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Development and Implementation of the Garford Dynamic Bolt at the Kanowna Belle Mine

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ABSTRACT

Kanowna Belle Gold Mine is a deep, high-stress, sublevel open stoping mine located near Kalgoorlie. Seismic activity during the development cycle presented problems, including concerns regarding the exposure of personnel. A number of seismic management systems were developed and tested to monitor seismicity and control the risk. It was recognised that a dynamically capable reinforcement and support system was required to be installed as part of the development cycle to reduce the risk of exposure of the underground workforce to uncontrolled movement of rock. The performance of a new Garford Dynamically capable bolt was measured in tests performed by the Western Australian School of Mines (WASM) at their Kalgoorlie Dynamic Test Facility. Detailed descriptions of the facility and data processing were reported by Player, Villaescusa and Thompson (2004) and Thompson, Villaescusa and Player (2004). The development of the Garford Dynamic bolt is described and dynamic testing results are presented and evaluated. This bolt was implemented in the mining cycle following the testing program; the observed performance is described and assessed in this paper.

INTRODUCTION

Overview of Kanowna Belle Mine – location, geological setting and mining method

The Kanowna Belle Gold Mine is located 18 km NE of Kalgoorlie and 2 km west of the historic gold mining centre of Kanowna, Western Australia.

The orebody is comprised of several ore shoots, including the large Lowes Shoot, and several smaller lodes including Troy, Hilder, Hanging wall and Footwall shoots, controlled by sets of structures of various orientations oblique to Lowes. Lowes contains some 80 per cent of known gold mineralisation, and strikes ENE (mine grid east), dips steeply SSW, and plunges steeply SW. Lowes Shoot has a strike length of 500 m, width of 5 m to 50 m, and down-plunge extent greater than 1250 m.

The deposit is hosted by sedimentary volcaniclastic and conglomeratic rocks, which are separated into hanging wall and footwall sequences by a major, steeply SSE dipping zone of structural disruption. This structure represents the product of at least three temporally distinct stages of deformation, comprising the Fitzroy Mylonite, the Fitzroy Shear Zone and the Fitzroy Fault, which have produced clear structural overprinting relations. Importantly, this structure has localised emplacement of the Kanowna Belle porphyry, which hosts at least 70 per cent of known mineralisation.

Other major structures have also been identified which have an influence on ground conditions. The most important structures include; the PMT porphyry zone, contacts of felsic intrusives and porphyries, the Hanging wall Shear and the Footwall Shear. Figure 1 is a cross-section showing the generalised geology and stoping blocks for Kanowna Belle (after Beckett *et al*, 1998).

The mine started as an open pit operation, which was mined to a depth of 220 m. The decline is currently at 1100 m below surface.

The mine has been split into mining blocks: A block – mined out, B – partly mined, C – mining almost complete, D – currently mining, E – developing. The mining method is longhole open stoping, with 30 m sublevels. Sequencing is centre out bottom up with paste fill. E block is likely to be top down to better manage increased stresses.

The mine is split into seven domains based on lithology. The main lithologies are Conglomaterates, Porphyrys and Felsic units. Recent drilling has shown a further hanging wall domain consisting of ultramafics, a highly broken and weak rock mass. The Fitzroy Fault is a zone of gouge with a width of 1 cm up to 1 m. The Hanging wall Shear is a well-defined contact located 2.5 to 14 m from the Fitzroy Fault. The Footwall Shear is less well defined and tends to be a series of splayed structures that have little impact on stability. Three felsic units exist, the Moore, Larkin and Isabelle units cross the footwall domains, but are halted by the Fitzroy Fault.

The rock mass, using the Q system (Barton, Lein and Lunde, 1974), in general can be classified as fair in the ore zone to very good at the decline position. Intact rock strength has been measured between 90 to 140 MPa, strong to very strong rock (Hoek, 1992). Up to four joint sets have been logged per domain, with local areas having two to three joint sets.

The major principal stress at 1000 m is 75 MPa and sub-horizontal trending 124 degrees. Table 1 shows the local stress regime at Kanowna Belle. Support systems and drive profiles have been developed to accommodate the effects of stress on the development at varying orientations.

TABLE 1

Kanowna Belle stress regime.

Principal stresses	Magnitude	Trend	Plunge
σ_1	= 0.0706 × depth (m) + 4.6468	124°	06°
σ_2	= 0.0416 × depth (m) + 5.8156	228°	17°
σ_3	= 0.0366 × depth (m) - 3.5759	041°	80°

Need for a one-pass dynamically capable support system at Kanowna Belle

The need to develop a one-pass dynamically capable support system is due to the need to adequately protect personnel from exposure to the effects of seismicity. With the increase in depth and the increasing amount of extraction the risk of seismicity in development areas is considered to be increasing.

