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Management of orepasses in poor ground: learnings from Carrapateena sublevel cave

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Abstract

At Carrapateena orepasses are a critical component of the material handling system, connecting sublevel cave (SLC) production levels to the primary crusher. Four orepasses were developed for efficient ore movement in the production ramp-up phase of the SLC, however, poorer than expected ground conditions created challenges for continual safe access and use of this infrastructure.

Two of the northern orepasses (MAP-200 and MAP-300) experienced overbreak of 2–3 times the design diameter within the first months of use, threatening productivity and safe access in a spatially constrained mine plan. A robust management system utilising LiDAR scanning, strict pass level control, extensometer monitoring and additional cable bolt support was successfully implemented, enabling productive use of these passes without lining or extensive rehabilitation.

Keywords: *orepass, LiDAR, monitoring, geotechnical, production, design, management*

1 Introduction

Orepasses are a common component of a mine's material handling system (MHS) and play a key role in the productivity of a sublevel caving (SLC) operation (Hadjigeorgiou et al. 2005; Sredniawa et al. 2022). Should these components fail, there are limited recovery options beyond filling & re-reaming, lining, abandonment or replacement, all with significant cost implications in addition to production delays (Skawina et al. 2018; Hadjigeorgiou & Stacey 2011). The optimal design of orepasses to avoid these problems has been well described by other authors (Bunker et al. 2015; Sjöberg et al. 2015), however, often a compromise is required between geotechnical considerations and operational feasibility.

Carrapateena is a sublevel caving mine located in the Gawler Craton, approximately 460 km north of Adelaide in South Australia. Initial undercutting begun in 2019 with breakthrough to surface occurring in December 2022. Since then, the mine has been in a production ramp-up phase, involving significant additions to the MHS infrastructure including a lower crusher chamber and connecting orepasses.

Carrapateena's orebody is an iron ore copper–gold deposit hosted within a hematite–breccia pipe of approximately uniform dimensions. Surrounding the breccia pipe is the host Donington Suite granite, which is a strong and moderately jointed rock mass with varying degrees of hydrothermal sericite–chlorite alteration, in which this mine infrastructure and level accesses are developed. A detailed study on the temporal framework and geology of the Carrapateena deposit can be found in Cave et al. (2024).

Multiple faults and shear zones have been identified and modelled within the Donington Suite granite, the majority of which are discrete with only local zones of fracturing. However, one major shear zone – the Reinette shear zone – was found to have significant influence on excavation stability. The Reinette shear zone is characterised as a strongly sericite–chlorite altered zone within the Donington Suite granite with alteration increasing with proximity to the orebody along a zone of 20–25 m thickness. Intact rock strength within the altered zone decreases by 30–50% due to pervasive alteration throughout the intact blocks, while the altered

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coatings of persistent defects within the shear zone reduce the rock mass quality and contributes to consistent overbreak from the backs of development drives. Measured geological strength index (Marinos & Hoek 2000) from development faces within the zone range between 45–65. These characteristics are compared to typical values in Table 1. Typical core trays of Reinette and 'normal' granite are shown in Figure 1.

These characteristics were not fully understood from existing diamond drilling, with the full significance only realised during later development after the crusher, associated infrastructure, and level development were designed and in execution.

Table 1 Typical intact and rock mass properties

Lithology	Density (t/m^3)	Uniaxial compressive strength (MPa)	E (GPa)	v	Geological strength index
Donington granite	2.7	100–125	40	0.20	70–80
Hematites	3.8	150–200	60	0.22	70–90
Reinette shear zone granite	2.7	60–90	30	0.21	45–65

Figure 1 Typical core runs of (a) Donington Suite granite and (b) Reinette shear zone granite. The Reinette shear zone core can be seen to have significantly increased alteration, veining and fracturing, reducing the intact and rock mass strength within the unit

The shear zone is within a larger structural corridor, with additional parallel faulting and zones of poor ground encountered through the region (Figure 2). Due to position and orientation with designed development and the orebody, it was not possible to readjust mining to avoid the zone, nor change the position of designed orepasses within it.

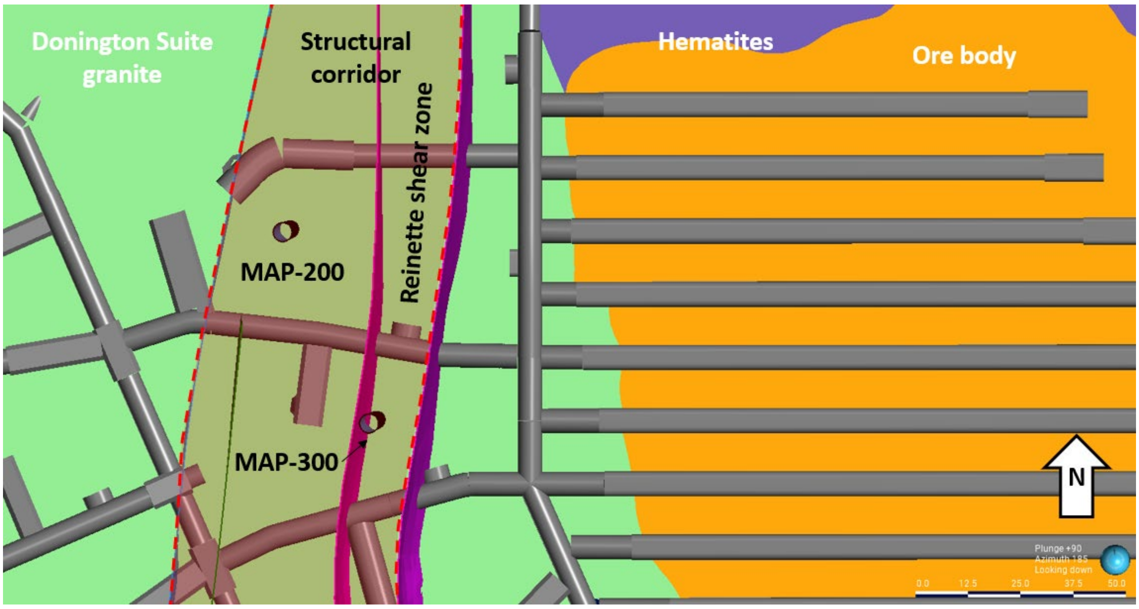

Figure 2 Location of the northern orepasses within a structural corridor at Carrapateena

2 Orepass design and strategy

The production expansion in the sublevel cave (SLC) at Carrapateena was planned to uplift output from 4 to 7 Mtpa. To complete this, a new crusher was designed to be built at the 4,195 m reference level (RL) and all SLC production levels were to be fed through 4 ore passes dropping to an extraction level. The criteria for this was a centralised crusher on the extraction level which would then be fed from 2 passes each side. The designed orepass layout for the Carrapateena SLC is shown in Figure 3, with crosscut drive colour corresponding to the orepass ore would be fed to.

