Twin strand cables replaced with Falcon Bolts at Tomingley Gold Operations

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ABSTRACT

This case study, conducted between Tomingley Gold Operations and Jennmar Australia, explores the full-scale adoption of pre-tensioned, post-grouted self-drilling bolts in lieu of manually installed cable anchors for intersection support, brow support, and other applications where cable bolts are typically implemented. The data required to justify and drive the change was collected during early trials and is also presented in this case study. The removal of cable cutting, pushing, plating and tensioning stages, as well as eliminating reliance on elevated work platforms for cable installations reduced the risk of associated injury to workers. Improvements in installation efficiency, the adoption of fast setting resins in place of cement grouts and the development of a high-capacity steel provide further opportunity for schedule optimisation and rapid development.

INTRODUCTION

Rockfall hazards present safety and production risks in underground mining, particularly near production areas where ground vibrations and changing stress conditions can destabilise structures. The larger spans of wide drives and intersections have increased risk of rockfall as they expose more structures. Primary ground support does not always provide sufficient capacity or depth of embedment to support these wedges. A typical intersection wedge failure is shown in Figure 1 along with a kinematic analysis used to perform ground support assessment.

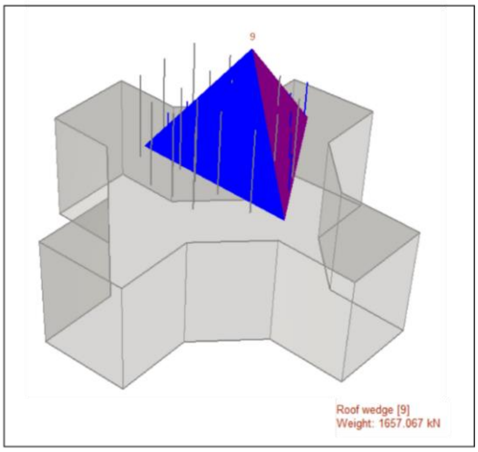

FIG 1 – (Left) intersection wedge failure leading to abandonment of development and bypass development. (Right) Typical kinematic wedge assessment to aid ground support design or failure back analysis.

Underground mines typically use 6.0 m cable bolts to achieve the required deeper embedment length and higher capacity to support these structures. Cables provide the length and strength to anchor a potential wedge into stable ground beyond wedge limits. While cable bolts are versatile and cost-effective, their installation can be challenging. A range of mechanised cable bolting machines are available that can circumvent these challenges, however if the planned amount of cable bolts to be installed does not justify the cost of purchasing and maintaining a dedicated cable bolting machine, or there are physical restrictions in mine design, mining operations may pursue manual installations. In this case, cable bolts are manually pushed into holes that are pre-drilled by Jumbos or production drills. This method of installation comes with its drawbacks, risks and challenges. Jumbos are not well suited to extension drilling 6.0 m holes vertically, and a variety of methods are employed to achieve this. Utilising production drills for development introduces additional tramming and they drill oversized holes, requiring additional grout. Hand installing cable bolts is a time-consuming process with increased potential for manual handling, chemical and eye injuries. These drawbacks may compel mining operations to pursue alternative options.

Small trials investigating replacement of cables with extension drilled SDAs (self-drilling anchors) have been conducted. In 2019, a limited number of extension drilled 15 m SDAs were installed at Malmberget in Sweden. These SDAs were drilled and grouted from an Epiroc Boltec M using a resin modified with an increased hardening time (Bray, 2019). It was noted that mechanising the installation process greatly improved operator safety and productivity. The trial concluded that the success of the extension drilled SDAs coupled with injected resin could provide an alternative to typical cable bolting.

In 2023, a small trial was conducted exploring replacement of cables with standard extension drilled SDAs at Kanmantoo Mine (Jardine, 2023). SDAs were installed using a typical Jumbo drill rig then post injected with resin from an IT Basket. It was found that installing SDAs in development intersections with a fast-setting resin could improve cycle time since the schedule did not need to account for grout cure time and SDA installations reduce manual work. A case study at St Barbara Gwalia Mine investigating how SDAs are installed and resin injected from an Epiroc Boltec M compares with typical ground support products (Safari, 2023). During this trial, extension drilled 2.4 m SDAs were substituted for cable bolts with 24 7.2 m installations and nine 9.6 m installations. The case study found the extension drilled SDA installation process to be more efficient than the cable installation process.

Falcon Bolt

Falcon Bolts are differentiated from typical SDAs. The Falcon Bolt features a mechanical anchor at its toe enabling it to achieve pre-tension and provides some capacity before the bolt has been grouted. This innovation allows tensioning to be completed with drill rotation prior to resin injection, removing the plating and tensioning process. Further, the Falcon Bolt is driven via a hex as opposed to a threaded coupling, simplifying connection and disconnection from drilling dolly This feature assists extension drilling, the drifter is retracted while the anchor also holds the bolt in position and a second or third bar can be coupled and installed. The Falcon Bolt is depicted in Figure 2.

FIG 2 – Falcon Bolt.

Tomingley Gold Operations and project background

Tomingley Gold Operations (TGO) currently comprises several underground hard rock mines over a 3.8 km (north–south) × 1.0 km (east–west) footprint in the greater western plains in New South Wales, Australia. Underground production depth ranges from 100 m to 450 m. Ultimate compressive strength of intact core ranges from 50 MPa to 300 MPa; and typically lie between 150 MPa to 200 MPa. Stress ranges from low, to medium confining stress at these depths. Given these conditions, site observations and numerical modelling, ground support and reinforcement are designed for static conditions.

At TGO, cable bolts were manually installed and predominately employed for development intersections and drawpoints. The number of cable bolt installations is growing in response to increased production and changing ground conditions as summarised in Table 1. The quantity of cable bolts required per month can be unpredictable, which presents operational challenges; particularly with less time available to service crew to attend to other tasks essential to supporting the development cycle. Constant feedback and requests were made to management to review hand-installation of cable bolts due to the nature of the work.

TABLE 1

Overview of Tomingley Gold Operations production and schedule overview.

	FY22	FY23	FY24	FY25 est.
Ore tonnes ('000s)	806	835	1047	1104
Development metres	5500	6500	7250	7000
Cable metres	13 900	14 700	16 000	18 450

In 2023 it was identified that additional resources would be required to meet the increasing number of cable bolt installations. TGO considered three options to meet this demand:purchasing a second-hand cable bolter to take over the task of installing cable bolts with contractor operation, or employing additional service crew and equipment to continue hand-installation. A summary of the cost comparison is shown in Table 2. Estimates for options 2 and 3 assumed that there would be no fleet changes.