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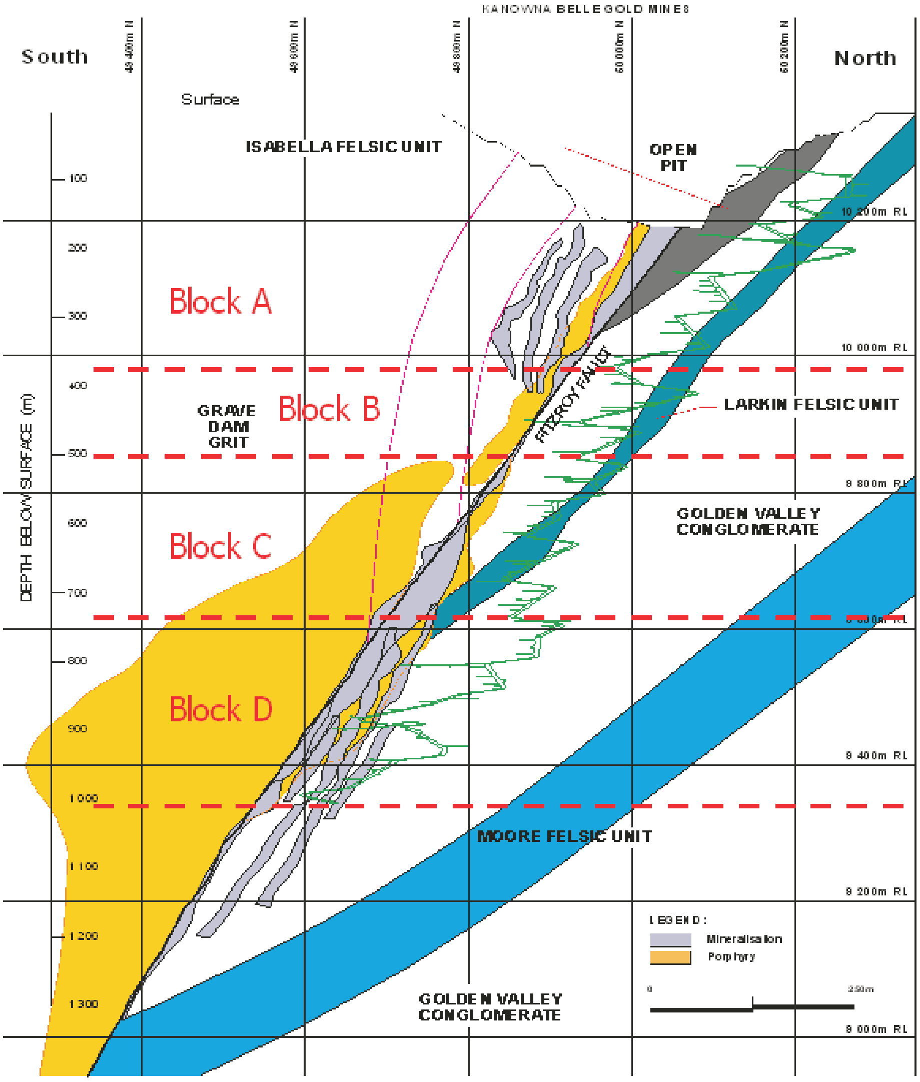

FIG 1 - Cross-section showing generalised geology and stoping blocks at Kanowna Belle.

Historic support systems at Kanowna Belle consisted predominantly of friction bolts, mesh and fibrecrete. Support system failures have occurred from dynamic loading due to large seismic events (0.5 to 2 local magnitude). These events have been interpreted to mainly occur along geological structures and are associated with failure depths of 1 - 2 m. Large events have occurred outside firing times either during the development cycle or during production activities, creating the need for improved development support.

BOLT SELECTION

Original selection process of the Garford Dynamic bolt

The Kanowna Belle geotechnical department identified the following assessment criteria for a dynamic resistant bolt:

- yielding mechanism, ie construction and load transfer characteristics;
- resin type and diameter with reference to possible supply issues;
- hole diameter in terms of practicality of equipment used;
- hole length crucial: will affect effectiveness of system;
- bolt length: suitability to rock mass and equipment;
- bolt diameter: core diameter – strength and mixing device;
- thread type: ease of installation;
- bolts installed by jumbo: practicality, speed and cost of installation;
- special equipment required: practicality, speed and cost of installation;
- installation problems: practicality, speed and cost of installation;
- high level in consistency in results: important for the system to work;
- debonding method: important to effectiveness of dynamic performance;
- maximum capacity achieved: required for design of system;
- maximum displacement: required for design of system;
- load at failure: required for design of system;
- failure mode: required for design of system and rock mass reaction;
- corrosion issues: need to identify for wet areas; and
- supply issues of system: cost and potential production delays.

