Caving 2022 - Y Potvin (ed.)

doi:10.36487/ACG_repo/2205_34

A monitoring strategy to assess the effectiveness of pillar wrapping

Y Yanagimura *New Gold Inc., Canada*

J Hadjigeorgiou *University of Toronto, Canada*

Abstract

Pillar wrapping using cable slings is an increasingly popular ground support strategy to control large deformations in block cave mines. Although installation can be relatively costly and labour intensive, pillar wrapping is attractive as it is more effective than other ground support options. This is due to the greater elongation capacity of cable slings compared to other ground support elements. At this time, however, the performance of pillar wrapping in block cave mines is mostly anecdotal and based on limited quantified performance data.

This paper presents a data-driven monitoring strategy to assess the performance of pillar wrapping at the New Afton Mine. The mine currently employs cable slings to support the junctions between the production drives and drawpoints in the B3 mining area. In a field investigation, as part of the pillar wrapping strategy, instrumented cable bolts have been installed to directly monitor the strain and loads that develop in the pillar wrapping support system during the cave initiation and propagation. The analysis of the cable instrumentation data provides for a data-driven approach for understanding the performance of the cables used for pillar wrapping. An objective of this investigation is to provide quality data to aid the mine to make informed cost-benefit decisions in its ground support decisions.

Keywords: *pillar wrapping, instrumented cable slings, ground support, block cave extraction level support*

1 Introduction

The use of cable slings, interchangeably called cable straps, for pillar wrapping is an increasingly popular ground support strategy utilised in block caving mines. Each sling consists of a seven-wire strand cable of variable length to strap the excavation surface. While there are a few ways in which a sling can be installed, they usually involve grouting one tail of a cable for anchoring, extending the remaining free length of the cable along the excavation and secured to a second cable using a connector block and grips. The slings can be tensioned with a cable bolt tensioner to a specified jack load. This results in an immediate support pressure against the rock mass to confine and hence preserve some of the self-supporting capabilities of a pillar. Installation can be relatively costly and labour intensive compared to other ground support system. However, due to the superior elongation capacity of strand cables, cable slings are generally considered as more effective than other ground support elements in squeezing ground as well as rockburst prone conditions.

In block cave mines, cable slings have been widely used for pillar wrapping at the extraction level. In this context, pillar wrapping refers to the application of cable slings for supporting the drawpoint corners at the junction between the production drives and drawpoints. These areas are prone to the damaging impact of induced stresses during the caving process (Laubscher 2000). The installation and the effectiveness of cable slings used for pillar wrapping has been documented at several cave operations (e.g. Jakubec 1992; Flores 1993; Wilson & Talu 2004). At this time, however, the performance of pillar wrapping in cave mining applications has been largely limited to observations and anecdotal evidence.

A comprehensive instrumentation system is critical for understanding the in situ behaviour and performance of a ground support system and make informed cost-benefit decisions. In a field investigation at the New

Afton Mine, instrumented cable bolts have been installed, as part of the pillar wrapping strategy, to directly monitor the strain and loads that develop in the pillar wrapping support system during the stages of cave initiation and propagation. The analysis of the cable instrumentation data can provide an improved understanding of the in situ performance of pillar wrapping used at block cave mines.

2 New Afton Mine – B3 mining area

New Afton Mine is a Canadian block caving mine operated by New Gold Inc., located 10 km west of Kamloops, British Columbia. The mine is developing the B3 and C-Zone mining areas, which will represent the major production sources over the next decade. The B3 extraction level is located approximately 760 m below surface and 160 m below and immediately west of the Lift 1 (B1 and B2) panel caves that are in final stages of the cave (Figure 1). The extraction level for the B3 mining area is currently under construction and a full production rate of approximately 8,000 tonnes per day is anticipated in the first half of 2023.

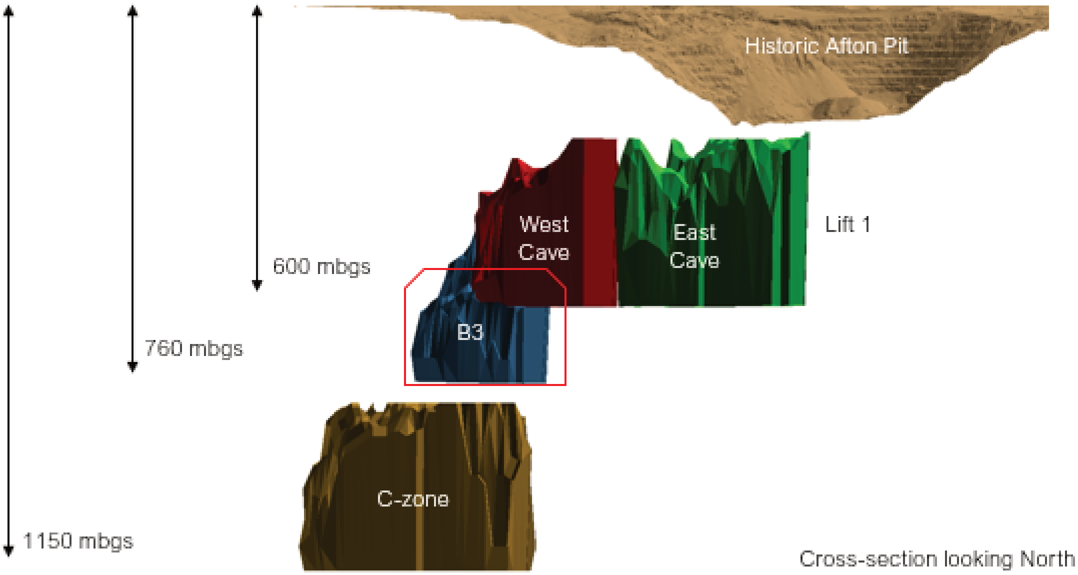


Figure 1 Overview of New Afton block cave mine

B3 extraction level utilises the El Teniente layout with four main production drives. The distance between the production drives is 27 m, measured centre to centre. The drawpoint drifts intersect the production drives every 16.5 m at an angle of 56°. There are 65 drawbells on this level, of which 24 are one-sided bells with a single drawpoint. The design cross-sectional profile of both galleries is 4.5 m wide by 4.3 m high. Developed above the extraction level, the B3 undercut level layout consist of five parallel drives separated by 13.5 m wide pillars, measured centre to centre. With the implementation of the advanced undercutting technique in B3, the drawpoint drift development trails behind the cave front such that the undercut destresses the rock mass in the extraction level prior to the start of drawbell construction.

