

# Relationship between energy per impulse and dynamic capacity of a rockbolt

K. Bosman

*Open House Management Solutions, Potchefstroom, South Africa*

M. Cawood

*New Concept Mining, Johannesburg, South Africa*

A. Berghorst

*New Concept Mining, Johannesburg, South Africa*

**ABSTRACT:** The capacity of a rockbolt subjected to an impulse of energy varies as a function of the magnitude of the impulse of energy applied. This paper explores the relationship between the magnitude of the impulse of energy applied to a rockbolt and the resulting dynamic capacity. The result of this research shows that for a given velocity at impact, there is a linear relationship between the magnitude of the individual impulses of energy applied to a rockbolt and the resulting dynamic capacity of the rockbolt. The dynamic capacity of a rockbolt is not a constant value. During this research, the relationship between the magnitude of the impulse and the resulting displacement of the rockbolt is also examined.

## 1 INTRODUCTION

It is considered imperative that ground support, used in rockburst prone mines, have sufficient capacity to be able to adequately resist the energy release during a seismic event underground. Considerable work has been conducted into the design and quantification of the energy absorbing capacity of rockbolts (Li. et al. 2014). Currently, there are two widely recognized testing methodologies that exist for the quantification of the energy absorbing capacity of rockbolts alone (Plouffe. et al. 2007) (Player et al. 2007). Whilst both testing methodologies are excellent in their own right, the simplifications required mean that in reality these testing methods are really most suited to comparative testing of ground support units.

The first of these testing methods, the Momentum Transfer Method, has been developed by Dr. John Player and the machine is currently housed in Western Australia at the Western Australian School of Mines. The other testing method, the Direct Impact Method, has been developed and adapted over a number of years, and the most well-known machine resides at CANmet in Ottawa, Canada. There is another Direct Impact Testing Machine, the Dynamic Impact Tester (DIT) in Johannesburg, South Africa (Knox. et al. 2018). The testing in this research has been completed on the DIT in Johannesburg, South Africa.

In measuring the performance of a rockbolt which claims to have dynamic capacity, it is important that

a clear distinction is made between the qualification and the quantification of the dynamic energy absorbing characteristics of the rockbolt. Whilst most often geotechnical engineers desire to quantify the ultimate energy absorbing capacity of a rockbolt, they normally have a specification of the amount of energy (with requisite impact velocity) that the rockbolt should be able to sustain without failing. What often happens is a test is undertaken at a specified energy (a given mass impacting at a certain velocity on the rockbolt) to qualify a rockbolt, and if the sample sustains this impulse of energy, the test is repeated until the rockbolt breaks. The capacity of the rockbolt is taken as the sum of the absorbed energy that the rockbolt sustained on each impulse.

In certain underground mining environments, it can be expected that the ground support will be required to sustain multiple seismic events (Louchnikov, 2017). Therefore, there is value in understanding how a rockbolt reacts as the magnitude of the applied impulse is varied until the rockbolt breaks. Li et al (Li. Et al. 2012) proposed that a rockbolt subjected to multiple smaller rockbursts may be able to absorb slightly more energy than a rockbolt subjected to a single large rockburst.

This relationship has been examined and it has been found that there is an inverse relationship between the magnitude of the individual impulse of energy applied to a rockbolt and the amount of energy

that the rockbolt absorbs. In addition to this a, definition of the true dynamic capacity is proposed.

## 2 TESTING REGIME

The series of tests, conducted in this research, has been completed using New Concept Mining's MP1 Bolt, which is a preloaded, post-grouted mechanized bolt with excellent dynamic capacity. The samples were 20mm in diameter and 2.2m long, with a loaded length of 1.37m between paddles. All samples were manufactured in a single batch with input materials sourced from a single batch.

As mentioned above, the samples were tested on the Dynamic Impact Tester (DIT) housed at New Concept Mining (NCM) premises in Johannesburg, South Africa. The DIT complies with the requirements of ASTM D4701-08 (ASTM, 2008). An impulse of energy is transferred to the sample by the impact of a Trolley of known mass being released from a known height.

