Ground Support 2026 - D Cumming-Potvin & J Wesseloo (eds.)
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doi:10.36487/ACG_repo/2625_42

Refurbishment: then versus now – pumpable resin systems for enhanced ground support in extremely poor ground conditions

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Abstract

With increasing mining depth, the in situ stress levels usually increase, inducing greater damage to the rock mass and a higher load on the ground support. This increase often renders previously adequate ground support systems ineffective.

Fully encapsulated resin cartridge rebar bolts are among the most widely used reinforcement systems and perform reliably in fair to very good, Q-value > 4, ground conditions. However, their performance becomes inconsistent in poor to exceptionally poor ground, Q-value < 4. This is primarily attributed to over-drilling, resin volumetric losses into fractures and voids, and other installation-related challenges.

In addition to technical limitations, operational inefficiencies arise in such conditions. Installation rates decrease due to the need for hole cleaning or re-drilling, while increased bolt density is required to compensate for reduced reliability. This leads to extended ground support cycle times and reduced excavation longevity, often caused by sub-optimal installation quality. Consequently, the frequency of refurbishment increases, resulting in significant costs associated with consumables and production downtime, and in some cases restricting access to valuable ore.

An effective alternative for such challenging ground conditions is the use of self-drilling anchor (SDA) systems combined with a pumpable (bulk) resin grout. These systems eliminate issues related to over-drilling and re-drilling by integrating drilling and installation into a single-step process. Furthermore, the low-viscosity resin can penetrate fractures and voids, ensuring effective encapsulation and load transfer.

Field applications have demonstrated up to a 60% increase in installation rates, along with near-complete installation reliability. In addition, pumpable resin systems enable a bolts full bearing capacity within minutes, in contrast to the extended curing times required for cementitious grouts used in conventional SDA systems. The performance of pumpable resin systems is highly dependent on the use of appropriately designed installation equipment. Mechanised bolting rigs such as the Epiroc Boltec series are specifically engineered to support high-quality, repeatable installation of self-drilling anchors with pumpable resin.

Such equipment integrates automated drilling, resin pumping, and bolt installation into a controlled and standardised process. This ensures consistent resin dosing, proper mixing, and accurate placement, which are critical parameters for achieving reliable encapsulation and load transfer in fractured ground.

Moreover, mechanised systems improve operator safety by reducing manual handling and exposure to unsupported ground. They also contribute to higher productivity through optimised cycle times and reduced variability between installations. The combination of suitable equipment and pumpable resin technology

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therefore represents a system-based approach, where both components are essential to fully realise the performance benefits in poor ground conditions.

Keywords: *self-drilling anchors, poor ground conditions, over-drilling, installation reliability, pumpable resin grout, mechanised bolting equipment*

1 Introduction

The current paper offers a summary and is based on Pereira et al. (2025) Master's thesis which, due to an embargo placed on the thesis, was not made public at the time of writing of this paper. This paper accompanies the data that was collected a year after the work done in Pereira et al. (2025) and it showcases the long-term effectiveness of the Pumpable Resin System characterised by self-drilling anchors and pumpable resin as grouting agent to bond the bolt to the rock mass.

This system was used at Somincor, a subsidiary of Boliden, due to its geotechnically challenging rock mass, predominantly within the fair to very poor in the Q-system classification range, $Q < 10$ based on Norwegian Geotechnical Institute (NGI) (2025). These types of rock masses cause several constraints, especially in permanent infrastructure, as conventional resin bolts have demonstrated low installation success rates in these areas.

As per NGI (2025), these types of rock masses usually have a higher number of joint sets which causes Q-values to be lower. A lower Q-value, in the case of Somincor, is translated by the lower uniaxial compressive strength (UCS), high degree of foliation, and some areas with infill between the foliations and medium to severe weathering within the very poor parts of the rock mass. This foliation in the poor areas of the mine has a low shear resistance due to the very thin planar structures within the rock mass, causing resin bolting to fail in the mechanisms/challenges described by Pereira (2025). While the fair ground is usually translated by the higher UCS, medium degree of joint sets but with little weathering and no foliation, no infill and rough discontinuities.

Some of these challenges present in the installation of bolts occur during the development phase of the tunnel, with resin bolts failing quality control standards due to the very poor rock mass. This becomes even more predominant during the rehabilitation works phase of tunnels, as the rock mass has already deteriorated even further.