- Option 1 – Purchasing a refurbished cable bolter to take over the task of installing cable bolts with contractor operation.
- Option 2 – Employing additional service crew and equipment to continue hand-installation.
- Option 3 – Using Falcon Bolts to replace cable bolts.

TABLE 2

Cost analysis carried out by TGO to assess how to meet requirements for additional cable bolts in FY24 and forward.

	Purchase cable bolter	Additional service crew	Falcon Bolts
Capital estimate	$ 800 000 (Refurbished cable bolter)	$ -	$ 100 000.00 (Resin basket + other)
Additional operational cost per annum	$ 940 000 (Contractor operation and maintenance)	$ 1 150,000 (Service crew + IT hire per annum)	$ 50 000.00 (Resin basket + other maintenance)
Additional cost of Falcon Bolts over cable bolts	$ -	$ -	$ 510 000

Year 1	$ 1 740,000	$ 1 150,000	$ 660 000
Year 2	$ 940 000	$ 1 150,000	$ 560 000

Through this period Jennmar and TGO conducted a series of trials focusing on single length Falcon Bolt installations. As Falcon Bolt development progressed, trials shifted to focus on extension-drilled variants, with an extensive campaign of over 100 6.0 m and 9.0 m lengths installed successfully, proving the bolt's capacity to provide deep embedment ground support. Based on the overall costs and the required capital outlay, TGO began looking closer at the Falcon Bolt as a replacement for secondary support, rather than a rapid development resin bolt.

As cable bolt use increased, three back strain injuries occurred over a six-month period. These injuries, and a string of successful trials and initial business case comparison, accelerated the decision to change secondary support install methods. In early 2024 TGO changed methods and commenced process to change from twin-strand cables Falcon Bolts. The flexibility of using production rigs to install cable bolts for stope brows meant cables were still hand installed in these applications. Subsequently In June 2024, another back strain occurred when pushing cables for an interim brow. As an outcome, the mine moved away from cable bolts entirely and transitioned to Falcon Bolts from July 2024.

During initial implementation, 50 per cent more Falcon Bolts were required to reach equivalent cable support capacity for a given intersection. Through a collaboration process to enable greater viability, Jennmar investigated and produced the R32X, a stronger variant that would allow a one to one replacement rate for cables.

In May 2023 health monitoring showed that a worker was exposed to respirable crystalline silica (RCS) above acceptable limits. The review identified the potential cause of the exceedance was the volume and manner of grouting. This has driven the development of a fit-for-purpose dedicated IT basket retrofitted with a polyester resin injection system to replace cementitious grouting as part of the second phase of Falcon Bolt implementation. The system also provides additional productivity and quality control benefits. Jennmar has designed and developed this system, at time of writing the Injection System has been successfully trialled, and is due to be commissioned in December 2024.

Technical comparison of twin strand cables and Falcon Bolts

Several ground control management plans for Australian mines use the parabolic arch or dome method for ground support design in wide accesses and intersections. The design aims to support the dead weight within a volume defined by an arch above the excavation. This dead weight is anchored to the competent rock mass beyond this theoretical arch by deep embedment rock bolts. This method provides a conservative estimate for ground support design. Based on extensive application in Australian underground mines for several decades this system appears to mitigate the majority of gravity/structurally driven roof failures (Potvin and Hadjigeorgiou, 2020). With sufficient site data, kinematic analysis on probable formed wedges is also used to verify and design bespoke intersection support systems allowing for variations in installation requirements. Figure 3 shows a visualisation of these respective methods.

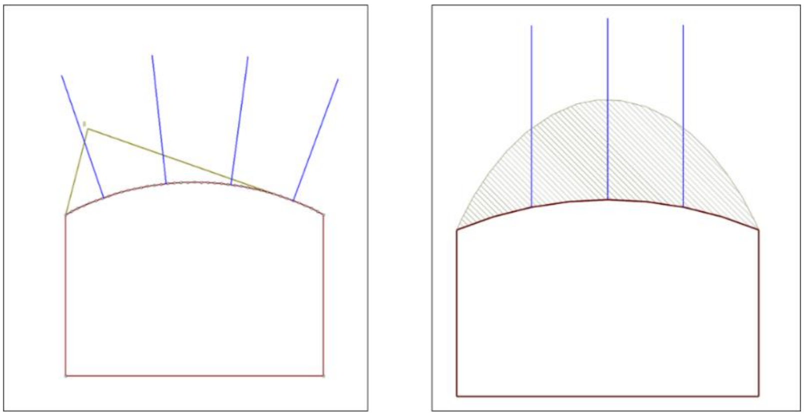

FIG 3 – (Left) Kinematic wedge analysis, (right) parabolic arch method.

Intersection and wide span ground support at Tomingley Gold is predominantly based on the parabolic arch or dome method to determine the embedment length and system capacity to control rockfall posed by increased wedge potential. As further data has been collected with progressing underground development, kinematic wedge analysis is being used to verify intersection and wide span ground support design. Intersection deep support at TGO consist of a two-pass system, with the majority of support installed prior to taking a drag and the creation of a wide-span (1st pass) and the remaining support installed as 'infills' in this drag cut (2nd pass).

Cable bolts and extension drilled Falcon Bolts are both capable of achieving the required deep embedment lengths. However, the behaviour of the flexible cable compared with the stiff, hollow bar in a ground support role can be contrasting, and the corresponding advantages and limitations must be explored. Testing showed no discernible changes in mechanical properties of Falcon Bolts that had been drilled to a depth 6 m with a typical jumbo.

Working from the yield strength, the R32S bolts have 43 per cent less tensile capacity than a twin-strand cable installation. This was initially managed by installing 1.5× more Falcon Bolts per supported area than 15.2 mm twin strand cables. As a permanent solution, Jennmar has developed a high strength 'X' grade R32 threaded steel, capable of supporting at least 480 kN in yield, reducing the number of Falcon Bolts needed to offer equivalent support as twin strand cables. These performance differences are presented in Table 3. The R32X has been successfully trialled with 24 bolts installed. TGO have switched from R32S to R32X in December 2024.

