ARMA 19–1641

Introduction and Application of the Dynamic Impact Tester

Berghorst, A.
New Concept Mining, Denver, CO, USA
Knox, G.
New Concept Mining, Johannesburg, GP, South Africa

ABSTRACT: New Concept Mining (NCM) has implemented the Dynamic Impact Tester (DIT) to conduct laboratory based dynamic testing on rock bolts. The DIT allows NCM to move rapidly through the R&D cycle for new rock bolts. This allows both a shorter time to market as well as comprehensive understanding of the performance of rock bolts. In addition to these benefits, the DIT is being used in several exciting ways to improve the understanding in the mining industry of the performance of dynamic ground support. An example is given where the dynamic testing database has been used to back analyze the quantitative performance of a Vulcan Bolt during an underground seismic event.

1. INTRODUCTION

As underground mines are going deeper, the stresses in the rock mass are approaching, and in some cases exceeding the strength of the rock mass. Supporting excavations in this type of ground comes with a unique set of challenges that go beyond the ability of regular ground support. In order to serve this need in the industry several companies have developed rock bolts and surface support solutions. New Concept Mining (NCM) is one of these ground support companies that has done extensive research and development to better understand and develop these ground support requirements. In order to understand these ground support solutions, NCM has built the Dynamic Impact Tester (DIT). The purpose of this DIT is to dynamically test rock bolts to quantitively interrogate the response of the support tendon, to a high strain rate axial event, as an approximation of the loading expected during a seismic event.

2. DYNAMIC ROCK BOLT TESTING LANDSCAPE

There are several testing machines around the world capable of testing dynamic ground support to one degree or another. SWERIM has recently developed a momentum transfer style dynamic testing machine out of Luleå, Sweden. The Western Australia School of Mines (WASM) also has a momentum transfer style dynamic testing machine out of Kalgoorlie, Australia (Player, et al, 2008). The Central Mining Institute out of Katowice, Poland has developed a unique dynamic testing machine aimed at qualifying rock bolts to support coal bursting (Pytlik, et al, 2015). Canmet has an impact based dynamic testing machined on which the ASTM D7401-08 (ASTM D7401-08) is based, out of Ottawa, Canada (Li, et al, 2011). Sandvik has developed a rig that can be used underground to dynamically test installed rock bolts at the proximal end (Darlington, 2014). Geobrugg has been involved in developing a testing machine that is likely the closest approximation to a system test, this is based in Walenstadt, Switzerland (Saner, et al, 2016). NCM has commissioned the DIT (Knox, et al, 2018a) in June 2017, it is an impact based dynamic testing machine complying with ASTM D7401-08 (ASTM D7401-08 – 03). The DIT is housed at the NCM testing facility in Johannesburg, South Africa.

3. THE VALUE OF LABORATORY BASED DYNAMIC TESTING OF ROCK BOLTS

Underground dynamic events are complex by nature. There is a relatively small body of knowledge around the causes, details, nature and predictability of these events.

This is summarized by Stacey, 2016 "*With the present state of knowledge, it is not possible to predict when, where, and with what magnitude and direction this dynamic loading will take place.*" Stacey goes on to note that in addition to the loading being unknown, the understanding of how ground support systems function is also limited. "*Whilst there is possibly suitable information on the behavior of individual elements of a system, there is no satisfactory quantitative knowledge of the capacities of support systems under dynamic loading.*"

It is fair to note that every current dynamic testing method is, at best a simplified approximation of an underground dynamic event. Mikula, et al, 2018 suggests three types of dynamic loading that should be at least considered in testing dynamic ground support. Currently all the dynamic testing machines will generally only test a single type of loading condition. It is well documented that all existing dynamic testing methods at best approximate the type of loading that is experienced underground (Potvin, et al, 2010). While Hadjigeorgiou, et al, 2011 agree with this sentiment, they also note that despite these limitations, this type of laboratory based dynamic testing does have significant value. "*There is a case to be made that these tests provide an adequate comparison of different reinforcement units or systems under the same test conditions… Despite the limitations of the impact tests, test rigs can provide repeatable results. It follows that the experimental data can possibly be correlated to in situ conditions and become usable for design purposes. The main advantage of the drop test approach lies in its capacity to perform a relatively large number of tests at reasonable cost, without interfering with mining operations.*"

