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Installation and underground testing of instrumented rockbolts with wireless communication

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Abstract

Monitoring ground support performance has historically been limited to monitoring of the rock mass, and using this data to infer the response of installed ground support to rock mass deformation and changes in stress regimes. Although this methodology continues to improve with advancements in technology, there is a gap in accurately quantifying the response of installed ground support. This paper details a case study in which a new generation of instrumented rockbolts were installed in an operational underground mine and monitored over a period of time. The data collected during the case study is analysed against mining activities (development and stope blasts), seismicity and squeezing ground to assess the impact on installed ground support. This information can be used to improve the assessment of ground support response to mining activities and the management of ground support systems, such as rehabilitation.

Keywords: *ground support, instrumentation, in situ monitoring*

1 Introduction

Maintaining the stability of underground excavations typically includes the use of reinforcement elements such as rockbolts and cable anchors. Critical performance parameters for these reinforcement elements are the ultimate tensile and elongation capacity of each element. Historically, it has been technically and economically challenging to directly monitor the applied loading on ground support. Current practice for monitoring the stability of excavations is typically to measure the deformation of the supported rock mass and use this deformation to infer the loading applied on ground support. Rock mass monitoring includes the use of visual monitoring, extensometers (Batkhuu et al. 2024; Bawden 2023) and more recently Lidar scanning (Batkhuu et al. 2024; Patwardhan & Karim 2024; Saydam et al. 2021).

Although these technologies provide valuable insight into the behaviour of the rock mass, the measured rock mass deformation does not necessarily correlate with the loading and/or deformation of installed reinforcement elements. Hales (2022) conducted research in which instrumented cable anchors were installed in squeezing ground conditions and the elongation of the cables was monitored over a 5 month period. This was then compared to data recorded over the same time span from multi-point borehole extensometers (MPBX) installed in the same area, as well as surface deformation of the excavation measured by Lidar scanning. This research showed that although a correlation was found between MPBX measured ground deformation and the elongation of the instrumented cable anchors in some instances, this relationship was inconsistent; hence MPBX data could not be relied upon to infer tendon behaviour. Additionally, in this study, surface rock mass deformation measured via Lidar scan comparison showed no relationship to the elongation of the instrumented cable anchors.

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Cannington mine, Figure 1, is a mature underground lead, silver and zinc operation in the shire of McKinley, northwest Queensland. The mine has been in production since 1997 and primarily employs the vertical retreat open stoping mining method with paste backfill. Both ductile deformation (squeezing ground) and seismicity (typically <M_L1.0) are experienced on account of the historical mining sequence and prevailing geotechnical setting. Ongoing regional yielding of the rock mass in the south zone coupled with high abutment stress typically result in convergence of drive walls up to approximately 1 m, necessitating frequent ground support rehabilitation campaigns. Seismic activity is concentrated around the footwall and hanging wall abutments, as well as the crown of the yielded amphibolite core pillar between the hanging wall and footwall (Figure 2). Seismic events to date have largely been non-damaging owing to the reduced stiffness of the yielded rock mass in the south zone and the attenuation of seismic energy in pre-conditioned (stress-damaged) ground.