TABLE 3

Bolt properties.

	15.2 m twin strand	Falcon Bolt E	Falcon Bolt S	Falcon Bolt X
Min ultimate strength	530 kN	280 kN	360 kN	570 kN
Min yield strength	490 kN	230 kN	280 kN	480 kN
Elongation	5%	15%	6%	5%
Number of Falcon Bolts to replace 1 twin strand cable		2×	1.5×	1×
Critical embedment length in grout	2 m	0.3 m	0.3 m	untested
Status	Not in use	Not in use	In use	In trial

Shear strength

When a ground support element is subjected to shearing rock planes, bolts do not tend to fail in shear, but respond with a bending moment. Since the softer supporting material (the rock mass) cannot support the displacing steel, the bolt will bend and ultimately fail in a combination of bending, shearing and tensile loading (Knox, 2022). This is supported by a review of shear test results. Aziz (2015) conducted double shear tests on a range of cables and observed that shear failure occurred between 95–100 per cent of tensile load. Stjern (1995) found that the shear strength of a rock bolt is between 80 per cent and 100 per cent of its tensile strength. Bending stiffness is thus a critical parameter when comparing the response of cables and self-drilling bolts to radial loading induced by shearing rock planes. Cables are not stiff in bending. They are formed with a weave of smaller, flexible strands (Figure 4), and each strand has a degree of freedom relative to its counterparts, allowing the network to flex and move as it is cantilevered. Once the system is loaded, these properties allow the cable to bend until the individual strands fail in tensile loading. Hollow bolts used in Falcon Bolts on the other hand are stiff in bending. They are formed with rigid steel and a consistent cross-section. While this stiffness enables the self-drilling property, the structure resists bending, resulting in bending stress.

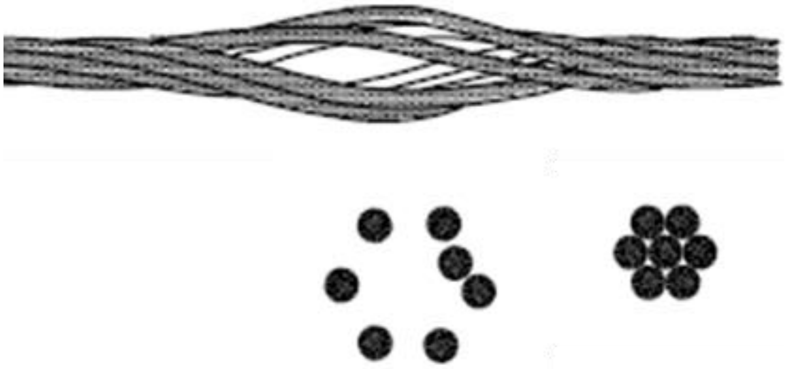

FIG 4 – …Typical Cable Bolt (Hutchinson and Diederichs, 1996).

To evaluate the different responses of each bolt in shear loading, double shear tests were conducted in collaboration with University of Wollongong (UOW). UOW developed a double shear system fitted with a Lateral Truss (LTS), which enables the tested tendon to respond as if it were supporting shearing rock planes. Each bolt sample is fit inside an assembly of three concrete cylinders with a UCS of 60 MPa. The concrete cylinders are cast with an internal reinforcing cylinder of 200 mm diameter 5 mm wall steel tube inside it. To replicate the Falcon Bolt, concrete blocks are cast with a 51 mm hole to replicate the cable bolt, samples are cast with a 65 mm hole. There are two blocks 300 mm in length, and a third block, which is 450 mm thick, is placed between the 300 mm blocks. There is a gap between these blocks to prevent frictional forces interfering with results. The bolt tendon is manually pushed into the cast hole. Hollow bar samples are pre-tensioned to 50 kN, then grouted with Jennchem TD80 grout to represent the Falcon Bolt installation process. Cables are grouted, then tensioned after the grout has cured. The cables samples are prepared so that each cable has a bulb grouted within each block, thus a twin strand cable has two bulbs cast within each block. The central block is then loaded radially relative to the external blocks, and the applied radial load is entirely reacted by the tested tendon. Load cells record applied radial load and axial load at each end of the tested tendon, and displacement of central block is measured. This test set-up is depicted in Figure 5.

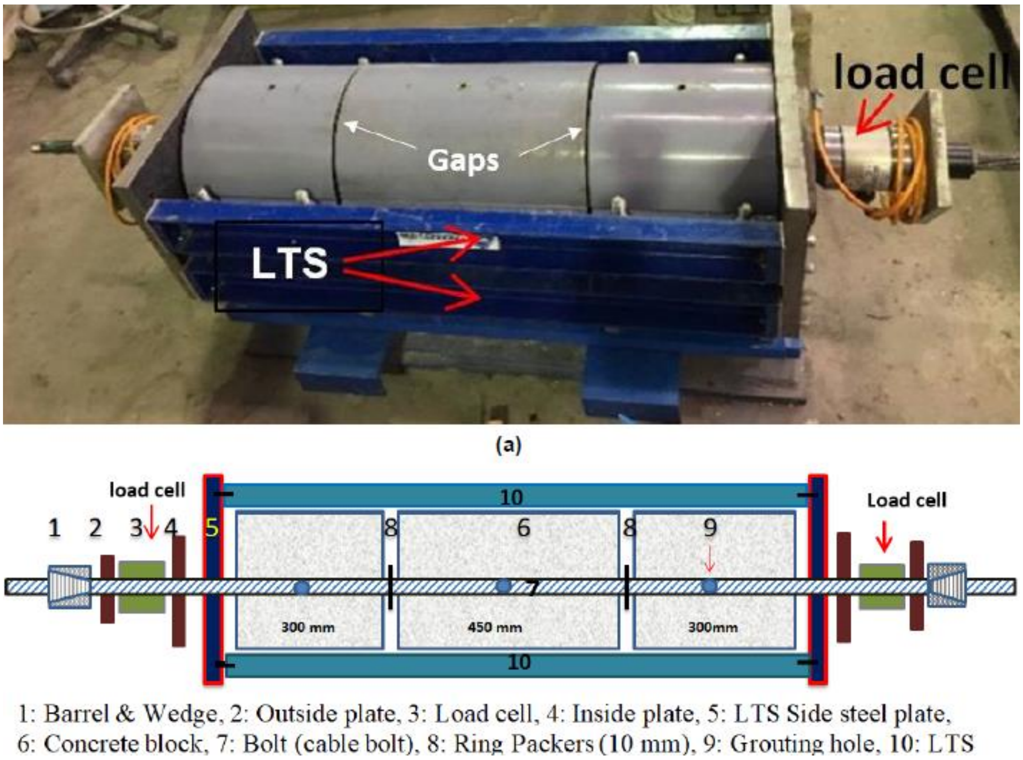

FIG 5 – Double shear test set-up.

