SSIM 2021 - PM Dight (ed.)
© Australian Centre for Geomechanics, Perth, ISBN 978-0-6450938-1-0
doi:10.36487/ACG_repo/2135_0.05

Novel techniques for rockfall management using remote equipment at Savage River Mine

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Abstract

Rockfall is a hazard in open pit mines with the potential to cause significant consequences. In December 2020, a rockfall event occurred at the Savage River Mine in Tasmania. In this event, a 675 t block detached from the highwall, and rocks subsequently landed onto an active work area 210 m below.

Post-event investigations indicated that several additional controls were required prior to the resumption of mining in the area. These included the installation of a rock fence, shear pins and a revised monitoring strategy to facilitate continued safe mining operations. However, installation of the rock fence and shear pins by traditional construction methods would expose personnel to an unacceptably high rockfall risk. Mitigation of this risk therefore required innovative techniques.

These included pre-fabrication of a sea container fence and installation by use of remotely operated machinery. The shear pins were also installed using a remote drill rig, a remote excavator with a custom attachment, and grouted by use of a long reach boom pump, thereby eliminating the previously required presence of exposed personnel in the elevated risk area.

This paper describes the construction and remote installation of the rock fence and shear pins.

Keywords: *rockfall, radar, rock fence, shear pins, remote equipment, stability monitoring, risk management*

1 Introduction

On the night of 8 December 2020 at 22:26, a batter scale failure and subsequent rockfall originated from the 260 mRL. A photo indicating the origin of failure has been included in Figure 1.

The rockfall event was interpreted to be a result of a complex series of failure mechanisms (Figure 2). An initial major planar failure occurred along a joint dipping 50° into the pit on the upper part of the batter below the 260 mRL crest (Part 1). After this initial detachment on the upper plane, a block from the crest of the plane dislodged (Part 2), leading to a toppling failure of the batter face along a steeply dipping foliation plane (Part 3) and subsequent blocks dislodging from the toe (Part 4). An image of pre- and post-failure batter faces have been included in Figure 2 with failure portions indicated.

The rock fall-out was further amplified by initial contact with the sub-horizontal joint plane below the detached blocks rather than a horizontal berm. This resulted in projection of the rocks, rather than containment by a berm, and thus caused greater scatter of rockfall material. Run-out was recorded down to the 50 mRL where drilling was being undertaken at the time. The incident was classed as a near-miss.

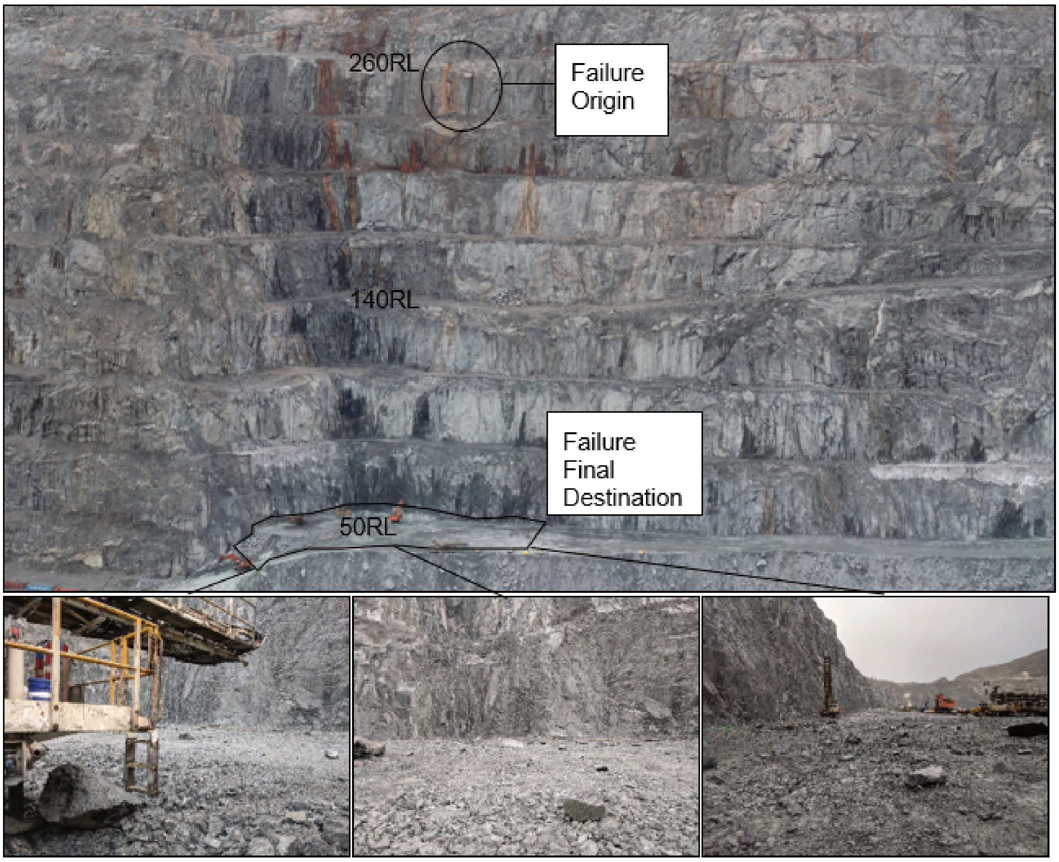


Figure 1 Photo showing failure location on the east wall of North Pit at Savage River Mine