The lithology in the B3 extraction level consists of a primarily volcanic fragmental breccia unit (BXF) with monzonite and diorite intrusions to the southwest and picrite to the south. Face mapping inspections have found that the rock mass encountered during the development of the extraction level to be in the RMR_{89} range (Bieniawski 1989) between 47 and 56, which classifies as fair to poor quality. Similar to the experience in the Lift 1 extraction levels, low quality rock mass has been observed to be largely associated with fault structures that intercept the B3 extraction level. There are regional structures that strike subparallel to the production drives on the outer boundaries of the extraction level and local extensional features that intercept some of the drawbells obliquely (Figure 2). The presence of these faults and orientations are corroborated by face mapping during the development of the production drives.

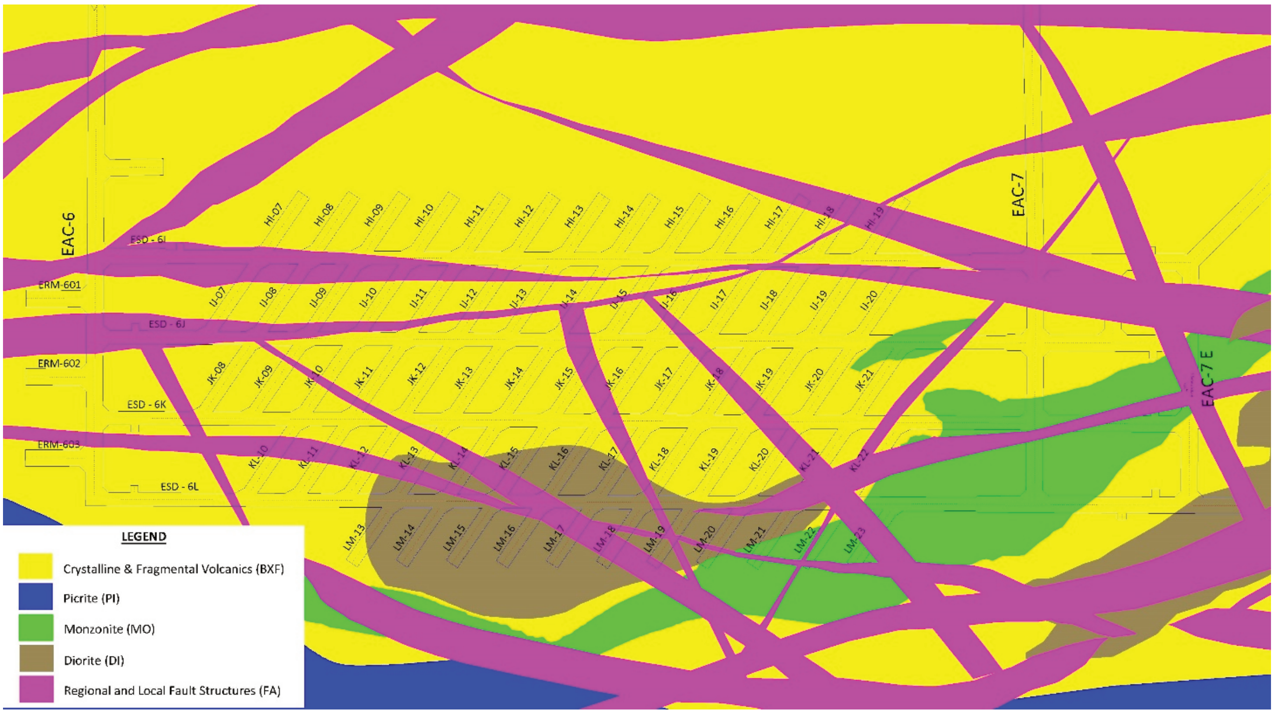


Figure 2 Geological map of B3 extraction level

2.1 Ground support design in B3 extraction level

The mine draws on multiple sources of information such as fault and shear structures present at the extraction level, rock mass characterisation, and numerical modelling results for the B3 cave, to reliably predict which drawpoint pillars may be impacted in advance of drawpoint drift development. The ground support design for this level entails the implementation of different ground support standards based on the predicted pillar condition. The ground conditions are reassessed through face mapping inspections conducted during drawpoint development (Figure 3). For pillars that have been found to be at high risk for early onset of deformation, pillar wrapping of the drawpoint corners is issued as part of the ground support.

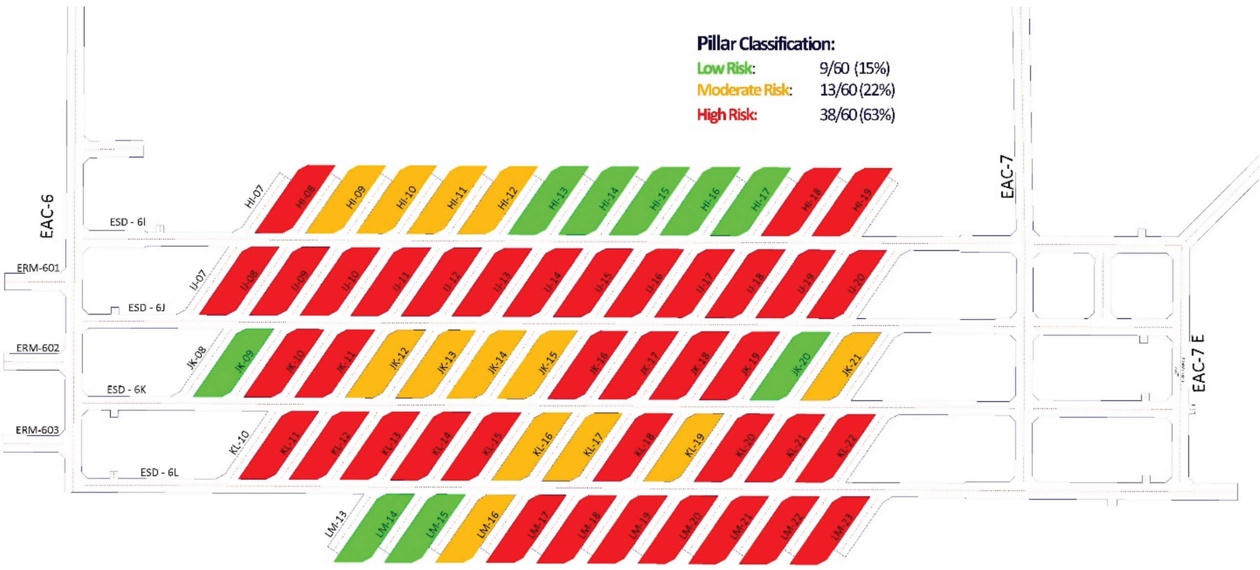


Figure 3 Pillar risk classification for B3 extraction level

Primary ground support, installed during the development stage, entails a first pass 75–100 mm of fibre-reinforced shotcrete, six-gauge welded wire mesh pinned with 2.4 m D bolts, 2.4 m MD bolts or 2.1 m hybrid bolts installed at 1 m effective spacing. The construction of the drawpoints trails behind development and begins immediately after the primary support installation is complete. The construction crew installs the secondary support system. Three rows of modified geometry cable bolts are installed in the walls and back at 1.4 - 1.5 m ring spacing. Self-drilling hollow bars are also installed at the sill to control low wall deformation. OSRO straps are installed along the long support, oriented parallel to the drift. If pillar wrapping has been issued, three rows of cable slings are installed over the OSRO straps along the drawpoint corners, both on the bullnose and camelback pillars. Cable bolts are fitted with a guide washer plate over a flat plate to pin the cable slings on the walls. Once the secondary support installation is complete, a second pass of fibre-reinforced shotcrete is sprayed to cover the walls to protect the support from equipment damage. A plan view of the pillar wrapping support system employed at the B3 extraction level is shown in Figure 4.