The challenges in ground support installation found at Somincor, with cartridge resin bolts, include:

- Over-drilling: occurs when the final nominal diameter of the drillhole exceeds the nominal diameter of the drill bit. When this phenomenon occurs in such a way that the diameter of the drillhole is excessive (e.g. the drillhole diameter is the same or greater than the bolt diameter + cartridge diameter side-by-side), the bolt can glide alongside the cartridge without piercing it, causing incorrect application of the system due to poor encapsulation and grouting.
- Highly fractured rock mass: a highly fractured rock mass increases the likelihood of over-drilling, as the fractures may intercept and create drill holes with a higher nominal diameter, increasing the void/resin ratio and, consequently, compromising the bolt encapsulation due to resin permeation in the fractures or non-puncture of the cartridges. This lack of encapsulation causes sub-optimal, if at all, bonding of the bolt to the rock. Cable bolts or cement grouted bolts can overcome this challenge to some degree, but do not allow for free percolation inside the rock mass and thus most fractures will remain open, allowing unravelling, movement between the bolts and free water percolation inside the rock mass, possibly degrading the ground support and the rock.
- Drillhole collapse: when the rock mass is extremely poor, it can induce failure within the walls of the drillhole, leading to collapse and re-drilling operations, which are very time consuming and increasing the likelihood of over-drilling and highly fractured rock mass.

To tackle these challenges, Pereira (2025) described a pumpable resin system that was introduced in conjunction with self-drilling anchors – an example of which is displayed in Figure 1 – which also proved very useful in the installation of welded mesh panels.

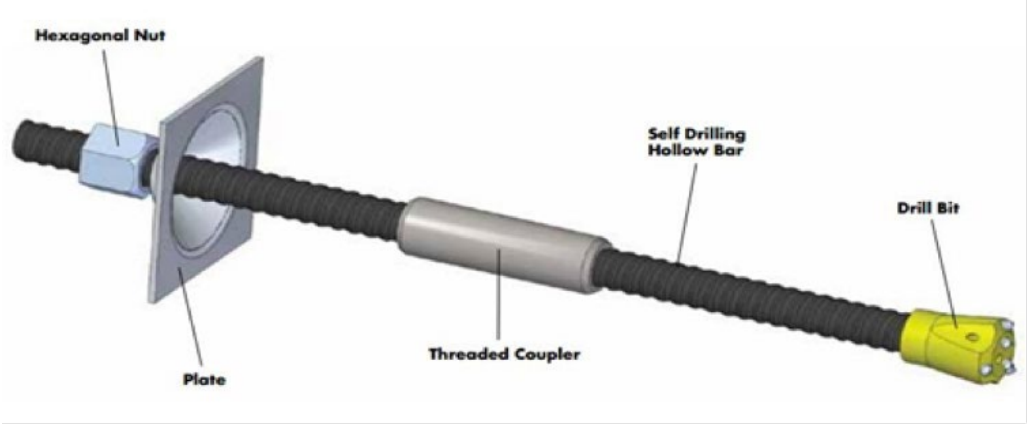


Figure 1 Self-drilling anchor

Self-drilling anchors (SDAs) are comprised of a sacrificial bit and steel bolt capable of withstanding the pressures of percussion and torque acting on the steel during the drilling operation, as well as the load capacity of conventional bolts. They bond to the rock mass using pumped grout, cement, or resin as stated by Li (2017).

The intention of correct ground support installation is, as stated by Hoek et al. (1993), to ensure safety of the workers and the mine's long-term operations by stabilising the ground and minimising the need for refurbishment works.

With this in mind, this system complies with the previous statement as it allowed for correct application in fractured grounds, guaranteeing embedment length and correct encapsulation of the bolts, as well as increasing the volume under load due to 'glueing' the rock mass itself, increasing the intervals between rehabilitation works, as described by Pereira (2025).

The system has been operational since 2023 and all sites are actively monitored to ensure that no further decompression takes place.

2 Mechanised pumpable resin system

The Mechanised pumpable resin system used in this industrial trial is comprised of 3 parts:

1. mechanised bolting rig: Epiroc Boltec M
2. pumpable resin: MasterRoc RBA 380 (curing time of 180 seconds) (Master Builders Solutions 2023)
3. self-drilling anchors: hollow bars with sacrificial bits.

Epiroc's Boltec M, showcased in Figure 2a, offers the capability of installing several types of bolts, such as expansion bolts, resin bolts, two-step hollow bars, and self-drilling anchors. These last 2 are possible due to the on-board resin tanks which hold up to 200 litres of each resin component, one of which is showcased in Figure 2b, and allows for continuous pumping.



(a) (b)

Figure 2 (a) Epiroc Boltec M; (b) RBA 380 in a heading (Pereira 2025)

The pumpable resin used in all the case studies showcased here was MasterRoc RBA 380, with a curing time of 180 seconds. While the curing time is considerably high, due to the high temperatures of the rock mass and of the headings, shorter curing times proved to be unreliable to the execution of extension bolts (4.4 and 6.4 m bolts), so RBA 380 was adopted as a standard to avoid the mixing of different types of resins while underground and in the surface stores.