The design of the layout enabled each finger pass to be fired early in the level development to assist with development material going to the crusher, rather than being stockpiled and trucked to the crusher through alternate passes. This layout resulted in a very small area to fit the passes between the decline and the orebody. This caused a compact level layout to fit in ore passes, finger passes, and surrounding accesses while also keeping a sufficient vertical pillar between finger passes.

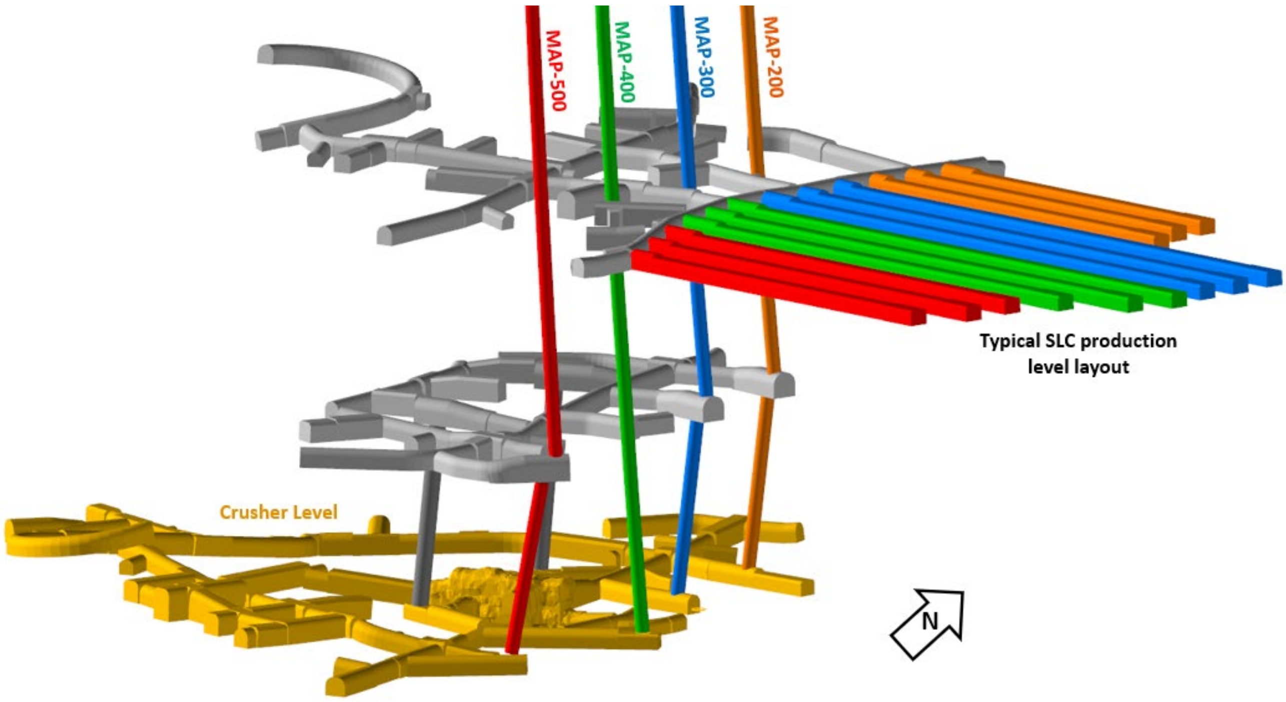

Figure 3 Overview of orepass layout within the material handling system system. Colour coding of production crosscuts aligns to the relevant orepass where production tonnes are directed

The orepass design selected was 4.5 m diameter raisebores drilled from 4,505 m RL and 3 × 3 m fingers fired into passes with a 1.2 m aperture sizing grizzly constructed on top. To fit between the orebody and decline it meant that the ore passes were steep in nature, with the original passes designed at 87°. A change in design occurred after productivity and material movement modelling occurred, resulting in rock boxes installed at the 4,245 m RL and the lower passes reoriented back towards the central crusher at 80°.

A minimum of 4 ore passes were designed to create operational flexibility while delivering the planned production profile. When a new level is mined lower in the mine, orepasses are taken offline sequentially to drill and blast a 3 × 3 m finger pass and build the grizzly, leaving 3 ore passes to bog from on 4,195 m RL extraction level at any one time. On the production levels, this increases tramming distance while travelling across zones, however, total loader fleet has been designed to account for this.

Table 2 shows the average productivity of the orepasses. The system is designed to produce more wet metric tonnes (WMT) through the orepass 300 and 400 due to the centralisation of these passes on both production levels and the 4195 extraction level, making loader movement more efficient for these passes.

Table 2 Average orepass productivity for Carrapateena sublevel cave

Side of cave	Orepass	Tram length (m)	Cycle time (s)	Cycles per hour	Bucket factor	Tonnes per hour	Hours	Wet metric tonnes per day
North	200	288	124	29	23	669	18	12042
North	300	184	100	36	23	829	18	14928
South	400	218	108	33	23	769	18	13843
South	500	290	124	29	23	667	18	11998

To manage the risk of orepass overbreak over their design life, a trigger action response plan (TARP) was developed by the geotechnical team during the early stages of orepass design and construction. This TARP documented the risk level and associated monitoring frequency and access restrictions based on several triggers, as shown in Table 3.

Table 3 Orepass triggers and associated risk level

Triggers	Normal: green	Level 1: yellow	Level 2: orange	Level 3: red
Status of pass	Operational	Operational	Blocked	Not operational
Total overbreak to design	≤2m	>2m, ≤4 m	>4 m, ≤6 m	>6 m
Pillar width to pass related development	Design ± 2m	≥5m	<5m, ≥3 m	<3 m
Pillar width to traffic access development	Design ± 2m	≥10 m	<10 m, ≥5m	<5m
Grizzly undercut	No undercut	No undercut	Finger near vertical, not undercutting	Finger undercutting grizzly
Last scan date	Orepass: within 12 months Finger: within 6 months	Orepass: 12 to 18 months Finger: within 6 to 12 months	>18 months	>24 months
Scan Frequency to operate	12 months for orepass 6 months for finger pass	6 months for orepass 3 months for finger pass	3 months for orepass 1 month for finger pass	1 month for orepass 2 weeks for finger pass

In addition, the reporting of any oversize to the crusher level triggered a stop to tipping and a LiDAR scan to determine the source location within the pass.

