Development of the MDX Bolt and in-situ dynamic testing at Telfer Gold Mine

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ABSTRACT: The Sandvik MDX bolt has been developed to provide strata support in a wide variety of rock conditions (weak and competent), and in particular seismic rock conditions. While the MDX bolt maintains the key features of the successful MD bolt, regarding the ease of installation (single pass with no grout or resin required), its performance in both the seismic and very weak rock conditions has been significantly improved. The MDX bolt development was undertaken in conjunction with Telfer Gold Mine, located in Western Australia. Telfer mining operation employs three mining methods in a high stress and seismic setting. This setting was selected for trial dynamic testing of the MDX bolt, using a unique, world first in-situ Dynamic Test Rig. The performance requirements set out by Telfer were to withstand an impact energy of 25 kJ, and limit displacement to 200 mm. The results were more than satisfactory, as the maximum bolt displacement was only 153 mm.

1 INTRODUCTION

There has been a demand for dynamic rockbolts for seismic conditions for a very long time. Recently, a number of bolt developments were attempted with varying levels of success; either through poor performance, cumbersome installation requirements, or a combination of both. Sandvik first developed the Mechanical Dynamic (MD) bolt in 2009, which proved very successful in supporting swelling and squeezing grounds. However, the MD bolt did not prove to be 100% consistent when tested with high dynamic loads (25-30 kJ). To rectify this, the MDX bolt was developed, with single pass installation in any ground conditions, utilizing conventional machinery, similar to the MD bolt.

The MD bolt is composed of a conventional friction bolt tube which contains a mechanical anchor, to create a single pass high capacity rockbolt. The MD bolt is currently successfully utilised in many underground mines, particularly in conditions where installation of resin or grouted bolts is hindered by poor or highly fractured ground.

The MDX bolt is an evolution of the existing MD bolt, involving two key design changes, which allow the MDX bolt to perform well under dynamic and seismic loading conditions. In order to determine the performance of the MDX bolt – under dynamic loading conditions – in-situ dynamic testing was conducted at Telfer Gold Mine.

This paper will present the design evolution of the MDX bolt, the Telfer requirements for a Dynamic rockbolt and field testing of the MDX bolt under in-situ Dynamic loading conditions using the Sandvik Dynamic Test Rig at Telfer Gold Mine.

1.1 *The demands of seismic loading conditions*

Even though significant work has been completed, previous research has found that the exact demands of a rockbolt under seismic conditions are unknown (Potvin & Wesseloo, 2013).

Under seismic loading conditions, rockbolts are subjected to a shock or dynamic load, which typically entails a high peak load, applied over a relatively short time. These loading conditions alter the reactive behavior of steel. In order for a rockbolt to react appropriately to this dynamic loading, it is critical for a dynamic rockbolt to have a capacity to yield in some manner, assisting to dissipate the shock loading.

The yielding capacity of a dynamic rockbolt can be achieved in several different manners; including frictional sliding, movement of a steel tendon relative to a ‘softer’ medium or pure elongation of a steel tendon (Li, 2017).

The method, by which a rockbolt yields to dissipate the applied load or energy, is critical to determine the “dynamic capacity” of the rockbolt. In the case of the in-situ testing conducted at Telfer Gold Mine, the dynamic capacity was deemed to be the energy absorbed by the rockbolt. This absorbed energy is determined directly from the load-displacement plot.

In Australia, there is an industry accepted guideline for the capacity of a dynamic rockbolt. This guideline states that a rockbolt must withstand an input load of 25 kJ, and displace not more than 300 mm. The reasoning behind this industry guideline will not be covered in this paper.

1.2 *The MDX Bolt*

The Sandvik MD bolt was developed in 2009 to alleviate a market demand of a simple, single pass high capacity rockbolt. The MD bolt targeted very poor or highly fractured strata, where resin or grouted bolts were experiencing issues during installation. The MD bolt comprises a 47 mm diameter friction bolt tube with an internal re-bar and wedge assembly at the toe end of the bolt (figure 1). The wedge assembly is activated during bolt installation to provide a point anchor to significantly increase the load capacity of the bolt. The MD bolt is now used in numerous sites across Australia; and has proven very successful in managing swelling and squeezing ground conditions. However, when tested with the Sandvik In-situ Dynamic Test Rig, the dynamic performance of the MD bolt proved inconsistent when subjected to high dynamic loads (25-30 kJ).