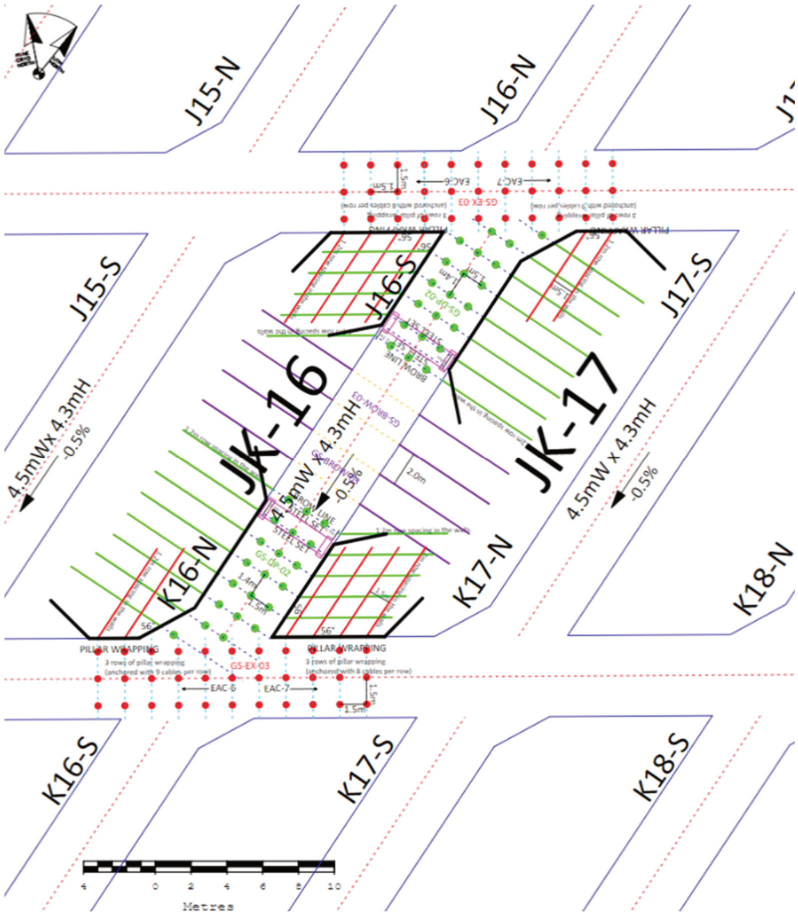


Figure 4 Pillar wrapping strategy adopted for pillars classified as high risk

3 Pillar wrapping applications in block cave mines

One of the earliest documented uses of pillar wrapping in block caving mining dates back to the 1970s. At the Shabani asbestos mine, located near Zvishavane, Zimbabwe, 70 ton Koepp hoisting ropes were successfully used for pillar wrapping to stabilise areas approaching a state of collapse (Laubscher 2000). Early versions of pillar wrapping utilised ropes, rather than cables, to apply lateral confining pressure against the excavation surface. Ropes were installed horizontally along the excavation with both ends grouted toward the pillar centre. Although difficult to install tightly against the excavation surface, they have been found to be effective for reinforcing critical parts of pillars. In effect, ropes function as a passive support system, whereby the onset of pillar deformation is a prerequisite for tension and load to develop in the ropes.

Cassiar Mine was a chrysotile asbestos mine located in Northern British Columbia with a block caving operation from 1990 to 1992. The ground support used as part of the development and rehabilitation of 1350 (North and South) production level has been documented by Jakubec (1992). Pillar wrapping was used at the extraction level to support the drawpoint corners to cater for the increased spans at the junctions. Through its operation, the pillar wrapping strategy used at the mine evolved based on observed performance. During earlier stages of drawbell development in the 1350 North level, two to four rows of 25 mm fibre-core ropes were installed horizontally along each 65° drawpoint corner with both ends grouted 3 m into the pillar. The ropes were later replaced with 16 mm cable bolts for the subsequent development of the 1350 South level to improve on the efficiency of the pillar wrapping support system, particularly to allow for pre-tensioning of the system. Seven rows of cables were installed on each drawpoint pillar in a configuration shown in Figure 5. Cassiar found success using this installation method for the most part, although it was found to be less effective when installed for rehabilitation purposes.

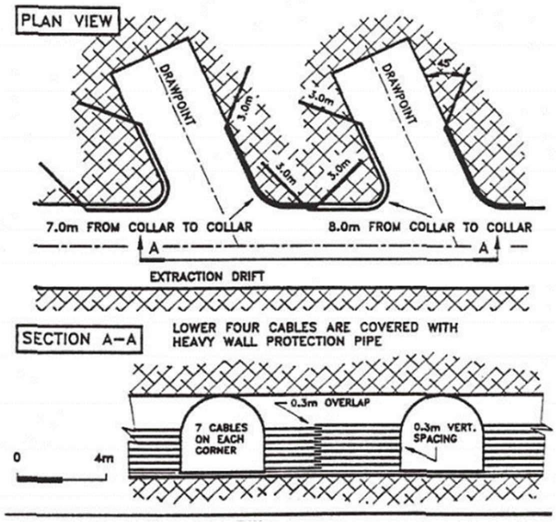


Figure 5 Pillar wrapping at the Cassiar Mine used in 1350 South level (Jakubec 1992)

El Teniente block caving mine was also one of the early proponents the pillar wrapping support system. Pillar wrapping system was incorporated into extraction level support design for Teniente-4 South sector, which was mined from 1982 to 2017 using the panel caving retreat method (Codelco 2017). The pillar wrapping support system was part of the permanent secondary support, which was installed approximately 50 m from the development face. It consisted of a 100 mm thick layer of shotcrete placed over chain-link mesh, 8 m to 10 m back cable bolts and pillar wrapping cable slings installed over the drawpoint corners (Flores 1993). Four rows of cable slings were installed on each pillar using connector blocks and pre-tensioned to 9 tonnes. The configuration of the pillar wrapping system used at El Teniente-4 South sector is shown in Figure 6.

