Ground Support 2019 - J Hadjigeorgiou & M Hudyma (eds)

doi:10.36487/ACG_rep/1925_41_Lee

How convincing is the quality of our resin rebar installation? A case study

O Gibbons *SRK Consulting (Canada) Inc., Canada*

C Lee *SRK Consulting (Canada) Inc., Canada*

Abstract

When designing ground support systems for a mining environment, the interpretation of technical specifications and the expected quality of installation must always be considered. These design considerations are easier to assess in an operating mine but are more difficult to gauge at an early stage of a new project. This paper is a case study on resin rebar design and installation as part of a fall of ground rehabilitation at an underground mine. The paper is focused on the design, testing, implementation, and installation of resin rebar as part of the primary ground support design. This includes the steps taken to go from a set of technical specifications to a functioning operating procedure based on the actual conditions and factors influencing the successful installation of resin rebar bolts. The operating procedures are closely related to installation equipment, in this case mechanised bolters and jackleg bolters. Quality assurance and quality control of the resin rebar installation to monitor installation quality and detect changes in the conditions are also discussed. Sample test results are presented to demonstrate possible installation and testing pitfalls.

Keywords: *ground support, resin rebar, quality control, quality assurance*

1 Introduction

An area of the North American mine discussed in this paper was recently in a state of care and maintenance following a 2,500 t fall of ground (FOG) event. Following the FOG, SRK Consulting (Canada) Inc. conducted a detailed geotechnical study of the crown pillar and concluded that the FOG was in a temporary state of stability, but the perceived risk of further instability still existed.

The underground mining activities in other areas of the mine were not expected to impact the crown pillar stability and the risk to personnel was managed by establishing a ground monitoring plan and evacuation procedures. However, the ongoing instability of the FOG remained a possibility that could ultimately put the mine and asset at risk due to its large span and proximity to a lake on surface.

Rehabilitation of the FOG area was the recommended approach to secure the crown pillar and to mitigate the risk of further instability. The FOG Rehabilitation Project was developed for the long-term stabilisation of the mine in a safe and practical way.

The project required support installation in the back and walls to a standard that is comparable to that of a civil engineering project. A rigorous quality control and quality assurance plan was implemented. As part of this rehabilitation project, over 6,300 resin rebar bolts were installed over a six month period using mechanised rockbolting machines and jackleg drills.

The effectiveness of the resin rebar bolts can be affected by sub-standard installation practices. Villaescusa et al. (2006) investigated the performance of resin rebar bolts through overcoring testing and found variability in load transfer along the length of individual bolts as a result of variable quality of resin mix along the length of the bolts. Potvin et al. (1999) discussed the difficulties in controlling the quality of the resin rebar bolts that resulted in ground falls at the Mount Isa Mine. Controlled field testing prior to full-scale bolting campaign and utilisation of standard installation procedures were recommended to improve the consistency of resin rebar bolt performances.

This paper presents the experiences that the authors learned from providing onsite engineering support for the FOG Rehabilitation Project with a focus on the design, testing, implementation, and installation of resin rebar as part of the primary ground support design. This included the steps taken to go from a set of technical specifications to a functioning operating procedure based on the actual conditions and factors influencing the successful installation of resin rebar bolts.

Quality assurance and quality control of the resin rebar installation will also be discussed. The aim is to encourage the readers to review currently accepted practices and check that the resin rebar system performance is meeting the design criteria.

2 Implementation of resin rebar design

Installation of resin rebar involves inserting resin cartridges in a drilled hole, then spinning the rebar bolt into the resin cartridges. As the rebar bolt is spun in, the plastic sheaths of resin cartridges break and the contents fill the gap between the rebar bolt and the surrounding rock while mixing to produce a chemical reaction that sets the resin. Resin provides minimal cohesive anchoring force but relies on the irregularities of the drilled hole and the rebar ridges for transferring of loads from the rock to the rebar bolt.

The performance of the resin rebar is affected by parameters that are decided during the engineering designing stage, which include:

- Drillhole diameter and length.
- Resin and rebar configuration.
- Installation equipment and procedure.

These design parameters are typically guided by generalised recommendations provided by the product manufacturer or past experiences of the personnel involved in the project. Testing of these parameters should be completed in the project-specific environments prior to large-scale implementation to optimise the performance of the resin rebar. This section discusses the aspects that were investigated during the rehabilitation project for these design parameters.