Results are presented in Table 4. The cable reacted more radial load and permitted greater deformation than the tested hollow bars. The lack of bending stiffness allowed the cable to transfer a large portion of the radial load to axial load. The applied shearing force was reacted axially back to the plate securing it to each side. The 2 m critical embedment length means axial load reacts back to barrel and wedge assembly, allowing a large bend radius. The cable can respond to radial load by bending until it ultimately fails in tension. This suggests that if a cable is sheared *in situ*, it would convert a large percentage of the radial load into axial load within the cable, thus its shear capacity is far more dependent on its critical embedment length and the quality of its encapsulation.

TABLE 4

Falcon Bolt double sheer test results.

Bolt	**Axial pre-tension (kN)**	**Max axial load at failure (kN)**	**Radial load at failure, (each side)**	**Corresponding displacement (mm)**	**UTS (kN)**	**SF/UTS (%)**
R32X	50	0	271.87	37.82	570	48%
R32X	50	0	258.61	34.92	570	45%
R32S	50	0	198.21	28.95	360	55%
R32S	50	0	203.21	31.43	360	56%
15.2 twin strand cable bolt	0	360 kN	466.9	95.57	2 × 250	93.4%

The hollow bolts have a much stiffer interaction between the bolt and the grout, requiring less than 300 mm to react the bolt's full strength. This stiffer interaction factor allows a much smaller bend radius, concentrating bending force and ultimately increasing stress in the steel. A weaker encapsulation medium would correspond to longer critical embedment length, which could allow a greater bend radius, corresponding to greater resistance to shearing rock planes. The testing should be repeated with J Lok P 1:1 to confirm this theory. These results indicate a SF/UTS ratio of 48 per cent and 45 per cent for R32X steel, with failure patterns suggesting the bolts may not be failing in shear but failing in bending. Note this test does not account for friction between sliding planes. Geotechnical calculations must consider the relative shear capacities of the R32 hollow bar used in the Falcon Bolt and an equivalent cable bolt. Additional testing will be conducted to assess the impact of the encapsulation medium on the bolt's bend radius and how this impacts bending capacity and therefore response to a shearing rock mass, and effort can be invested in developing a steel that allows greater bending capacity. Further testing could explore how the Falcon Bolt's pre-tensioning property may enhance friction between sliding rock faces to improve shear resistance *in situ*, and ensuring that the shear test accurately models the response of a rock bolt to a shearing rock mass.

Site trials

Initial trials conducted early in the development of the Falcon Bolt focused on single length installations up to 3 m, aiming to direct the design path and verify engineering decisions. Early trials investigated and resolved issues such as drill bit design, grouting issues, and overall installation consistency. As Falcon Bolt development progressed and TGO expressed interest in cable replacement, trials aimed to assess specific performance parameters defined by TGO to ensure the Falcon Bolt can effectively replace cables.

Critical embedment length

Once the bolt has been installed and the threaded profile is encapsulated in grout, the grout moulds a physical inverse of the bolts thread. If the bolt is loaded axially, the loading force shears the grouted thread profile. Assuming the bolt geometry remains consistent, the resulting stress is a function of tensile force on the bolt, bolt geometry, and length of bolt in contact with grout. The critical embedment length defines the length where the bond shear strength of a given grout or resin is greater than the tensile strength of the bar, at which point the bar can be fully supported by the grout. The critical embedment length is a crucial parameter for the TGO ground support design methodology.

A campaign of short encapsulation pull tests is conducted aiming to determine the critical embedment length of an R32 self-drilling bolt in J Lok P pumpable resin and TD80 grout. This campaign aims to verify the critical embedment length of the bar itself, and the capacity of the toe anchor inclusive of drill bit. It was anticipated that the 51 mm drill bit would greatly increase the capacity of the system. Note the shell anchor is not tested, as the mechanical interface could skew results. This approach focuses solely on assessing the encapsulation strength, with any additional strength from the mechanical anchor considered a supplementary benefit. All tests are performed at the same location. A summary of results to date are presented in Table 5. Due to the large number of tests and the logistics involved in allowing pre-defined cure durations, tests are conducted in batches.

Test process as follows:

- Boreholes are predrilled to 51 mm and bars are manually inserted with centralisers to maintain position in the borehole, without compromising testing (Figure 6).
- Bars are fully grouted with either TD80 or J Lok P 1:1 resin.
- Each sample is pull tested to 90 per cent of UTS.

FIG 6 – Bolt configuration for embedment length testing.

TABLE 5

Critical embedment results.

J Lok P 1:1 R32X Critical Embedment to reach 520 kN (90% UTS)			
	Cure time		
	1 hr	**3 hr**	**24 hr**
R32X with drill bit	600 mm*	600 mm*	600 mm*
R32X	1200 mm – 1800 mm**	1200 mm – 1800 mm**	1200 mm – 1800 mm**
J Lok P 1:1 R32S Critical Embedment to reach 320 kN (90% of UTS)			
	Cure time		
	1 hr	**3 hr**	**24 hr**
R32S with drill bit	600 mm*	600 mm*	300 mm
R32S	*Not yet tested*	900 mm	450 mm
TD80 Grout R32S Critical Embedment to reach 320 kN (90% of UTS)			
R32S with drill bit	300 mm	-	-
R32S	300 mm	-	-

* – Shorter lengths not tested. ** – Length within range.