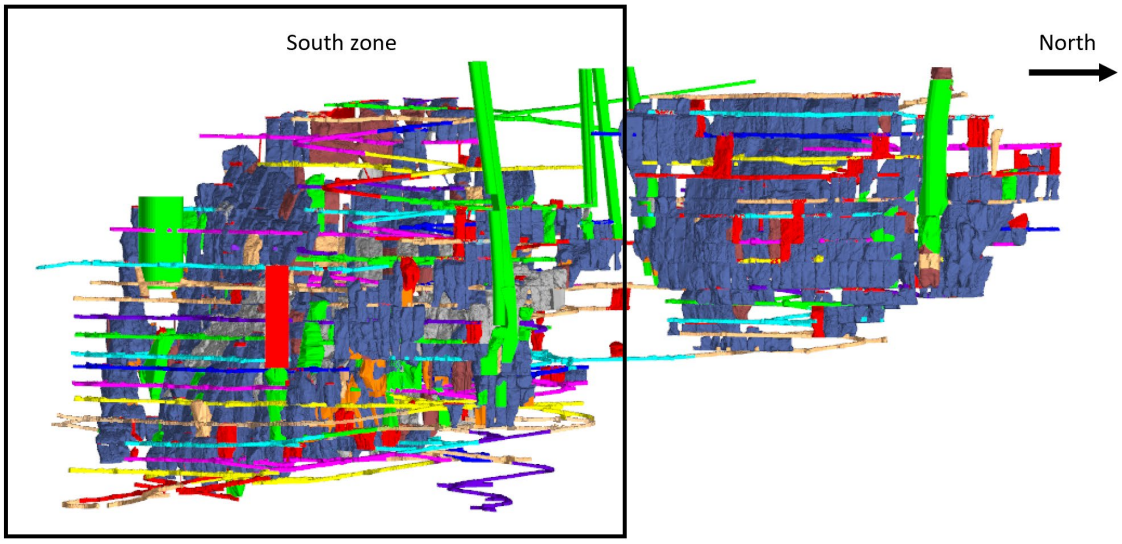


Figure 1 Cannington mine layout

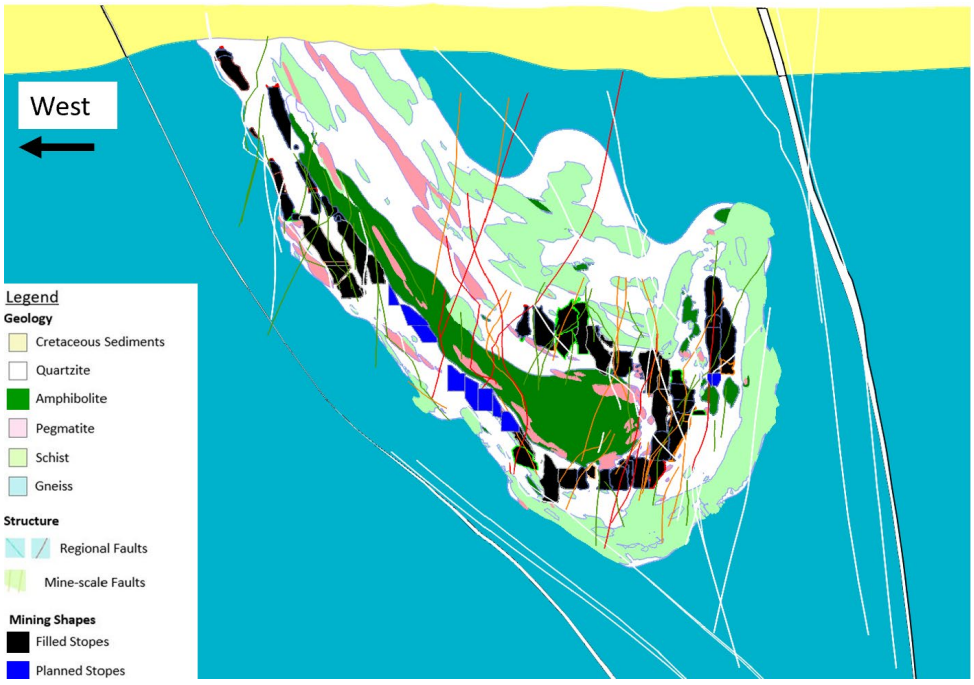


Figure 2 Typical cross-section showing geological interpretation of Cannington relative to historical and planned stopes

Current strategies utilised at Cannington to ascertain ground support rehabilitation requirements and estimate the residual capacity of reinforcement elements are based on visual inspections combined with Lidar scanning and MPBX measurements; the latter which is expensive and only installed at discrete locations. To improve monitoring of installed ground support performance and proactively manage rehabilitation requirements based on quantifiable in situ bolt deformation data, an array of instrumented resin bolts with wireless communication capability were installed at 2 locations where squeezing and seismic activity have been observed and expected to be ongoing. The response to mining activities and background yielding of the rock mass were monitored over a 5 month period.

2 Instrumented rockbolt hardware, networking and Cloud interface

The instrumented rockbolt system trialled comprises a network of instrumented rockbolts, wireless gateways and a Cloud where data is stored and can be presented for end-users to interpret.

Figure 3 below shows a simplified view of the network architecture, with a series of installed rockbolts connecting to a gateway which serves as a bridge between the mesh network and the mine's own local network infrastructure, which in turn is connected to the Cloud.