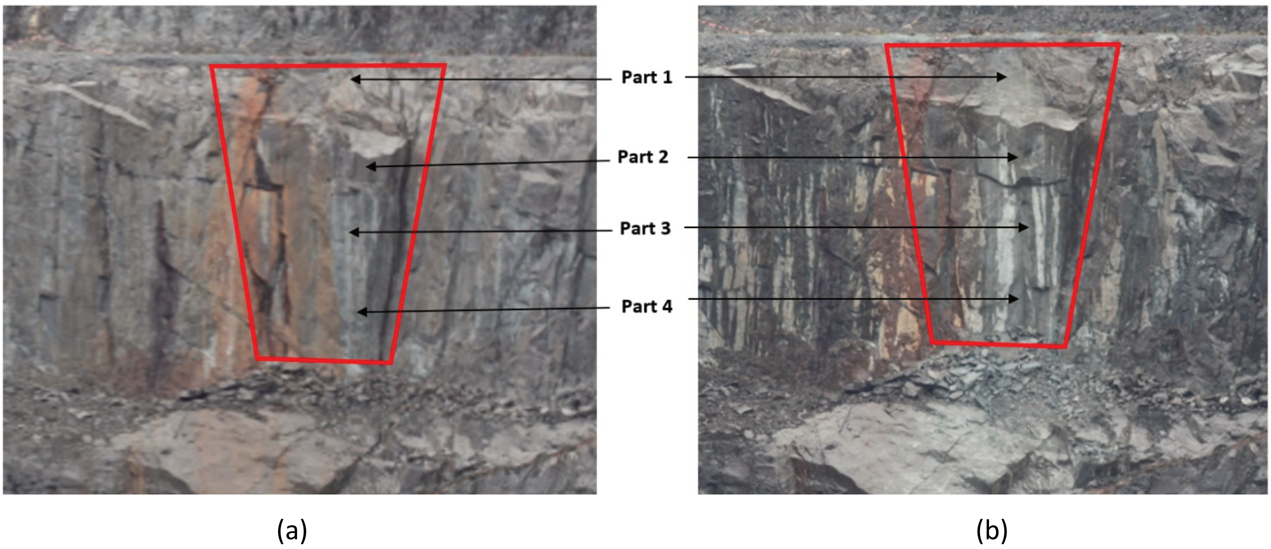


Figure 2 (a) Pre- and (b) post-failure images of 260 mRL batter

2 Surveyed rockfall run-out

Laser scanning of the east wall post-failure and reconciliation with pre-failure survey scans revealed a rockfall origin volume of 270 m^3 (~675 t). Figure 3 shows the rockfall run-out volume based on before and after laser scan of the slope.

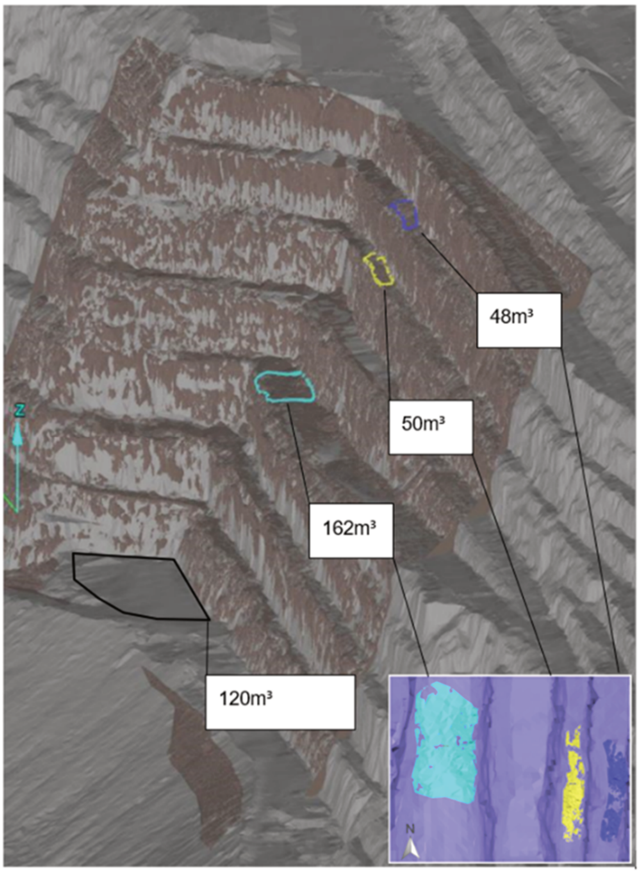


Figure 3 Rockfall run-out volume survey based on before and after laser scans of the slope

From drone images, the rockfall pathway correlated with the radar coherence data and rock fragmentation analysis was possible for the scatter pattern on the 50 mRL. Although initial survey volumes indicated that 270 m^3 of rockfall dislodged from the 260 mRL batter face point of origin, it is reasonable to assume that a larger volume would have been included in the final failure volume with loose material on lower berms being assimilated. On the 50 mRL, volumes were calculated from the larger clast sizes only and thus no finer material was included. A final total volume of 380 m^3 was calculated considering bulking of materials and dislodging of additional materials from each berm below (Figure 3). Considering the volume present on the 50 mRL, an estimate of percentage of rockfall passing the critical point (80 mRL crest) is $120\ m^3/380\ m^3 \times 100 = 32\%$. If an additional volume of 20 m^3 is included into the 50 mRL to account for finer material, the passing percentage increases to $140\ m^3/400\ m^3 \times 100 = 35\%$. This was not considered acceptable in this area.

3 Rockfall modelling

Sections were taken through the rockfall zone (Figure 4) and modelled with Rocscience’s RocFall software to evaluate the theoretical run-out path. 2D modelling was used in this situation as good historic calibration data and site-specific parameters existed. The modelling results were then compared and calibrated to the surveyed run-out distances to establish a baseline for remediation plans. Good correlation existed between what was seen and what was modelled and thus the model created could be further used for determining the correct remedial actions.