During this testing, each sample was tested in a Split Tube configuration, and the impact velocity was kept constant at approximately 5.4m/s. The energy was altered by increasing the Trolley mass, giving a total of five different values for the input energy per impulse. The energies applied per impulse were 8.1kJ, 17.4kJ, 30.1kJ, 37.4kJ, and 46.7kJ. A total of five samples were tested to destruction for each batch of each energy values. This gave a total of twenty-five individual samples tested. Since most samples required multiple impulses of energy to break; a total of eighty-nine individual impulses make up the data set that is used in these analyses.

## 3 RESULTS

The results of these tests are summarized in Figure 1 to 3, where the smoothed average graphs are shown for each batch of tests.

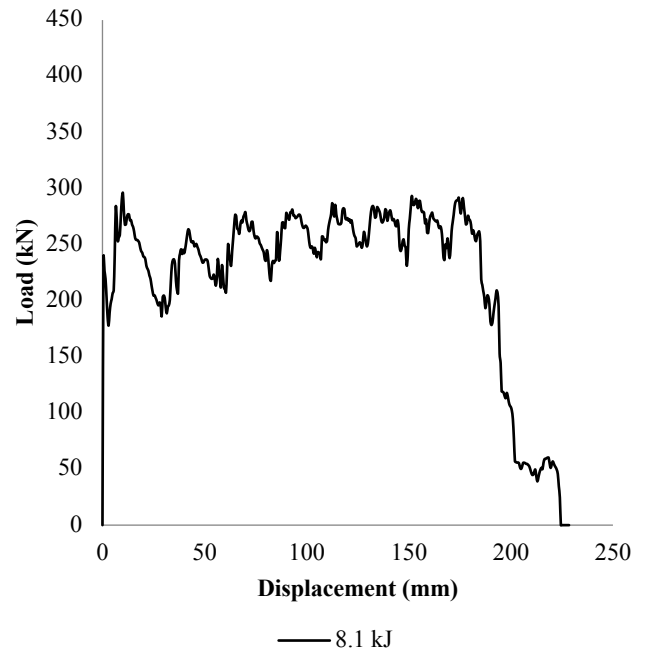


Figure 1. Averaged Load versus Deformation curve for the 8.1kJ of input energy per impulse batch of tests.

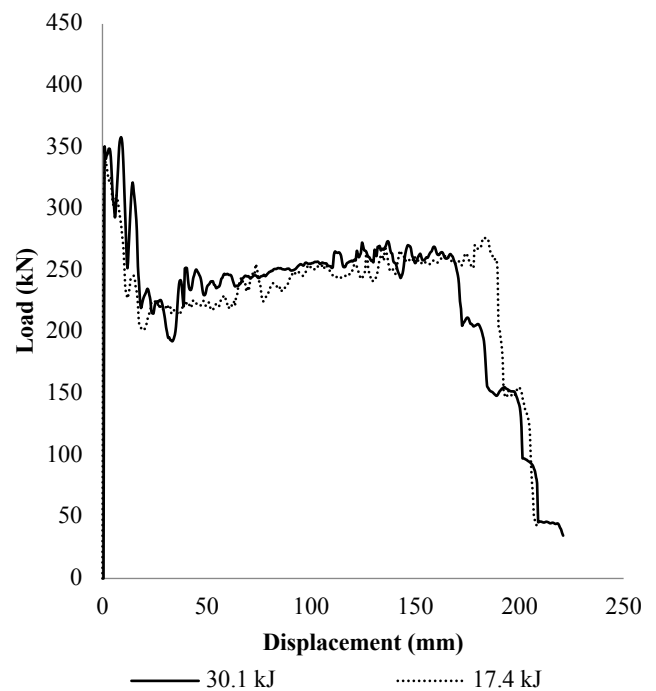


Figure 2. Averaged Load versus Deformation curves for the 30.1kJ and 17.4kJ of input energy per impulse batches of tests.