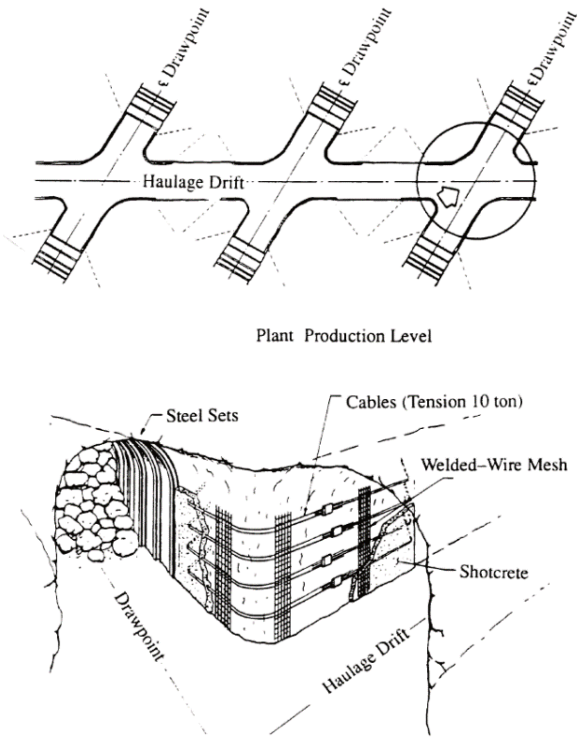


Figure 6 Pillar wrapping at the El Teniente mine used in Teniente-4 South sector (Flores 1993)

The use of cable or rope slings on drawpoint corners has been recommended by Laubscher (1994), given the importance of effective lateral constraint on the rock mass. Pillar wrapping has been installed at several active block cave mining operations, including El Teniente (Cachapoal, Chile), Palabora (Limpopo, South Africa), Finsch (North Cape, South Africa), Northparkes (New South Wales, Australia), Argyle (East Kimberly, Australia), New Afton (British Columbia, Canada) and Oyu Tolgoi (South Gobi, Mongolia) mines to control large deformations in the extraction level. A summary of pillar wrapping systems adopted at these mines is presented in Table 1.

Pillar wrapping, commonly used for supporting the drawpoint corners, can also be used to support the excavation back. The most popular installation technique for pillar wrapping utilises connector blocks and grips to connect and tension cables with the other tail end grouted into the rock mass. Using the connector blocks, the tension applied to the cable slings can be controlled with precision using a cable bolt tensioner. The cable slings are typically tensioned to a load between 5–8 tonnes. The cable slings are also pinned to the excavation surface using short support (i.e. resin rebar bolts) or long support (i.e. cables) plated with custom guide washers to secure the cable slings in place but allow them to move freely through the washers.

Pillar wrapping can be used as part of the initial ground support installed during the development of the production drives and drawpoints. It can also be used for rehabilitation of damaged pillars. In general, it has been found that pillar wrapping is less effective when used for rehabilitation purposes as the rock mass is already in post-peak state. Extreme loading of the pillar wrapping system can cause the system to fail at the connector block or, in some instances, exceed the breaking strength of the cable. Applying shotcrete over the installed pillar wrap cables have been observed to result in point loading on the cable slings and/or cause seizing at the connector blocks. Consequently, at some mine sites, the exposed segments of the cable slings are protected using a pipe covering and/or greased before spray to mitigate these issues. Nevertheless, the general observation and consensus is that cable slings provide very high support resistance and allow the load to be distributed between adjacent tendons along the strap (Wilson & Talu 2004). The large yielding capacity of the pillar wrap cables also allows the rock mass to become de-stressed without disintegrating.

Table 1 Examples of pillar wrapping used at block caving mines

Mine (country)	EXT level approx. depth (m)	Pillar wrapping application	Pillar wrapping usage
Finsch (South Africa)	780	Development	Pillar wrapping used to support corners of 300 drawpoints during development of the Block 4 extraction level. Minimal repair work was required for the life-of-mine (Wilson 2008).
El Teniente (Chile)	Depends on topography	Development	Pillar wrapping was used to support the drawpoint pillars in Teniente-4 South extraction level (Flores 1993). Pillar wrapping and other cable lacing systems were found to be resilient support systems even in rockburst prone conditions.
Palabora (South Africa)	~1,200	Rehabilitation	Pillar wrapping used to strap drawpoint pillars impacted by cave column loading (Talu, pers. comm., 2021).
Northparkes (Australia)	580	Rehabilitation	Pillar wrapping used for rehabilitation of drawpoint bullnose pillars in the E48 Lift 2 extraction level (Talu, pers. comm., 2021). It was found to provide efficient lateral support for pillars.
Argyle (Australia)	600	Rehabilitation	Pillar wrapping used for rehabilitation of drawpoints. Failure at the connector blocks and at the cable observed under extreme deformation (Talu, pers. comm., 2021).
New Afton (Canada)	770	Development	In the B3 extraction level, 15.2 mm twin cable slings pinned with cable bolts used to support the drawpoint corners (bullnose and camelback pillar) impacted by fault structures. To date, 33 out of 65 drawbells have been blasted and no major repairs have been required in the extraction level.
Oyu Tolgoi (Mongolia)	~1,300	Development	17.8 mm twin cable slings pinned with cable bolts installed in the back and walls of the production drives and drawpoints (Talu, pers. comm., 2021). Installations in production drives began before the commencement of undercutting. First undercut blast taken in Feb 2022.

4 Instrumentation strategy

Despite its widespread use, there is very limited quantitative data available to confidently evaluate the effectiveness of pillar wrapping for block caving application. Given the relatively costly and labour-intensive nature of the support system, there is a need to quantify the performance of pillar wrapping and allow the making of data-driven informed cost-benefit decisions for ground support design.

To monitor the strain and load on the cable slings installed in New Afton's B3 extraction level, it was proposed that instrumented cable bolts are used to replace the cable slings. Two main objectives were outlined for the proposed instrumentation strategy:

- To monitor the load and strain profile on the cable slings through different stages of caving and verify the support mechanism and, possibly, their modes of failure.
- To outline the best practices for the design and installation of pillar wrapping, and in turn, provide recommendations for New Afton's current pillar wrapping design and adopted installation procedure to improve upon its performance.

Following a technology review, Stretch Measurement of Assess Reinforcement Technology (SMART) cable bolts, commercially available from Mine Design Technology (MDT), were selected for a field trial. A SMART cable bolt consists of a miniature multi-point borehole extensometer (MPBX) recessed into the king wire of a seven-wire strand cable. By combining the support capacity of a seven-wire cable, with the displacement monitoring capacity of a MPBX, it is possible to directly monitor the load and strain distribution along the cable. The instrument can measure the displacement of up to six anchor points located along the length of the cable as it stretches under tensile loading. The reliability of SMART cable bolts has been proven through laboratory and field trials since 1998 (Hyett et al. 1997; De Graaf et al. 1999).