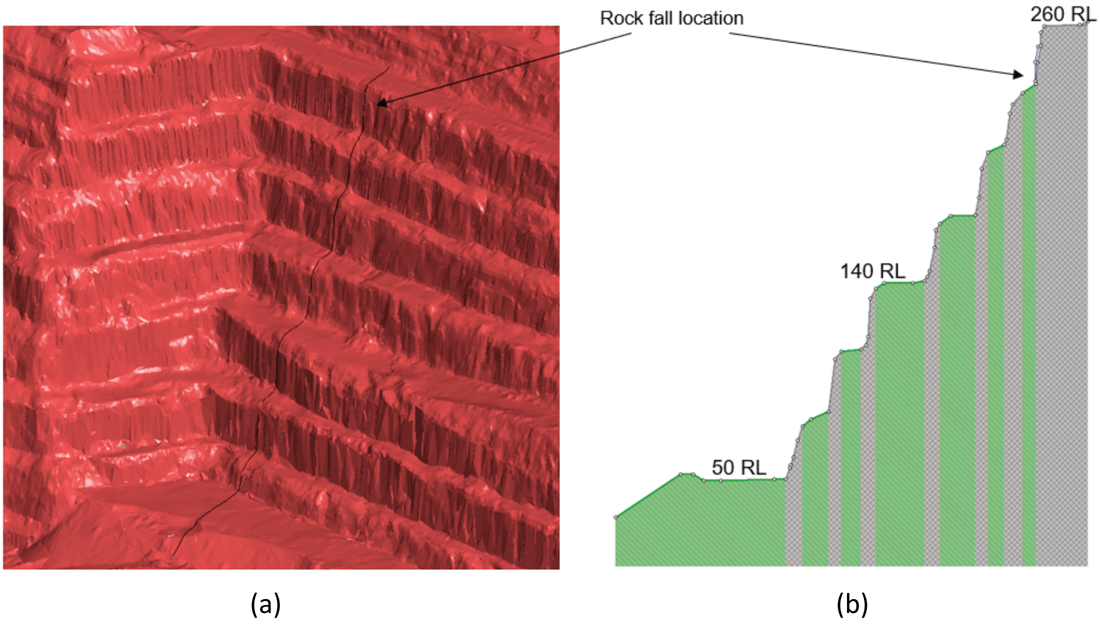


Figure 4 (a) Isometric view showing rockfall analysis section location; (b) Associated Rocscience RocFall section through the rockfall pathway

3.1 Model assumptions and limitations

The lump mass model was used with the material properties indicated in Table 1. These parameters were gained from previous back-analysis of rockfalls on the east wall of Savage River's North Pit. The seed points were selected based on the location of the original rockfall. The rock fences were assumed to stop any rock impacting them.

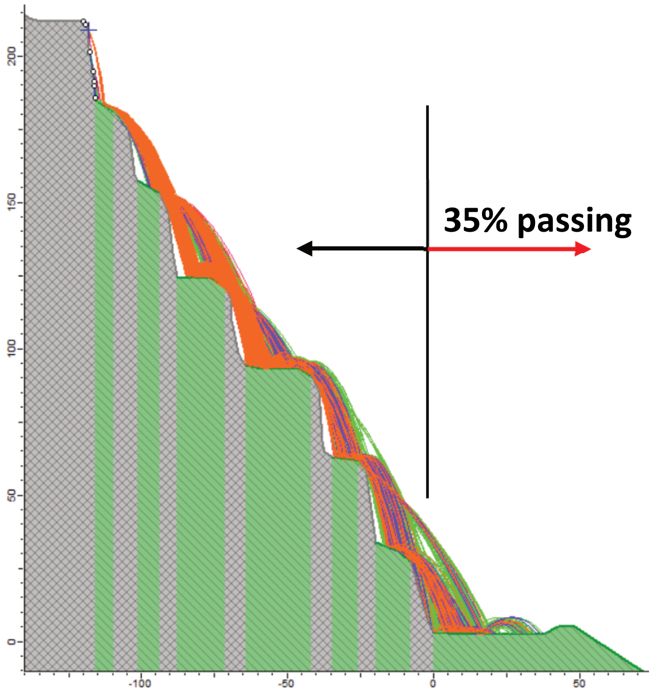
Through modelling of the conditions and parameters as indicated in Figure 4 and Table 1, it was evident that the bench configuration catchment was not acceptable. A run-out distance of roughly 35 m was modelled from the toe of the 80 mRL with 35% of the material passing the critical point (80 mRL crest).

Table 1 Rocscience RocFall parameters used

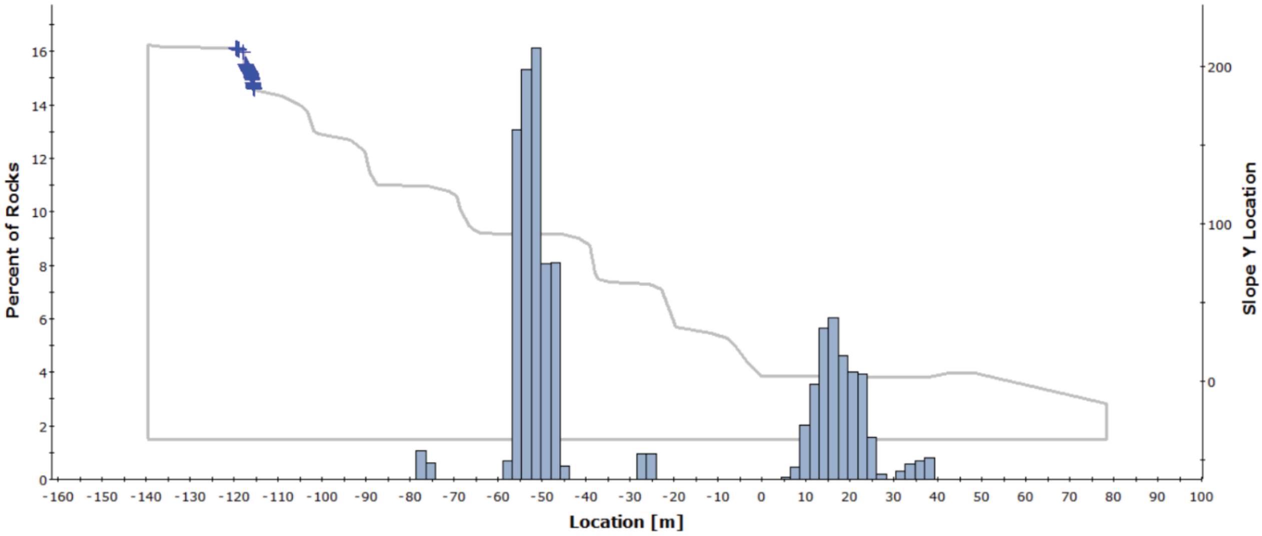
Material name	Represents	Distribution	Normal restitution	Tangential restitution
Bedrock savage	Clean bedrock, ski jump joints	Normal	Mean: 0.5 Std: 0.04 Rel. min: 0.12 Rel. max: 0.12	Mean: 0.95 Std: 0.04 Rel. min: 0.12 Rel. max: 0.05
Berm	Berms, haul roads, windrows, loose material, talus	Normal	Mean: 0.25 Std: 0.02 Rel. min: 0.06 Rel. max: 0.06	Mean: 0.75 Std: 0.02 Rel. min: 0.06 Rel. max: 0.06
Rock seeder properties				
Seeder group	**Seeder type**	**Number of rocks**	**Mass (kg)**	**Density (kg/m³)**
Seeder 1	Line	1,000	1,000	2,700
Seeder 2	Point	500	300	2,700
Seeder 3	Line	1,000	800	2,700
Seeder 4	Line	100	100	2,700

The results were in good agreement with the actual rockfall trajectory including the percentage retained on each berm and run-out distance at the 50 mRL, and thus investigation into remedial action based on this model was considered applicable.