The following commercially available bolts were assessed against the criteria: the Garford Dynamic bolt, the yielding Secura threadbar, the modified cone bolt (MCB), the Posimix threadbar and the Swellex MN24.

In conjunction with an independent assessment undertaken by WASM (Thompson and Player, 2005), the following characteristics led to the selection of the Garford Dynamic bolt over the alternatives:

- The yielding mechanism gives a controlled yielding mode. This is achieved through an engineered mechanism, rather than relying on material failure of the encapsulation or bolt material.
- The use of resin grout enables a single pass installation with the bolts becoming effective immediately after installation.
- Practical system compatible with current equipment, which can be installed in a 45 mm hole, ie no change of bits or rods from development drilling is required.
- No significant problems with installation were encountered during trials.
- No corrosion problems were identified with the bolt.
- A high level of consistency was obtained in bolt performance during testing.

Technical description of the Garford Dynamic bolt

Figure 2 shows the Garford Dynamic bolt currently being installed at Kanowna Belle. The bolt consists of a 20 mm mild steel solid bar with a M24 thread. The resin mixing device is a 350 mm long, 43 mm diameter coarse threaded steel sleeve crimped on to the end of the bolt. The dynamic section is a patented sliding anchor mechanism that is pressed on to the bolt below the mixing device. The remainder of the bolt is covered in a polyethylene sleeve. This debonds the bolt behind the dynamic section. When the bolt is subjected to a ground movement the bolt is forced through the constriction and elongates.

WESTERN AUSTRALIAN SCHOOL OF MINES TESTING

Planned objectives for the Western Australian School of Mines testing program

The objectives that Kanowna Belle required of WASM in their testing program were:

- test the static capabilities of the Garford Dynamic bolt,
- test the dynamic capabilities of the Garford Dynamic bolt,
- undertake comparative tests of the bolt in resin and grout simulated to underground conditions, and
- assess the bolt for consistency of performance and identify issues (both under dynamic loading and installation underground) that could result in inconsistency.

Two configurations of the Garford Dynamic bolt were tested. The second configuration was based on recommended improvements to the first bolt configuration (Thompson and Player, 2005). Two main technical issues were identified. The first related specifically to the pulling of the bar through the anchor ferrule without reaching the tensile strength of the element. The second issue related to the generally poor implementation of resin bolts in the underground metalliferous mining industry.

Background to the testing facility and process

The Western Australian School of Mines (WASM) dynamic test facility was built for the Minerals and Energy Research Institute of Western Australia (MERIWA) under projects M349 and M349A. The facility was constructed in recognition of the need to understand the performance of reinforcement and support systems subjected to dynamic loads resulting from seismic events. The facility is capable of dynamic testing of reinforcement and support components or complete ground support systems in an engineered environment. Different systems can be compared under repeatable, controlled conditions.

The primary results from this type of test facility should be the dynamic force displacement response for the tested system, the energy absorbed by the system and the velocity that the system was subjected to during the loading. The WASM facility is described in detail by Player, Villaescusa and Thompson (2004); Thompson, Villaescusa and Player (2004), with an analysis of other facilities by Player, Villaescusa and Thompson (2005). The dynamic loading mechanism and dynamic test facility are described in these proceedings by Player, Thompson and Villaescusa (2008).

Normally, the WASM analysis is based on a single loading cycle. The first 'drop' provides the primary results for each analysis of a reinforcement system. This is because in practice, it is not expected that after yielding, the ejected rock would still be intact and able to sustain repeated loading.

Test program

Four components were specified for the test program:

- Dynamically test the first version of the Garford Dynamic bolt cement grouted into a thick wall steel pipe of equivalent stiffness 80 GPa, based on calculations from Hyett, Bawden and Reichardt (1992).