2.1 Drillhole requirements

The drillhole size and length requirements are dependent on the dimensions of the rebar that is chosen to provide the necessary ground support embedment and yield strength. DSI Underground (2017) recommends that the annular space (annulus) between the rebar and the hole should not exceed 6−10 mm. The risks of oversized drillholes are shortened encapsulation length and poor mixing of resin, which will reduce the bond strength. Undersized drillholes can result in difficulties during bolt installation and insufficient thickness of resin to allow transferring of loads.

As a guide, it has been the experience of the authors that the hole should be drilled to a length that is 50 mm shorter than the rebar length. This is to allow for a sufficient length of threaded section of the rebar bolt to stick out of the hole for an effective installation of a plate washer. The resin rebar design for the rehabilitation project consisted of 2.4 m long and 22 mm diameter rebar. Based on these dimensions, holes for the bolts were designed to be 2.35 m long and 34 mm diameter.

The diameter of drilled holes is controlled by the size of the drill bit, but is also influenced by the ground conditions. The hole diameter can be significantly larger than the bit size in weak rocks that are susceptible to overbreak. Rock masses that are highly jointed may result in significantly irregular hole wall conditions that cause difficulties in loading resin cartridges and inserting the rebar.

Test holes should be drilled and inspected to ensure the hole condition is adequate and the diameter is as expected. If the rock mass varies across a site, testing should be done to ensure all rock types are represented. In this case study, a borehole camera was used to inspect the test holes that were drilled with varying bit sizes and it was found that a bit size of 33 mm was required for an average hole diameter of 34 mm. A 34 mm bit was found to produce a hole that was too large, causing an annulus that was too large.

Figure 1 shows borehole camera images from four different drillholes that were drilled using a mechanised rockbolter with a 33 mm drill bit. Although the holes were drilled in the same rock type, the wall condition and the hole diameter were variable in the presence of geological features such as discontinuities.