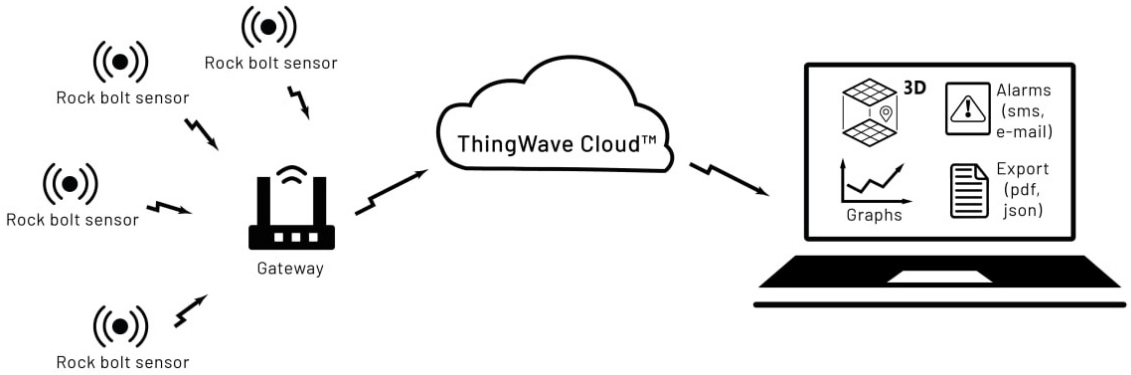


Figure 3 Schematic of the wireless communications system

2.1 Instrumented resin bolts

The standard resin bolts utilised as ground support at the mine are modified to accommodate a sensor cable and are fitted with an instrument housing unit at the head of the rockbolt comprising a displacement sensor, batteries and a mesh network sender/receiver unit, Figure 4. The modification of the bolts requires cutting a small groove into the side of the rockbolt along its full length. A sensor cable is fixed into this groove and the distal end of the cable is fixed to the tip of the rockbolt and the proximal end of the cable is connected to a displacement transducer in the sensor housing unit at the head of the rockbolt. The transducer measures elongation of the bolt with a resolution of 0.02 mm and has a maximum measurement range of 250 mm.

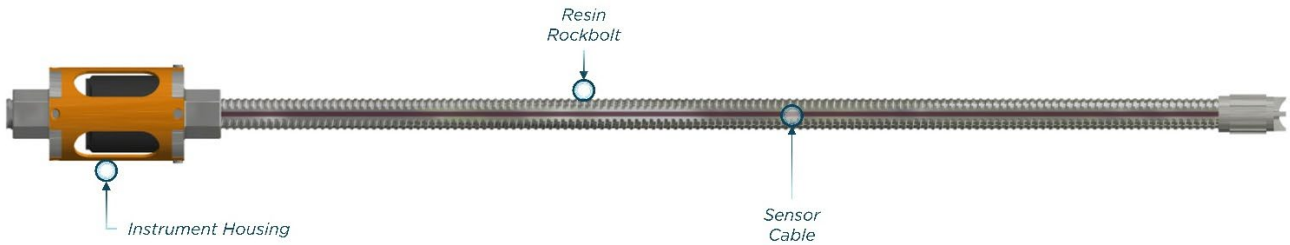


Figure 4 Instrumented resin rockbolt

The instrumented bolts communicate using an ultra-low power wireless mesh network technology and thus creates their own network infrastructure which self-extends with every sensor installed. This approach enables wireless coverage in areas without mine network infrastructure. The mesh network runs on 2.4 GHz

and is fully Wi-Fi compliant. The data from each bolt is secured during transmission with military grade encryption to prevent unauthorised access.

The result is the conversion of a standard rockbolt into a self-monitoring support element which records and communicates overall tendon elongation at set measurement intervals, which allows for installation with a standard jumbo.

2.2 Wireless network gateway

A mesh gateway, shown in Figure 5 below, can operate in 2 different modes: network or standalone (USB). In network mode, it continuously streams bolt data in near real-time to the Cloud. However, if no network coverage is available underground, gateways can operate in USB mode, where data is downloaded from each gateway using USB drives and then manually uploaded to the Cloud server. Although the use of the USB system does not allow for near real-time data access, it does provide a simpler installation onsite with minimal approvals required from organisational IT to install and test the system, allowing for the derived value to be proven prior to full-scale implementation with near real-time monitoring. When data is transferred using USB, it is also encrypted and can only be decrypted by the Cloud server upon data upload. This ensures that even if a USB drive is lost, its content is unusable to external parties.