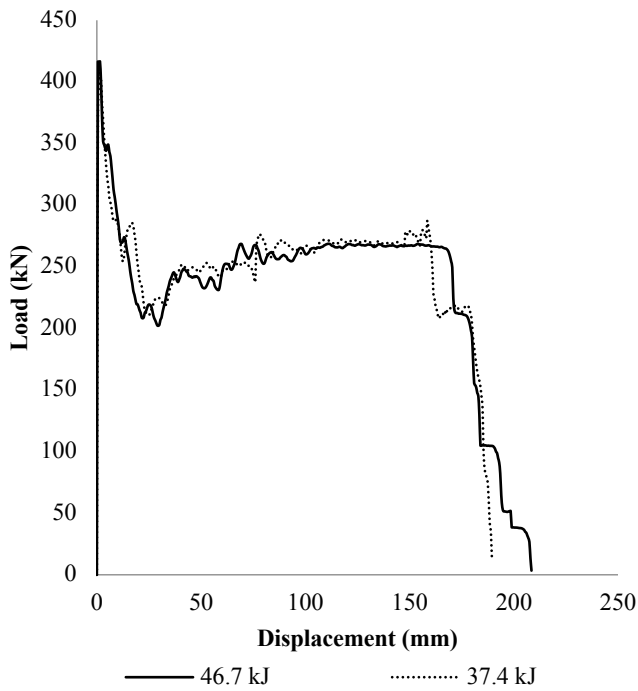


Figure 3. Averaged Load versus Deformation curves for the 46.7kJ and 37.7kJ of input energy per impulse batch of tests.

From these figures it should be noted that all but one of the batches of tests required more than a single impulse of energy to break the samples that were tested.

The shape of the above load versus displacement are relatively consistent for all the samples measured. This is due to the nature of the MP1 Bolt. This rockbolt consists of a paddled smooth bar within a patterned steel sleeve. The dynamic capacity of the MP1 Bolt is dependent on the mechanical properties of the steel that the bar and the steel sleeve is manufactured from. The dynamic capacity of the MP1 Bolt is a function of the loaded length and the dimensions of the bar and sleeve.

The results for each batch of tests are detailed in Table 1 below. It is important to note that the results summarized in the table are the averages measured for each batch of tests.

Table 1. Average results for each batch of tests.

Input energy per impulse (kJ)	Number of impulses to break the samples	Average duration of impact (mS)	Average final cumulative displacement (mm)	Average maximum cumulative absorbed energy (kJ)
8.1	8 to 10	15.2	187.6	64.9 (133%)
17.4	4	23.7	192.2	55.8 (114%)
30.1	2	37.0	192.0	54.0 (111%)
37.4	2	37.9	174.4	51.0 (104%)
46.7	1	57.3	181.5	48.8 (100%)

From analyses of the test results, depicted in Figures 4 to 6, it can be seen that there is an inverse relationship between the magnitude of the input energy per impulse and the cumulative maximum absorbed energy. A similar relationship holds true for the cumulative final displacement. This means that the higher the input energy applied to a rockbolt, the less total energy the rockbolt can absorb before breaking, and the lower the resulting displacement.

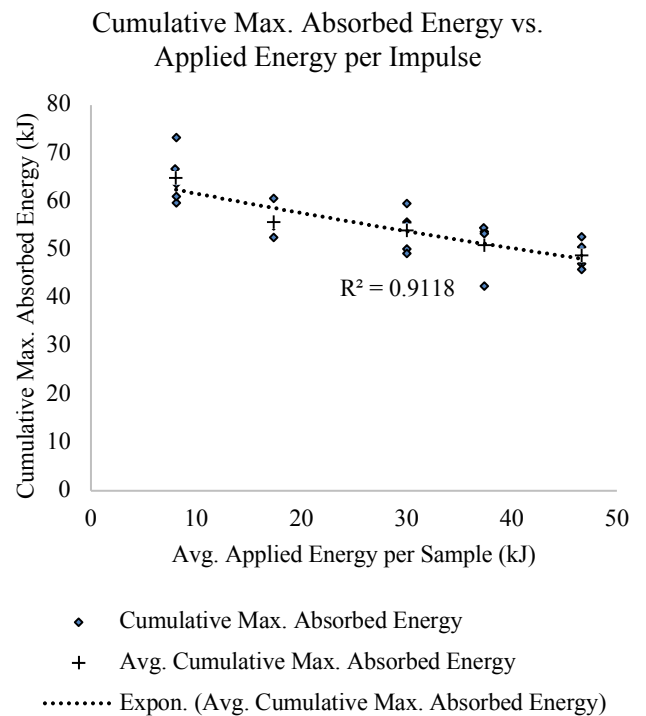


Figure 4. Cumulative maximum absorbed energy versus the applied energy per impulse.