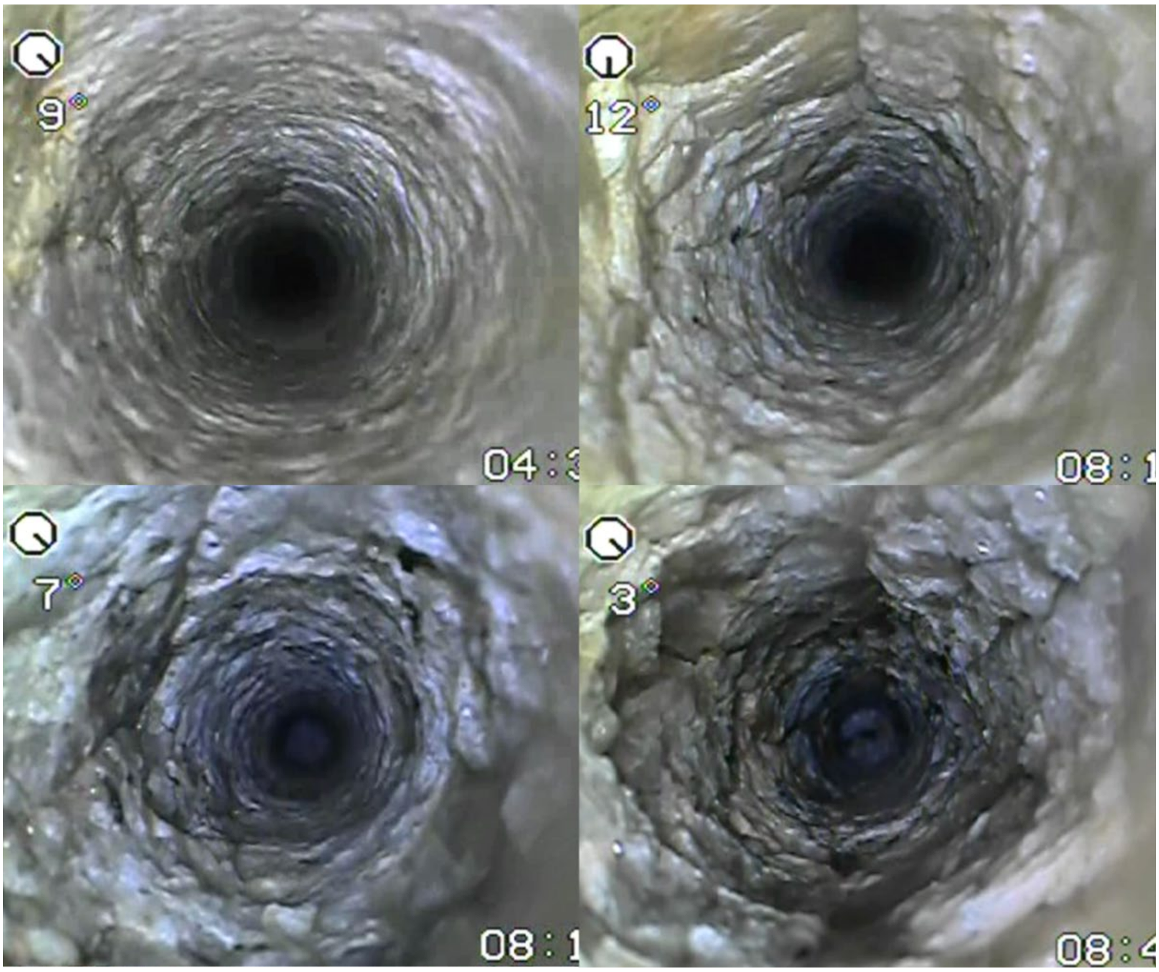


Figure 1 Variability of drillhole conditions; all holes were drilled using 33 mm diameter drill bits in the same rock type

2.2 Resin requirements

Various resin combinations can be used to achieve specific results when installing rebar. In this case study, there was a need to tension the installed rebar bolts. This was achieved with the use of a combination of fast-setting resin at the toe of a hole, and slow-setting resin in the remainder of the hole (Hoek et al. 1995).

The fast resin sets quickly and locks the rebar in place, thus as the plate washer is tightened, it tensions the rebar. The slow resin then provides encapsulation along the remainder of the bolt after it has been tensioned and the resin must be sufficiently slow-setting to allow the plate washer and nut to be installed and the bar tensioned before the resin sets.

DSI Underground (2017) specifies that as a general guideline, when bolts are to be tensioned, fast-setting resin should be used at the toe of a hole for ⅓ the bolt length (minimum 610 mm). Slow set resin is used for the remaining ⅔ length to fully encapsulate a bolt.

DSI Fasloc X-treme resin was used in the case study rehabilitation project. Both slow and fast resin cartridges were 25 mm in diameter and 457 mm in length. A 30 second fast resin and a 130 second slow resin set times were used as a baseline configuration, as had been recommended by the manufacturer. This configuration was maintained in installations performed using a mechanised rockbolting machine, but was adjusted for use with a jackleg to account for its slower rebar insertion and drill rotation speed, as is described in Section 2.3.

The two different resins had slightly different packaging, making it easier for an operator to visually keep track of consumables, as well as for quality control observations. Based on the size of the resin capsules, seven capsules were required in installations of 2.4 m long, 22 mm diameter rebar. In this case, two fast resin capsules and five slow resin capsules were used. It was decided that this was the closest ratio to that which was specified as best practice.

It is recommended that resin cartridges are selected to be of a size that is appropriate for filling the required volumes without the need to be cut or adjusted for volume in the field. Partial resin cartridges were used in special circumstances during the rehabilitation project, but this is not considered best practice.

2.3 Installation testing

The installation procedure of resin rebar is closely related to the installation equipment and installation environment. The FOG Rehabilitation Project utilised mechanised rockbolting machines and jackleg drills to install resin rebar bolts on to the back and vertical walls, respectively. Both types of installation equipment are capable of installing resin rebar but require separate installation procedures and resin setting time configurations due to the difference in the methodology of loading the resin capsules into the hole, drill rotation speed, and rebar insertion rate. Trial installations were conducted to investigate the latter two factors and to establish appropriate spin and hold times.

DSI Underground (2017) recommends 30 to 40 rotations of the rebar to adequately mix the resin. Villaescusa et al. (2008) noted that poor resin mixing is the main cause for low load transfer. Underspinning will cause inadequate mixing, and overspinning will destroy the resin as it sets by breaking the early internal resin bonds. Both cases result in insufficient resin strength. Furthermore, the resin set-time should be compatible with the installation equipment's rotation speed as the required number of rotations should be achieved well within the resin set-time.