Figure 5 Wireless gateway

2.3 Cloud-based reporting system

Once data has been received by the Cloud server, either by near real-time network connectivity or manual USB data upload, the information is stored in a secure database. Data can be accessed, viewed and analysed in the Nucleus web-portal (Figure 6), or, where preferred, data can be sent to consolidated site-wide monitoring platforms commonly used by site practitioners.

The system can be hosted either on the internet or on the mine IT infrastructure, noting that the latter allows access to the Cloud system even if internet connection is lost.

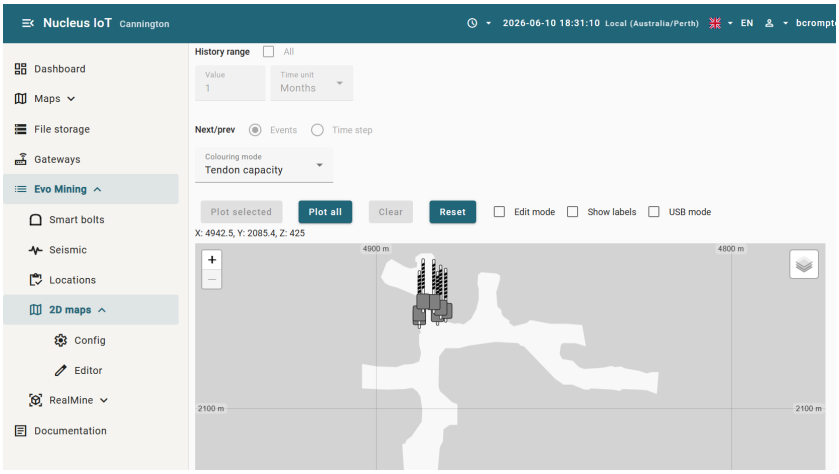


Figure 6 Web-browser access to Cloud service

3 Installation underground

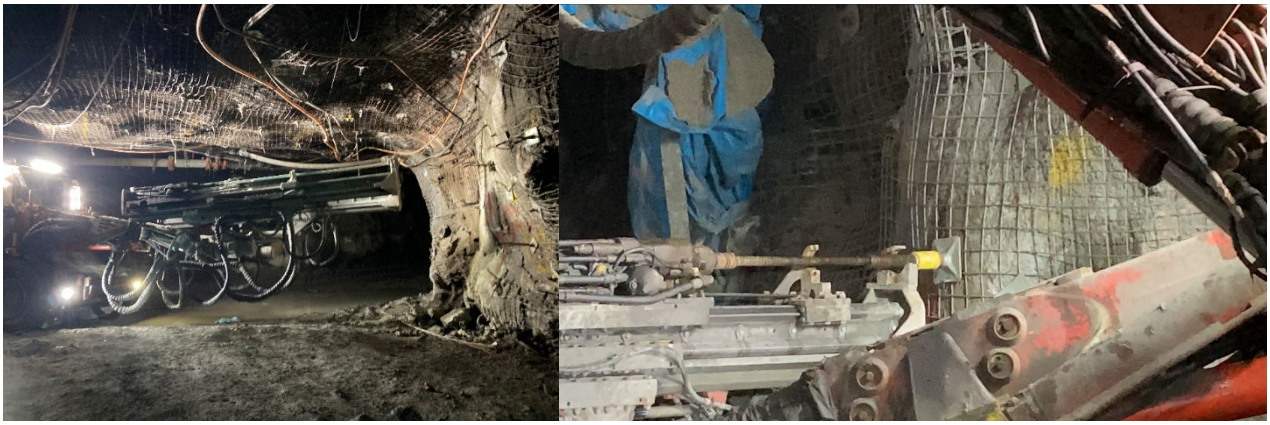
Two trial sites with a history of background seismic events were selected in areas of observed and expected ongoing bulking of the rock mass. Figure 7 provides the layout of the 2 trial sites at Level 425m Vc88DS (Figure 7a) and Level 425m Sg67DN (Figure 7b), showing the approximate location of all installed instrumented rockbolts.