TARP levels were applied for main orepasses and individual finger passes. Finger passes, being more frequently accessed by underground personnel, were assigned a higher rate of monitoring. Scans were generally taken of the full pass each time as no tipping was possible during any scanning activity.

TARP levels were recorded in a tracking spreadsheet maintained jointly by the survey and geotechnical department. This tracker enabled forecasting and scheduling of scans in the weekly and 13-weekly schedules, aligning to planned shutdown works whenever possible.

Upon a scan being obtained, geotechnical engineers would review the point cloud or solid, determine the TARP level across the pass, and escalate as required. This would be communicated to all relevant teams, and the pass released for tipping to resume if safe to do so. Where TARP levels were out of tolerance (red TARP), access controls such as remote tipping only were applied. In the most extreme cases, abandonment of finger passes were necessary, with ore from that cave section redirected to adjacent passes.

3 Orepass performance

Initial scans revealed an alarmingly rapid growth of the MAP-200 and MAP-300 passes within the structural corridor, triggering red TARP levels despite minimal throughput. The magnitude and location of overbreak also threatened surrounding development, introducing a safety risk to underground personnel. These factors lead to an expansion of the monitoring and management strategy around the orepasses, detailed in the following sections.

Figure 4 shows the trend of average orepass span over time, combined with the cumulative tonnes tipped into each orepass over the same period. Span was measured as the maximum diameter of the pass on a 2D section in plan, with the trend an average of multiple section measurements along the orepass length for each scan date (measured at approximately 10 m vertical increments). Markers on the line chart represent a LiDAR scan. Span is plotted in increments of 4.5 m which is the designed diameter of the raises.

Interestingly there was no significant difference in average span between the 2 passes despite substantially more ore tipped into the MAP-300 owing to its more centralised position in the cave. This suggests that overbreak at Carrapateena was largely controlled by rock mass strength and induced stress conditions, rather than having a direct correlation to throughput.

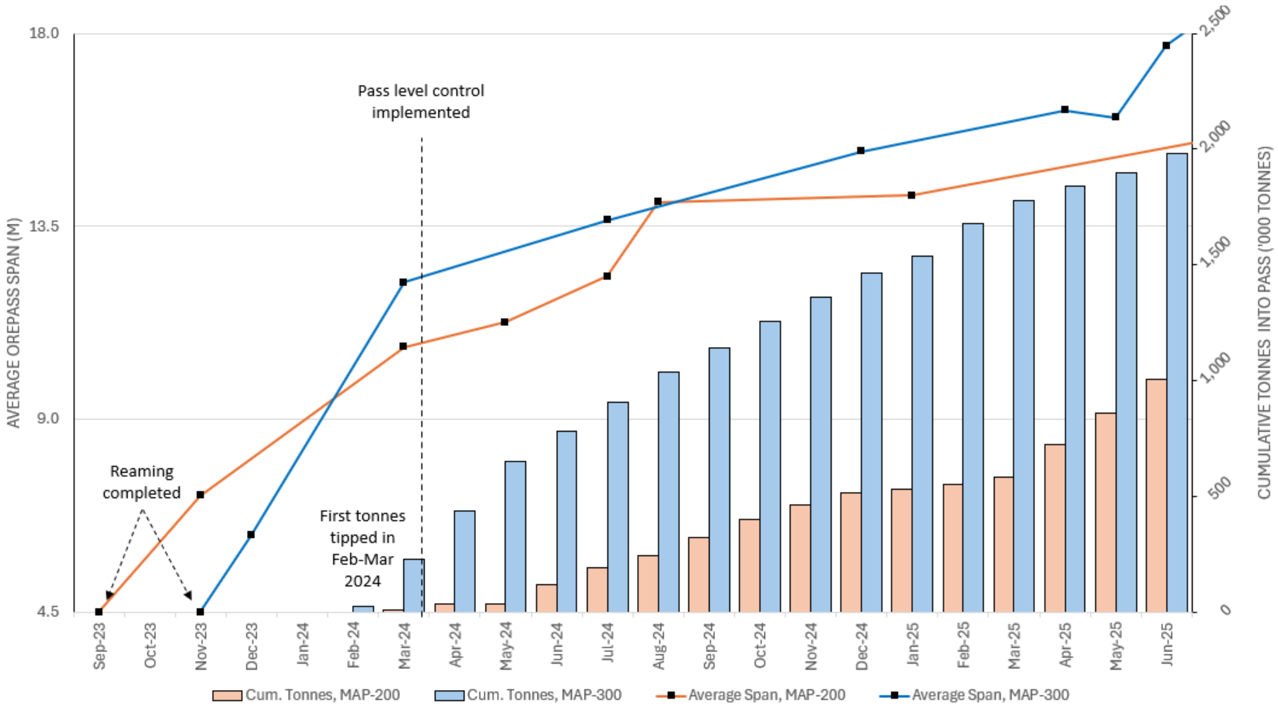

Figure 4 Average orepass span plotted against cumulative tonnage through passes, for the MAP-200 and MAP-300 since initial reaming to June 2025

Both orepasses within the structural corridor experienced ~50% overbreak from design prior to any tipping. This was attributed to stress induced fracturing along with some influence of finger pass drilling and blasting into the main raise. A scan was triggered for both passes soon after first tipping following reports of oversize at the crusher level, showing overbreak increasing the diameter to 2–3 times the design.

Rate and magnitude of overbreak varied greatly along the orepass length. A heatmap of overbreak to design is shown in Figure 5, highlighting the spatial variability of growth. Any management system must account for this variability in rate and location, with controls and mitigation efforts concentrated on areas where personnel access would be threatened by progressive expansion.