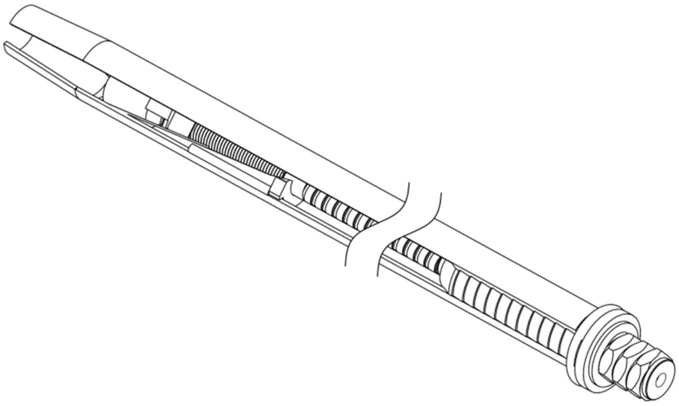

Figure 1. The Sandvik MD Bolt

The design platform of the MDX bolt comprises a similar friction bolt tube and wedge expansion system to the MD bolt (figure 2). The key differences between the MD and MDX bolts are the wedge assembly and the load transfer mechanisms.

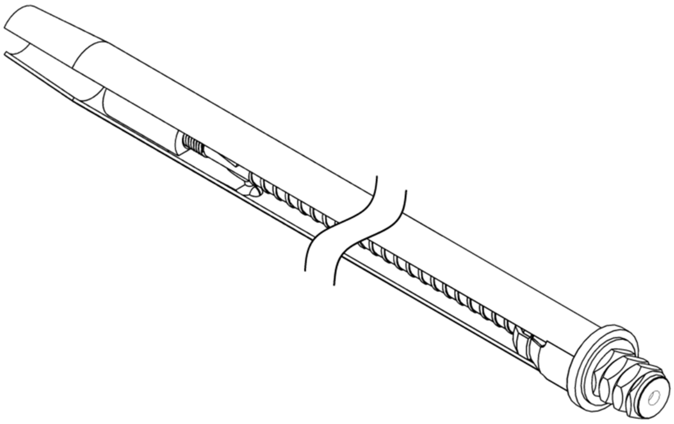

Figure 2. The Sandvik MDX Bolt

The wedge assembly of the MDX bolt has been reviewed to increase the maximum expansion from 52 mm (MD bolt) to 64 mm. This increased expansion capacity has a two-fold effect; firstly, the MDX bolt is suitable for a greater range of ground conditions. Additionally, the wedge assembly will assist with the dissipation/absorption of dynamic energy.

Possibly the most important design change to the MDX bolt, is the load transfer mechanism. The MD bolt utilizes both tube and rebar components to absorb load, whereas the MDX bolt relies solely on the rebar to absorb dynamic loads. This design alteration is the key to consistent responses when subjecting the MDX bolt to dynamic loading.

The MDX bolt has a high potential uniform elongation, where the ‘free-length’ of the rebar (loading member) is 2.1 m (for a 2.4 m bolt). This large free length lends to a large possible elongation, as tensile testing has resulted in a 15% uniform elongation for the rebar. Therefore, with this uniform elongation over a 2.1 m free length, the bolt can elongate up to 300 mm prior to failure. This design feature is markedly important for mines experiencing swelling ground. In such conditions, the MDX bolt is capable of sustaining high strata loads for large ground movement.

1.3 *The development site*

The Telfer Gold Mine, located in the Great Sandy Desert of Western Australia, is a mature bulk mining operation employing three mining methods in a high stress and seismic setting. The mature Sub Level Cave (SLC) development extends to 1100 m below surface. The SLC is hosted within a highly jointed quartzite, sandstone and siltstone lithological sequence of very high IRS (average host rock UCS of 250 MPa) bisected by a complex network of ore bearing vein and reef structures. The mine and development is also intersected by numerous faults, thrusts and shear zones. This setting provides stiffness contrasts between the high strength host sediments, moderate strength ore bearing structures, and low strength faults. This contrast, coupled with a significant cave geometry (1000 m depth, 1000 m strike length, and

300 m width) enables high displacements, resulting in significant seismic deformations and hazard; average 300 events per day, and an Mmax of 2.9 logP.