(a) (b)

Figure 7 Maps showing instrumented rockbolt installation sites (a) 425 m Vc88DS and (b) 425 m Sg67DN

The instrumented rockbolts were installed in a similar manner to standard resin rockbolts utilising a typical twin-boom jumbo, i.e. drilling of support hole, insertion of twin-speed resin capsules, insertion of resin bolt and mixing of resin and tensioning of the rockbolt plate, see Figure 8. The sensor housing unit at the head of the rockbolt had an outer diameter larger than could be accommodated by the jumbo centralisers. To facilitate installation of the rockbolts, the centralisers were opened up to provide more clearance for the sensor housing to pass through. The instrumented rockbolts were successfully installed, although the opening of the centralisers required careful manipulation of the rockbolts during installation to prevent damage to the sensor housing, misalignment of the bolts or decoupling from the tensioning dolly.



(a) (b)

Figure 8 Jumbo installation of instrumented rockbolts. (a) Level 425 m Sg67DN (b) Level 425 m Vc88DS

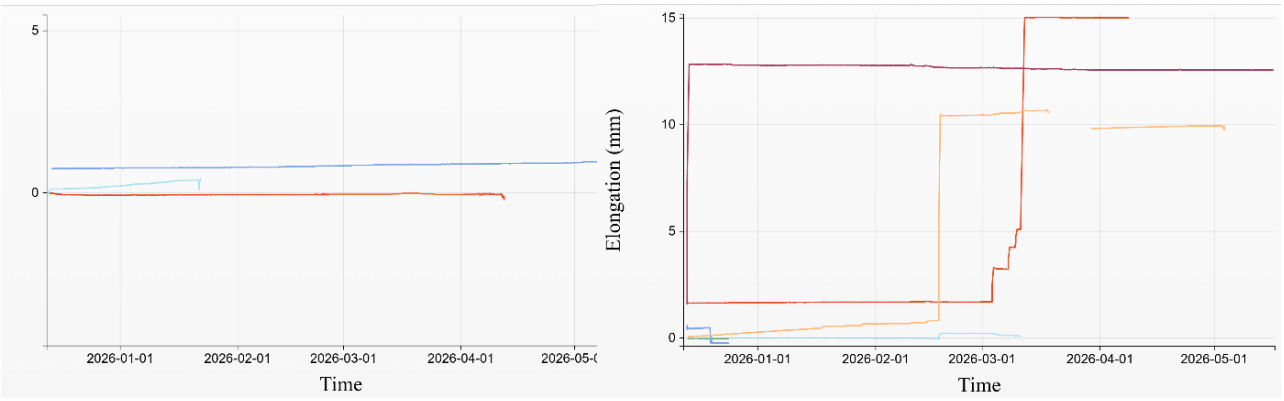
Figure 9 shows a closer view of level 425m Sg67DN western pillar where 4 instrumented rockbolts were installed in an identified area of high deformation, evident by observed guttering in the shoulder and dilated cracks within the applied fibrecrete. The highly fractured nature of the rock mass at the installation sites was observable through difficulty in inserting the resin cartridge in some holes.



Figure 9 Array of instrumented rockbolts installed at the western pillar of level 425 m Sg67DN

4 Monitoring and observations

Figures 10a and 10b plot the total elongation of the bolt with time for all instrumented bolts installed at level 425m Sg67DN and Vc88DS respectively, at the time of writing this paper. The data presented in the graphs shows absolute deformation and has not been adjusted to a zero datum at the time of installation; thus, the net elongation of the bolts is the resultant change between the first data point after installation and the last data point on each curve.



(a) (b)

Figure 10 Elongation-time plots of instrumented bolts at (a) Level 425 m Sg67DN and (b) Level 425 m Vc88DS

Four distinct trends were observed and are analysed as thus:

1. time of installation (Figure 11a):
    - The time of installation of each rockbolt is identifiable by observed step-changes in elongation when tensioning the bolt. This measurement is an artifact of the installation process and not an indication of true elongation of the rockbolt. True elongation is subsequently calculated using the first data point after installation as a datum.

