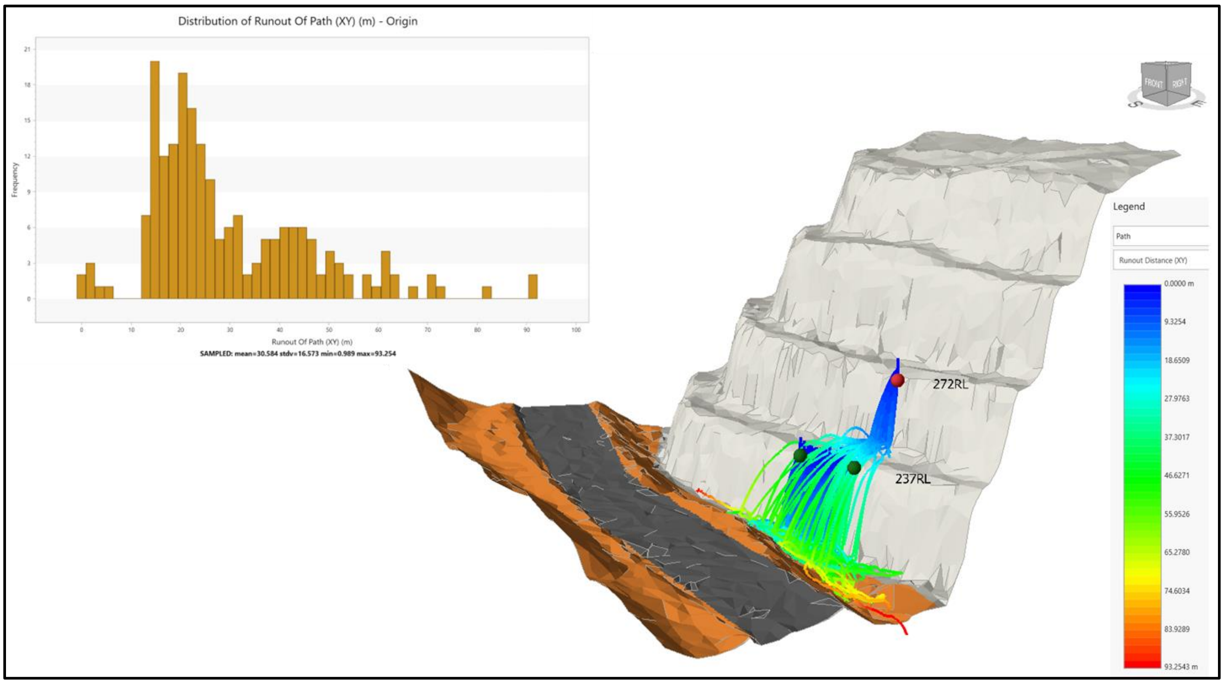

Fig. 8 Rockfall analysis to determine bunding height

4.2.5 Developing Hazard maps

The 3D kinematic assessment results highlight the key areas to focus on within the operation in terms of hazard mitigation, including rock fall arrestor bunding, slope monitoring and inspections. The exercise above was undertaken at several locations around the mine with the results able to be presented as a hazard map of the current operation with recommended controls to put in place. Controls were dependant on exposure to the activities occurring at the time.

Hazard zones identified were then assigned Trigger Action Response (TARP) level dependant on the residual risk to operations (Figure 9).

5 Conclusion

With the recent advance in rapid topographical data collection with the use of UAV drone and LIDAR technology for the collection of mine surface data that can be undertaken and provided in a usable format in only a matter of hours it is possible to provide an operational hazard map in a short space of time. Utilising available industry software into a process flow allowed drone imagery collected over a matter of hours be turned into a site wide hazard map within days.

Mitigation measures were able to be optimised such as rock arrester bund locations, heights and extents as well as areas for targeted slope monitoring rather than applying a generic ad hoc approach to hazard management. This approach was not only shown to be beneficial to the operation by improving safety but also financially by reducing downtime of machinery to deal with hazards or the hazards preventing operations occurring that may lead to design non-conformance and a loss in retrievable resource.