The mechanised rockbolting machine and jackleg were tested for drill rotation speed and insertion rate by instructing the operator to load the resin cartridges, push the rebar bolt into the hole as quickly as possible while spinning at a lower rate, then spin at the maximum speed once the rebar reached the toe of the hole. Multiple trial installs were video-recorded to allow for slow-motion video review of rotation speed and number of rotations in the fast and slow resin cartridges placed in the drillhole.

The outcome of the trial installations was that two sets of resin configurations were required due to the slower rotation speed and insertion rate of the jackleg. It was specifically the slow insertion rate of jackleg that caused underspinning of fast resin and overspinning of slow resin. For jackleg installations, a low rotation speed for the first ⅔ length of hole was specifically highlighted to avoid overspinning of the slow resin.

The installation environment also plays a role in developing an installation procedure. Of note is the sensitivity of resin to temperature. DSI Underground (2017) states that set times are based on chemical reactions at 13°C and a 10°C rise in temperature reduces the set time by approximately 50%, and 10°C drop in temperature will approximately double the set time. A colder temperature also increases the viscosity of resin that may be of concern when installing longer bolts using hand-held equipment.

The last step towards implementation of resin rebar was pull testing. The short encapsulation pull tests, as discussed by Mark et al. (2002), were conducted to confirm that the resin rebar installed using the chosen drillhole requirements, material specifications, and installation procedures would result in resin rebar that meets the project design criteria of 10 t of pull-out strength for every 305 mm length of resin encapsulation.

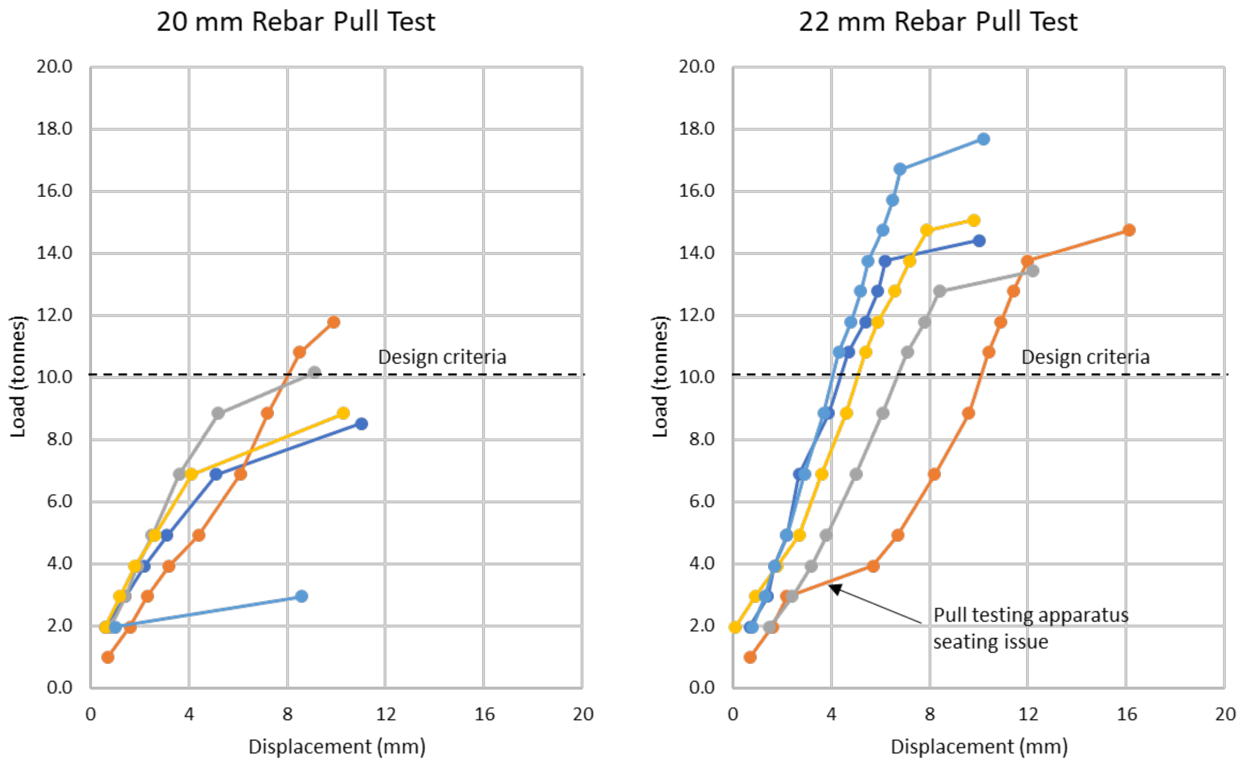
In the case study, the resin rebar configurations were confirmed by short encapsulation pull tests where only the fast-setting resin is installed at the end of the hole to provide one foot (305 mm) bond with the rebar. Figure 2 presents example pull test results of five 20 mm rebar bolts and five 22 mm rebar bolts that were installed in 34 mm holes using the mechanised rockbolting machine. The five 22 mm rebar bolts were capable of holding loads that exceeded 13 t, whereas four of five 20 mm rebar bolts failed prior to loads reaching