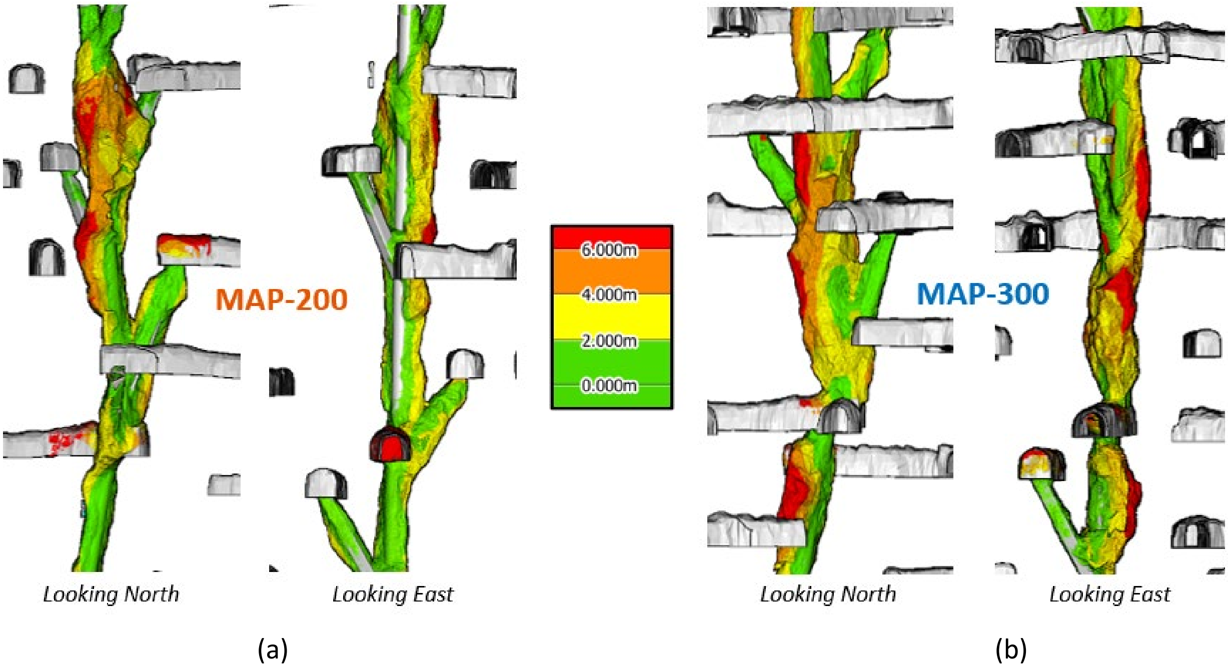

Figure 5 **Spatial location of overbreak along the (a) MAP-200 and (b) MAP-300 orepasses. Contour shown is overbreak to design diameter, as of June 2025**

To design engineering solutions to manage the overbreak, it was first essential that the mechanisms governing failure were well understood. Orepasses are subject to multiple damage modes simultaneously (Hadjigeorgiou et al. 2005), complicating the problem. LiDAR scans at Carrapateena showed evidence of 4 distinct failure modes influencing the growth of passes, as demonstrated in Figure 6.

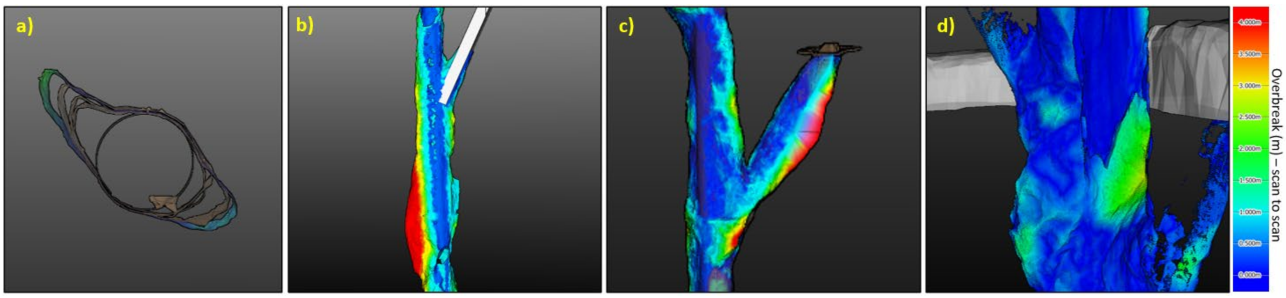

Figure 6 **Failure modes observed in Carrapateena orepasses shown on scan-to-scan comparisons. (a) Stress-induced fracturing; (b) Impact damage from tipping; (c) Abrasion/wear of walls; (d) Structurally controlled wedge**

The intact strength to in situ stress ratio for orepasses within the Reinette shear zone is in the range of 0.6–0.8, where brittle failure can be expected (Kaiser & Kim 2008; Martin et al. 1999). While significant seismicity was not recorded around the passes (potentially due to orepass noise classifiers), notching aligned with the intermediate stress orientation is clearly observable in the vertical orepass walls, the depth of which is variable along the strike of the pass and increased in proximity to discontinuities.

It is theorised that stress induced fracturing is the root cause of overbreak from the pass, with fracturing extending the failure zone deeper into the surrounding rock mass and impact from tipped ore providing the mechanism to dislodge it. This impact mechanism was substantially greater for finger passes oriented parallel to the intermediate stress orientation, where the impact zone coincided with stress induced fracturing and notching.

Structural wedge failure was not a dominant failure mechanism but became more prevalent over time as the pass diameter increased and confinement was lost through stress redistribution. Identification of wedge failure in LiDAR scans often followed reports of oversize at the crusher level, and usually involved persistent fault planes within the structural corridor. No pass blockages were experienced as a result of these wedges.

Wear overbreak was observed consistently over the life of the passes, attributed in part to the higher strength and abrasivity of the hematite ore compared with the sericite altered granites within the shear zone. In some fingers, this abrasivity resulted in a digging out of the footwall, with the angled fingers progressing to be vertical below the grizzly tip points by the time levels had completed. This mechanism did not present a significant hazard to operations but did contribute to continual growth of orepass size over time.

While other authors have highlighted cohesive hang-up of material within the pass as a major consideration (Bunker et al. 2015; Salmi et al. 2024) this did not materialise as a major threat to operability at Carrapateena, likely owing to the resultant size of the orepasses within poor ground.

No correlation was found between the rates and magnitudes of stress induced overbreak observed at Carrapateena with published empirical or numerical methods (Martin et al. 1999; Perras & Diederichs 2016). This is likely due to the heterogeneity of the rock mass within the structural corridor and the multiple failure mechanisms introduced by orepass use that cannot be easily replicated in numerical models – hence efforts were instead focused on management and response rather than attempting to predict failure depth or rate.

4 Orepass management strategies

With the performance of the orepasses understood, additional control measures were put in place to try and arrest the rate of overbreak. These strategies, combined with the existing TARP, helped to maintain productive use of the passes while ensuring pillar stability and safe access for personnel.

4.1 Minimum orepass level

Impact damage from tipped ore was a major driver of early rapid orepass growth. To eliminate this failure mode, minimum pass levels were established for the MAP-200 and MAP-300 orepasses. These levels were set so that the impact zone from the highest active finger pass was covered by an ore blanket – ore tipped into the pass would impact the ore column and not the pass walls, changing the overbreak mechanism from rapid impact damage to slower abrasion and wear.