The seismic hazard is managed through geometry, sequencing, exclusion protocols, and ultimately the engineered support systems. The geotechnical setting described provides challenges in implementing highly effective support systems, which are highly susceptible to bolt shear (and resulting bolt potential ejection) and inefficient bolting cycle times.

2 DYNAMIC TESTING

Dynamic testing is typically performed to quantify the capability of a rockbolt to absorb or dissipate dynamic energy. Traditionally, this testing has been performed under laboratory conditions; however, over recent years there has been an increase in the popularity of Sandvik conducted in-situ dynamic testing.

2.1 *Laboratory dynamic testing*

At present, there are two industry utilised laboratory test facilities; West Australian School of Mines (WASM), located in Kalgoorlie, WA, and CANMET, located in Ottawa, Canada (Li, 2017).

The WASM facility utilises a momentum transfer method (Villaescusa, 2015) to apply a dynamic load to the test specimen, whereas the CANMET facility employs a “freefall of mass onto the rock plate”. The WASM test facility tests rockbolt specimens installed into a thick-walled steel pipe filled with a cement/concrete aggregate with pre-drilled bore-hole. The CANMET facility tests rockbolt specimens installed into a thick-walled steel pipe welded around pre-drilled granite cores.

The test methods and data obtained from laboratory testing are useful; however, the data is often not directly useable for ground support design purposes (Hadjigeorgiou, 2007). Some benefits of the laboratory testing include:

- All tests are performed under controlled conditions.
- Specimens can be easily dissected and analysed post-test.
- Data capture, recording and analysis is simple.

As with every test method, there will be limitations or drawbacks, some of these include:

- The thick-walled steel pipes filled with cement/concrete aggregate do not accurately represent a bore-hole drilled in strata.
- The simulated bore-holes are suitable for testing resin or grouted bolts, but not for friction style rockbolts.
- The test methods do not allow for non-axial loading (static or dynamic) on the rockbolt (Villaescusa, 2015).
- Laboratory testing typically requires long set-up, preparation and reporting times.
- Laboratory testing can be a time consuming and expensive exercise.
- Sample preparation (bore-holes) is susceptible to error, which may results in deviated bore holes.
- Localized confinement of a wedge arrangement may be compromised when installed in relatively thin concrete & steel pipe.

2.2 *In-situ dynamic testing*

Another method to determine the dynamic capacity of rockbolts is in-situ dynamic testing, which tests rockbolts in the underground mining environment. In-situ testing is widely used for quasi-static testing to determine in-process installation quality. One major benefit of in-situ testing is that is takes into account the rock mass environment and the mines ground support installation practices, good or bad.

In-situ dynamic testing has been previously used at two sites in Australia, as an installation quality control mechanism for cable bolt grouting. However, the test method was very basic, utilising a steel drum and chains, resulting in an assumed applied load.

Unlike laboratory testing, which has many years of history and numerous testing regimes, in-situ testing is only in its infancy. Due to this, there is no published dynamic performance data for any in-situ testing. This lack of data creates an interesting challenge; as there is no benchmark data, with the exception of MD bolt testing at Mt Charlotte Gold Mine (Mikula, 2013).

2.3 *The Sandvik In-situ Dynamic Test rig*

In light of the inherent limitations of lab testing for friction type bolts, there was a clear need to design an in-situ dynamic test apparatus. Sandvik completed the design of the in-situ dynamic test apparatus in 2012. However, due to time limitations, the full build of the testing equipment was not possible for the initial testing held at Mt Charlotte Gold Mine in 2013 (Mikula, 2013). Therefore, Sandvik worked closely with Rocktech and Mikula Geotechnics to develop a simple/hybrid in-situ dynamic test rig for this initial testing. The testing proved successful, and provided an opportunity to trial some components of the Sandvik test rig. Since the completion of the Mt Charlotte testing, the in-situ test apparatus has undergone several design improvements.

The apparatus utilises the ‘free fall of mass onto rock plate’ load transfer mechanism. However, as the testing is performed on rockbolts pre-installed in rock, a ‘slide rod’ is required to apply the dynamic load to the test bolt. This slide rod transfers the impact load from the drop mass onto the test bolt, and also acts as a guide for the drop mass. The drop mass is a pack of steel plates, which can be varied to apply impact loads between 12-35 kJ.

The connection method to the rockbolt is important, as the apparatus must minimise the time required to test each rockbolt. The current embodiment of the connection method is in the form of a claw assembly, which contains domed connections top and bottom, which allow for variations in bolt installation angle (up to 12° from vertical).