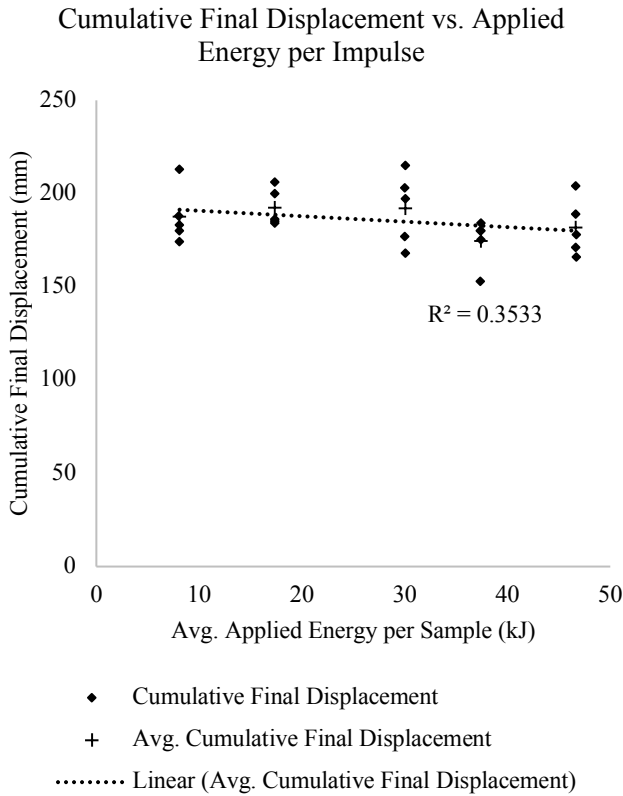


Figure 5. Cumulative final displacement versus the applied energy per impulse.

The data depicted in Figures 7 to 9 demonstrate the relationship between the final displacement and the absorbed energy, and the final displacement and the maximum energy absorbed per impulse, with the duration of the impulse.

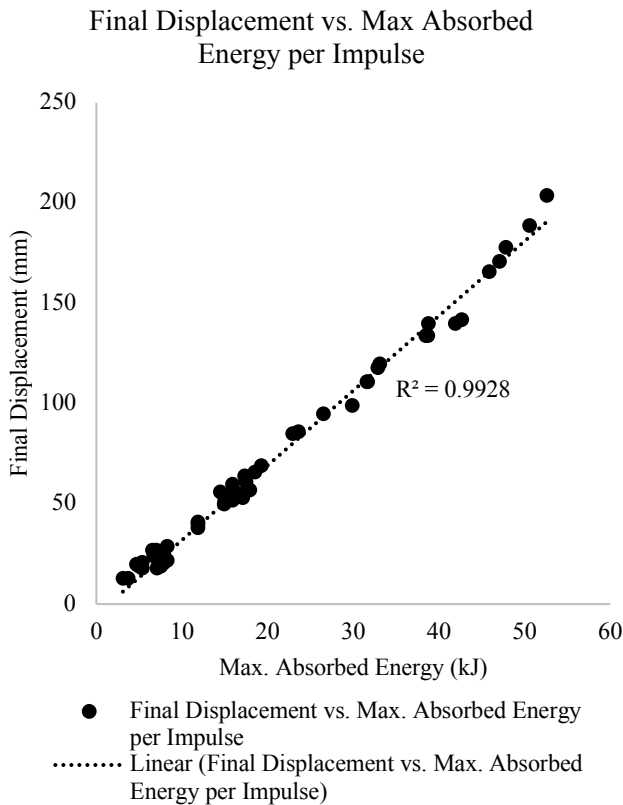


Figure 6. Final deformation and Maximum absorbed energy per impulse versus impulse duration.