Testing needs to be completed to a greater resolution to identify the critical embedment length for the R32X bar, however it is known that 1800 mm can easily support 90 per cent of UTS after 1, 3 and 24 hrs. R32S with drill bit also needs to be tested with shorter lengths, to identify the minimum encapsulation required, however it is known that the critical embedment length for R32S bar with a drill bit fitted encapsulated with J Lok P 1:1 is 300 mm after 3 hrs. 600 mm will support 90 per cent of UTS after 1 hr, however further testing is needed to determine the minimum length required. An R32X bar with a drill bit fitted can be supported to 90 per cent of UTS with 600 mm of embedment after 1 hr. To achieve an equivalent anchor, a plain strand cable bolt requires a critical embedment length of 2.0 m with cement grout (Bawden, 1994). Since 2 m of the 6 m cable bolt is needed to support the other 4 m, a 6 m cable can conveivably be replaced with a 4.3 m Falcon Bolt injected with J Lok P in a 1:1 ratio after 1 hr cure time. Pull tests of installed 6 m Falcon Bolts encapsulated in J Lok P 1:1 consistently pull test to 28 t (typical ram maximum) after 1 hr cure with no sign of displacement or failure.

In-situ anchor testing

The key advantage of the Falcon Bolt is the mechanical anchor at the bolt toe. This allows the bolt to pre-tension, facilitates extension drilling and provides confidence the bolt will not move while waiting for the grouting process. The initial Falcon Bolt design brief required that the mechanical anchor alone without grout or resin should hold at least 100 kN capacity in typical conditions. As part of the trial process, 6 m installations were pull tested prior to grouting to test this criteria, providing a large quantity of data in a range of rock conditions.

Early designs of the mechanical anchor typically exceeded the required 100 kN load, with some anchors exceeding the capacity of the ram, and others only achieving 20 kN before pulling out of the borehole. In lab conditions, all anchors consistently achieved 200 kN or more, consequently a campaign of trials was conducted to identify the cause for the inconsistent anchor strengths. As part of the campaign, five 1 m Falcon Bolts were installed in hard and soft ground and the anchors were pull tested. Each anchor achieved more than 100 kN, with three anchors exceeding 250 kN. This particular trial indicated an issue that was occurring during the 6 m installation process. Following a thorough investigation, a new anchor design was developed to address the identified issue. Since implementing the revised anchor, 100 per cent of pull tests have achieved 100 kN or more prior to grout injection. Testing is ongoing to monitor the performance of the improved mechanical anchor.

Pre-tension

The advantages of rock bolt pre-tension are well researched. For example, a study found that pre-tensioned bolts improve the distribution and transfer path of compressive stress in a fractured rock mass, ultimately enhancing the shear strength of joints (Yongshui Kang, 2023). A laboratory shear test (Roberts, 2013) found that the application of 50 kN pre-tension applied sufficient friction along the sliding shear plane to increase the shear capacity of the system by 42 per cent. Simulations conducted by (Fu-Qiang Gao, 2008) also showed that when pre-tensioned rock bolts are installed in the backs (roof), the preload applied by the bolt subjects the supported rock mass along the bolt's axis to compression. This stiffens the structure, allowing load to transfer and distribute to a greater area and thus reduce stress. When pre-tensioned bolts are installed in the walls, Fu-Qiang found that the increased horizontal stress stiffens the wall creating a strengthened boundary that assists in supporting vertical roof stress, reducing load on bolts in the backs. The simulation found that the benefits of pre-tension were proportional to the amount of pre-tension applied.

The Falcon Bolt pre-tensions the supported rock mass, prior to resin or grout injection. The amount of pre-tension the Falcon Bolt applies is dependent on torque output of the drill rig. Typical jumbos will achieve around 50 kN, however newer systems can theoretically achieve up to 100 kN (Galluzzi, 2023). The 15.2 mm twin strand cables cannot apply pre-tension. Instead, the cables are tensioned after the grout has cured. This post-tension only loads the plate against the rock face and cannot apply compression along the entire length of cable, instead only compressing a shallow depth about the collar.

The stiffer ground support system afforded by the decreased critical embedment length and pre-tensioning during installation is considered favourable for ground support design condition at TGO. In particular, frictional forces between potential failed wedges and intact rock bridges or asperities that prevent kinematic sliding can allow structures to self-support, and this can be a critical component to maintaining stability. However, such wedges may be rendered unstable later with changing conditions and stresses from adjacent mining or production voids, weathering of surfaces or the ongoing effects of water. These low stress regions are susceptible to wedge failures as the normal 'clamping' forces acting on the wedge faces are insufficient. The compressive load applied by the bolts pre-tension can assist this 'clamping' force.

Pre-tension can also work to provide resistance to shear and tension across pre-existing discontinuities by preserving the confinement and shear resistance across these faces. Allowing the faces of a wedge to maintain this self-supporting element by limiting any initial movement of a wedge can be critical. If a bolt system with increased dynamic capacity is required, Falcon Bolt variations optimised for dynamic loading can be implemented. These variations feature a smooth debonded section, and offer more than 50 kJ dynamic capacity (Galluzzi, 2023).

Installations process and time comparison

Hand installed cable bolts at TGO

The hand installtion of cable bolts consists of three key phases:

1. Drilling cable holes with either a Jumbo or production drill depending on location, purpose and timing of the ground support cycle.
    - Drilling cable holes with a production drill allows for more precise installation around production holes but also results in a larger diameter hole which requires more grout and grouting time. A greater grout anulus between the cable and hole also places the cable at risk of reduced strength due to increased sensitivity to grout strength.
2. Pushing cable bolts into these pre-dilled holes whilst working from an integrated tool carrier (IT) basket and grouting them.
    - This step includes first configuring cable bolts: unfurling them from a coil (stored energy with potential for injury), cutting grout tubes, and joining these to the cable lengths using tape.
    - These cables are then pushed vertically into the pre-drilled holes from an IT basket, which is a manually intensive operation (back injuries occur) with the added risk of disloddged rock framents falling from the pre dilled holes (eye injuries occur).
    - The hole collar must then be blocked before grouting can commence, another time consuming proccess usually carried out using cotton wadding. This wadding also results in a section of ungrouted hole at the cable collar, allowing cables to debond. (Plates are installed later in the process to prevent this.)
    - Manually mixing and pumping cementitious grout using pnuematic equipment and a breather tube means the quality is highly dependent on several work processes. Often, grout is mixed thinner than specified as it is faster and easier for operators. This results in weaker grout. Stringent QA/QC is required to constantly verify mix and grout strengths, with weak cable bolts requiring replacement.
3. After sufficient time for the grout to cure, the cables are plated and tensioned, again using an IT and basket.
    - Although the plating and tensioning is not time consuming, the IT must again be mobilised. This can mean significant tramming time for a small task, meaning ITs are not always effectively utilised. Additionally, the portable hydraulic jacking units are susceptible to high wear and tear from the underground operators.