For the hollow bars, the diameter chosen was R28 with 38 mm sacrificial button bits with the specifications displayed in Table 1 (Pereira 2025).

Table 1 Hollow-bar specifications (Pereira 2025)

R28 Hollow-bar	Specifications
Diameter (mm)	28
Length (m)	2.4
Maximum length (m)	6.5
Drilling diameters (mm)	38 and 45
Yield Load (kN)	20
Rupture load (kN)	26

3 Sites

3.1 Ventilation and piping infrastructure

The largest scale test where this system was used was in an infrastructure tunnel that was, historically, rehabilitated every 3–4 months due to its converging rock mass (Pereira 2025). A map of the area is presented in Figure 3.

This tunnel was of high importance due to the various reticulation pipelines present, horizontal and vertical water and paste pipelines, mostly to the Lombador Orebody, and connections to the 2 main ventilation shafts that supply Lombador with fresh air, Shaft 22 and 26 (Pereira 2025).

In the past, the interventions were very limited due to the lack of redundancy, but for this intervention, most of the infrastructure was decommissioned as alternatives were available (Pereira 2025). Due to the very poor rock mass, end encapsulated resin bolts were applied with low success rates, as the torque applied on the

bolts was enough to rupture the rock itself, the correct application of the bolt failed, with the resin not bonding effectively to the rock mass (Pereira 2025).

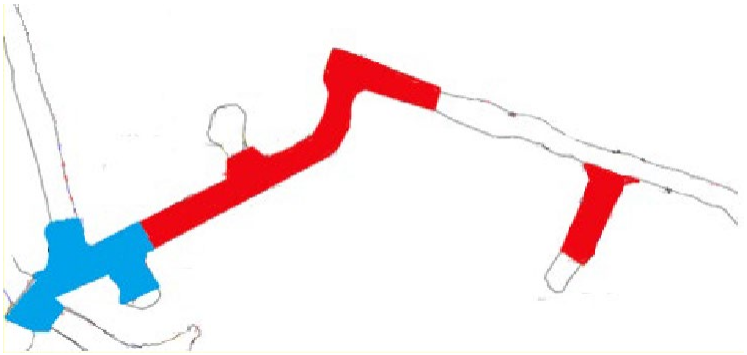


Figure 3 Ventilation and piping infrastructure (Pereira 2025)

The ground support requested for this intervention was (Pereira 2025):

- surface support: 5 cm fibre-reinforced shotcrete and 5 mm mesh
- bolting length: 2.4 m and 4.4 m bolts
- number of 2.4 m bolts per ring: 15
- spacing of the 2.4 m bolts: 1.0 x 1.0 m
- number of 4.4 m bolts: 10.

On the main crossing, identified as blue in Figure 3, the geotechnical team requested 4.4 m pumpable resin bolts to consolidate the back of the tunnel. The new mesh was applied with SDAs and pumpable resin, while the old mesh was just reinforced with SDAs and pumpable resin (Pereira 2025).

In accordance with the last case, this area was also, historically, heavily rehabilitated. Smaller rehabilitation works occurring every 3–4 months, causing major constraints in the surrounding levels and in Lombador due to not being able to backfill through the reticulation in the area while works were being carried out for safety reasons.

3.2 Ramp intersection

The first site where the long-term effectiveness of the system was evaluated, is characterised by being an intersection between 2 major ramps: Ramp 12 and Ramp 17 (Pereira 2025). A map of the area is presented in Figure 4.

Ramp 12 connects level 700 to level 550, it is one of the main ramps that connects the 2 levels. Ramp 17 is one of the secondary ramps to the Corvo Orebody, it has just a few active levels, mostly drift and slash and occasionally stopes (Pereira 2025).

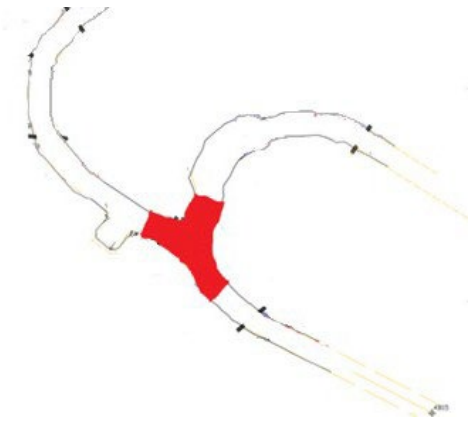


Figure 4 Area of rehabilitation works of ramp intersection (Pereira 2025)

At the time of the rehabilitation works, some stopes were directly above this intersection and during the rehabilitation works, scaling in the back of the ramps did not exhibit signs of heavy decompression; however, the pillar in Ramp 17 showed signs of stress fracturing, creating significant voids within itself (Pereira 2025).