2. time-dependent deformation (Figures 11b and 11c):
    - Several bolts showed clear time-dependent deformation trends. These were installed around grade line where drive convergence has historically been pronounced. Measured total elongation of each of these bolts (excluding machinery damage) is sub-millimetre, suggesting a potentially deeper horizon of ground deformation than the instrumented bolt length.
3. machinery damage (Figures 11c and 12):
    - Several of the instrumented bolts installed around grade line were damaged by machinery. This is evident by sudden large step-changes in elongation often accompanied by an immediate loss of communication with the instrumented bolt or a loss of communication shortly after the impact event. Physical inspection of the bolts together with sudden large step-changes in elongation data were used to confirm machinery damage.
4. step-changes in deformation (Figure 11d):
    - Two bolts were observed to experience a set of elongation step-changes over a period of several days. Unfortunately, these were irrecoverably damaged by machinery before they could be inspected for confirmation as to whether or not these changes were induced by ground movement or other factors.

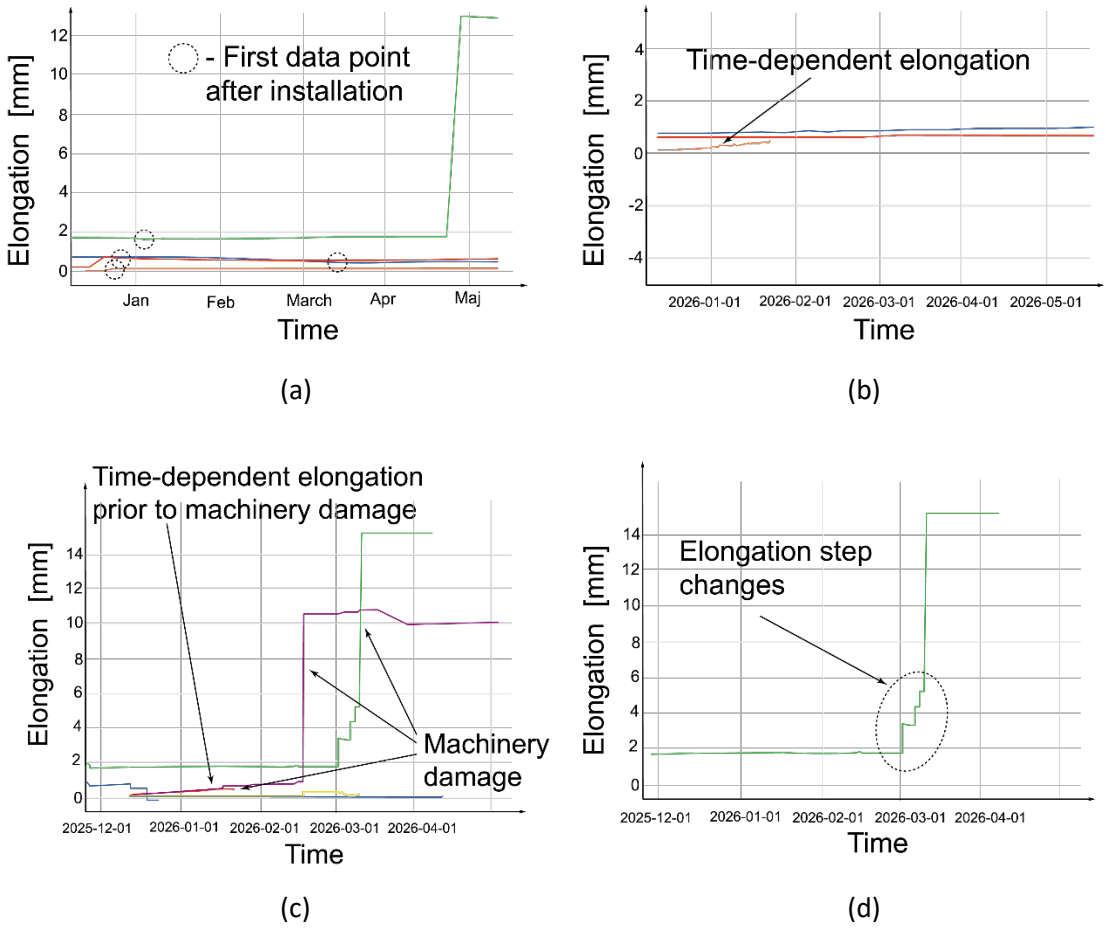


Figure 11 Observed monitoring trends



Figure 12 Photographs of instrumented bolts installed at Level 425m Vc88DS (southern pillar) before and after machinery damage

Review of the elongation – time graphs of bolts installed at Level 425m Vc88DS (Figure 13) indicated concurrent elongation across several bolts at several periods in time. These time periods of concurrent bolt elongation were cross-checked against both blasting (stopes and development) and seismic activity within a 300 m radius.