Falcon bolt installation at TGO

Falcon Bolt installation for deep intersection support consists of two steps:

1. Drilling, installing, and tensioning the Falcon Bolt.

- Falcon Bolts are drilled and tensioned, and are considered effective to 10 t capacity.
- Without the flexibility and precision of using a production rig to drill and install Falcon Bolts, additional planning and coordination is required when planning brow support to stop interaction with production drilling and holes.
- As Jumbo operators learn to work with a new bolt type and installation methodology, it is observed that initially Falcon Bolts are wasted at an average rate of 15 per cent. This is accounted for in all proceeding calculations. As more time was spent installing Falcon Bolts, this improved to 5 per cent.

2. Service crew grouts Falcon Bolts using a thixotropic grout.
   - Thixotropic grout pumped in a 'top down' injection principle removes the need for wadding and breather tubes. A quick release grout lance also increases efficiency of process.
   - Thixotropic properties prevent grout from dripping from borehole and can be mixed thicker than cementitious grout resulting in increased grout strength

Process improvement times are demonstrated through a reduction in time required by service crew to install Falcon Bolts compared to cable bolts (Figure 7 and Table 6). The additional required 'installation' and 'plate/tension' time for cable bolts adds an additional 4 to 5 hrs to the cable installation time to support to a three-way intersection at TGO. When the curing time is included in the comparison, (12 hrs for grout versus 1 hr for resin) major process improvements can be achieved.

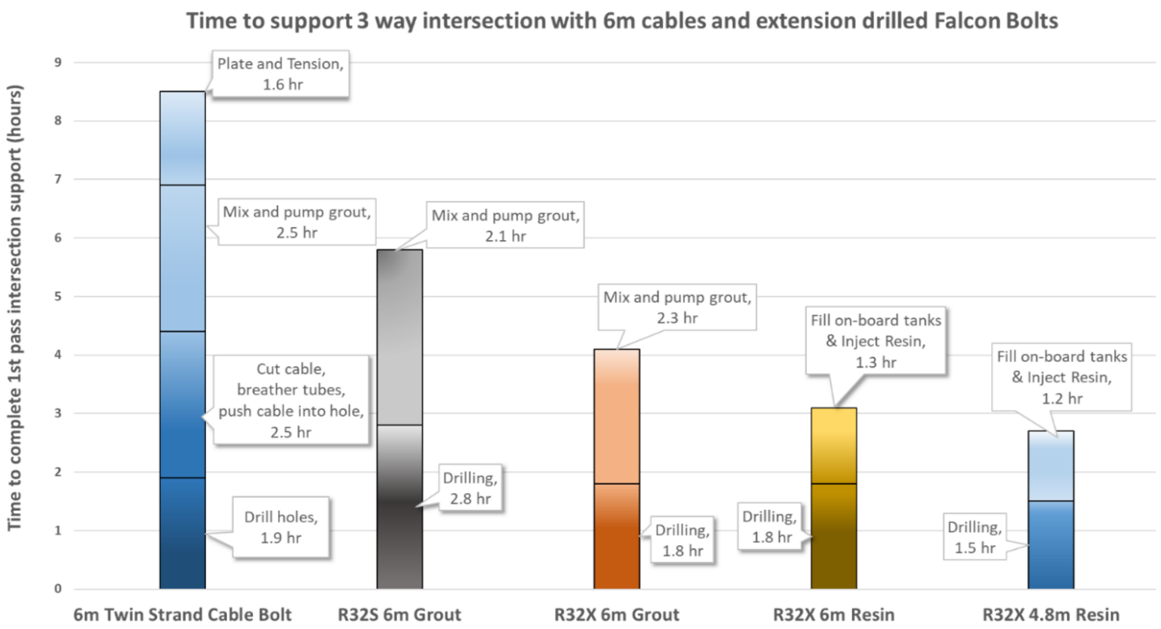

FIG 7 – 'Time on Bolt', Installation steps and times for 6.0 m twin strand cable bolt and various Falcon Bolt configurations.

TABLE 6

Deep support installation time comparison for a three-way intersection at TGO.

		Falcon Bolt				
		6.0 m Twin Strand (hrs)	**R32S 6.0 m Grout (hrs)**	**R32X 6.0 m Grout (hrs)**	**R32X 6.0 m Resin (hrs)**	**R32X 4.8 m Resin (hrs)**
1st pass (hours)	Drill holes	1.5	2.2	1.3	1.5	1.2
	Install	4				
	Grout/resin		2.1	1.6	0.8	0.7
	Cure	12	12	12	1	1
	Plate and tension	1	(Completed during installation)			
2nd pass (hours)	Drill holes	0.4	0.6	0.4	0.4	0.3
	Install	1				
	Grout/resin		0.9	0.8	0.6	0.6
	Cure	12	12	12	1	1
	Plate and tension	0.6	(Completed during installation)			
Total time (hours)	Jumbo time	1.9	2.8	1.8	1.8	1..5
	Service crew time	6.6	3.0	2.3	1.3	1.3
	Total install incl. Curing	32.5	29.7	28.1	5.1	4.7

Resin injection

The implementation of injected polyester resin provides further improvements to overall development efficiency, cost and safety. Using injected J Lok P, Jennmar's pumpable polyester resin, the total calendar time for installation and curing time for an intersection or heading was reduced from 33 hrs to 4 hrs. Jennmar and TGO collaborated closely in the design of the J Lok P resin injection system, culturing an environment that considered both the practical requirements of the mine and the engineering constraints of the manufacturer. The synthesis of these perspectives facilitated the development of an effective and usable system that integrated well into the existing mining infrastructure. This success underlines the importance of collaboration between mining operations and equipment manufacturers.The J Lok P Resin Injection System is retrofitted to an Integrated Tool (IT) Basket (Figure 8) and aims to replace conventional cement grouting with a rapid resin injection process.

The Injection System is primarily designed to streamline the installation of rock bolts by reducing the time, labour, cost and risk associated with cement-based grouting. The J Lok P Resin Injection System is powered with compressed air and delivers resin injection via two piston pumps. J Lok P polyester resin is delivered in a 1:1 ratio via an injection lance equipped with a mixing system, ensuring that the resin components are thoroughly combined before injection. Once mixed, the resin solidifies within 10 mins, achieving usable strength in 1 hr and full structural strength within 24 hrs. Through testing, it was found that the high-pressure injection enables the encapsulation of a 6 m Falcon Bolt in approximately 1 min with a single operator. The design removes the labour intensive mixing and wash-down procedures, and the risk of silica exposure inherent to cement grouting. Resin is transferred to the basket from IBCs using a specially developed transfer system.