The back-analysis model used to confirm the rockfall parameters is shown in Figure 5.



(a)



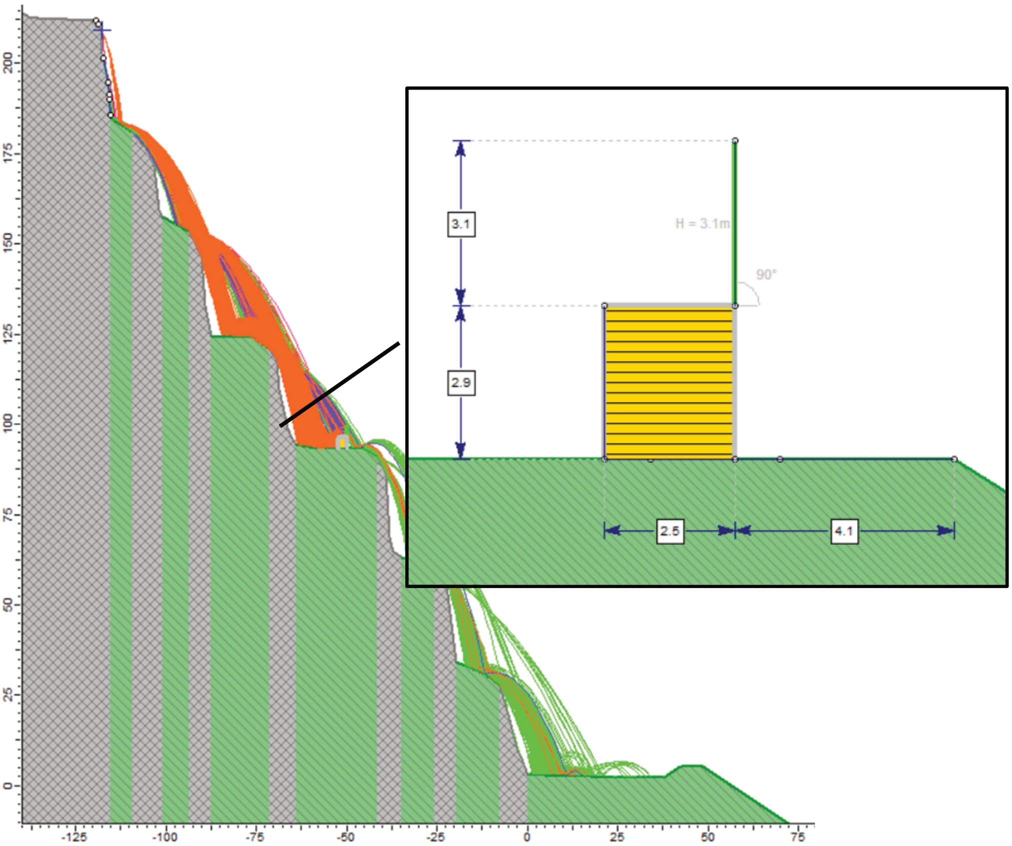
(b)

Figure 5 Modelled rockfall run-out back-analysis used to confirm rockfall parameters. (a) Associated Rocscience RocFall section through the rockfall pathway; (b) Model result showing the percentage of rocks retained on each berm

Considering that the current bench configuration did not provide adequate catchment for possible future rockfall events from the 260 mRL (Figure 5), additional mitigation measures were required. Using the model parameters from Table 1, three different remedial options (windrow, shipping container wall, or shipping container wall with fence on top installed on the 140 mRL berm) were investigated with only one providing an adequate solution.

3.2 Remedial shipping container with fence analysis

To intercept future rockfall from the 260 mRL, modelling determined that a line of shipping containers with a fence installed on top was required. Similar techniques have been employed by Williams et al. (2020) and Hutchison et al. (2020). 2D analysis indicated that 94% of rockfall would be intercepted on the 140 mRL with a shipping container (2.9 m high) topped by a 3.1 m high fence with only 6% passing the critical point (Figure 6).



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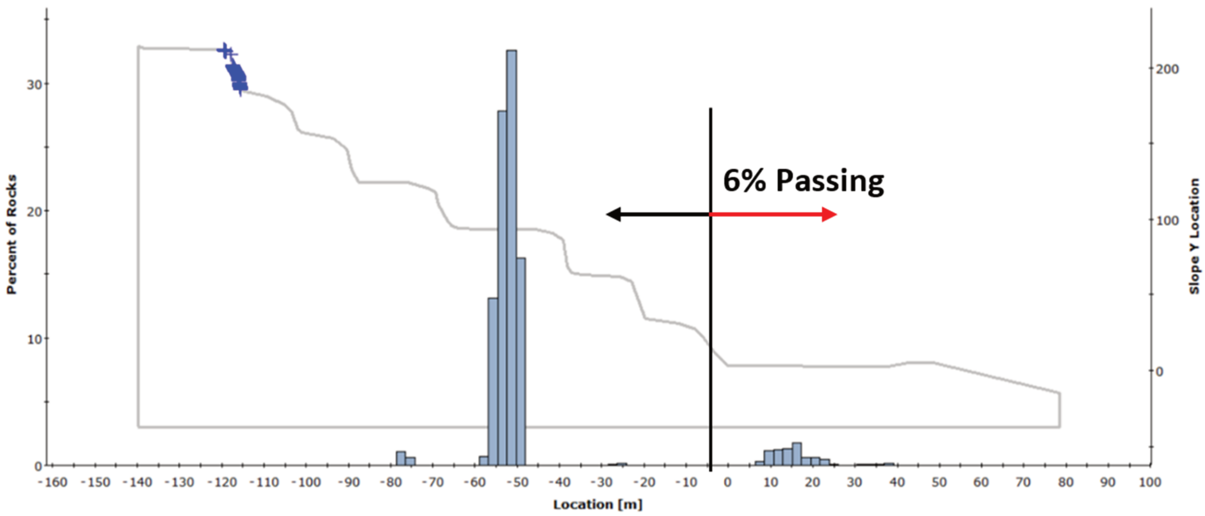