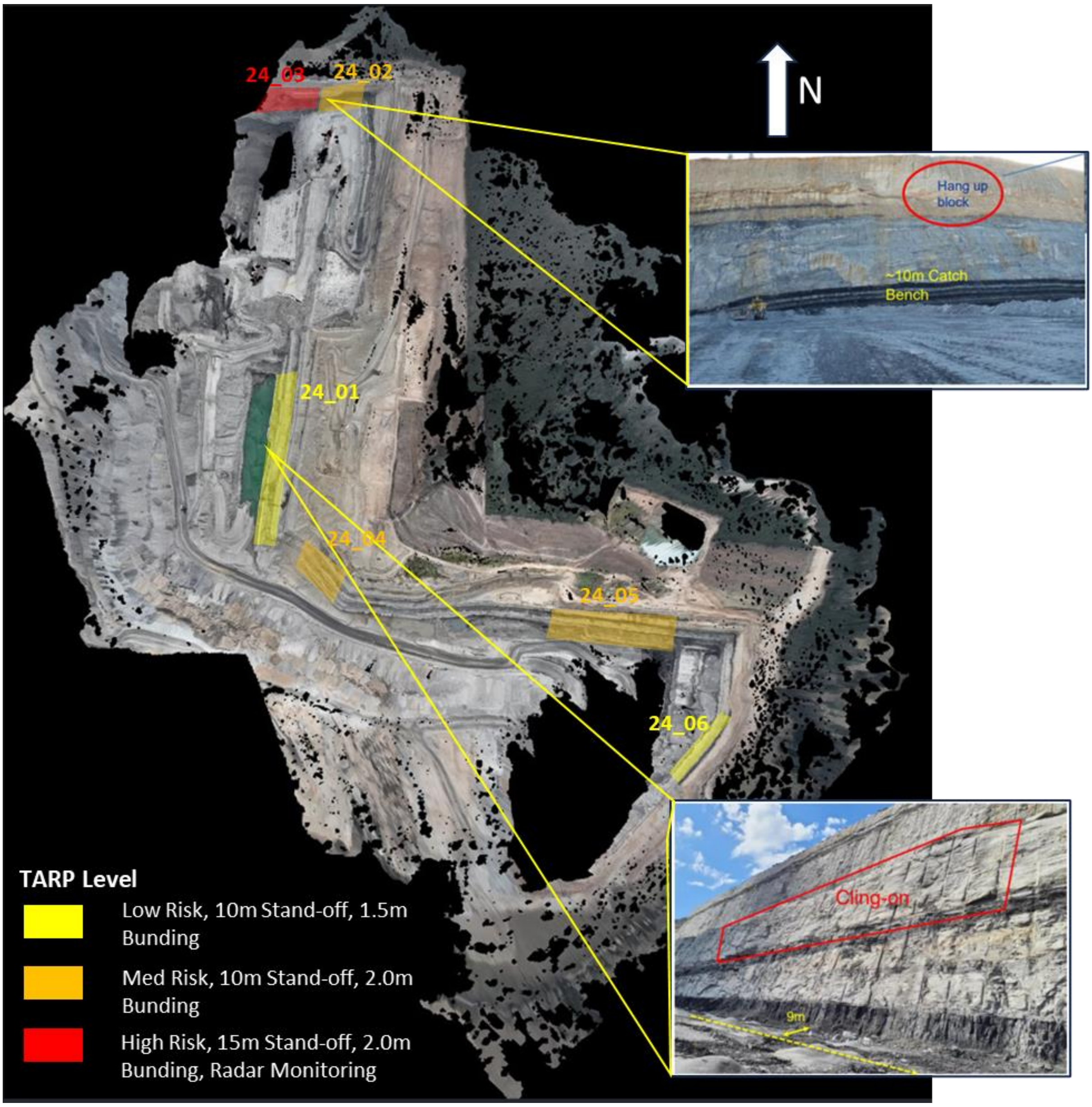

Fig. 9 Hazard Map developed for the operation

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