4.1 Configuration strategy for instrumenting cable slings

The following design parameters were taken into consideration for the instrumented cable configuration used for instrumenting the cable slings used at New Afton (Figure 4):

- Each cable sling consists of twin, 15.2 mm diameter plain strand cables.
- For each cable, 3 m of the cable tail on one end is embedded in the rock mass at a 45–60° angle (from the surface) in a borehole drilled in the opposite and slightly upwards direction to the cable slings. The tails are grouted in place with cement grout using the breather tube or toe grouting method.
- The other end of the cable is passed through the tensioner block and tensioned to a jack load of 5–8 tonnes with a cable bolt tensioner.
- Total free length of cable sling (i.e. the segment of cable sling that strap the pillar surfaces and is not embedded in the boreholes) is designed to be approximately 13–14 m for the camelback pillar and 10–11 m for the bullnose pillar.

For consistency, all SMART cables used were 15.2 mm diameter plain strand cable type. To instrument the cable slings, one of the twin cable strands was replaced with a SMART cable. In effect, two SMART cable instruments are used to fully instrument a single row of cable slings. Since the cable slings require tensioning, the potentiometer readout was placed in the head-at-toe (HAT) configuration (Figure 7). This allows for the potentiometer to be recessed into the ends of boreholes and become fully encapsulated when the cable ends are grouted. CL65 expansion shells were added to the end of the instruments to mitigate the potential risk of pre-mature slippage at the cable-grout interface, particularly during the tensioning process.

The position of the six anchors along the instrument were chosen so that at least one anchor point measures the load and deformation along the grouted section of the cable, and the remaining anchor points are distributed equidistantly along the free length of the cable slings. Figure 8 depicts the schematic of the SMART cables used to instrument the cable slings used at New Afton. Data from each of the installed SMART cables are collected through the Newtrax platform. The Newtrax Wireless Node, created by Newtrax Technology Inc, transfers instrumentation data through the wireless network that allows for real-time monitoring.

Figure 7 HAT configuration of the SMART cable with the CL65 shell on the grouted tail end

Figure 8 Schematic of SMART cables used to instrument cable slings at the K12N drawpoint (not to scale)

4.2 B3 EXT pillar wrapping instrumentation program

An instrumentation field trial was completed at the K12N drawpoint (i.e. southern drawpoint of the JK-12 drawbell) where only the middle row of pillar wrapping cable slings were instrumented. One of the key purposes of the instrumentation trial was to walk through and refine the installation method for replacing cable slings with SMART cables. This was an innovative application that ensured that SMART cables and their configuration, particularly the anchor node locations and instrument length, met the objectives for instrumenting cable slings. Two contract miners with experience installing cable slings onsite assisted with the installations. Installations were completed on 21 October 21 2021. Figure 9 shows the layout of the instrumented cable and their anchor locations along the pillar surface. Each anchor location is assigned a name (e.g. A1.3) based its distance from the anchor closest to the connector block (i.e. A0). Figure 10 shows a photo of the installation.

No major issues were encountered during the installation of the SMART cables. Based on the K12N trial, minor modifications were made to the instrument length and anchor locations used for the full instrumentation program planned in JK-16 to ensure that the connector blocks are positioned in areas better protected from damage caused by (load–haul–dump) LHD impact.

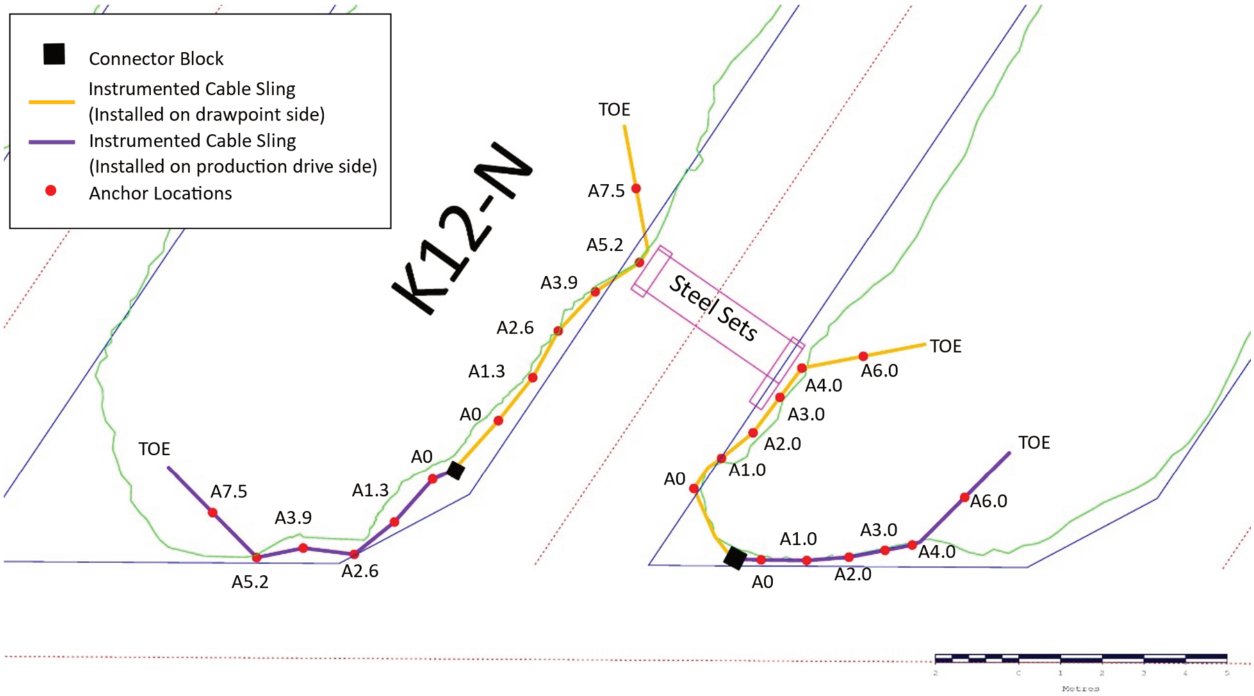


Figure 9 SMART cable bolts used to instrument cable slings at the K12N drawpoint

As part of the monitoring strategy for assessing the effectiveness of pillar wrapping, the three rows of cable slings installed on the camelback and bullnose pillars of the JK-16 drawbell were replaced with SMART cables. In total, 24 instruments were installed (12 per drawpoint). All installations were completed on 20 April 2022.