(b)

Figure 6 Modelled rockfall run-out for preferred container wall and fence option. (a) Associated Rocscience RocFall section through the rockfall pathway; (b) Model result showing percentage of rocks retained on each berm

4 Remediation approach

Due to historic rockfall incidents and the associated hazard rating of the area, no human access was permitted on the 140 mRL berm. This included crewed machinery. Therefore, the installation of the shipping container fence would need to be installed by remote operated machinery only.

The 140 mRL shipping container fence required pre-fabrication and weighting (to limit movement upon impact) of the container fence module prior to it being moved into position using a remote operated excavator (Figure 7). Skids were welded to the base of each of the containers to assist in moving them into place. A DJI Phantom 4 drone was used for aerial live footage purposes to allow different angles for the operator to view the installation from. Figure 8 shows the fence positioned in its final location.

Figure 7 Operator installing shipping container rock fence using remote excavator

Figure 8 Shipping container fence installed using remote machinery on the 140 mRL berm

After installation of the shipping container fence on the 140 mRL berm, work on the 50 mRL could continue with controls developed during a risk assessment process. This included work being completed from behind mobile rock fences, the use of remote drilling (Figure 9), and loading of blastholes by use of a Grange Resources patented Merlo Roto 40.25 Remote Explosive Blasting Unit (Figure 10) (Hutchison & Widelski 2007). Figures 11, 12 and 13 give brief insight to the remote shear pin installation and grouting works.

Figure 9 Remote drilling used for shear pin and production drilling

Figure 10 Grange Resource's patented Merlo Roto 40.25 Remote Explosive Blasting Unit

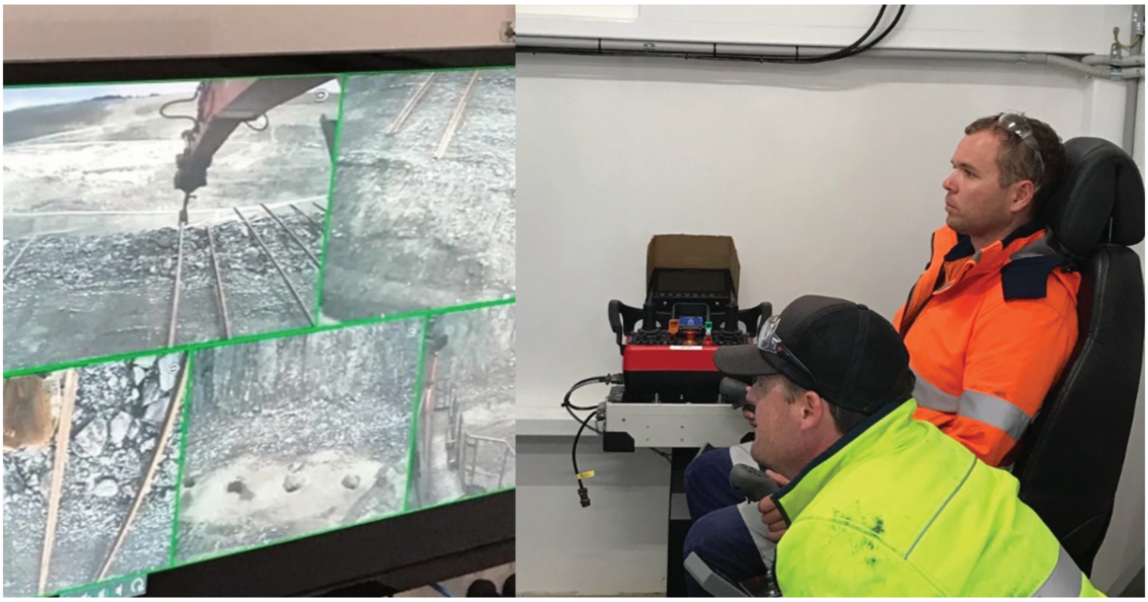

Figure 11 Operator installing shear pins remotely using in-house developed shear pin holding attachment

Figure 12 Remote excavator installing shear pins using in-house developed shear pin holding attachment

Figure 13 Concrete boom pump grouting shear pin holes

Where shear pins needed to be installed for the retention of wedge blocks on the crest, the same remote approach was used. Through use of a modified hook attached to the remote excavator's quick hitch (Figures 11 and 12), these pins could be installed from a safe location and grouted in place remotely using a remote-control concrete boom pump (Figure 13) limiting exposure to rockfall hazards. Again, a DJI Phantom 4 drone was used in aerial live footage as judging depth when installing the pins was difficult without a different angle of the shear pin installation.

To facilitate a safe working environment below the 20 mRL, installation of a 500 m long rigid rock fence with 1,000 kJ capacity was proposed. The project was initiated mid-March 2021. The location, height, and design of the proposed rock fence was based on a detailed investigation particularly considering previous rockfall events, the as-mined batter berm profile, modelled rockfall trajectories, and run-out distances. Figure 19 shows the location of the rock fence on the 20 mRL berm.

The project was implemented by installing shear pins along the crest of the 20 mRL. Remote drilling was adapted and a total of 272 10 m long steel shear pins were installed. As in the above 50 mRL berm, an excavator was used to install the pins using a new iteration of the quick hitch lifting hook; a modified hydraulic rod handler attached to the remote excavator's quick hitch.

The rock fence installation works were carried out under specific job hazard analysis (JHA) to quantify and manage the risks when working under the highwall in hazardous zones. Figure 9 shows the remote drilling and Figure 14 shows the mobile rock fences used to facilitate a safe working environment for the project.