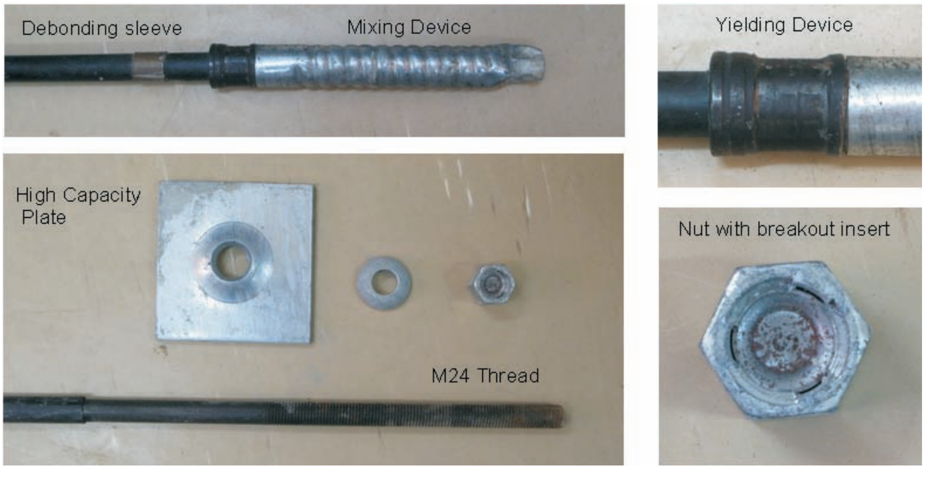

FIG 2 - The Garford Dynamic bolt installed at Kanowna Belle.

- Dynamically test the second version of the bolt cement grouted into thick wall steel pipe of equivalent stiffness. This tests the bolt under ideal conditions.
- Development of a simulated borehole that allowed installation of the bolt by a jumbo with resin into a suitably 'rough' borehole, equivalent stiffness of 35 GPa. The rough borehole should be similar to what the bolt would be installed into underground.
- Dynamically test the second version of the bolt installed by a jumbo into the simulated holes; dissect the simulated holes and examine the samples for the effectiveness of resin encapsulation and damage to the bolt during installation.

Results from initial tests

The first version of the Garford Dynamic bolt performed consistently with an average load of 125 kN and displacement of 274 mm at the simulated discontinuity, resulting in 33 kJ of energy being absorbed from a standard test. The dynamic force displacement response of the first version of the Garford Dynamic bolt is compared to 22 mm diameter cone bolts in high or low strength grout mixes in Figure 3.

The more a reinforcement system displaces during a dynamic loading event, the greater the energy that the reinforcement system must be capable of adsorbing due to the additional potential energy input from the 'rock' moving into the drive. Yielding systems that allow large displacements due to their softness may also result in excessive fracturing/bulking of the rock mass, resulting in adverse loading of the support system. A soft response from a reinforcing system will also allow higher ejection velocities of the rock into the drive.

Based upon the initial results a second version of the bolt was produced with a higher sliding resistance to the dynamic load and an end stop mechanism. This would maximise the energy absorption capability by ultimately breaking the shaft of the bolt. The second version of the bolt was tested both grouted into a thick wall steel pipe and installed by a jumbo with resin into a simulated rough hole.

Simulated boreholes for jumbo installation of the Garford Dynamic bolt

The construction of simulated boreholes allows the testing of reinforcement systems that are sensitive to installation methodology or borehole geometry. The reinforcement system is installed by the equipment that will undertake the task underground. The complete system can then be dynamically tested. A high strength grout and basalt aggregate mix was cast about a polystyrene central guide inside an 80 mm internal diameter, 100 mm outside diameter, steel pipe. The required hole was drilled into the high strength grout and basalt aggregate mix by an airleg with an appropriately sized bit. The complete unit was pushed into a hole drilled in the drive wall. This allowed the jumbo to install the resin encapsulated bolt into the simulated hole in a drive wall as shown in Figure 4.

FIG 4 - Simulated boreholes.