These claws also house the ‘smart’ components of the In-situ Dynamic Test Rig, which include an accelerometer and load sensor (see figure 3).

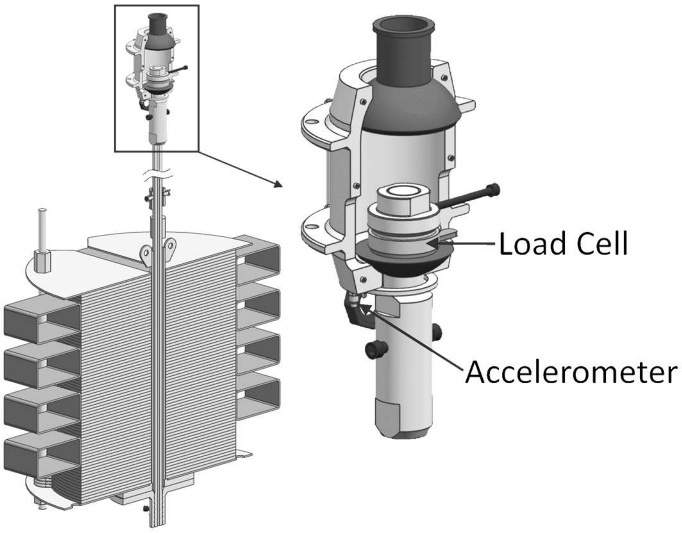

Figure 3. The Sandvik in-situ dynamic test rig

These sensors have a sample rate of 25 kHz (25,000 samples per second), and are programed to record at this rate for 10 seconds. The data is recorded through a Toughbook laptop, which also contains the control system to remotely release the mass. The release mechanism is a 4500 kg rated quick release latch, which is remotely released using an air actuator. The release trigger is linked into the central control system, and requires a set sequence of events to activate, preventing any accidental release.

All recorded data undergoes a filtering process to “smooth” the appearance of the plots, and removes any noise from the signal data.

2.4 *Testing regime*

The testing regime carried out at Telfer Gold Mine conducted dynamic tests on a sample set of 26 MDX bolts. Each bolt was subjected to a single dynamic load.

Prior to the commencement of the trial, discussions were held between Sandvik and Telfer, to identify the requirements for the trial. This covered both the safety requirements for the test apparatus, and more importantly the minimum performance requirements for the MDX bolt. From these discussions, the MDX bolt was required to survive a dynamic impact energy of 25 kJ, and displace not more than 200 mm. This requirement is stricter than the unwritten Australian industry guideline, which requires an impact energy of 25 kJ, with displacement limited to 300 mm.

The loading sequence for the trial was divided into three groups; “qualification energy” (22 kJ), “specification energy” (24-27 kJ) and “high energy” (28-30.5 kJ). The qualification energy level was used for the first four bolts tested, and was used primarily to gauge the performance of the bolts at a lower impact energy (as these were the first ever MDX bolts subjected to dynamic loading). The specification energy level was used for the next five samples, after which point, the bolt responses suggested some additional capacity. The following nine samples were tested within the high energy level range, which identified the ‘spare’ capacity available in the MDX bolt. For the final eight samples, the load was reduced to the specification energy level.

3 TEST OUTCOMES AND DATA ANALYSIS

The results from the tests conducted are outlined in table 1, where the impact velocity varied from 5.4 to 5.9 m/s for impact energies from 22.1 to 30.5 kJ respectively. The “energy absorbed” value was obtained from integrating the measured load (kN) by the bolt displacement (mm), and ranged from 90 to 99%, indicating minimal losses in the test apparatus.

The displacement of each bolt is measured using an accelerometer in the claw assembly, where the acceleration signal is integrated twice to obtain the displacement relative to time. The position of the test bolt is also recorded before and after the test (position relative to a fixed point is measured and photographed).