Pass levels were established using RocFall2 (Rocscience 2022). While primarily designed to manage rockfall hazards for open slopes and civil engineering projects, the software is essentially a physics engine that can be used to simulate the travel path of ore tipped through finger passes similar to the simulations in Esmaieli & Hadjigeorgiou (2009). For level setting only the range of impact location was necessary (no calculation of impact velocity or force), hence the application of simplified software.

Ore was modelled as a round block using a diameter equal to the maximum allowable dimension of the grizzly biscuit, in Carrapateena's case ~1.2 m. A line seeder was positioned along the likely loader bucket location for tipping, and a large number of rocks simulated with varying initial horizontal and vertical velocity.

The result of this simulation is a range of potential impact points along the opposing pass wall. By corresponding these locations to geospatial coordinates, a minimum ore column RL to eliminate the impact mechanism can be determined. Where impact zones do not directly threaten nearby development, a risk-based decision can be made to optimise the level setting, maintaining a balance between stability where it is needed and pass capacity. An example of this is shown in Figure 7.

Once an appropriate RL was determined, volumes and tonnages were calculated using the latest LiDAR scan of the pass. These values were used to convert pass levels into tonnages which could be easily tracked through the site operations centre (SOC) using a 'buckets in/buckets out' method, ensuring the ore level remained above threshold.

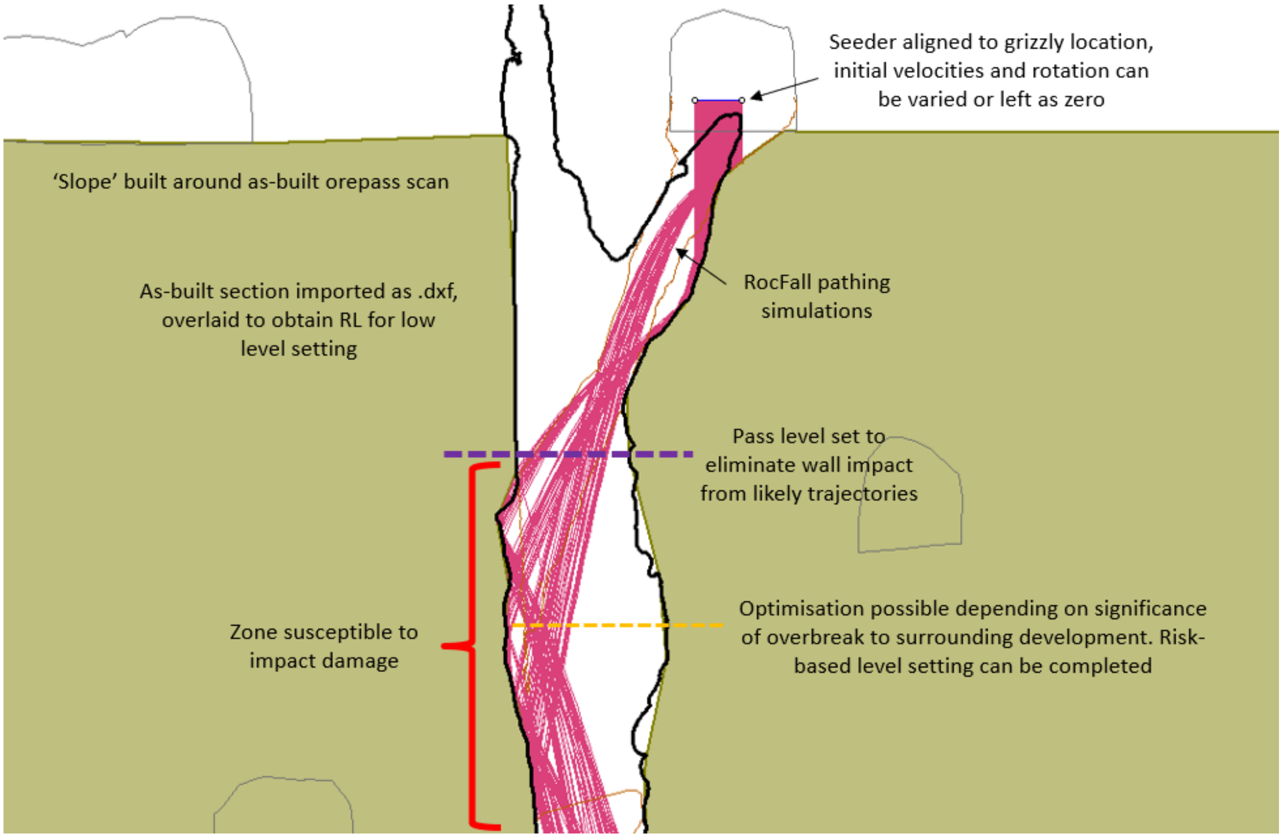

Figure 7 Example of RocFall analysis for pass level setting

The result of these level controls were shown in the trends of orepass span in Figure 4. While an effective method of eliminating impact damage to pass walls, these minimum levels do come with a significant trade-off in the productivity of orepasses. Available volume to tip into is reduced, particularly for fingers located below the minimum ore level which would only be able to fill a finger pass volume before becoming choked.

Another complication of pass levels is the conflicting goals of keeping ore level maintained to protect the walls, and the need to empty the pass to obtain a full LiDAR scan and properly understand the condition and risk. At Carrapateena, passes were emptied on a regular schedule, with surrounding passes utilised for tipping until a scan could be obtained. When re-filling the pass, a bottom-up approach was required to reduce impact as far as practical. This was a slow but necessary process to maintain stability for future production.

Adjustment of pass levels as the active production front gets deeper must also be carefully managed. The period between taking final rings off a level and the ramp-up on new production levels pose a particular challenge where the risk to the pass must be weighed against the need for added capacity. This becomes a risk-based decision based on the trend of pass performance, exposure of the impact zone to surrounding development and the forecast tonnages remaining to be tipped.

It is recommended that pass level control be used whenever finger pass orientation directs ore unfavourably into the stress fractured zone. Despite the production challenges, minimum ore levels were arguably the most effective strategy utilised to reduce overbreak of the MAP-200 and MAP-300 orepasses.

4.2 Geotechnical design

Magnifying the severity of orepass overbreak at Carrapateena was the compact level design, which placed small pillars between the passes and surrounding development at the design stage. Early finger pass design was also often a function of access location rather than a result of geotechnical assessment, resulting in unfavourable alignments.