4. DIT LAYOUT AND CONFIGURATIONS

The primary purpose of the DIT is to aid in the rapid development and qualification of NCM's energy absorbing rock bolts. To this end, the ability to rapidly prototype and quantify the performance of rock bolts in the R&D cycle is invaluable. This also gives NCM the ability to qualify the performance of rock bolts in the precise configuration and parameters that a mine may require.

4.1. Overview

The NCM DIT is designed to apply an impulse of energy to a rock bolt sample, the energy is imparted by raising a known mass to a known height above the impact plate of the sample. This mass is released and accelerates the distance of the drop height under the effect of gravity to impact onto the impact plate of the sample. The specifications of the DIT are detailed below.

Table 1: DIT specifications

Specification	Value
Max. Kinetic Energy at Impact	65 kJ (47 935 ft.lb)
Max. Velocity at Impact	6.42 m/s (21.2 ft/s)
Max. Drop Mass	3171 kg (6 991 lb)
Min. Drop Mass	551 kg (1 215 lb)
Max. Drop Height	2.1 m (6.9 ft)
Max. Sample Length	3.5 m (11.5 ft)
Height of Structure	8.2 m (26.9 ft)

4.2. Mechanical Layout

The structure of the DIT consists of an H-Frame, with two vertical columns 8.2 m (11.5ft) high with two C-Channels connecting these. The trolley is guided by sets of wheels running on vertical rails that constrain the trolley such that it travels parallel to the axis of the sample being tested. The frame should be significantly stiffer than the sample being tested. This minimizes erroneous displacements of the frame being attributed to the rock bolt during tests. A series of tests were performed and the reaction of the frame and samples were analyzed. The frame has a stiffness of 121.3 kN/mm (692.6 lb/in) while the sample was 1.7 kN/mm (9.7 lb/in), the frame is significantly stiffer than the samples (Knox, et al, 2018a).

4.3. Dynamic Components

The kinetic energy of the trolley is transferred to the sample during the test. This kinetic energy is determined by varying the mass of the trolley and the drop height, which determines the velocity of the trolley at the point of impact. The mass of the empty trolley is 551kg (1 215 lb), and this mass can be increased by adding combinations of 90 kg (198 lb) and 190 kg (419 lb) steel plates to the trolley to the maximum mass of 3 171 kg (6991 lb). The velocity is a function of the height from which the trolley is released, and this can be varied from 0 m/s up to 6.42 m/s (21.2 ft/s).

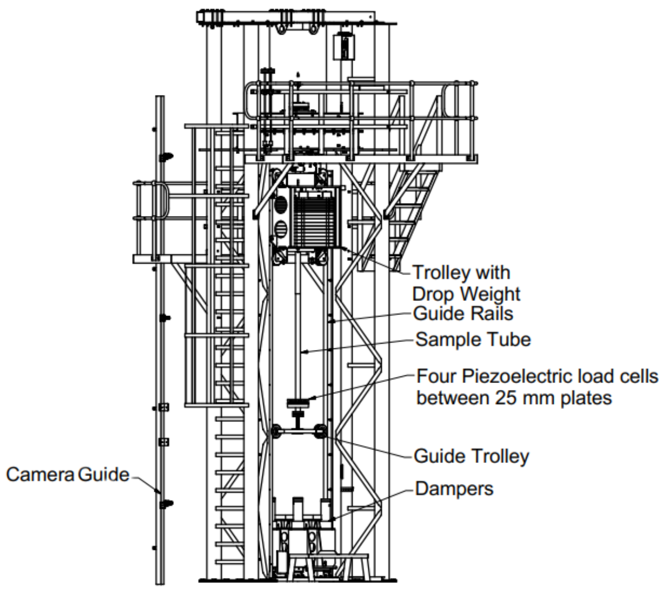

Figure 1: Overview of the layout of the DIT (Knox, et al, 2018a).