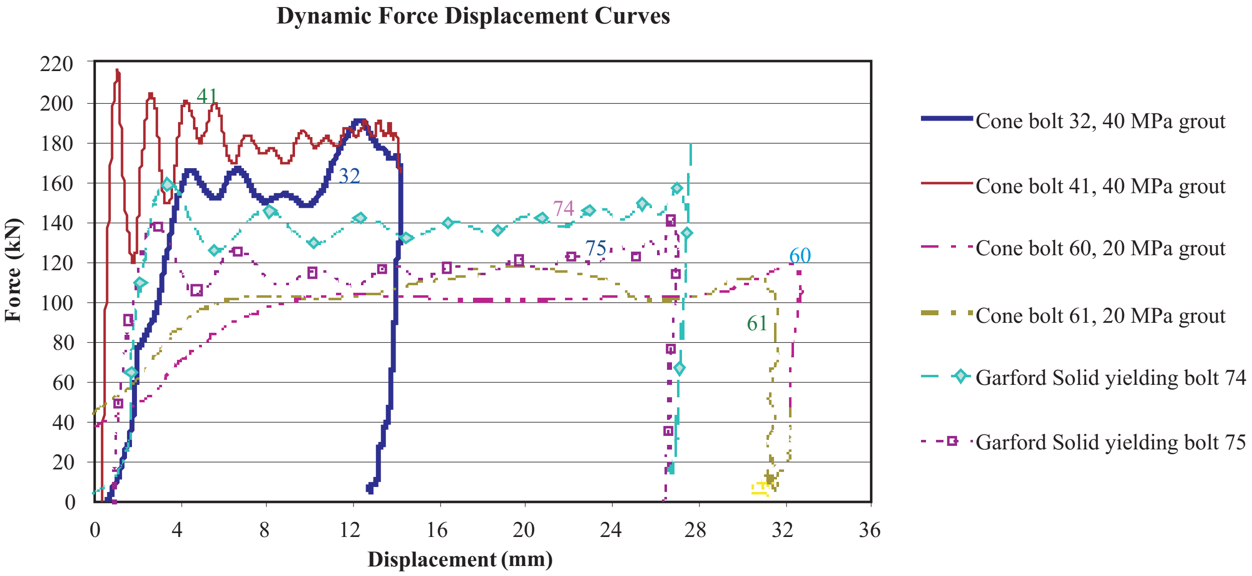

FIG 3 - Dynamic force displacement curves.

Results from second stage

Dynamic testing of the second version of the Garford Dynamic bolt indicated both a satisfactory end stop mechanism, whereby the complete capacity of the steel bar was utilised during rupture of the bolt and higher load transfer and shorter displacements from each dynamic load cycle. The test bolts survived remarkably well from their first drop at the test facility. The first drop is considered the most important for analysis as in the field the ground would not be expected to remain intact and hence would be incapable of reloading the bolt in a similar manner during subsequent seismic events.

Reinforcement systems that are shown to survive multiple loadings should also have a single test with the input energy similar to the sum of the energy absorbed by multiple loadings to assess consistency in behaviour across a range of loadings. The dynamic force displacement responses from the first loadings are shown in Figure 5 for the improved Garford Dynamic bolt.

The tests on the second version of the bolt identified a number of key elements:

- The second version of the bolt when installed in grout had short displacement (180 mm) and high resistive force (145 kN) to loading when compared to the first version of the bolt that allowed 274 mm at 125 kN. The shorter displacement means less energy is required to be absorbed because of the smaller change in potential energy of the loading mass following impact.
- The resin-encapsulated bolt behaved slightly differently when compared to bolts encapsulated in grout, with slightly shorter displacements.
- It was possible for the bolt to be damaged during installation, allowing resin to leak into the yielding mechanism, increasing the resistive force and decreasing the displacement, eg bolt 97 (particularly on the first loading).
- The end stop mechanism worked well with 'cup and cone' fracture of the steel bar from dynamic loading.

Dissection of simulated boreholes

The simulated boreholes with jumbo installed, resin-encapsulated bolts were dissected after dynamic loading. This examination showed:

- the mixing device was very effective; however, the best performance was achieved by rotating the bolt and slowly pushing the bolt through the entire length of the resin;
- over-drilling the holes by 100 mm to 150 mm allowed the resin bag to move to the end of the hole and not wrap around the mixing device; and
- a resin length of 240 mm below the yielding device on the bolt was sufficient to break the shaft of bolt once the end stop mechanism was reached.

Dependence on loading velocity

A dependence of the dynamical frictional resistance of the steel bar pulling through the yielding device to the velocity of impact has been identified from comparing bolt 100 (8 m/s impact velocity) to bolts 89, 90 and 99 (6 m/s at impact) results (Figure 5). This occurs even though the majority of energy consumed is by plastic deformation of the solid bar as it is pulled through the engineered yielding device (Figure 2). A change in dynamic friction has been reported by numerous authors across a variety of fields, including Forrester (1946) in steel; Spurr and Newcomb (1957) for bitumen and Toro, Goldsby and Tullis (2004) in quartz for earthquake faults. The explanation for the process varies depending on the properties of the materials involved. The main aspect is that the Garford Dynamic bolt performance exhibits a loading velocity dependence that increases the sliding velocity and decreases the resistance to yield.

The test on bolt 100 also showed that cumulative energy absorbed from several drops leading up to breakage is not necessarily the same as the energy required to break the reinforcement system from a single impact. Bolt 100 absorbed 53 kJ with the end-stop mechanism taking significant load, while bolts 89 and 90 apparently absorb the same amount of energy on the first two drops without reaching the end stop mechanism. The suggested total energy absorption capability from summing smaller impacts of 65 to 70 kJ from bolts 89, 90 and 99 is shown to be an overestimate of the capacity of the bolt's capability by the test on bolt 100.

This also implies that to be able to determine the true energy absorption of a reinforcement system, the test apparatus must be able to break the reinforcement on the first loading cycle.