10 t. The 20 mm rebar bolt installation test was considered inadequate and additional tests were conducted to determine suitable installation configuration and procedures. As a reference, former US Bureau of Mines' extensive study of resin bolt anchorage considered 90% passing rate as adequate for determining the minimum anchorage lengths (Mark et al. 2002).

The optimal rebar size, drillhole diameter, and spin and hold times for installations using mechanised rockbolting machine and jackleg drill at the case study mine are presented in Table 1.

Table 1 Resin rebar configurations used for fall of ground (FOG) Rehabilitation Project

Install equipment	Rebar size	Drillhole diameter	Resin set time	Spin/hold time
Mechanised rockbolting machine	22 mm (#7)	34 mm (using 33 mm bit)	30 sec fast, 130 sec slow	9 sec/15 sec
Jackleg drill	20 mm (#6)	33 mm (using 32 mm bit)	60 sec fast, 130 sec slow	25 sec/70 sec *Low rotation speed for the first ⅔ length of hole



(a) (b)

Figure 2 Pull test results of (a) 20 mm and (b) 22 mm rebar bolts installed in 34 mm drillhole using mechanised rockbolting machine

3 Quality control and quality assurance of resin rebar installation

3.1 Quality control

All aspects of resin rebar bolt installation should be checked throughout a project. Performing quality control at the introduction of new elements does not guarantee that the installations are being performed to specification throughout the installation process. This section discusses the focused areas, documentation, and tests that were conducted during the rehabilitation project.

3.1.1 Focus areas

The following areas of materials and installation procedures were crucial to the quality control process and therefore the successful installation of the resin rebar:

- ***Materials specifications***: The correct materials must be used. As there are often several variations of the same materials onsite, such as bolts of different lengths or diameters, the specifications of the bolt must be checked before being installed.
- ***Material condition***: The condition of materials must be checked as materials may be expired, weathered, or otherwise damaged. New shipments of materials should be checked regularly as it has been the experience of these authors that suppliers may ship incorrect materials.
- ***Hole diameter***: The bit size does not equate to hole size. A new bit will have a specified diameter, but the use of a bit will wear the bit down with a rate of wear dependant on the rock mass in which it is used. Hole overbreak will also affect the required drill bit diameter. Bit diameter should be checked on a regular basis by both operators and quality control personnel to ensure bits are replaced regularly. Undersized bits could cause undersized holes, which in turn will affect the resin annulus between the hole walls and bolt itself.
- ***Hole length***: The drillhole must be of a sufficient length to allow for full encapsulation to ensure that the full length of rebar bolt is providing active support. A hole should not be over-drilled as this could cause resin quantities to be insufficient. In the case study project, a paint mark was a simple method of marking the required drill length with the use of jackleg drills. It was found that a pin could be adjusted on the older mechanised rockbolting machines to limit the depth to which drill steel could be extended to ensure that holes were not over-drilled.
- ***Resin temperature:*** The quality of resin rebar installations was affected by the installation environment and colder surface weather conditions. This factor was critical when using the jackleg as the resin temperature had to be controlled to avoid installations that would result in rebar unable to be fully inserted into the hole or rebar nut shear pins breaking prematurely. Resin cartridges were kept in a heated storage area and inside insulated containers at the working face to ensure that installations were done with the resin at an optimal temperature.
- ***Air pressure***: Another installation environment factor encountered was the fluctuation of mine air service pressure during jackleg installations. Lower than required pressures resulted in poor mixing of resin due to slower drill rotation speed. An additional air pressure regulator was installed and monitored to ensure a constant feed of air was provided to the drill.