4.4. Instrumentation

During each impact the drop height, impact forces and proximal and distal displacements are measured. While the data is continually gathered from the string potentiometer during the test, this is only used to measure the drop height of the trolley relative to the impact plate before the trolley is released.

Up to three load cell sets measure the impact forces during the test. These load cell sets each consist of four PCB205C load cells sandwiched between two 25 mm thick steel plates. The first load cell set measures the impact load, this is the load transferred from the trolley into the sample. The second load cell set measures the load transferred from the sample into the frame during test. In the case of an indirect test (Split Tube Test) a third load cell set is installed between the faceplate and the proximal end of the sample tube. This measures the loads that are transferred to the faceplate during a test. The loads from the load cell sets are fed through a set of PCB 483C05 signal conditioners and are then logged at a rate of 10 kHz.

The displacements are measured using two Basler Racer GigE line scan cameras that track the movement of a black and white flag (rigid black and white stripped marker). The first flag is fixed to the proximal end of the rock bolt and the second flag is fixed (with an extension rod) to the distal end of the rock bolt. The first flag, at the proximal end measures the displacement of the proximal (faceplate) end of the rock bolt. The second flag measures the displacement at the distal end of the rock bolt. The signals from the line scan cameras are recorded at 10 000 frames a second, and synchronized with the data acquisition from the load cell sets.

The load and displacement signals are aligned using the ADC sample clock signal, from the PCIe-6434 DAQ. The data that is presented from these tests are not filtered by either hardware or software.

4.5. Data Processing

The raw data is saved as a backup before the automated data processing starts. LabVIEW™ is used for the automated data processing, and the output from this is automatically reported in a Microsoft Excel Workbook. The region of interest is analyzed from the point that the impact load begins to rise until this load reaches zero. The fully recorded data set for a single test is shown in Figure 2. The region of interest is the Period of First Impulse (Figure 2) also described as the Impact Duration (Figure 3), any subsequent oscillations are captured and always available for analysis, however, these aren't automatically reported.

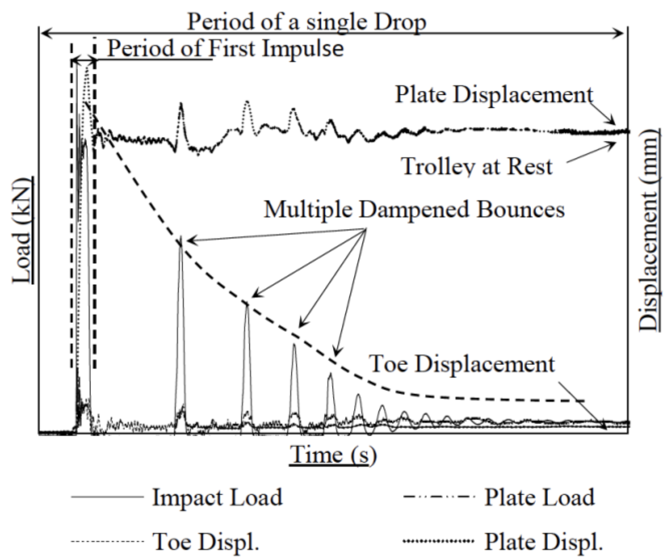

Figure 2: Typical load and displacements for a single drop on the DIT (Knox, et al, 2018a)

In the full report on a single sample test a total of 35 data categories are tabulated in 6 groups, some of these data categories are shown below in Figure 3. Each impulse is graphically represented in these reports, with the loads and displacements as a function of time and another plot of the load and energy absorbed as a function of the plate (faceplate) displacement as illustrated below.