Historically, this area had always been refurbed every 5–6 months due to the proximity with stopes above and below. At the time of the refurbishment displayed here, there was an active stope above the crossing and several development headings advancing in very close proximity.

Here, the ground support required for the rehabilitation was (Pereira 2025):

- surface support: 5 cm fibre-reinforced shotcrete and wire mesh
- end encapsulated resin bolt pattern: 1.0 x 1.0 m
- number of bolts per ring: 15
- bolt length: 2.4 m.

After scaling and shotcrete application, welded mesh was placed in the entire rehabilitation works using resin rebar bolts. However, a pumpable resin system was needed as the operators had significant drillhole collapses due to the extremely poor rock mass and once the change was made, resin consumption proved that there were indeed some voids inside the pillar (Pereira 2025).

It is important to note that, historically, this area underwent rehabilitation works twice a year and heavily impacted the stope sequence and mining in the months that it was closed due to rehabilitation, causing major constraints in this area of the mine and production as a whole.

3.3 High-grade ore access

The last case study demonstrated here was executed in a high-grade ore infrastructure – survey outlines map in Figure 5 – a tunnel in Corvo Orebody that intersects a major fault, resulting in very high overbreak in its cross-section and low success rate in the installation of end encapsulated bolts when pull-tests were conducted (Pereira 2025).

After some drifts were developed and filled, stability challenges emerged and had to be intervened to be stable again, although it was usually refurbed every 6 months for minor instabilities (Pereira 2025).

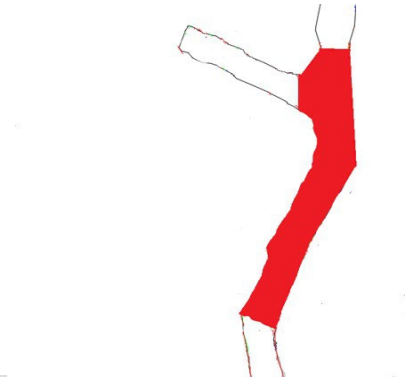


Figure 5 High-grade ore access (Pereira 2025)

The ground support requested for this intervention was (Pereira 2025):

- superficial support: 5 cm fibre-reinforced shotcrete and 5 mm mesh
- bolting length: 2.4 m end encapsulated resin bolts
- number of bolts per ring: 12
- bolting pattern: 1 x 1 m.

Mesh installation was carried out using resin bolts with the intention of pinpointing areas where they were ineffective, with pull-out tests being performed to identify zones where the standard resin bolts did not meet expectations.

Once the bolts were pull-tested, until 180 kN as per the mine's standard, a failure rate of 75% was identified, with a maximum of 150 kN achieved in only 2 bolts out of 22 failed. The remaining 'failed' bolts could be rotated by hand with a torque wrench, which meant that this tunnel had to be reinforced with some other kind of rock support (Pereira 2025).

Pereira (2025) stated that cable bolting would not be an option, as the ground consolidation offered by cable bolting would be limited and the ground would be able to decompress around the cables. Pumpable resin was issued but since there was the high probability of excessive resin consumption, it was decided to limit the resin to 40 Litres per bolt to consolidate as much as possible while controlling the costs.

Figure 6 showcases the ring pattern requested for this area, with a burden of 2 m between rings (Pereira 2025).

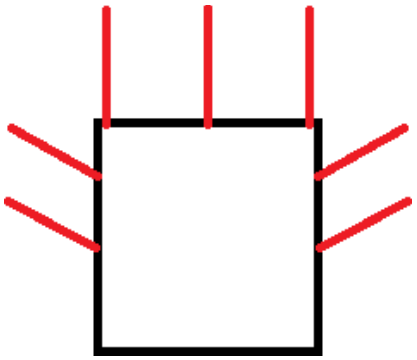


Figure 6 Pumpable resin bolts pattern

4 Results

4.1 Ramp intersection

Three years after the last rehabilitation in the area, this crossing still showcases close to no deformation in the area where it was treated with the pumpable resin.

While this rehabilitation doesn't contemplate a cost comparison like the next 2 cases, it is still very interesting, as it was the first trial of the resin in a major infrastructure that was rehabilitated frequently (every 5–6 months).

Ever since this round of rehabilitation, the system has been allowed to 'skip' 6–9 rounds of rehabilitation up until now, with traffic being allowed in the area without restraint. It has allowed the extraction of ore without unplanned stoppages due to instability arising from stope blasting or the rock mass converging.