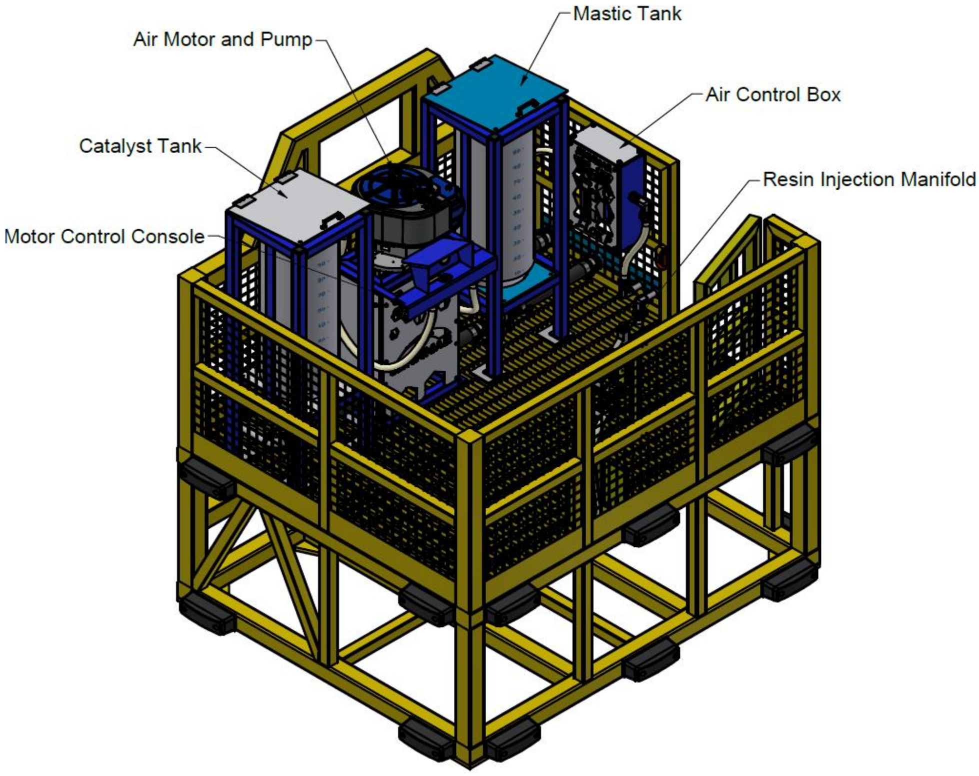

FIG 8 – Resin injection IT basket.

Prior to comissioning the Resin Injection System, three trials were undertaken to test the baskets functions and identify and rectify potential issues. During the first trial 11 6 m Falcon Bolts were injected. Some improvements were identified to prevent minor resin spills from occurring with the trial considered as successful. It was determined that injection time could be reduced from over 4 mins to 1 min if operators ensured that mixed resin is flushed from the injection lance if the system remained idle for more than 2 mins. This is due to the exponential increase of material viscosity over time once the resin components are mixed. Following the incorporation of this adjustment into the injection procedure, trials 2 and 3 demonstrated a clear improvement in operational efficiency. In trial 1, 11 bolts were injected in 1 hr, corresponding to an average duration of 6 mins per bolt. In trial 3, eight bolts were injected in 17 mins. This corresponds to an average duration of 2.1 mins per bolt to capture the entire process, with approximately 1 min dedicated to injection alone. This data is presented in Figure 9 and Table 7.

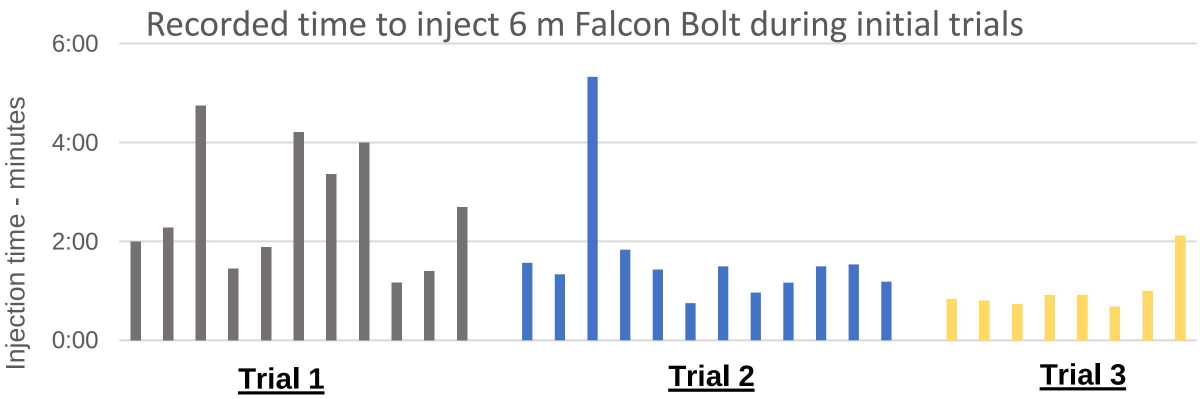

FIG 9 – Injection time per bolt.

TABLE 7

Injection trial summary.

Trial	Number of Falcon Bolts injected	Total duration	Average time per bolt
1	10	60 min	6 min
2	13	34 min	2.6 min
3	8	17 min	2.1 min

In trial 3, operators had become profficient in the operation of the resin injection system. The task consisted of tramming to worksite, connecting air and water services, then completing injection of eight bolts in 17 mins with a crew of one IT operator and one service crew operating the injection system. Note the resin injection process is very clean, the system does not require wash-down and mixing is automated, thus operators do not need to come into contact with raw resin. An equivalent grouting process can require three to 4 hrs to complete multiple mixes, injection, wash-down and plating/tensioning processes with a larger crew of one IT operator and two service crew workers. Further, the use of resin removes risk of silica exposure and dependence on cement and water ratios, which can be inconsistent. At time of writing, the system is in trial stages, however given success of J Lok P injection the system is due to be commissioned at Tomingley Gold Operatons in December of 2024. After a period of use the impacts on schedule optimisation, service crew utilisation, safety and cost will be further evaluated.