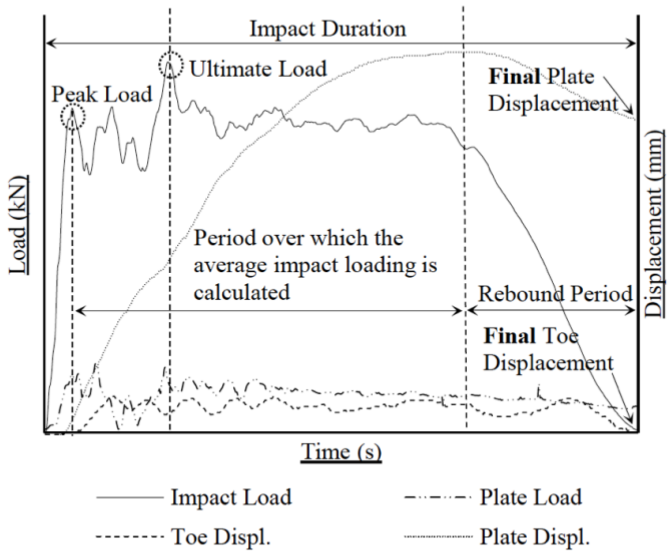

Figure 3: Illustration of the some of the data categories reported from the DIT per sample (Knox, et al, 2018a)

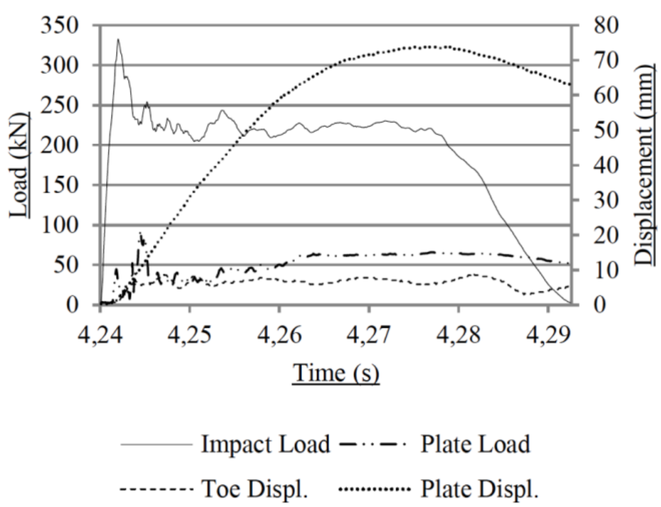

Figure 4: DIT Load and displacement as a function of time for a single impulse (Knox, et al, 2018a)

For tests where the test parameters may require multiple impulses of energy, the cumulative result of these are reported as shown in Figure 5. In the example, the rock bolt relies on stretching steel to absorb energy, and at the testing parameters specified, it required multiple impacts to break. After each impulse, the steel retracts slightly, this retraction is the difference between the Maximum Displacement after an impulse and the Final Displacement after an impulse. The NCM testing method defines that the Cumulative Final Displacement is the summation of the Final Displacement from each impulse, not the summation of the Maximum Displacements, this is the conservative approach and is shown in Figure 5.

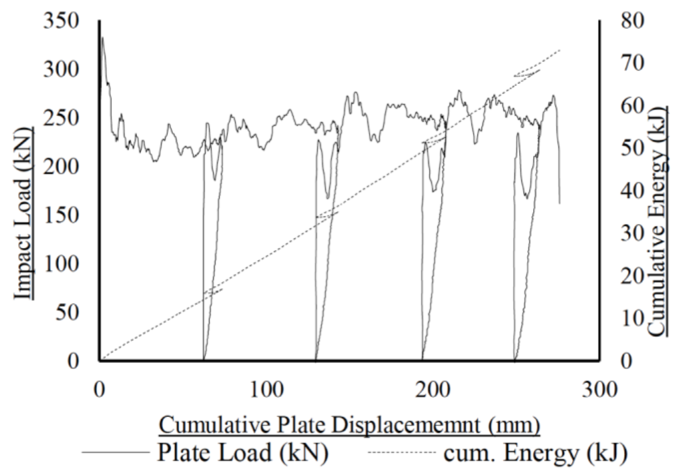

Figure 5: DIT Impact and Cumulative Energy as a function of plate displacement (Knox, et al, 2018a)

5. TESTING DATABASE AND OUTCOMES

As discussed previously, the primary motivation for NCM to build the DIT was to aid in the rapid R&D of technically innovative ground support solutions. Therefore, a lot of the testing that is done on the DIT is a proof of concept and iterative design change quantification. In addition to this, the DIT allows NCM to quantify the performance of the rock bolt systems (including interstitial medium – resin or grout) at the aproximate expected dynamic design parameters for each region of a mine. However, there are three other areas which the DIT has added great value.