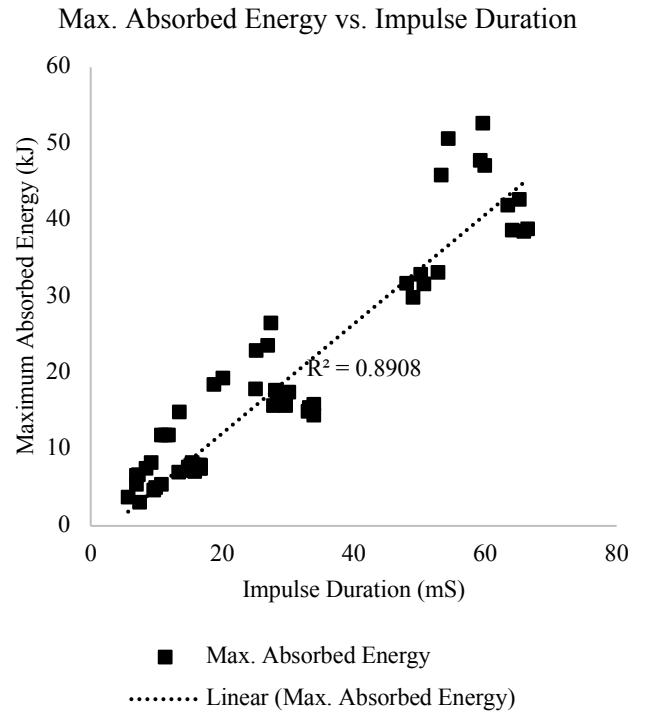


Figure 7. Maximum absorbed energy versus impulse duration.

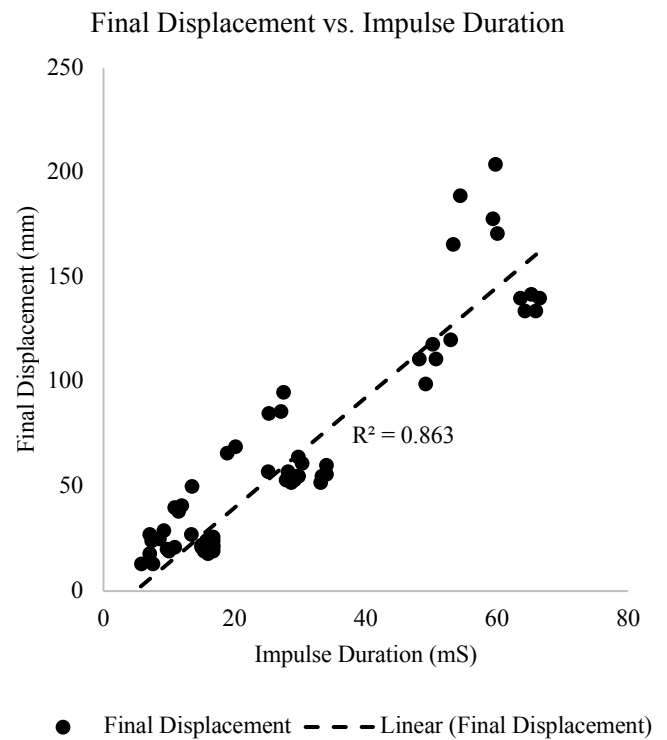


Figure 8. Final displacement versus impulse duration.

From the Figure 8, it can be seen that there is a clear linear relationship between the final displacement of the rockbolt after the impulse to the maximum amount of energy it has absorbed. This distinct relationship is a function of the method that the rockbolt uses to absorb energy. In the case of the MP1 Bolt, energy is absorbed as the steel stretches. Since the grade of steel is very closely controlled, this leads to a highly consistent linear relationship.

The results depicted in Figures 9 and 10 shows both the maximum absorbed energy and final displacement for each impulse as a function of the duration of the impact. Again, in both of these results, there is a linear relationship. The longer the duration of impact (which is the duration of time that the Trolley is in contact with the sample), the more energy is absorbed and displacement is noted. This is as expected from the energy absorbing method that this rockbolt utilizes.

Li et al (Li. et al. 2012) demonstrates the relationship between the Impact Duration and the Normalized Momentum during the impact of the Trolley onto the rockbolt can be characterized by the Equation 1.

$$t = \frac{1}{\sigma_a} \cdot \frac{M}{A} \quad (1)$$

Where  $t$  = Impact duration (ms);  $\sigma_a$  = Average dynamic tensile strength of the rockbolt (MPa);  $M$  = Momentum of the trolley (product of the mass and velocity) (Ns); and  $A$  = Cross sectional area of the material being tested ( $\text{mm}^2$ )

The MP1 Bolt has a patterned steel sleeve around the steel bar, and both of these are loaded elements integral to the function of the MP1. This means that the average dynamic tensile strength of the MP1 is not as simple a calculation as shown in the above formula.