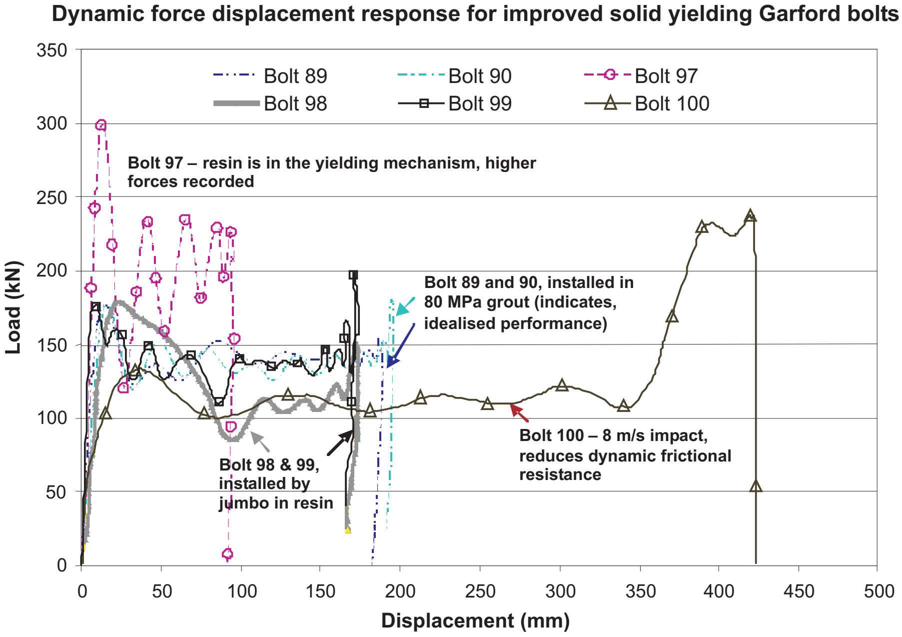

FIG 5 - Dynamic force displacement curves – Garford Dynamic bolt, version 2.

SUPPORT SYSTEM DESIGN

Figure 6 shows the Garford Dynamic bolt support pattern that is currently being implemented at Kanowna Belle Gold Mine. This support pattern was derived from a modification of the original friction bolt support standards employed at the mine.

The effective bolt spacing shown in Figure 6 is 1.5 × 1.5 m along the backs and 1.5 × 0.75 m along the walls of the development. Static support requirements per bolt are calculated in Table 2 for an effective 1 m and 1.5 m depth of failure. A worst case depth of failure of 1.5 m is adopted in the support design based on observations from historic dynamic failures at Kanowna Belle Gold mine (internal investigation reports).

The equivalent dynamic support response of the system is calculated in Table 3. The following assumptions were made in the calculations:

- Each bolt and depth of failure was assessed for a potential ejection velocity ranging from 0.5 m/s to 5 m/s. These ejection velocity values were adopted as they are considered to be within the range of current industry design practice.
- The energy demand per bolt was calculated from the resultant kinetic and potential energy requirement to stabilise the mass acting on each bolt (Li *et al*, 2004).
- The dynamic yielding load of the bolt was assumed to be 150 kN in the range of 0 to 2 m/s; 140 kN for 3 m/s; 130 kN for 4 m/s and 120 kN for 5 m/s. These values were interpreted from the results of the WASM testing program (Player, 2007).
- From the dynamic yielding load and the energy demand for each bolt, a bolt displacement value could be calculated for each potential ejection velocity. As such, the effectiveness of the bolting pattern could then be assessed in terms of its ability to restrict rock movement acting under a dynamic perturbation.
- Table 2 analyses only the bolt response, ignoring the energy absorption capabilities of the surface support incorporated into the support system. As such, this analysis represents a worst-case scenario.
- The support pattern is assessed in terms of the surrounding rock mass bulking and bolt stability rating according to the following bolt displacement criteria:
  - 0 to 20 mm: low rock mass bulking,
  - 20 to 150 mm: medium rock mass bulking,
  - 150 to 300 mm: high rock mass bulking, and
  - >300 mm: extreme rock mass bulking.
- Where the bolt displacement is calculated to exceed 300 mm, integrity of the bolt can no longer be guaranteed, and as such the bolt is rated as unstable.

The results in Table 3 show that the wall bolts will be in the stable range up to an ejection velocity limit of 4 m/s. The equivalent stability range of the bolts in the backs would extend only to an ejection velocity limit of 2 m/s. This is a function of the effective bolt spacing incorporated into the support design.