5.1. Quality Assurance

NCM develops and supplies rock bolts that are designed to be used in seismically active environments. It is a potential risk to run quasi-static based quality assurance on raw materials that are intended to work both quasi-statically and dynamically. Most materials respond differently under different loading rates (Malvar & Crawford, 1998), therefore if something performs satisfactorily under low loading rates (quasi-static) there is no guarantee that it will perform satisfactorily under high loading rates (dynamically), however, the reverse holds true. To this end, the DIT allows NCM to test critical raw materials under dynamic loading conditions before manufacturing dynamically rated rock bolts with the material. The DIT also allows NCM to run suitable dynamic testing on finished products under the QA program. This verifies that mines are supplied with suitable safety critical ground support.

5.2. Pure Research

NCM is a ground support supplier who aims to sell safe, good quality ground support that is the best solution for each mine. NCM believes that it is in the entire industries' best interest to better understand the unknowns related to supporting excavations in a rock mass that may behave dynamically. The DIT is a valuable tool that in this regard. NCM strives to collaborate with industry using the DIT to expand this body of knowledge.

An example of this is the DIT being used to assess the difference in measured dynamic capacity for a rock bolt that is subjected to a single large impulse, compared to multiple smaller impulses of energy (Bosman, et al, 2018). The purpose of this is to help industry understand the risks and benefits in specifying the expected magnitude of the impulse of energy that a rock bolt should withstand. The DIT has also been used to develop a third configuration for testing specific types of ground support (Knox, et al, 2018b). The DIT has also been used to research the effect of impact velocity on the measured dynamic capacity of a rock bolt (Knox, et al, 2018c). NCM is making the DIT available to industry as a resource to be used to further our collective understanding of ground support subjected to dynamic loading.

5.3. *Database*

To date, NCM has tested over 600 individual samples, and has in excess of 1000 sets of data from individual impulses of energy applied to a variety of rock bolts under varying parameters. A large portion of these tests have been used to quantify the effect of a design change in the R&D process. Figure 6 and Figure 7 below show a summary of some qualification tests that have been performed on some of NCM's dynamic rock bolts since the DIT was commissioned in July 2017. While there are many variables that affect the outcome of a dynamic test, the summary shown in Figure 6 and Figure 7 shows each sample as a single data point of the Cumulative Absorbed Final Energy against the Cumulative Final Plate Displacement.