3.1.2 Monitoring documentation and testing

Ongoing monitoring documentation and testing of key elements of the resin rebar installation process were critical for quality control. These elements included:

- ***Spin and hold time:*** Documenting spin time and hold time helps ensure that installation procedures are being followed by the operators. It also allows the identification of poorly installed bolts and rapid remediation of non-conformances. Documentation proved to be useful during the rehabilitation project when a batch of inert resin capsules were accidently used for installations. The project team was able to easily isolate the impacted area and install replacement resin rebar bolts.
- ***Spanner test:*** As part of the quality control program, spanner tests were performed to ensure that the shear pins in the nuts on the rebar bolts were broken and plate washers were tensioned. The initial intent was for these to be performed immediately after installation, but it was found that due to the need for high-lift equipment to reach the installed bolts, it was easier to schedule testing to be conducted over larger areas. A wrench was used to check that nuts were tight on bolts. Approximately 10% of all installed bolts were tested and 1% of the bolts tested failed this

test. A failed test would initiate additional tests in the surrounding bolts to ensure that there is no trend in poor installation quality.

- ***Pull test:*** Another quantifiable means of quality control is a pull test program. For the FOG Rehabilitation Project, a short encapsulation non-destructive pull test program was designed to ensure that the required bond strength of resin was being achieved throughout the project. Pull tests were not conducted on full encapsulation installations as the bond strength of full column resin would typically exceed the ultimate yield strength of the rebar bolt. The testing frequency was outlined as once every week if more than 500 resin rebar bolts were installed during the specific week, or once every two weeks if less than 500 resin rebar bolts were installed during a single week. Each pull test involved testing of five resin rebar bolts, each installed using a fast-setting resin capsule that would provide approximately 305 mm encapsulation at the toe. Testing was conducted on full length rebar. The test was considered successful if all five bolts were able to hold a load exceeding 10 t. A failed pull test set would trigger an investigation and corrective actions would be implemented. Fifteen sets of tests were conducted during the FOG Rehabilitation Project and all produced successful results.

3.2 Quality assurance

Many sites and projects will establish a comprehensive quality control program, but will not follow up on this program to ensure that the testing is performed correctly and that the data being collected are accurate and representative. This section describes the main aspects reviewed by the quality assurance personnel for the rehabilitation project.

3.2.1 Observations

Observations made during the drilling and resin rebar installation process helped ensure that quality control data were accurate. The following were aspects of observations:

- ***Drilling practice*** was observed to check for the size and wear on the drill bit and ensure that the drillhole length controlling measures are in place. The drill should be oriented perpendicular to the excavation profile and cuttings should be observed to be flushed out during the drilling process.
- ***Bolt installation process*** was video-recorded on occasion by quality assurance personnel to aid in observations. An installation video could be slowed down to help identify issues, and spin times and hole times could be measured more accurately. The materials for installations were monitored to ensure that the correct type and quantity were being used.

3.2.2 Visual inspections

Visual inspection of installed resin rebar was key in identifying larger-scale issues than those observed by the quality control personnel, or things missed in the quality control process. The following were aspects of visual inspections:

- ***Bolt spacing and bolt orientation*** were items that were difficult to quantify as there were no instruments to measure these aspects of the installation during the installation. It is likely that the bolt is not pre-tensioned properly when it is not installed perpendicular to the rock surface.
- ***Length of rebar sticking out of hole*** was a check to ensure that bolts were protruding the correct amount out of the rock surface. While there were checks on the bolting machines to aid in drilling correct length holes, there were occasions where these did not suffice, or other issues caused bolts to protrude too far. If an excessive length of bolt was protruding, the threaded section of the rebar bolt would stick out of the hole collar and not allow the plate washer to push against the rock surface. The cause of a bolt protruding too far was not always known, but it was a clear indication of an error in the installation.

4 Discussion

One of the most important variables are the rock mass characteristics and rock conditions into which ground support is installed. Different rock types will behave differently. In this case study, layered rock which had been exposed for many years was encountered in the crown pillar rock mass. The separation between slabs often caused tears in resin cartridges. This would not have been an issue in soft rock, intact rock, or possibly layered rock that had been freshly blasted.