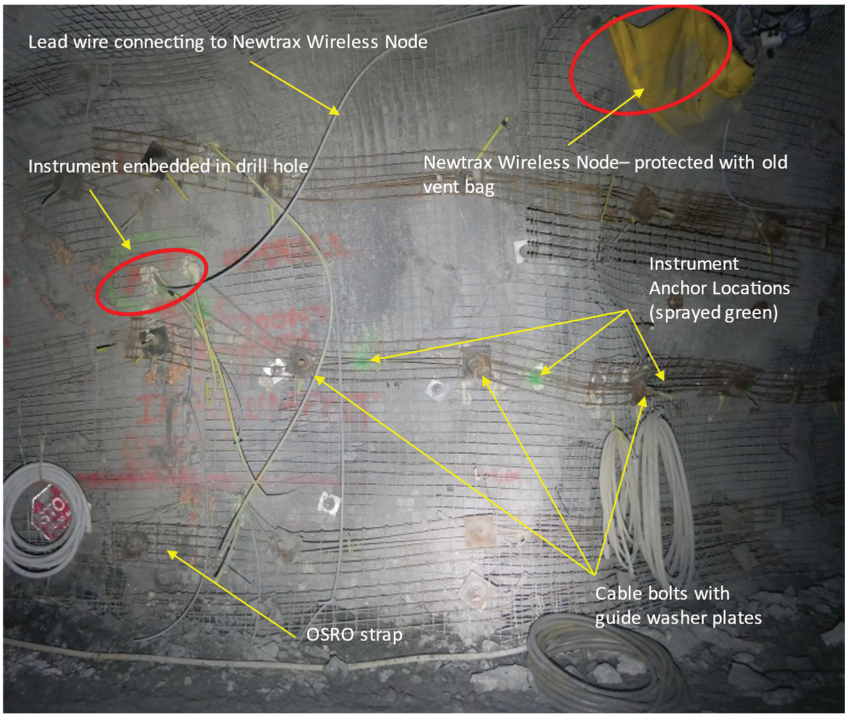


Figure 10 Photograph of the SMART cable installation on the K12N camelback pillar

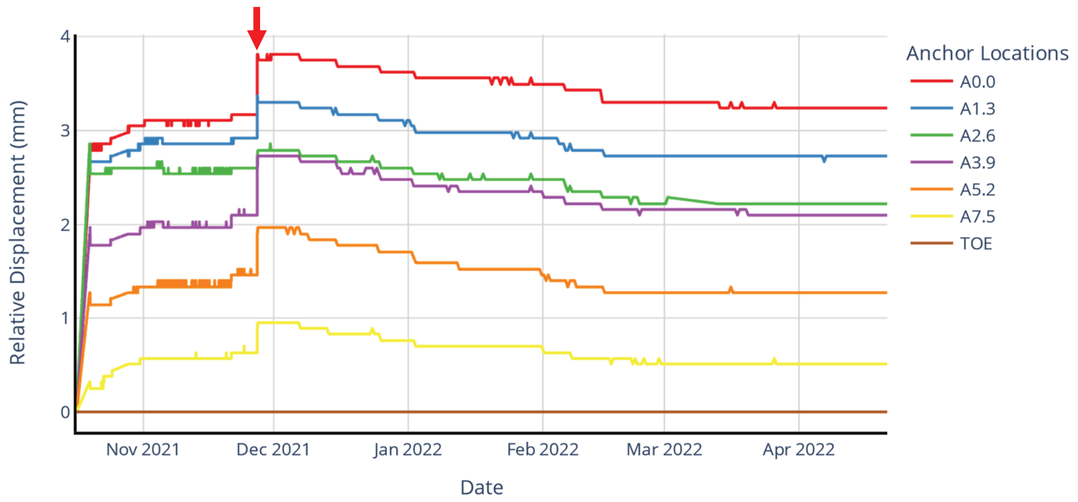
5 Preliminary results

The trial has been ongoing for six months. Preliminary results obtained from the instruments installed in K12N (JK-12) drawpoint are presented in this section. The data has been used to distinguish the early behaviour of pillar wrapping cables as the undercutting advances in the B3 mining area. These instruments are collecting readings every 12 hours. In cases that the sensors capture a minimum 1cV change (equivalent to 0.25 mm relative displacement) at any of the anchor locations, this is also recorded.

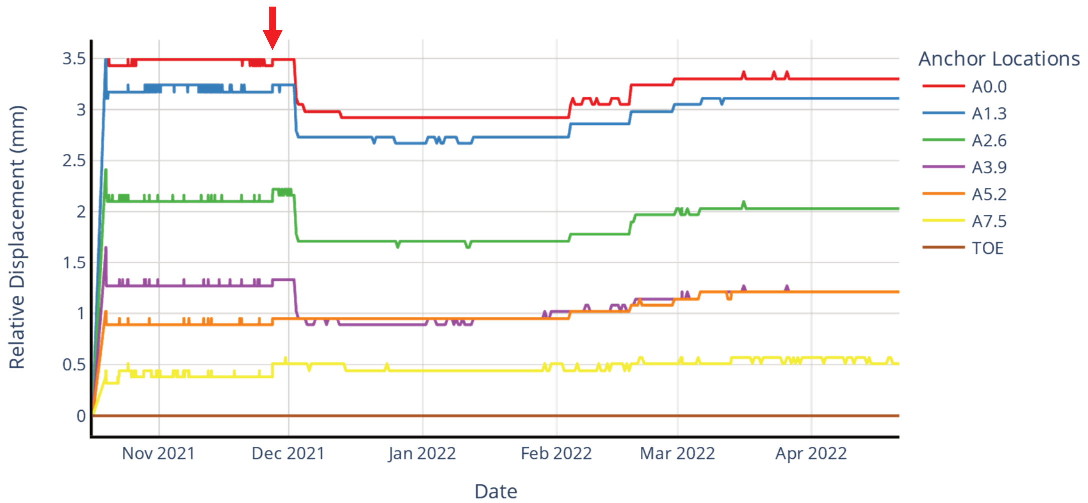
The blast for the JK-12 drawbell was taken on 27 November 2021. Slightly before the blast was taken, one of the instruments installed on the K12N bull nose pillar (embedded on the production drive side) was damaged while long support drilling was being completed in the adjacent JK-13 drawbell. It is believed that one of the long support drill holes intercepted the potentiometer at the toe of the instrument, rendering it unrepairable. For this reason, instrumentation data is not available from the cable sling installed in this area after 20 November 2021. This incident highlighted the potential for interactions between the installed support. This has led to identifying modifications to the installation sequence and/or support design to minimise the risk of damage to the instrumentation units. The data from this instrumentation unit is not discussed further in this paper.