A good correlation was observed between nearby mining activity (stope and development blasts) and recorded bolt elongation. This was particularly evident in the 42v.77HG stope firing (Figure 13) approximately 87 m from the trial site, for which several operational instrumented bolts recorded concurrent elongation.

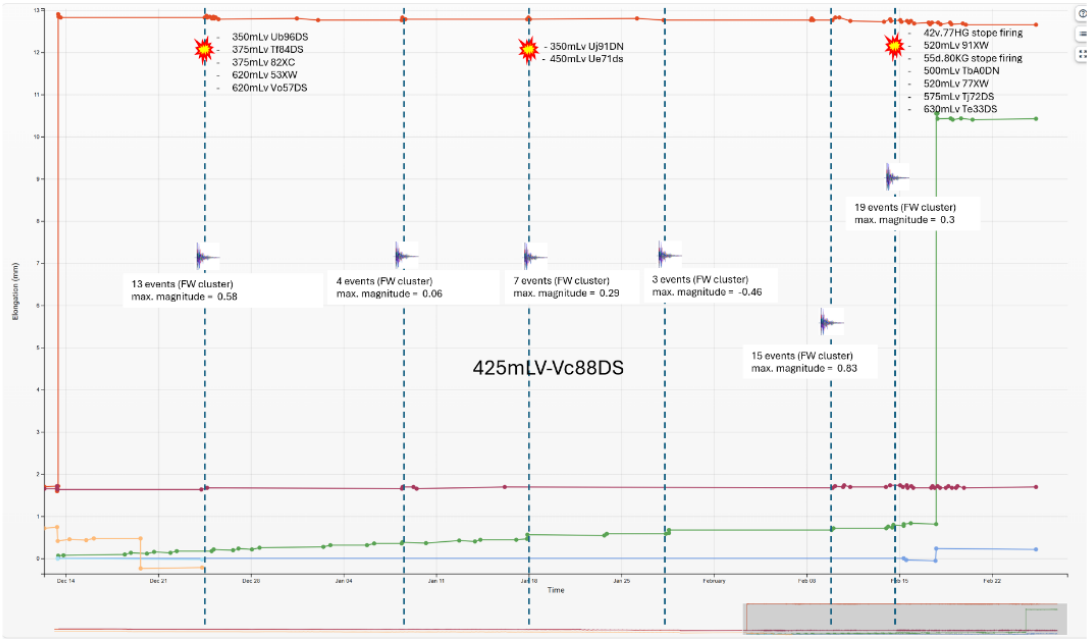


Figure 13 Overlay of Level 425m Vc88DS instrumented bolts elongation with blasting and seismic activity

On the contrary, no correlation was observed between background seismic events and recorded elongation across all bolts. This may be attributable to the fact that regional yielding of the rock mass in which the instrumented bolts are installed dampens seismic response and/or the magnitudes of seismic events were insufficient to induce observable bolt elongation at the trial locations.

It is noted that the concurrent elongation across several bolts is likely influenced by background yielding (squeezing) of the rock mass, as evidenced by visual inspection of the trial area (fibrecrete cracking and bulking) and observed time-dependent elongation of bolts installed in this area (Figure 11c). An attempt was made to compare Lidar-measured surface convergence of the trial area with bolt elongation data; however, this was not possible given that the magnitude of drive convergence since the bolts were installed is less than the accuracy of the Lidar scan (<30 mm).

5 Conclusion

A new generation of instrumented rockbolts with wireless communication were trialled in a bid to accurately monitor the in situ performance of the rockbolts, determine residual capacity and proactively manage ground support rehabilitation. Whilst the trial showed that the instrumented rockbolts are capable of accurately monitoring in situ bolt performance (elongation) and quantify residual capacity in response to mining activities (stope and development blasts) and in squeezing ground (time-dependent drive convergence), no correlation was observed between background seismic events and bolt elongation.

A key issue encountered during installation was that the outer diameter of the sensor housing unit could not be accommodated by the jumbo centraliser, thus, the centralisers were opened to provide clearance for the sensor housing to pass through. This will need to be improved on to ensure the bolts can be installed safely.

Given that the total elongation of the instrumented bolts is sub-millimetre, the monitoring period has been extended so that the bolts can be monitored to failure and allow comparison with Lidar-measured surface convergence.

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