Table 1. Dynamic test results

Sample ID	Loading mass (kg)	Drop height (m)	Input energy (kJ)	Absorbed Energy (kJ)	Peak input load (kN)	Displacement (mm)
1	1495	1.51	22.1	21.0	333	104
2	1495	1.51	22.1	21.0	259	109
3	1495	1.51	22.1	20.0	291	104
4	1495	1.51	22.1	21.7	300	98
5	1495	1.61	23.6	22.2	308	114
6	1495	1.68	24.6	22.7	289	97
7	1495	1.68	24.6	22.8	286	93
8	1780	1.51	26.4	25.6	281	108
9	1780	1.51	26.4	26.0	308	128
10	1780	1.61	28.1	26.5	271	129
11	1780	1.61	28.1	25.9	277	115
12	1780	1.61	28.1	25.6	273	126
13	1780	1.61	28.1	28.0	297	126
14	1780	1.75	30.5	29.3	289	153
15	1780	1.75	30.5	29.0	249	153
16	1780	1.68	29.3	28.4	289	145
17	1780	1.75	30.5	29.7	322	147
18	1780	1.75	30.5	16.0	291	2400
19	1780	1.54	26.9	25.0	276	125
20	1780	1.54	26.9	25.3	304	113
21	1780	1.54	26.9	24.4	302	138
22	1780	1.54	26.9	24.9	269	129
23	1780	1.54	26.9	26.0	277	121
24	1780	1.54	26.9	26.0	283	128
25	1780	1.54	26.9	25.5	272	120
26	1780	1.54	26.9	25.7	269	127

For each of the three loading levels (as described previously), there was a range of displacements. For the qualification loading, the displacement ranged from 98 to 109 mm; for the specification loading, the displacement ranged from 97 to 138 mm, and for the high loading, the displacement ranged from 115 to 153 mm. This demonstrates a somewhat linear relation between the applied load and bolt displacement, which is better illustrated in Figure 3.

Sample 18 was the only exception to this trend, as this bolt failed to arrest the applied dynamic load of 30.5 kJ, absorbing 16 kJ prior to failure. Failure of this bolt occurred through overloading the wedge system, resulting in the re-bar and threaded wedge pulling past the welded wedges. Given that the failure load of this sample was in the "high energy" range (30.5 kJ), the remainder of the bolts were tested at the specification energy level. Upon detailed inspection of the failed sample, the design has been altered to prevent this type of failure occurring in the future.

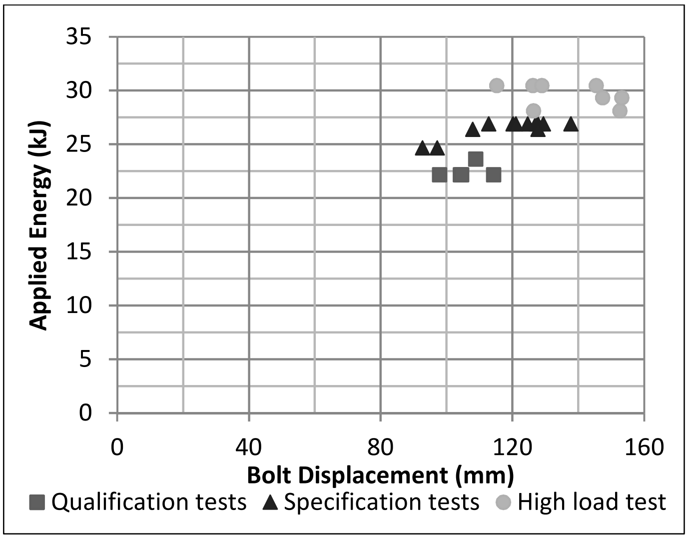

Figure 4. Applied Energy plotted against bolt displacement

From figure 3, the close grouping signifies a high level of repeatability in the function of the bolt, which in practice provides a high confidence in the expected performance of the bolt.

The response of the MDX bolts to the dynamic loads was extremely consistent, which included a high peak load followed by a high sustained load (Figure 4).