During this rehabilitation, a significant increase in bolting installation speed was noted (Figure 7) due to mitigating the challenges previously stated. However, this increase was limited to 38% due to the resin curing time, if the resin's curing time was lower it is estimated that it could increase upwards of 65% of bolting installation speed in very poor ground, and be comparable with cartridge resin bolts in good ground.

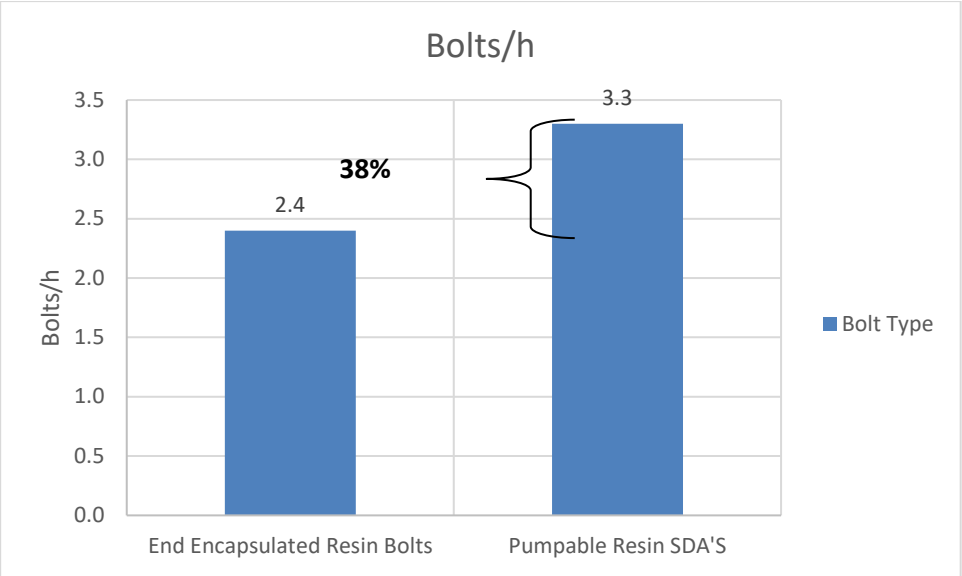


Figure 7 Bolt installation effectiveness with a 38% improvement in bolts/h (Pereira 2025)

Figure 8 contains a side-by-side comparison between the just finished rehabilitation (Figure 8a) and 1.5 years after its completion (Figure 8b), showcasing that only where the resin wasn't used, highlighted in the red circle, show signs of instability, while where the pumpable resin SDA's were used, in the blue circle, there is no signs of instability.

Figure 9 showcases the same crossing 3 years after rehabilitation works were carried out. This proves the efficiency of the system, as the area treated with pumpable resin shows no signs of deformation/instability.



(a) (b)

Figure 8 (a) Rehabilitation after completion; (b) 1.5 years after completion

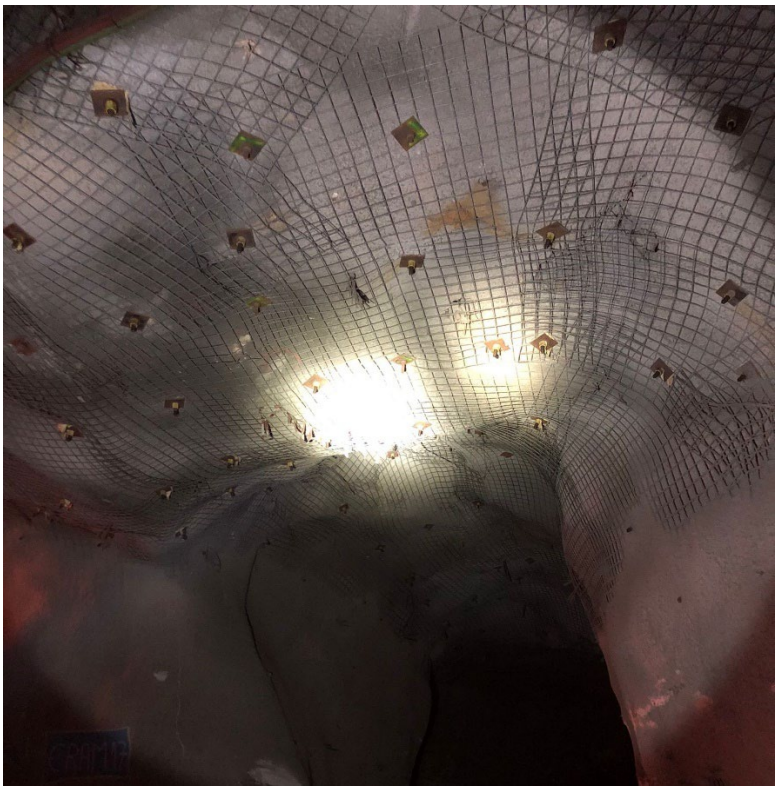


Figure 9 3 years after rehabilitation works

4.2 Ventilation and piping infrastructure

One and half years after the main intervention, while some further signs of decompression can be seen, it remains one of the most successful cases within Somincor, as similarly to the last case, this area hasn't suffered another intervention since.