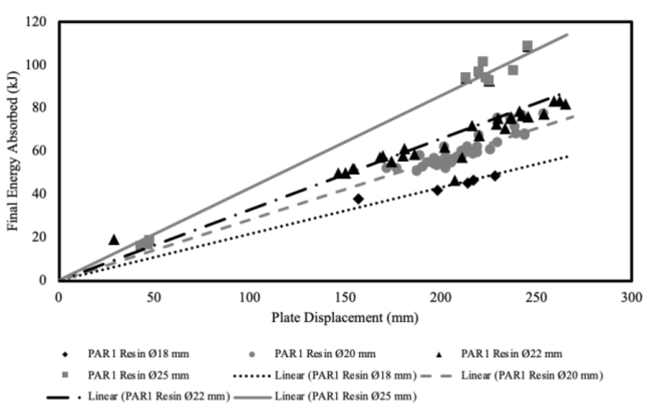

Figure 6: Summary of qualification tests on NCM's PAR1 Resin Bolts

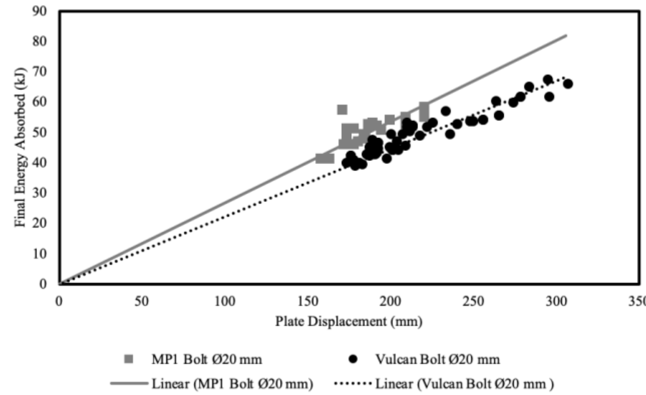

Figure 7: Summary of qualification tests on NCM's Vulcan Bolt and MP1 Bolt

This kind of data base has proved useful in several ways, one of these is in the back analysis on the Vulcan Bolts installed in an ultra-deep gold mine in South Africa. An excavation that was supported with 2.4 m long Vulcan Bolts and Steel Mesh experienced a 1.3 ML seismic event approximately 30 m from this excavation. The effects of this can be seen in Figure 8 below. It can be seen how Vulcan Bolts have stretched and worked with the Steel Mesh to create a support system sufficient to contain the energy released during this event.

In examining the details of one of the Vulcan Bolts, it can be seen that one of the Vulcan Bolts stretched approximately 160 mm (6.3") during the seismic event. From the graph shown in Figure 7 showing the data gathered from many dynamic tests on the Vulcan Bolt a trendline has been extrapolated, shown in Figure 10. The R^2 value for the trendline for the Vulcan Bolt in Figure 7 is 0.86, which gives a reasonable confidence. Taking the measured stretch of the steel for the Vulcan Bolt at 160 mm, and the trendline generated from the DIT for the Vulcan Bolt, it can be estimated that in this seismic event this Vulcan Bolt absorbed approximately 36 kJ as illustrated in Figure 10. While there are some clear assumptions and simplifications in this approach, given enough data on the dynamic performance of a rock bolt from the DIT this form of back analysis can be conducted.

Should this approach be applied across all the Vulcan Bolts in this area a form of a seismic response could be mapped. Again, this may be a simplified approach, since the effect of the Steel Mesh is not considered, the angle of the installation compared to the direction of the seismic impulse is not analysed. However, the fact that NCM has these kinds of data sets on the performance of the rock bolts from the DIT, the potential for more meaningful back analysis is now possible.

Figure 8: Area subject to seismic event with one of the Vulcan Bolts highlighted.

Figure 9: Close-up analysis of one of the Vulcan Bolts that absorbed some of the released energy

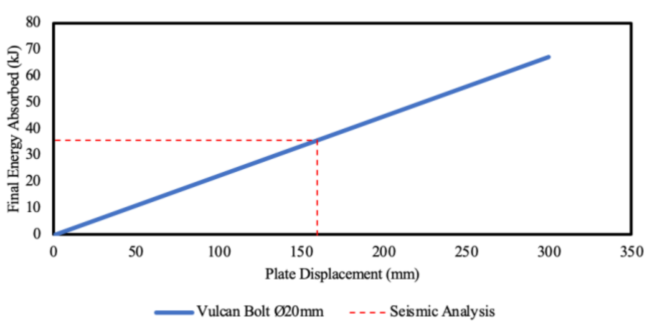

Figure 10: Back analysis of energy absorbed under pure tensile loading for a given displacement.

6. CONCLUSION

While there are limitations to the value ascribed to a laboratory based dynamic testing of rock bolts, it can be seen that there is merit in performing this type of test. Part of the difficulty in this type of work is that there is still a lot of research being conducted to fully understand the demands placed on ground support subject to dynamic loading underground. Therefore, the DIT and the other dynamic testing systems are useful for the qualification and quantification of ground support. It is essential that rock engineering practitioners strive to understand the demands that will be placed on the rock bolts in these underground environments. The DIT can be used by rock engineering practitioners to get a much better understanding of the real dynamic performance of their existing or new ground support systems to make underground a safer and more profitable environment for all.