Figure 11 shows the displacement of the instrument anchors relative to the potentiometer head resulting from the tensioning process as well as the drawbell blast. The distance between adjacent anchors is used to estimate the strain and load that develop in the segment of cable between them (Figure 12). Subtle changes to cable load are observed once the pillar wrapping cables are tensioned, but there are no strong indications that they have unloaded or loaded because of pillar movement. This is consistent with the understanding that abutment loading from undercutting poses the largest risk during early stages of caving (Laubscher 2000). The undercut front has advanced significantly away from the JK-12 drawbell that it no longer poses any major risk of stress damage to the drawpoint pillars. The subtle changes to the cable load over time are most likely caused by progressive transfer of load through the system. This is evident when comparing the two instrumented cable slings installed in the K12N camelback pillar, which are part of the same pillar wrapping system. An increase in the relative displacements observed in one instrument is matched by a decrease of a similar magnitude in the other instrument. The drawbell blast induces a redistribution of the load along the cable.

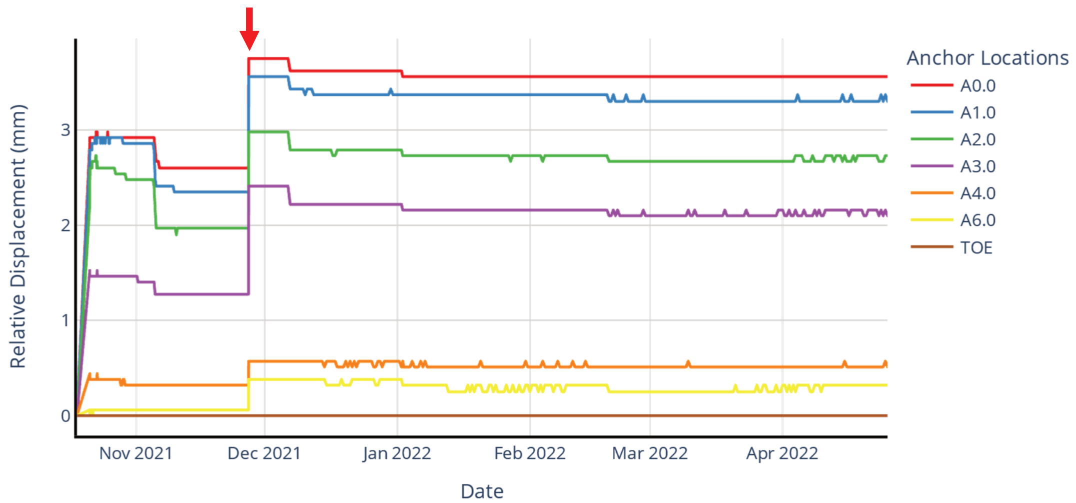
The cable loads estimated between anchor locations post-installation also show that the distribution of the tension along the cable sling is characterised by non-uniformity, whereby certain segments of the cable along the sling tend to remain more loaded than others. In concept, the cable slings are supporting the pillars as a continuum, whereby load that develops in one section of the cable should efficiently transfer to other sections of the cable over time. Discontinuous response in the anchor points located along the free length of the cable sling may indicate point loading along sharp corners on the excavation surface or cable binding at one or more of the guide washer plates. As more data become available over time, it will be possible to confirm the continuum concept interpretation. If the support system is acting as a continuum, it is anticipated that the differential loading of the pillar wrapping cable should become more uniform as the pillar begins to take additional load and more tension develops in the cables.



(a)



(b)



(c)

Figure 11 Total displacement measured relative to the toe over time for instrumented cable slings installed in the K12N (JK-12 drawbell blast date shown in red arrow). (a) Cable sling anchored on the camelback pillar, drawpoint side; (b) Cable sling anchored on the camelback pillar, production drive side; (c) Cable sling anchored on the bullnose pillar, drawpoint side

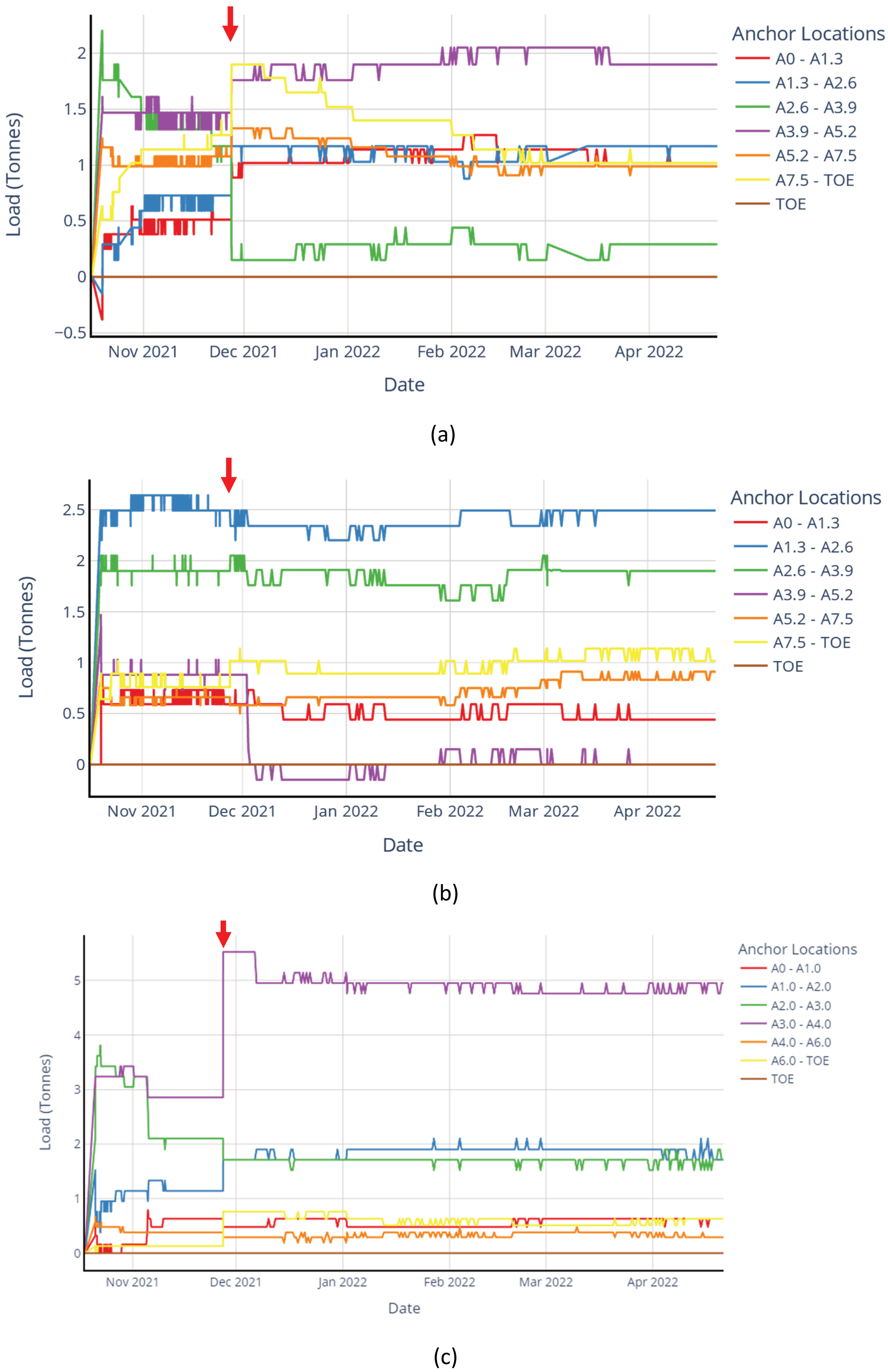


Figure 12 Cable load estimated between anchor locations over time for instrumented cable slings installed in the K12N (JK-12 drawbell blast date shown in red arrow). (a) Cable sling anchored on the camelback pillar, drawpoint side; (b) Cable sling anchored on the camelback pillar, production drive side; (b) Cable sling anchored on the bullnose pillar, drawpoint side