This area had the highest upfront cost of the 3 rehabilitations but had the overall highest cost to benefit ratio with −318% cost reduction despite a 556% price increase in consumables, as can be seen in Figure 10. The graph showcases the cost comparison between methods, where the benchmark – red line labelled as 'Theoretical cartridge'– assumes a theoretic consumable cost of end encapsulated resin bolts. The blue bars display the relative cost difference of the consumables when compared to 'Theoretical cartridge' and the green line displays the relative cost difference of the whole refurbishment with each ground support method.

One other 'unaccounted' benefit is the reduced downtime caused by this rehabilitation. The fact is, using this system, the area 'skipped' 4–5 interventions of at least 2 weeks each, providing the mine with an 'extra' 8–10 weeks of uninterrupted work that would not have been possible with conventional methods.

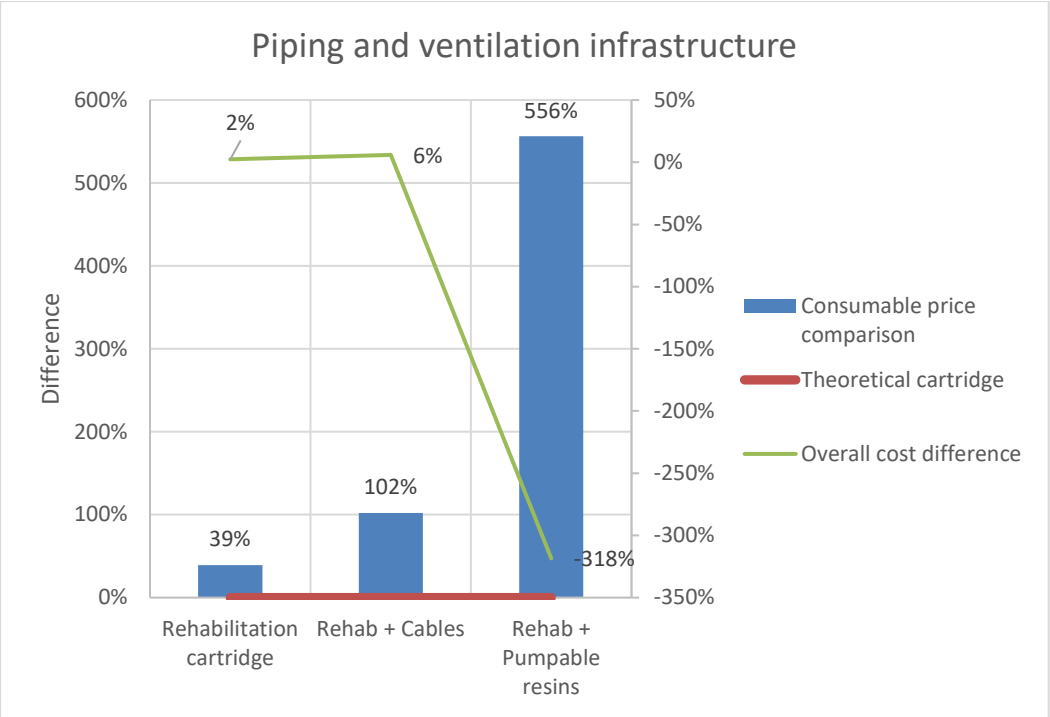


Figure 10 Cost comparison

Here, however, as stated previously there is still a slight convergence taking place, although slower than previous ground support methods, and may require another round of rehabilitation in the following years.

One curious aspect to note is that before this intervention, the end encapsulated resin bolts showed some signs of deformation but nothing too significant. However, when the pumpable resin bolts were installed, these started showing more bent plates than the conventional methods.

One possible option is, since they are stiffer and guarantee correct encapsulation and anchorage, they are correctly ‘mimicking’ the ground movement, in contrast with the conventional methods that just ‘moved’ along with the ground due to incorrect application. It could be argued that the hollow bars simply have a lower yield load and deform ‘earlier’ than the end encapsulated resin rebars available at the mine, but both methods offer 200 kN of yield load, being very similar in load bearing capabilities.

Figure 11 and 12 showcase the results of this system 1.5 years after the rehabilitation works were complete, showing little signs of decompression.