The 'dynamic' empirical basis for the design bolt spacing along the backs (1.5 m × 1.5 m) is:

- The design utilised historic bolt spacing practices as a basis. This was originally calculated from static considerations and incorporated friction bolts, with limited dynamic failure initiation historically observed along the backs.
- All development is blasted in an arched shape. This shape is inherently stable and, as long as the arch shape is maintained, frictional resistance will act to restrict dynamic movement of key-blocks, reducing the energy demand acting on the bolts. This is interpreted to play a role in the design, but is not quantified in this analysis.
- In addition to the above, the arch shape and key-blocks are locked into place through the application of in-cycle fibrecrete (100 mm thick, 40 MPa fibrecrete). This will act to further improve the stability of the excavation backs.
- Initial calculations indicate that when surface support and arch stability effects are incorporated into the design calculations, the energy absorption bolt displacement requirement could reduce from 325 mm to 160 mm for a 3 m/s ground velocity and a 1 m depth of failure.

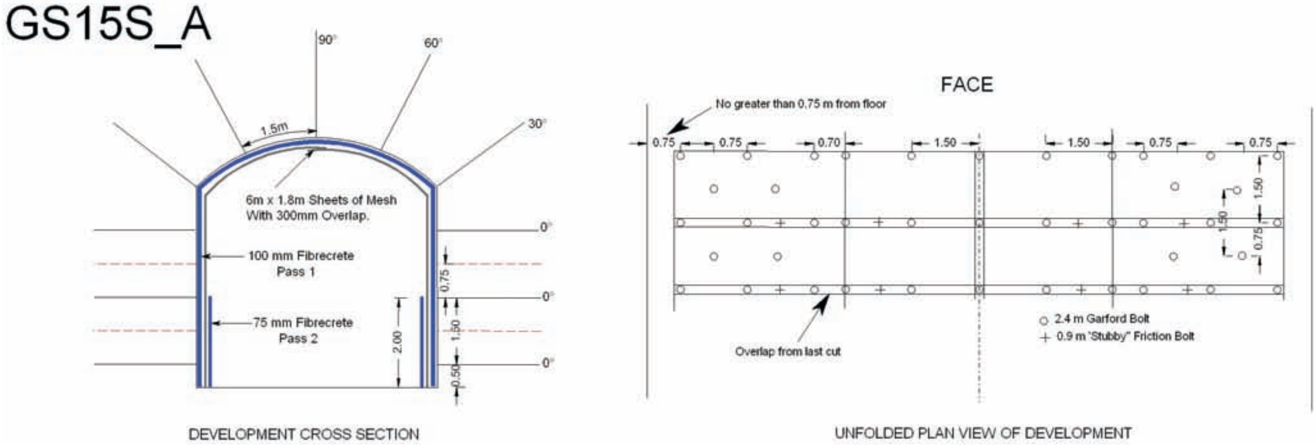

FIG 6 - Garford Dynamic bolt support pattern.

TABLE 2

Static support requirements per bolt.

	Area (m^2/bolt)	Volume 1 m depth (m^3/bolt)	Volume 1.5 m depth (m^3/bolt)	Mass 1 m depth (kg/bolt)	Mass 1.5 m depth (kg/bolt)
Bolt wall area coverage	1.13	1.13	1.69	3150	4725
Bolt backs area coverage	2.25	2.25	3.38	6300	9450

TABLE 3

The equivalent dynamic support response of the system at walls and backs with varying depths of damage.

GS15S – Wall bolts (1 m depth of failure)

Mass (kg/bolt)	Ejection velocity (m/s)	Energy demand (kJ/bolt)	Req bolt displ (mm)	Est bolt yield (kN)	Bulking rating	Bolt stability rating
3150	0.5	0.4	3	150	Low	Stable
3150	1.0	1.6	11	150	Low	Stable
3150	2.0	6.3	42	150	Medium	Stable
3150	3.0	14.2	101	140	Medium	Stable
3150	4.0	25.2	195	130	High	Stable
3150	5.0	39.4	329	120	Extreme	Unstable

GS15S – Wall bolts (1.5 m depth of failure)

Mass (kg/bolt)	Ejection velocity (m/s)	Energy demand (kJ/bolt)	Req bolt displ (mm)	Est bolt yield (kN)	Bulking rating	Bolt stability rating
4725	0.5	0.6	4	150	Low	Stable
4725	1.0	2.4	16	150	Low	Stable
4725	2.0	9.5	63	150	Medium	Stable
4725	3.0	21.3	152	140	High	Stable
4725	4.0	37.8	290	130	High	Stable
4725	5.0	59.1	491	120	Extreme	Unstable

GS15S – Backs bolts (1 m depth of failure)

Mass (kg/bolt)	Ejection velocity (m/s)	Energy demand (kJ/bolt)	Req bolt displ (mm)	Est bolt yield (kN)	Bulking rating	Bolt stability rating
6300	0.5	1.4	9	150	Low	Stable
6300	1.0	5.0	33	150	Medium	Stable
6300	2.0	20.0	133	150	Medium	Stable
6300	3.0	45.7	325	140	Extreme	Unstable
6300	4.0	68.9	530	130	Extreme	Unstable
6300	5.0	97.3	810	120	Extreme	Unstable