Weathering and the opening up of discontinuities may not be the only things to play a role in ground support installation. Old excavations may also have old support installed. This old support could make it difficult for equipment to access and install new support. For example, the presence of corroded welded wire mesh could prevent even and effective application of shotcrete to a rock surface, or broken bolts could damage resin cartridges during the installation of new resin rebar. The specifics of each excavation must be assessed when designing ground support elements, installation procedures, and quality assessment criteria.

Another critical requirement in this project was that the ground support design and implementation approach had to manage the risk related to the rehabilitation of a large FOG. This area also had a span much larger than most conventional mine workings. A mining contractor had been selected to perform the work, but at times there was difficulty in ensuring that the contractor management team, and their underground personnel, understood the purpose of the strict installation protocols and the required level of quality control. In an industry where underground personnel are often paid on the basis of a quantifiable value such as metres developed or t moved, there was a cultural change that was difficult to instil in the short project time span to promote a focus on quality rather than quantity of installations.

In selecting a contractor team, it is important to assess the experience the contractor has with similar projects and specifically understands the project risks and risk management strategies. A misunderstanding of the scope or purpose of a project approach could lead to schedule and cost overruns throughout the project. This applies not only to the contracting company, but also to the specific personnel onsite, since a company will often have multiple projects and multiple project teams with different experience and expertise working on different projects.

Quality control is important in a project, especially when working on a new project or non-standard application, with a new project team or contractor. Furthermore, quality assurance is important to verify that there is no complacency in quality control approaches. An observation that had been made during this rehabilitation project was that regular quality control assessments would often assume that correct materials were used and procedures were followed. Quality control should not be a paper exercise of ticking boxes. It must involve thorough physical checks and measurements.

5 Conclusion

Ground support systems for a mining environment must be designed to high level technical standards, but there are several field considerations that must not be ignored to ensure that these standards are attained. The interpretation of technical specifications can be just as complex as the initial support design stage. This paper discussed the pitfalls of transferring technical specifications to appropriate operating procedures experienced by the authors at an elevated risk FOG Rehabilitation Project, with specific reference to the installation of resin rebar bolts as part of primary ground support.

The implementation of a reliable resin rebar support system required an investigation into drillhole and resin requirements. Test installations were found to be key in finalising the selection of materials and fine-tuning installation procedures.

Quality control and quality assurance were also important aspects in identifying problems in ground support installations following the implementation of finalised operating procedures. It is the authors' opinion that resin rebar installation procedures and accepted practices at well-established mines could also benefit from a thorough review of topics discussed in this paper.

Acknowledgement

The authors would like to acknowledge the personnel involved in the FOG Rehabilitation Project. While the site has chosen to remain anonymous, we would like to thank Nico Viljoen and Bruce Murphy of SRK Consulting (Canada) Inc. for their invaluable experience and input throughout the project.

References

DSI Underground 2017, DSI Underground Mining and Tunneling Products Catalogue, catalogue, viewed 15 April 2019, https://www.dsiunderground.ca/fileadmin/downloads/dsi-underground-canada/dsi-underground-americas-mining-and-tunneling-products-catalogue-us.pdf

Hoek, E, Kaiser, PK & Bawden, WF 1995, *Support of Underground Excavation in Hard Rock*, A.A. Balkema, Rotterdam.

Mark, C, Compton, C, Oyler, D & Dolinar, D 2002, 'Anchorage pull testing for fully grouted roof bolts', National Institute for Occupational Safety and Health, Pittsburgh National Laboratory.

Potvin, Y, Tyler, DB, MacSporran, G, Robinson, J, Thin, I, Beck, D & Hudyma, M 1999, 'Development and implementation of new ground support standards at Mount Isa Mines Limited', in E Villaescusa, CR Windsor & AG Thompson, *Rock Support and Reinforcement Practice in Mining*, A.A. Balkema, pp. 367–371.

Villaescusa, E, Thompson, A & Windsor, C 2006, 'Some ground support considerations in rapid excavation for mining development', *Proceedings of the 2006 Australian Mining Technology Conference*, The Australasian Institute of Mining & Metallurgy, Melbourne.

Villaescusa, E, Varden, R & Hassell, R 2008, 'Quantifying the performance of resin anchored rock bolts in the Australian underground hard rock mining industry', *International Journal of Rock Mechanics and Mining Sciences*, vol. 45, iss. 1, pp. 94–102.