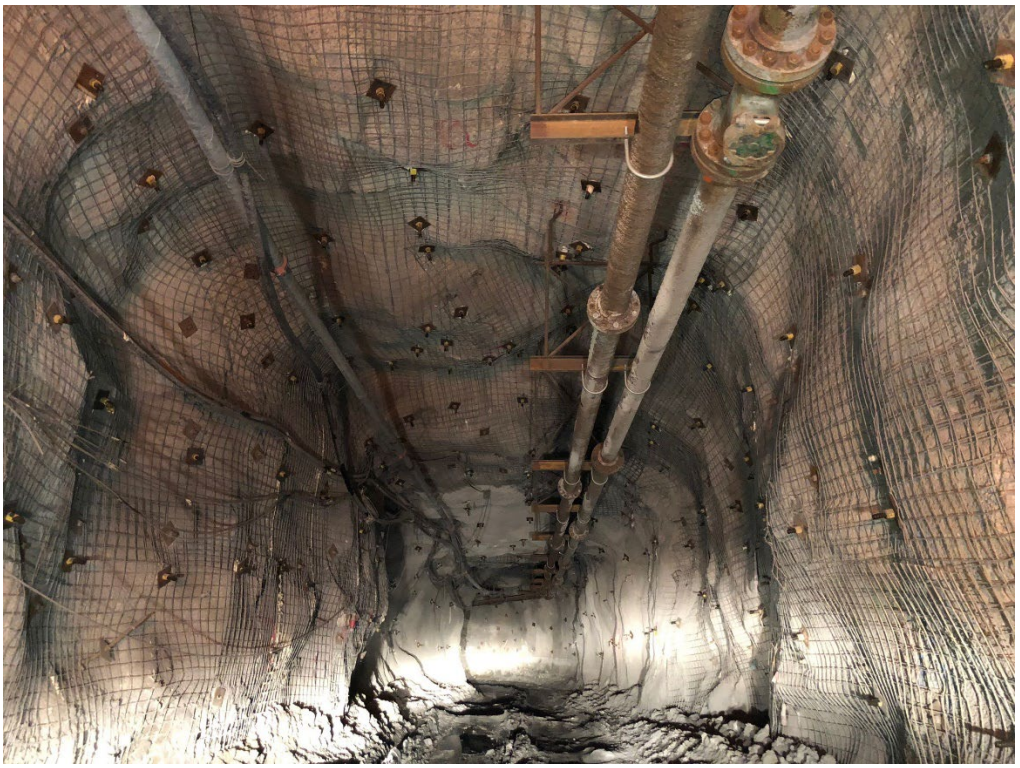


Figure 11 1.5 years after rehabilitation works: beginning of red area



Figure 12 1.5 years after rehabilitation works: end of red area

4.3 High-grade ore access

As the last case, one year after the last intervention the rehabilitation still shows no signs of instability and decompression, allowing the mining sequence to be executed without major setbacks on the geotechnical aspect.

With historical data considered, in this last year the area should have suffered 2 rehabilitations that would last approximately 2 weeks each, with a total of one month of the area being interrupted due to rehabilitation. This time was then added to the mine's cycle and allowed needed ore to be extracted.

Considering this, with an increase in 53% in upfront cost in consumables, this rehabilitation ended up being 104% cheaper – as of the writing of this document – than conventional methods, as seen in Figure 13. This graph should be read the same as Figure 10.