Large reductions in critical embedment length and consequently reductions in cable bolt performance can occur if there are deficiencies in grouting. In particular, cables encapsulated using the breather tube methodology can be grouted with a low water:cement ratio, greatly reducing bond strength, and therefore shear strength. The manual installation and grouting of ground support systems is becoming less common, presenting challenges in the effective transfer of skills and adherence to proper procedures, particularly during periods of staff turnover. Strict quality assurance testing and control protocols are essential to uphold the integrity of ground support performance. It is not uncommon for grout testing results to fall below established standards, necessitating the reinstallation of ground support in affected areas. The transition to Falcon Bolts and the implementation of an automated resin dosing and injection system to replace the traditional method of manually mixing and injecting cement grout is designed to enhance encapsulation consistency. This shift aims to ensure consistent installation quality and reinforces the assurance that ground support is being installed in accordance with design specifications.

Installation costs

A comparison of the operating costs of supporting a three-way intersection at TGO using 15.2 mm twin strand cables and Falcon Bolts with grout and resin is presented in Table 8. Installation costs build on the recorded process durations presented in Table 6, and data recorded during resin injection trials presented in Table 7. The study found that the direct costs to purchase ground support equipment does not represent the total cost of intersection reinforcement; machine time and labour are the most substantial cost contributors.

A thorough cost analysis shows that the Falcon Bolt R32X can reduce the direct costs of supporting intersections when compared to typical twin-strand 6.0 m cable bolts. The final costs in Table 8 are presented as a range calculated using TGO labour rates and results of Falcon Bolt installation time and motion studies. Contractor labour rates can be higher, which has a major influence on total cost per intersection, in this case the cost advantages of the Falcon Bolt become more pronounced. The analysis shows while Falcon Bolts have a higher unit cost, particularly when resin is included, their enhanced installation efficiency corresponds to an overall improvement in the operating cost of intersection support. Overtime, operators are gaining proficiency in Falcon Bolt installations, therefore installation efficiency and cost can be expected to improve. Further, as Falcon Bolt production numbers increase, the unit cost is also anticipated to decrease.

TABLE 8

OPEX cost comparison of different support options, total cost for a three-way intersection.

		Falcon Bolt			
	6.0 m Twin strand cable bolt	**R32S 6.0 m grout**	**R32X 6.0 m grout**	**R32X 6.0 m resin**	**R32X 4.8 m resin**
	No longer used by TGO	Currently used by TGO	-	In Trial	Not yet trialled
Element Supply, Grout/Resin and Consumables	Reference price (100%)	281%	238%	307%	276%
Drilling cost		122%	97%	97%	78%⁺
Service crew and IT cost		30%	27%	10%	10%⁺
Cables: Cut, attach breather, push, grout, plate and tension					
Falcon Bolt: Inject grout or resin					
Total cost per intersection (% of reference)		88–100%*	74–83%	80–89%	70–78%⁺

* – Drilling and installing 1.5× more in the case of R32S 6.0 m Falcon due to lower steel strength. ⁺ – Not yet trialled, projected based on available measurements.

The introduction of the R32X steel, which offers equivalent strength to twin strand cables, allows a bolt pattern similar to the previously used twin strand cables. During trials, the time needed to drill and tension a pattern of R32X Falcon Bolts was found to be nearly equivalent to the time required to pre-drill holes for cable bolts. The additional time spent tensioning the Falcon Bolt is offset by the reduced hole size and the elimination of drill steel extraction and decoupling processes. The greatly decreased critical embedment length provides further opportunities for optimisation through the use of a 4.8 m Falcon Bolt, with projected installation times detailed in Figure 6. Eliminating the plating and tensioning process negates the need for a return visit, further alleviating pressure on the development cycle. As summarised in Figure 6, the time required from the service crew is substantially reduced. The direct savings are presented in Table 8.

The broader benefits to schedule optimisation and the additional time now available to service crew are more complicated and harder to quantify. A brief comparison of TGO's scheduled versus actual cable installations and scheduled versus actual development metres before and after implementation of Falcon Bolts attempts to investigate these benefits. Since the adoption of Falcon Bolts as secondary intersection support in April 2024. Although Jumbos spend more time installing Falcon Bolts (1.5× drill metres due to lower strength R32S steel and production rigs no longer pre-drilling brow support) the development metres have not decreased, and the variance to schedule has actually improved. Similarly, improvements are evident in the variance between scheduled versus installed cable/Falcon Bolts. Further practical benefits are expected with the adoption of the stronger R32X Falcon Bolt and resin injection. Development and intersection support schedules are influenced by a broad array of factors, and a more comprehensive analysis will be conducted to explore the impacts of this ground support strategy on the overall mine development process.

CONCLUSIONS

This case study presents key learnings from the development and implementation of a self-drilling bolt to replace cables at Tomingley Gold Mine. The project was driven by the impracticality, inefficiency and high-risk exposure of manual cable installations. After investigations, it was found that the geotechnical design methods and conditions were favourable for the change, however Jennmar was requested to improve the strength of the R32S bolt, developing the R32X. Upon the full-scale implementation of the 6 m Falcon Bolt R32S as a replacement for 6 m twin-strand cables, it was determined that the overall cost per installed intersection remained comparable despite requiring more bolts, and the implementation of the R32X Falcon Bolt in 6 m format is expected to reduce costs of ground support installation. The efficiency of the installation process provided opportunity to optimise priorities for service crews and jumbos, correlating with an improvement to scheduling. For the first time, actual development and number of intersections installed exceeded schedule. Testing is currently underway to justify a change to a 4.8 m Falcon Bolt, which is anticipated to reduce costs further still. The commissioning of a purpose developed resin injection system is expected to offer further benefits to scheduling, installation efficiency, risk reduction, and QA/QC.

Feedback from operators across all four crews involved in the development process has been positive, and the active pursuit of input from workers across these crews at TGO was crucial to the success of the change management and the product development process. The safety improvements offered by the removal of the cable installation process are significant. In six months, three injuries occurred as a direct result of the cable installation method, these hazards are now entirely removed. This opportunity emerged from the collaboration between Jennmar and TGO management and geotechnical team, and the project's success highlights the importance of such collaborative efforts.

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