While the main orepass had already been constructed, lower production levels allowed for optimisation of development and finger passes, taking learnings from performance in upper levels and building redundancy into the design. The following considerations were built into subsequent level and orepass designs:

- All finger pass designs were re-aligned as parallel to major principal stress (σ_1) as possible.
- Development adjacent to modelled impact zones were relocated and ground support increased.
- Pillars less than 10 m were cablebolted prior to finger pass firing.
- Finger pass firings were taken in multiple smaller lifts when unfavourably aligned.
- Monitoring holes were designed and drilled and sensors were installed prior to finger pass use on each level.
- Baseline LiDAR scan of all new finger passes were taken prior to first tipping.

Incorporating these considerations into the design process was effective in reducing the rate and magnitude of orepass damage in subsequent levels. Reorientation of finger passes not only reduced the degree of impact damage from tipping, but created more favourable stress conditions in the 'V' pillar at finger pass breakthrough. The effect of re-orientation of finger passes on the 4305 level can be seen in the elastic stress results in Figure 8.

Wider spacing between development and orepasses was built into the level design, particularly for pillars in the overbreak orientation. This greatly reduced the impact of overbreak on mine operations when it did occur, justifying the added development metres.

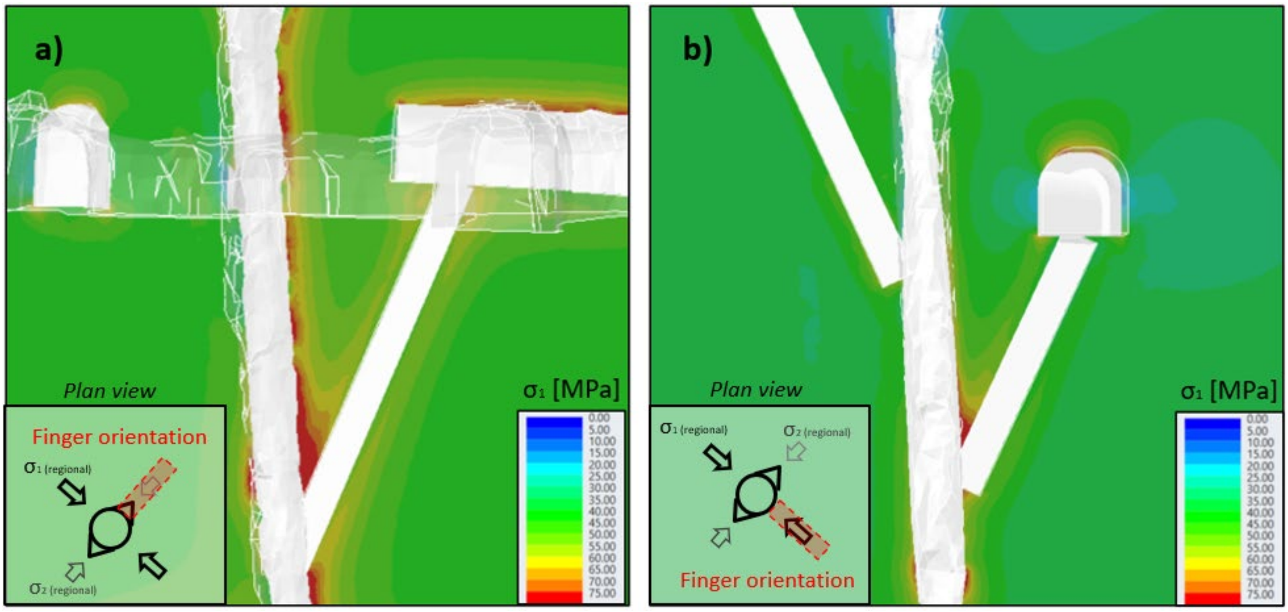

Figure 8 Difference in local major principal stress between the 4305 finger pass and the MAP-200 when oriented (a) perpendicular to regional major principal stress (σ_1) and (b) parallel to regional σ_1

4.3 Cable bolt support

Cables were installed in accessible drives surrounding the orepasses as required upon the identification of overbreak. A TARP was not implemented for a certain pillar thickness before cables were installed. Instead, each pillar was assessed individually considering the mechanism of failure, orientation of the failure with respect to the pillar and the exposure to personnel.

Cables were installed in various configurations including fanned rings to strengthen small pillars, uphole cables below finger passes experiencing wear, and as ‘umbrella’ cables above the hanging wall of finger passes. Examples of these applications are shown in Figure 9.

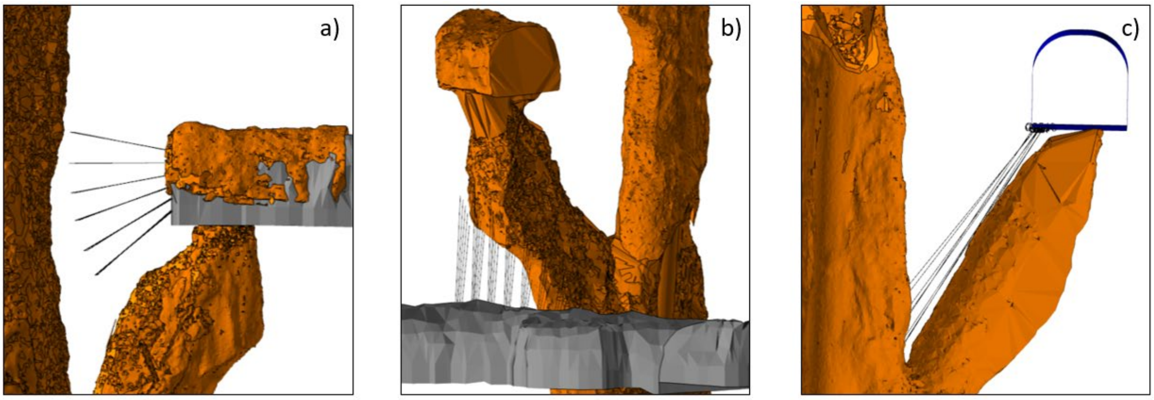

Figure 9 Example of cablebolting applications at Carrapateena. (a) Thin pillar support; b) Uphole cables below finger passes; (c) ‘Umbrella’ cables above finger pass hanging wall

Pillar cables were installed as fanned rings that were plate and tensioned. These cables performed well, arresting overbreak in most instances. Of the rings that continued to see overbreak only the last 0.5–1.5 m of cables were consumed past the designed tail location, with no damage observed in drives where installed. A learning from these fans is to allow for a buffer distance to the orepass itself, as in one instance cable holes were over-drilled and tails installed into the main pass wall, causing a build-up of material on the wall and in 2 instances nearly causing the loss of the cage-mounted LiDAR when the cable was snagged on the tails.