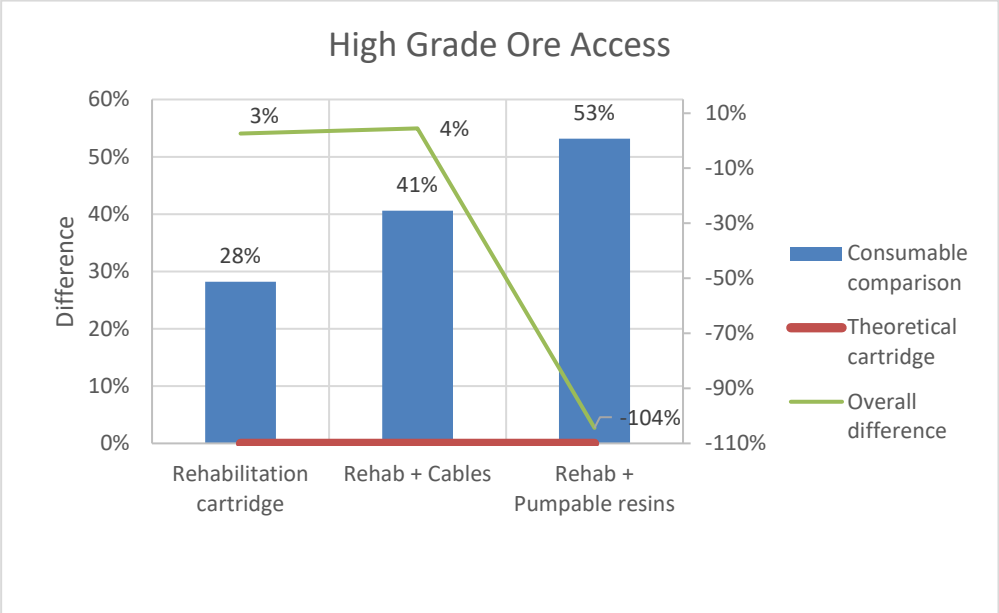


Figure 13 High-grade ore access cost comparison

Figure 14 showcases the refurbed area 1 year after the works were completed and it is possible to see no instability has occurred during this timeframe.

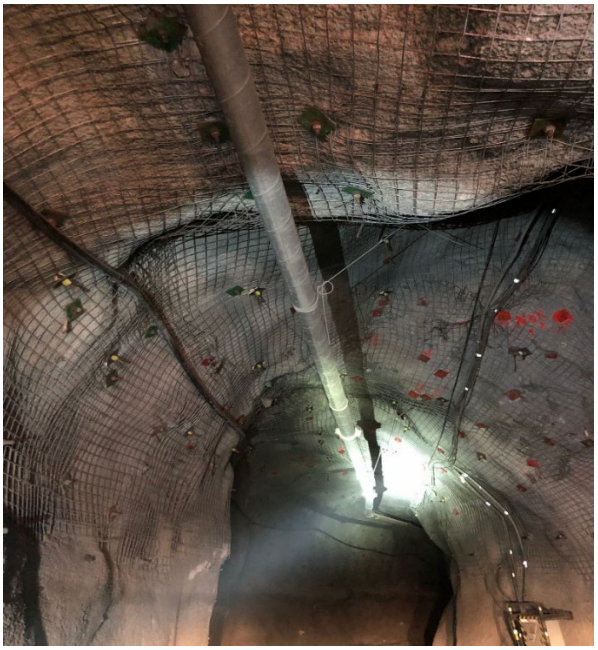


Figure 14 High-grade ore access 1 year after rehabilitation works

5 Conclusion

While the system requires a significant investment upfront, the cost savings are noticeable in the short-term and even more pronounced in the long-term.

As disclosed before, the effectiveness of this ground support method's installation speed and reliability in poor to exceptionally poor ground creates an increase in production rates and delivers rehabilitation works

significantly faster than with conventional methods due to nullifying the challenges numbered in the introduction of this document. Some conventional methods will fail faster in these types of grounds as they are out of their design intentions,

This effectiveness increase is more pronounced in the long-term as the ground support is correctly supporting the ground in which it is installed, increasing the intervals between rehabilitation works or even nullifying them all together.

One un-said aspect of the effectiveness of the system is the crew's morale and confidence while working underground. With this system in place, the crews saw the advantages of the system at the time of installation and see the long-term advantages 3 years later, having good confidence in the system and knowing that once they find Poor ground, it will be correctly supported.

For the last 3 years all sites have been monitored and haven't shown significant decompression, giving the mine ample return on investment due to correct ground support installation and allowing for the rehabilitation crew to work in new headings instead of rehabilitating the same areas almost in a cycle.

While this system is only being used in rehabilitation works, one possible improvement to help diminish these costly operations could be using the system in new development headings, where the ground requires it, to help decrease downtime due to ground support installation and increase ground support effectiveness over time.

One other improvement is decreasing the resin curing time from 180 seconds to 90 seconds. This reduction in curing time increases bolting installation speed, and a 90 seconds cure time resin is now available for trial.

One important mention is that this ground support does not intend to completely replace more conventional methods like end anchored resin rebars or cable bolts within the mine's cycle, but it gives the rock mechanic engineers more tools to tackle problems related to ground support failure due to incorrect application or to tackle poor ground.

In truth, conventional methods are 'conventional' because they work, but only reliably in the grounds for which they were designed and it is expected that they will start to fail when used outside of their scope; as it happened with the previous designs of the cases showed herein section 3, the ground support failed when subjected to the stress conditions and incorrect application.

Each ground support method should be used in its respective scope. The pumpable resin system has shown to be very effective in very poor to exceptionally poor grounds that are prone to display the challenges mentioned in the introduction of this work. The pumpable resin system is a more cost-effective method than conventional systems when employed correctly, reducing the time and cost of the refurbishment cycle, while increasing productivity of the method application and ore availability.

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