The steel sleeve and the bar have a similar strain to failure. However, the ultimate tensile strength of the Bar is much higher than the Sleeve. This means that there is an uneven load distribution between these two elements. The average ratio between the stress induced in the bar to the sleeve for a given strain is defined by  $\alpha = 2.15$ . This means that the above average dynamic tensile strength for the MP1 Bolt is approximated by the Equation 2.

$$\sigma_a = \frac{F_{AVG}}{(A_{Bar} + \frac{A_{Sleeve}}{\alpha})} \quad (2)$$

Where  $F_{AVG}$  = Average impact force measure per relevant impulse (N);  $A_{Bar}$  = Cross sectional area of the Bar ( $\text{mm}^2$ );  $A_{Sleeve}$  = Cross sectional area of the Sleeve ( $\text{mm}^2$ );  $\alpha$  = Ratio Bar and Sleeve stress for a given strain.

Using the impulses for which the sample did not break, the data points in Figure 9 is generated.

It can be seen that the theoretical projection based on the measured average impact data is plotted on the in Figure 9, This plot gives a fairly accurate fit for the data. The resultant theoretical relationship is defined in Equation 3 as:

$$t = 1.53 \cdot \frac{M}{A} \quad (3)$$

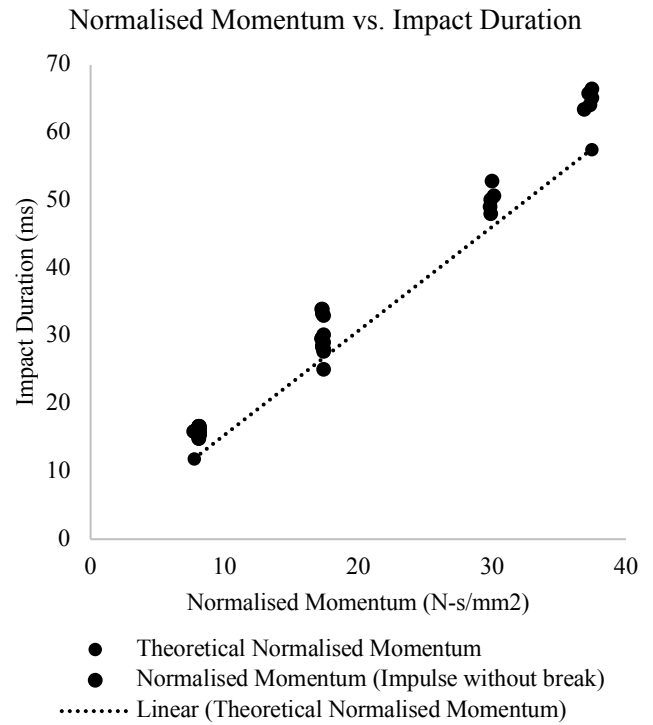


Figure 9. Impact duration versus the normalized momentum adapted from Li. et al 2012

#### 4 CONCLUSION

The conclusion to this research is that the dynamic capacity of a rockbolt is not constant, the manner in which a rockbolt is loaded will affect the dynamic capacity of a rockbolt. The more energy applied to a rockbolt until it breaks, the lower the dynamic capacity of a rockbolt. This shows the importance in developing a better understanding of how a rockbolt is loaded during a rockburst when specifying the capacity of a rockbolt.

This research also gives some insight into the potential additional longevity of a rockbolt that may be subjected to multiple small events when compared the expected lifespan of the same rockbolt subjected to a single large event.

The final point at the conclusion if the current stage of this research, is a proposed definition of the

actual dynamic capacity of a rockbolt. There is merit for a supplier to quote the energy capacity of a rockbolt when tested in a large number of low input energy impacts rather than a single large energy impact.

Therefore, if a strict definition of the quantification of the dynamic capacity of a rockbolt is required, the following is suggested. *The true dynamic capacity of a rockbolt is the amount of energy a rockbolt will absorb (at a given impact velocity) such that the rockbolt slows the impact mass down to zero velocity at the point that the rockbolt breaks.* This definition requires that the velocity of the impact mass be measured during the impact, which exceeds the current requirements of ASTM D7401-08 (ASTM, 2008), however in light of this research it is expected that there is significant value in understanding how the rockbolt affects the impact mass during a test of this nature.

It is expected that further work will be conducted in understanding how the nature of a dynamic impulse affects the capacity of a rockbolt. This research has investigated the relationship between the magnitude of the impulse to the resulting dynamic capacity of a rockbolt. However, this has all been conducted at a single impact velocity. There would be merit in further work to understand how the variation of the impact velocity affects the dynamic capacity of a rockbolt.

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