Uphole cables below the finger passes were not anticipated to completely mitigate wear-related overbreak but instead slow the rate at which it developed. These cables performed surprisingly well, with LiDAR scans showing a clear contrast in the area where cables were installed compared to the unsupported zones in a scan-to-scan analysis. It is theorised that the cables may be acting by preventing broken/fractured rock at the base of the finger passes from being dislodged down the finger, acting as a buffer zone protecting the intact rock beneath.

‘Umbrella’ hanging wall cables were not plate and tensioned owing to their position in the floor of tip-point drives, and were installed in large diameter holes as the long down-holes were drilled by production rigs during finger pass drilling. As a result these cables were likely not acting as intended in most instances, resulting in poor performance. While some finger pass scans showed some evidence of success, most of these cables were found to fail or allow the rock mass to unravel around them. These cables have since been discontinued from all but the poorest sections of the shear zone, where a tighter pattern was used with mixed success.

5 Orepass monitoring

A robust monitoring system was employed for all active orepasses at Carrapateena, consisting primarily of drone and cage-mounted LiDAR systems. After observing the rate and magnitude of orepass overbreak, the monitoring system was expanded to include multi-point borehole extensometers (MPBX) and time-domain reflectometry (TDR) cables.

The combination of these systems ensured that the condition of the passes and the pillar thicknesses to surrounding development could be determined with confidence, and early warning of overbreak detected between scheduled scans. These systems and their usefulness at Carrapateena are detailed in the following sections.

5.1 LiDAR scanning

LiDAR scanning is conducted primarily using an Emesent Hovermap ST scanner mounted in a protective cage (Figure 10). This is either lowered down the main orepass itself using a winch and swing-arm system mounted at the top of the pass, or through apertures of the grizzly and run down the angled finger passes into the main shaft. Carrapateena's survey department rigged the cage on a larger frame of bike wheels, which both protected the LiDAR unit from impact and also allows it to run (relatively) smoothly down pass walls.

(a) (b)

Figure 10 Cage-mounted LiDAR scanner (a) set-up and (b) being lowered through grizzly aperture

In the event of mechanical breakdown of the winch system, Flyability Elios-3 drones were flown into the pass to capture a LiDAR scan. These flights required a stricter set-up to be feasible – passes must remain choked at the bottom of hole, extraction fans turned off for the flight duration and sufficient time allowed for dust to settle prior to the flight mission. Coupled with the reduced range of connectivity to the drone unit and limited range compared to the Hovermap system, drone scans were used only as a secondary option for scanning. These drones proved invaluable backup optionality for urgent scans, in many cases justifying their cost by enabling production activities to resume when the winch system faced mechanical or electrical issues.

Scans were processed and georeferenced on site by the survey department, who provided both solids and raw point clouds for interpretation to the geotechnical department. These were analysed in PointStudio (Maptek 2024) or Deswik to identify locations of overbreak and quantify total and scan-to-scan overbreak.

Solids, while familiar and easy to work with, do not provide sufficient detail for identification of failure mechanism within the pass. Analysing the point cloud directly in PointStudio provided far greater resolution of the wall and finger conditions, along with other details that proved important such as cables protruding into the pass, or differentiating between an intact pass wall and hang-up within the narrow notches that may be obscuring the actual pass dimensions (Figure 11c). It is recommended that geotechnical teams investigating orepass behaviour utilise high resolution point clouds instead of simplified solids to ensure the value of this data is fully realised.

Simple distance-to-object functionality within the software allowed for rapid analysis of changes between scans, generating an easily interpretable contour of overbreak painted onto the pass solid (Figure 11a). These contours were valuable communication tools to mine management and operators to explain the condition and emerging hazard of the orepasses. This feature also allowed for proximity to the orepass to be mapped onto drive solids, quickly highlighting development that was at threat from future overbreak and may require additional ground support or monitoring (Figure 11b).

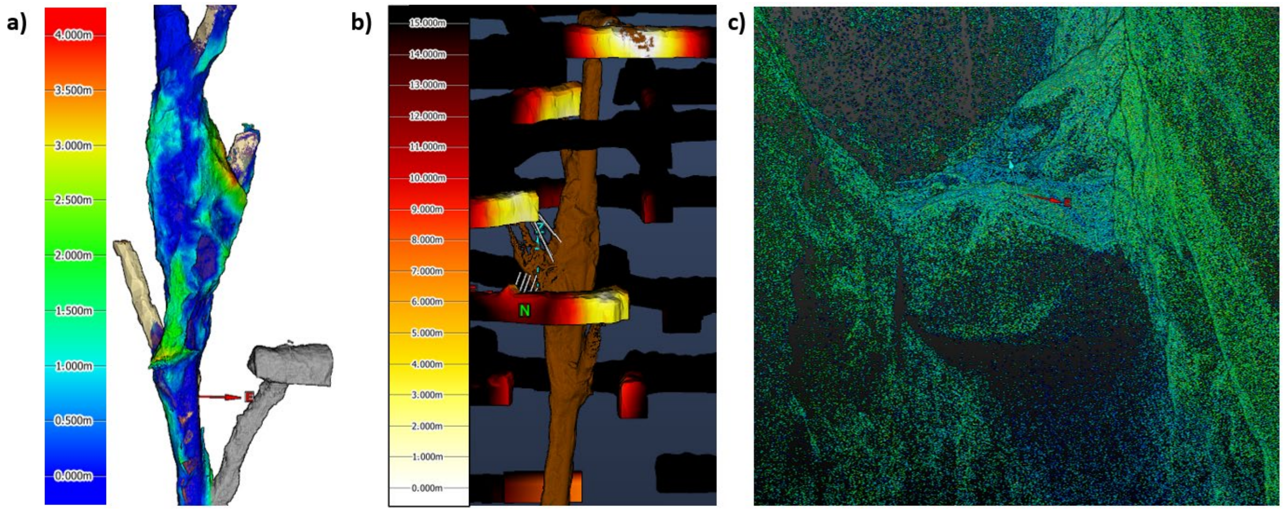

Figure 11 Examples of analysis completed in PointStudio: (a) Scan-to-scan comparison to generate heatmap of overbreak; (b) Heatmap of proximity to surrounding development to target inspections/support; (c) Internal pass visualisation to aid in understanding actual pass condition

5.2 Time-domain reflectometry

TDRs and extensometers were installed within rings of cablebolts installed for thin pillars and from surrounding access drives to supplement the LiDAR scanning routing with near live information. The intention of these sensors was not to provide discrete measurements of strain or displacement, but to identify changes in behaviour in the rock surrounding the orepasses and escalate controls as required.