GS15S – Backs bolts (1.5 m depth of failure)

Mass (kg/bolt)	Ejection velocity (m/s)	Energy demand (kJ/bolt)	Req bolt displ (mm)	Est bolt yield (kN)	Bulking rating	Bolt stability rating
9450	0.5	2.6	17	150	Low	Stable
9450	1.0	9.4	63	150	Medium	Stable
9450	2.0	42.1	280	150	High	Stable
9450	3.0	70.3	501	140	Extreme	Unstable
9450	4.0	103.4	793	130	Extreme	Unstable
9450	5.0	145.9	1215	120	Extreme	Unstable

- A bolt spacing of 1.5 m × 1.5 m versus 1.5 m × 0.75 m along the backs equates to a cost and productivity saving of installing eight bolts per 3 m of development.
- Horizontal clamping forces act to clamp the backs together, promoting the mechanical model outlined above. However, increasing clamping forces may result in extensive failure and rock mass deterioration in the backs, which would be detrimental to the arch stability. Further work is required to clarify this risk.

The 'dynamic' empirical basis for the design bolt spacing along the walls (1.5 m × 0.75 m) is:

- the design utilises a denser bolting pattern than historic bolt spacing practices;
- historically, dynamic failure has been interpreted to initiate along the walls of the development, ie the walls are most vulnerable to dynamic failure;
- the walls are not locked into an arch shape, and as such the walls have the potential to 'flap' (oscillate) in a dynamic situation;
- rock mass relaxation occurs in the walls, easily allowing block movement under dynamic conditions; and
- the wall integrity is integral to maintaining the arch shape and as such supporting the stability of the backs.

The support design is currently derived from empirical observations in combination with the dynamic capacity of the bolts as derived from the testing undertaken at WASM. The following optimisation design work is planned:

- Dynamic testing of the individual surface support components and the combined support system in collaboration with WASM. This will improve understanding of the role of the surface support under dynamic conditions.
- Collect near field (10 to 50 m source range) peak particle velocity data utilising low frequency geophones. With the establishment of the relationship between seismic hazard categorisation and peak particle velocity, reliable site specific seismic demand calculations can be established for support design optimisation.
- Quantify the damaged zone surrounding the development. This will provide information on the potential depth of failure, allowing for the optimisation of bolt lengths and spacing.
- Back analyse large events occurring in the vicinity of the new dynamic resistant support system in order to verify the empirical design assumptions listed above, verify the underground performance of the support system and identify any potential design weaknesses.

BOLT IMPLEMENTATION AT KANOWNA BELLE

The installation issues experienced with the Garford Dynamic bolt are listed below:

- Operators unfamiliar with bolts installed with resin – this has resulted in incorrect hole depth, spin and hold times, in turn resulting in the resin bond breaking. The debonding sleeve has been stripped off due to incorrect installation angle. There were also difficulties in installation of the resin cartridge.
- Logistics of operator training.
- Operator turnover.
- QAQC – the only controls are observations on installation. Pull testing is not a suitable method and overcoring is logistically difficult and expensive.
- Developing a practical installation standard and design – this has resulted in several modifications to the ground support standard so as operators are able understand the installation procedure.
- Installation in seismically damaged ground has not been successful to date; this may be due to operator inexperience, sequence of installation and drilling technology.

To date the bolt has not been subjected to any significant seismic event and has not been dynamically tested in the field. Attempts to install the bolts in ground that was damaged by previous seismic activity were unsuccessful. This was due to the ground collapsing into the hole, preventing the insertion of the resin and bolt. Other support and reinforcement methods are being adopted for this type of ground; these include increased surface support and self drilling bolt technology.

CONCLUSIONS

Kanowna Belle mine identified that there was a significant risk to personnel during development and stoping operations from seismic events due to high stress and the presence of geological structures. Seismic events have occurred during the development cycle outside the normal blasting and re-entry times, exposing people to hazards.

The problem has been addressed through the selection of a commercially available dynamically capable bolt. A rigorous testing program with state-of-the-art dynamic test facility at WASM was carried out. The support system was designed to improve the current support systems employed at Kanowna Belle. Additional work is required to fully develop the system, including:

- assess the effects of surface support – dynamically test the full support system, including fibrecrete, mesh and bolts at the WASM test facility;
- collect more information on performance and installation practices; and
- collect more information on demand to optimise the support systems.

In conclusion, Kanowna Belle has successfully implemented a well-tested, one-pass dynamically capable support system as part of the development cycle at the mine.

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