Figure 14 20 mRL rock fence installation completed behind mobile rock fences

5 Slope stability monitoring strategy

Slope stability radars play a key part in managing the rockfall risk at Savage River. These radars continuously monitor the pit highwalls with the aim to detect wall movement indicative of an impending rockfall. If the wall movement passes a threshold set by the site geotechnical engineer, the radar will activate an alarm and trigger the evacuation of personnel to safety away from the highwall in line with the current trigger action response plan (TARP).

A radar was monitoring the highwall at the time of the rockfall in December 2020, but the alarm was not activated until 11 minutes after the failure for reasons that are discussed shortly. Radar monitoring, like other tools, have limitations and provide one of several layers of control within the hierarchy of controls for geotechnical hazards on site. One of the primary limitations includes the brittle nature of the rock, which results in there being very little movement prior to failure. Secondary limitations include the potential for suboptimal radar alarm settings, long radar scan times, rapidly changing weather conditions and radar pad subsidence. At ~675 t, the December 2020 rockfall is the largest rockfall on record for which no prior radar alarm was received. The size and potential consequences of the rockfall led to a project to address the secondary limitations of the radar monitoring strategy and thereby improve their effectiveness.

The first step of this project was to determine whether a change in the radar alarm settings could have enabled the radar to give a warning prior to the rockfall. When the failure occurred, the radar was set to activate an alarm if two contiguous pixels showed more than 3 mm of movement over six hours and the radar was receiving a new scan of data every 12 minutes. To determine the reasons why the radar failed to alarm prior to the failure, the movement versus time of each of the pixels of the failed area was plotted and assessed against the alarm settings. The failed area was simplified and interpreted based on the pixels trigged, as in Figure 15. This analysis showed that to receive an alarm prior to failure, the number of required contiguous pixels, the deformation threshold, and scan time would all need to be reduced (Figure 16). If a scan time of four minutes, a limit of 2 mm deformation over two contiguous pixels, and one scan were used as alarming parameters, it would have triggered at 22:17 pm and provided a nine-minute forewarning of failure (Figure 17). The site standard contiguous pixel and deformation threshold requirements were therefore changed to these settings. Reducing scan times while still covering the same scan area required the implementation of a second radar, thereby allowing the same wall area to be split into two smaller zones with correspondingly reduced scan times.

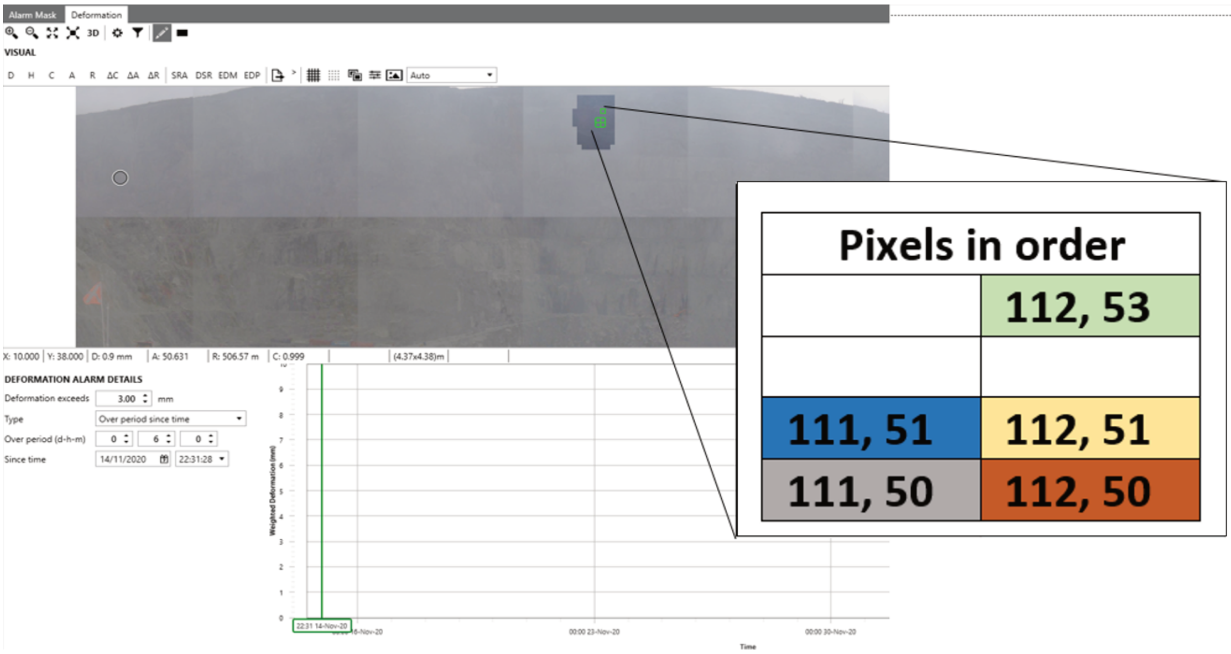

Figure 15 **Simplified area based on the pixels triggered at the failure ('pixels in order' gives the area of interest based on X and Y coordinates and the colour legend represents different pixels within the area of interest)**