TDRs were installed to provide an indicator that pass overbreak had occurred and trigger a LiDAR scan to identify the cause and location. Arrays were able to be installed due to the inexpensive nature of the cable and intended to be connected to flash-boxes at tip-point entrances, to alert loader operators to the hazard.

Unfortunately, in almost all cases, these cables did not survive for a sufficient time period to prove useful, with even minor equipment interaction rendering the sensors unusable. Manual readings of cable length were also not accurate across the relatively small cable length and conflicted with scan measurements. TDR installations were discontinued for later production levels.

5.3 Multi-point borehole extensometers

Extensometers proved especially useful in understanding the rock mass behaviour surrounding the orepasses, and were less susceptible to damage as no cable runs were required along the tip-point drives. Readings of the sensors could be taken remotely using a Bluetooth enabled tablet, removing underground technicians from potentially hazardous areas.

MPBXs provide additional data in relative displacements between nodes along the length of the sensor, allowing for an understanding not just of total movement but where along the hole the movement is occurring. This information was especially useful in lower sections of the orepass below the minimum ore levels, which could not be seen directly in all LiDAR scans.

Six-node MPBXs were installed for orepass monitoring, with an equal spacing along the cable length. Data was initially recorded hourly during early stages of use, but reduced to 4-hourly recordings due to data storage limitations. The data was recorded on a datalogger installed parallel with the MPBX – collected via a Bluetooth tablet on a weekly basis– and converted to a relative displacement between each node, plotted and reported to mine management in a monthly report. An example of the trends recorded is shown in Figure 12.

Extensometer data recorded spikes of deformation which the geotechnical department was able to correlate to the pass level being lowered beyond the specified low-level. This proved a useful tool to reset operator discipline and/or trigger a re-calibration of the levels set in the SOC.

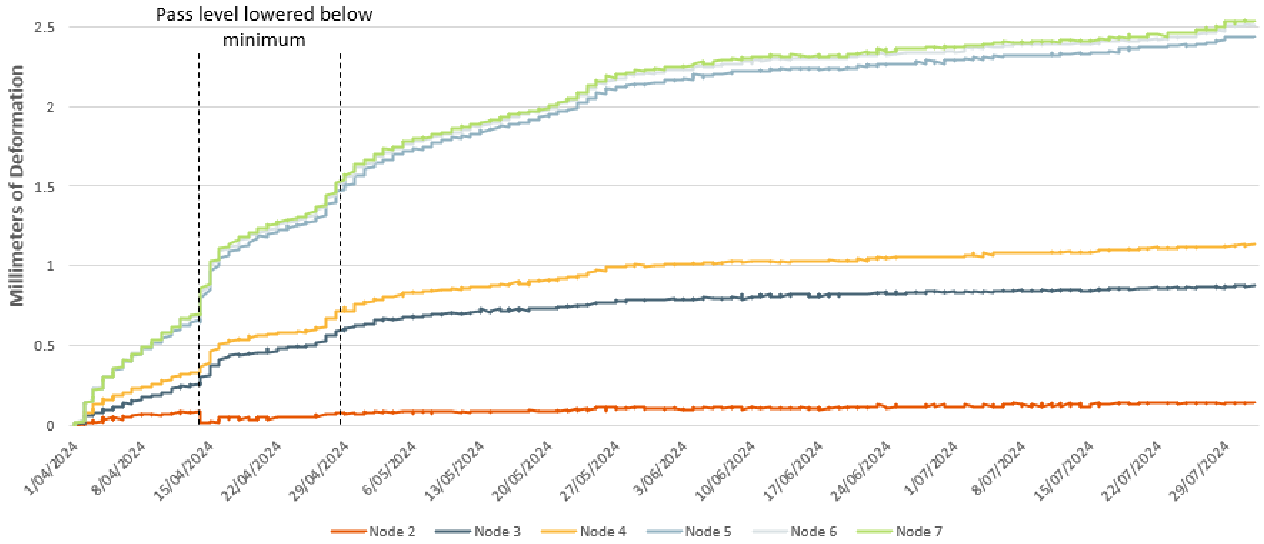

Figure 12 Example of data trend from extensometers installed for monitoring. Nodes represent location along the borehole, for this example 1 m increments

5.4 Monitoring system usefulness

A summary of monitoring systems in shown in Table 4. By far the most useful system for decision-making and hazard identification is LiDAR scanning as it is the only method which allows for full 3D imaging of the pass.

The trade-off for this value is the need to empty the passes prior to scanning to obtain the full condition of the pass. Whenever possible, orepass scans were taken during planned crusher maintenance when aligned with scan frequency requirements to reduce the impact on mine production. Care must also be taken to fill passes from bottom-up once emptied, to limit impact damage.

While these have potential to cause delays and frustration, proper integration of LiDAR scanning into the mine schedule can keep these disruptions to a minimum. The multiple orepasses at Carrapateena also allow for redirection of production ore to other passes during these scans, maintaining production across a shift albeit with a longer tram distance for production loaders.

Table 4 Monitoring system usefulness at Carrapateena

System	Advantages	Drawbacks	Effectiveness
LiDAR (cage)	Data obtained is high density, allows for 3D interpretation of conditions; winching system not affected by airflow in pass	Need to empty or lower pass levels to obtain scan; reliability of winching system	High
LiDAR (drone)	Good quality point cloud data obtained (less density than cage); Less reliability issues than winch system; quick to collect scan	Range limited by control communication, often limited data coverage; susceptible to airflow and dust inside pass	Moderate
MPBX	Continuous data collection over time; easily installed in borehole; remote data connection	Only 1-dimensional data collected; sensitive to borehole orientation; cannot determine failure mode, only measure rate and magnitude	Moderate
TDR	Cheap, many sensors can be installed in an array	Cable easily damaged, rendering sensor unusable	Low

6 Conclusion

Orepasses at Carrapateena experienced significant overbreak during initial use, caused by various failure modes within an area of poor ground. This overbreak threatened safe production due to the proximity of surrounding drives and the rate of overbreak with time.

A robust management strategy consisting of minimum pass levels, LiDAR scanning, borehole monitoring, cable bolt support and refined design was employed to successfully manage the risk to personnel. Orepass lining or major rehabilitation was avoided with these strategies, reducing financial impact to the operation while maintaining productivity. The rate of overbreak of the passes were successfully reduced, with increased control around the orepasses leading to safer and consistent production.

Designs of future orepasses are suggested to involve early geotechnical drilling to predict performance, build redundancy into surrounding development pillars to maintain flexibility, align finger passes for the in situ stress field, and build in monitoring systems during construction.

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