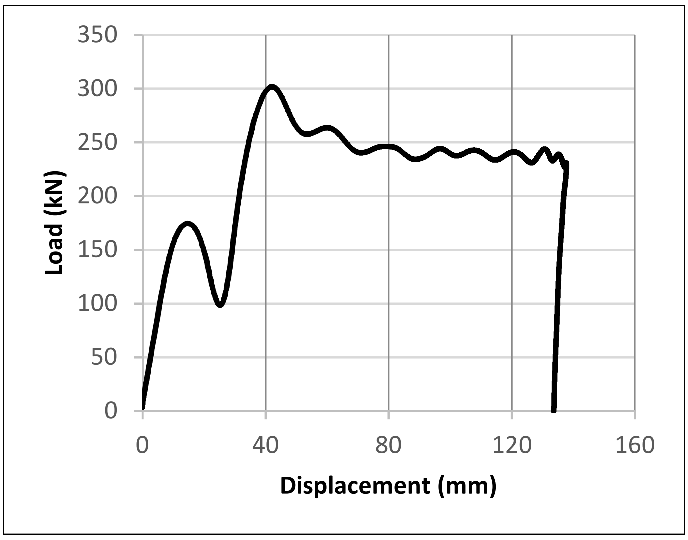

Figure 5. Bolt 21 Displacement response to loading

As seen in Figure 4, there are two distinct responses to the applied load; the initial peak of approximately 175 kN, which is believed to be the load required to 'set' the wedges. This is then followed by the high peak load (302 kN), and the subsequent sustained load (240 to 250 kN) until the maximum displacement. This response was typical of all bolts that arrested the applied load, as shown in Figure 5. The initial "wedge set" load ranged from 150 to 250 kN, the peak load between 250 to 330 kN, and the sustained load between 175 to 250 kN.

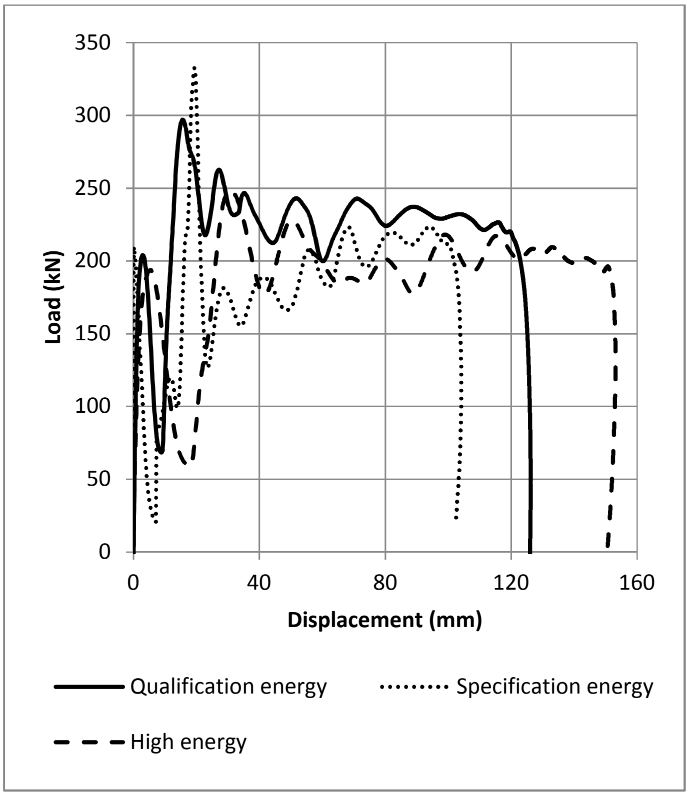

Figure 6. Summary of displacement response to applied load

The primary mode of displacement experienced with the MDX bolt was through elongation of the rebar component.

4 CONCLUSION

The In-situ Dynamic Test Rig was very successful in applying dynamic loads to the sample MDX bolts. The apparatus provided the high resolution data required to accurately monitor the performance of the MDX bolt under dynamic loading and site specific rock conditions. With quick test times (average of eight bolts tested in a single shift), the In-situ Dynamic Test Rig can be used as a suitable test method to determine the performance of rockbolts in site specific conditions. The data recorded was extremely useful to analyse the response of the test samples.

In general, the in-situ testing apparatus and method has been very well accepted by those involved in the testing, which has been performed at six separate sites across Australia.

The requirement set for the MDX bolt was to displace less than 200 mm when subjected to a 25 kJ impact load.

The MDX bolts were tested with 3 levels of input energy (all with a single impact). The bolt was successful in satisfying the impact loading of 25 kJ, with a maximum displacement of 138 mm. In addition to this, nine bolts were tested with higher impact loads (28.1 to 30.5 kJ), and the bolts that arrested the dynamic load resulted in a maximum displacement of 153 mm. One of these nine samples failed to arrest the impact load; however, the design has been modified to eliminate this failure mechanism.

From these results, the MDX bolt met the requirements of the testing regime, and the results have been accepted by Telfer Gold Mine.

At the time of writing this paper, the MDX bolt has been incorporated into the ground support plan at Telfer Gold Mine. The next step is to monitor the rollout of the MDX bolt, and the performance when subjected to a “live” seismic event.

5 ACKNOWLEDGEMENT

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