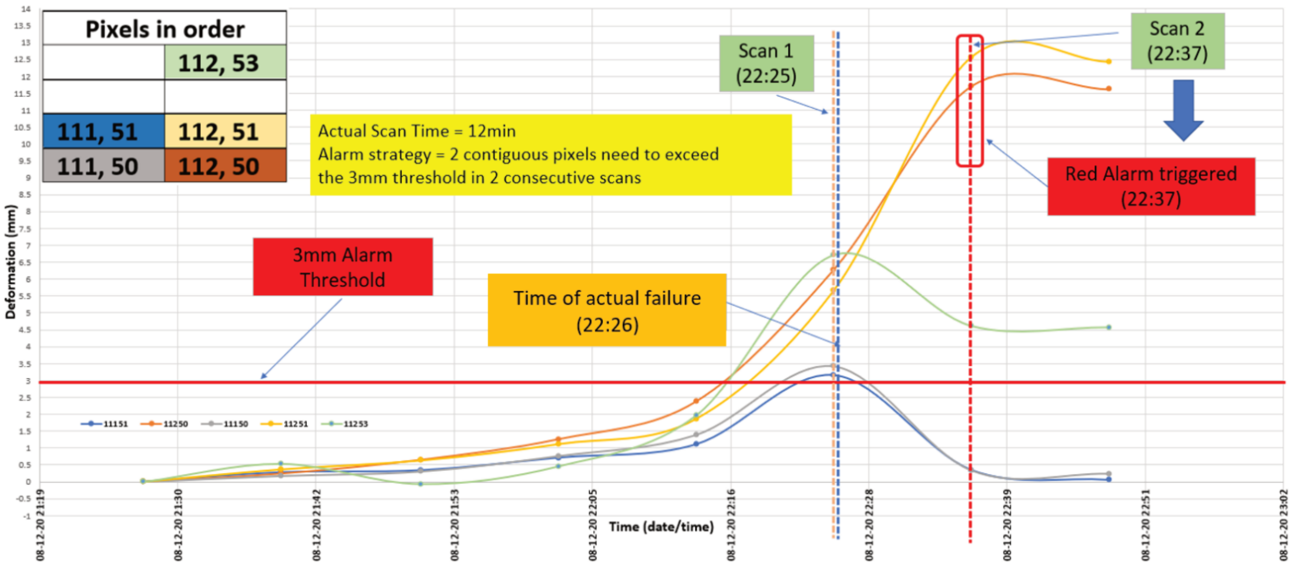

Figure 16 **Deformation versus time curve for each pixel with original radar alarm parameters and radar alarm response strategy (only pixels (112, 51) and (112, 50) satisfy the requirement to trigger a red alarm, which triggered 11 minutes after the actual rockfall)**

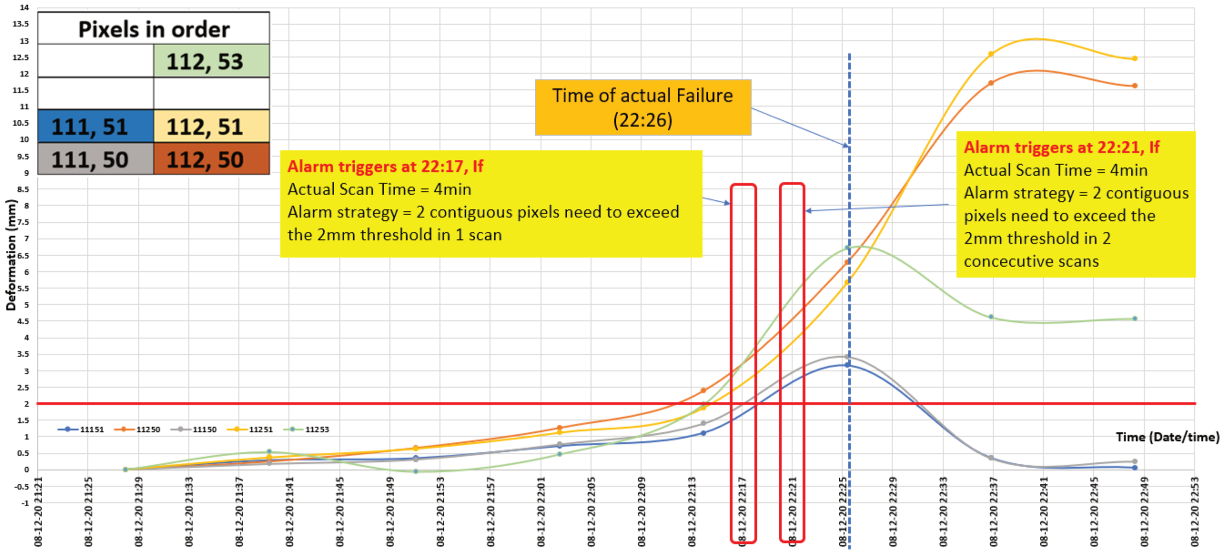

Figure 17 Deformation versus time curve for each pixel with modified radar setup and alarm parameters

6 Administrative controls

6.1 Job hazard analyses

JHAs are a written procedure developed to identify work steps, their associated hazards, and to put in place appropriate controls to minimise the risk of those hazards. After the incident on 8 December 2020, robust JHAs were developed for the shear pin and rock fence installation, drilling, mining, and other operational work to quantify and manage the identified risks when working under the highwall in hazardous zones. Each job was carefully divided into steps and listed under the heading of job steps. Hazards involved in each step were identified and described under the heading of hazards identified. After identifying the hazards, initial risk rankings were given to each step based on the risk matrix. Controls were identified to minimise the hazard risks and assigned an inherent risk ranking.

Some of the special controls implemented to minimise the hazards identified are listed below:

- Dedicated radar.
- Mobile rock fence/physical barriers.
- Use of remote equipment.
- Spotters.
- Dedicated radio channels.

The JHAs were constantly revised as the job evolved or conditions changed.

6.2 Trigger action respond plans

A TARP outlines the response levels to an identified geotechnical hazard as part of an area specific JHA. Figure 18 gives an example for a radar TARP implemented at the Savage River Mine site.

Grange Resources Savage River Mine – Radar Alarm Response TARP 27th June 2021 - Version 3				
Radar Alarm	TARP (Trigger Action Response Plan)			
	Mine control	Geotechnical Engineer	Mine Worker	Mine Manager
Grey Alert	Contact the onsite Geotech Engineer and notify them of the alarm. Follow instruction from Geotech Engineer.	Evaluate the grey alert and advise mine control what is the outcome. Notify relevant stakeholders if required	Follow instructions given by Mine Control.	Notify stakeholders under Geotechnical recommendation
Geotech	Contact the onsite Geotech Engineer to verify whether the alert is due to real wall movement. Follow instruction from Geotech Engineer.	Evaluate monitoring data and advise Mine Control about the location of the alarm and geotechnical recommendations Notify relevant stakeholders if required	Follow instructions given by Mine Control.	Notify stakeholders under Geotechnical recommendation
Critical	Mine control to evacuate all personal working out of the alarming work area to immediate safe location/muster point. Liaise with the Geotechnical Engineer or delegate about when it is safe to restart work in the relavant work area.	Evaluate monitoring data and advise Mine Control about the location of the alarm and geotechnical recommendations. Advise Mine Control if it is safe to restart work in the pit. Notify relevant stakeholders if require	Comply with emergency evacuation procedures. Minimise radio chatter.	Notify stakeholders (including emergency services if required). Agree on recovery plan.