REFERENCES

ASTM Standard D7401, 2008 (withdrawn), "Standard Test Method for Laboratory Determination of Rock Anchor Capabilities by Pull and Drop Tests," ASTM International, West Conshohocken, PA, 2008, DOI: 10.1520/D7401-08, www.astm.org.

Bosman, K., M. Cawood, and A. Berghorst. 2018. Relationship between energy per impulse and dynamic capacity of a rockbolt. In *Proceedings of the 3RD International Conference on Rock Dynamics and Applications (ROCDYN-3), Trondheim, 26-27 June 2018*, eds. C.C. Li et al, 379-384. Boca Raton: Balkema. (https://www.newconceptmining.com/papers_presentations.html)

Darlington, D. 'Sandvik MD Bolt and In-situ Dynamic Testing of Ground Support.' 2014. Presentation.

Hadjigeoriou, J., and Y. Potvin. 2011. A Critical Assessment of Dynamic Rock Reinforcement and Support Testing Facilities. In *Rock Mech Rock Eng*, 44:565-578

Knox, G., and A. Berghorst. 2018. Increased agility for the research and development of dynamic roof support products. In *Proceedings of the 3RD International Conference on Rock Dynamics and Applications (ROCDYN-3), Trondheim, 26-27 June 2018*, eds. C.C. Li et al, 373-378. Boca Raton: Balkema. (https://www.newconceptmining.com/papers_presentations.html)

Knox, G., A. Berghorst, and P. de Bruin. 2018. An empirical comparison between new and existing laboratory-based dynamic sample configuration. In *Caving 2018, Australian Centre for Geomechanics, Perth. Vancouver, 15-17 October 2018*, Y. Potvin, 775-786. Perth: ACG. (https://www.newconceptmining.com/papers_presentations.html)

Knox, G., A. Berhorst, and B. Crompton. 2018. The relationship between the magnitude of impact velocity per impulse and cumulative absorbed energy capacity of a rock bolt. In *AusRock 2018: The Fourth Australian Ground Control in Mining Conference, Sydney, 28-30 November 2018*. 160-169. (https://www.newconceptmining.com/papers_presentations.html)

Li, C. C., and C, Doucet. 2011. Performance of D-Bolt Under Dynamic Loading. *Rock Mech Rock Eng (2012). 45:193-204.*

Malvar, J. L., & Crawford, J. E. (1998). *Dynamic Increase Factors for steel reinforcing bars.* Twenty-Eighth DDESB. Seminar. Olrando.

Mikula, P.A., and B.M. Brown. 2018. The need for additional dynamic testing methods for ground support elements. In *Proceedings of the 3^RD^ International Conference on Rock Dynamics and Applications (ROCDYN-3), Trondheim, 26-27 June 2018,* eds. C.C. Li et al, 425-432. Boca Raton: Balkema.

Player, J., A. Thompson, and E. Villaescusa. 2008. Dynamic Testing of Reinforcement Systems. In *6th International Symposium on Ground Support in Mining and Civil Engineering Construction, Cape Town, 30 March – 4 April 2008,* eds. T.R. Stacey et al, 597-622. South African Institute of Mining and Metallurgy.

Potvin, Y., J. Wesseloo, and D. Heal. 2010. An interpretation of ground support capacity submitted to dynamic loading. *Mining Technology*. 119:4, 233-245.

Pytlik, A., S. Prusek, and W. Masny. 2016. A methodology for laboratory testing of rockbolts used in underground mines under dynamic loading conditions. *The Journal of the South African Institute of Mining and Metallurgy*. 116: 1101-1110.

Saner, A., and Murri, R. *Testing of the Rockburst Codelco Setup S3, performed on September 08, 2016*. Romanshorn: Dynamic Test Center AG. 2016. pSi-16-1231.

Stacey, T.R. 2016. Addressing the Consequences of Dynamic Rock Failure in Underground Excavations. *Rock Mech Rock Eng*. 49:4091-4101.