Another interesting observation is the significant difference between the design load and the actual cable residual load during tensioning. The design cable load for the pillar wrapping is intended to be between 5 to 8 tonnes at New Afton. The specified jack pressure used with the tensioners for tensioning the pillar wrap cables was specified based on the load conversion factor (i.e. area of the ram in the jack). Nevertheless, instrumentation data revealed that at most anchor locations, cable slings were only experiencing up to 3.6 tonnes, and more commonly between 0.5–2 tonnes at any locations along its free length once the slings were tensioned. This is significantly less than the design load. There is an estimated loss between 30–90% when comparing the tensioner jack load and the residual load remaining in the cables. The difference highlights the inherent inefficiencies associated with the tensioner jacking configuration. This has triggered a review of tensioning practices to establish the nominal jack load and pressure that to meet the desired residual load in the installed pillar wrapping cables.

Preliminary analysis of the K12N instrumentation data points to the specific importance of pre-tensioning pillar wrapping cables. By tensioning, this ensures that lateral restraint is always maintained by the system. The load on the cable slings continue to re-distribute during the undercutting, influenced by the pillar's dynamic response to mining activities. The instrumented cable slings installed in the B3 extraction level will be used to identify opportunities of improvement in the installation process. For example, contrary to some methods adopted at other mine sites, the exposures of the pillar wrapping cables along the excavation surface are not protected by pipe coverings to enhance debonding of the cables prior to the secondary shotcrete cover. Collected instrumentation data will be used to determine whether debonding practices are necessary for the long-term performance of pillar wrapping cables.

6 Conclusion

Pillar wrapping is an increasingly popular ground support strategy used at the extraction level of block cave mines. Nevertheless, their performance has not been quantified up to now. In this paper, a monitoring strategy for assessing the performance of pillar wrapping has been proposed. This entails the use of SMART cable technology to instrument cable slings used to support the drawpoint corners.

These instruments were installed during the cable bolting cycle immediately following the completion of the drawpoint drift development. The only deviation from the usual practice on site was the utilisation of the CL65 shells on the instruments to make the installation less sensitive to the cable grouting process.

To date, the instruments installed continue to acquire data through the cave initiation and propagation of the B3 cave. Visual damage mapping and convergence scan analysis conducted at the drawpoints where the instruments were installed do not show any major deformation impacting the pillars at this time. It is anticipated that the performance of the pillar wraps will become more apparent as the cave continues to propagate and eventually breaks through into the Lift 1 cave. The drawpoint pillars are expected to experience the impact of the induced stresses resulting from abutment and cave column loading over time.

Upon the collection of more data from the instruments installed at K12N and more recently installed in the drawpoints of the JK-16 drawbell, the in situ performance of pillar wrapping cables through different stages of caving will become more apparent. Currently, one of the main challenges with the installed instruments is their maintenance in an environment where equipment damage by LHDs is very common. Weekly inspections of the drawpoints will be continued to ensure that a shotcrete cover over the support and instruments remains intact. Visual damage mapping and convergence scan analysis of the instrumented areas will also be conducted routinely and examined in conjunction with the instrumentation data.

Acknowledgement

The authors wish to thank the management of New Gold Inc. for the opportunity to publish this work. The authors also acknowledge the mine operations (rehabilitation/construction), automation and the geotechnical team at New Afton Mine for their support and contributions to the instrumentation project.

Corey Kamp (New Gold Inc.), Peter Lausch (MDT) and Sami Talu (Rio Tinto) have provided additional background and useful suggestions.

References

Bieniawski, ZT 1989, *Engineering Rock Mass Classifications: A Complete Manual for Engineers and Geologists in Mining, Civil, and Petroleum Engineering*, John Wiley & Sons, New York.

Codelco, 2017, *El Teniente Operaciones: Homenaje a los Pioneros de la Minería Subterránea*, Codelco, Santiago, viewed 20 April 2022, http://j.mp/2spXSHr

De Graaf, PJ, Hyett, AJ, Lausch, P, Bawden, WF & Yao, M, 1999, 'Hudson Bay Mining and Smelting Co.'s field trials using 'SMART' technology–successful ground support design through in situ cable bolt performance evaluation', *Proceedings of the 101st Annual General Meeting of Canadian Institute of Mining, Metallurgy and Petroleum*, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal.

Flores, GE 1993, *A New Mining Sequence to Minimize Stability Problems in Block Cave Mines*, MASc thesis, Colorado School of Mines, Golden.

Hyett, AJ, Bawden, WF, Lausch, P, Ruest, M, Henning, J and Baillargeon, M, 1997, 'The SMART cable bolt: an instrument for the determination of tension in 7-wire strand cable bolts', *Proceedings of the 1st Asian Rock Mechanics Symposium*, A.A. Balkema, Rotterdam, pp. 883–889.

Jakubec, J 1992, 'Support at Cassiar underground mine', in HW Glen (ed), *Proceedings of MassMin 1992*, Southern African Institute of Mining and Metallurgy, Johannesburg, pp. 111–123.

Laubscher, DH 1994, 'Caving mine – the state of the art', *Journal of the South African Institute of Mining and Metallurgy*, pp. 279–293.

Laubscher, DH 2000, *A Practical Manual on Block Caving*, prepared for International Caving Study, Julius Kruttschnitt Mineral Research Centre and Itasca Consulting Group, Inc, Brisbane.

Wilson, AD & Talu, MS 2004, 'A review of the support systems being applied to the Block 4 cave project of De Beers Finsch mine', South Africa', in A Karzulovic & MA Alfaro (eds), *Proceedings of MassMin2004*, Instituto de Ingenieros de Chile, Santiago

Wilson, AD 2008, 'Effectiveness of support systems employed in the Finsch mine Block 4 cave', *Proceedings of the 6th International Symposium on Ground Support in Mining and Civil Engineering*, Southern African Institute of Mining and Metallurgy, Johannesburg, pp. 489–502.