Figure 18 Trigger action response plan (TARP) implemented by Savage River Mine

7 Summary of major actions taken after the rockfall on 8 December

Figure 19 summarises this paper by giving a visual timeline which shows the sequence of events/actions taken from failure to the 20 mRL GBE-1000AR engineered rock fence installation project. The summary of the events is as follows:

- The rockfall occurred on 8 December 2020.
- Production below the area was stopped until a container rockfence was developed and installed on the 140 mRL on 31 December 2020.
- Shear pins were required to be installed on the 50 mRL to maintain berm crests and catch capacity but installing them conventionally was not considered safe and a remote method was developed and implemented to install these which was completed on 7 January 2021.
- The following months were then spent planning, preparing, and installing the 20 mRL rockfence which was completed over March–June 2021.
- With the installation of this rockfence, the exposure to rockfall risk on the mining levels below was reduced significantly.

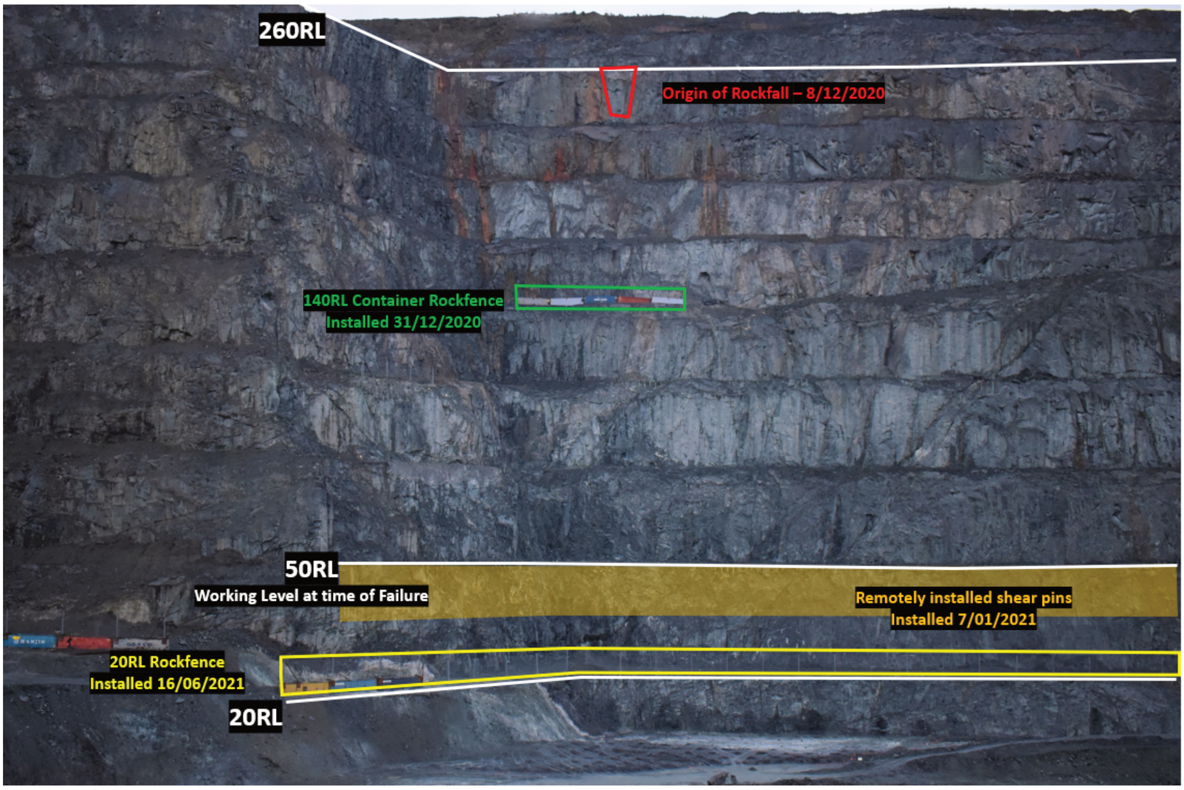

Figure 19 Visual timeline depicting the sequence of events from failure to 20 mRL rock fence installation

8 Conclusion

After a near-miss rockfall incident at Savage River Mine, resuming work under the area using existing controls and traditional mining methods would have exposed personnel to an unacceptably high safety risk. Work was stopped until the risk could be assessed and additional controls with measurable impact could be put in place. This required the use and development of novel techniques to remove personnel from the working floor directly under the highwall and the development of a new monitoring strategy in addition to other administrative controls. It was possible to safely manage rockfall risk and continue mine development by implementing a robust risk assessment and associated hazard control layers such as:

- Installation of rockfall barriers.
- Use of remote equipment (drills, excavators, bulldozers, shot loading and ground support/shear pin installation).
- Robust slope monitoring and alarm systems.
- Rock support and improved berm retention.
- Rockfall modelling and analysis.
- Robust administrative controls (JHAs, TARPs and safe operating procedures).

An additional positive outcome of this process was an increase in efficiency and reduced manual handling risk for many of the tasks involved.

To reduce rockfall risk further and pursue continuous improvement, Grange Resources is developing a novel remote highwall scaling machine to clear identified rockfall hazards in a safe and controlled manner (Anderson & Johnson 2020). Ongoing developments are also in progress to continuously improve existing remote capabilities (improved reliability and range of remote operation) and expand the capability to other equipment on site.

Implementation of remote operations, work under JHAs, installation of rock fences, and a robust slope monitoring and TARP systems have demonstrated that it is possible to provide a safe working environment around known hazards while also achieving production targets safely.

Acknowledgement

The authors thank Grange Resources for its support and permission to publish this paper. Also, the great work completed on site would not have been possible without the amazing effort, skill, and tenacity of the Savage River Dayworks and Operations teams.

The authors also thank Grange Operators Ali Hills and Joshua Russell for allowing the use of their photos within this paper.

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