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A new high-capacity dynamic impact test facility

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Abstract

Dynamic impact test facilities are widely accepted for the testing and qualification of ground support systems intended for use in dynamic ground conditions, namely seismicity and rockbursting. As more underground mining operations target extraction of ore in higher rock stress environments, the demand for dynamic ground support continues to increase. It is therefore important that designers and manufacturers of ground support are capable of qualifying support systems under extreme loading conditions. To support industry requirements, Jennmar has designed and commissioned a direct impact dynamic test facility (the 'DIT105Z') which is capable of testing support elements with high energy impulse of up to 105 kJ in a single impact. The DIT105Z is capable of conducting dynamic tests with a quick turn-around and processing of data, allowing for agile research and development and product verification. Over the past 2 years, several new dynamic products have been developed and tested on the DIT105Z and these products are now implemented at a number of mines globally. This paper presents the capabilities of the DIT105Z and the results of a number of dynamic testing campaigns.

Keywords: *ground support, dynamic testing, direct impact, seismicity, rockbursting*

1 Introduction

The effectiveness of installed ground support is critical for both safety to personnel and equipment whilst achieving economic extraction of reserves (Villascuesa et al. 2023). Ground support design typically entails a combination of empirical, analytical and numerical modelling approaches (Potvin & Hadjigeorgiou 2020) which require input parameters defining the performance capacity of support elements. Laboratory test methods are commonly utilised to provide ground support test data under reliable and consistent testing parameters (Potvin & Hadjigeorgiou 2020).

In use, ground support can be subjected to both static and dynamic loading conditions. Static loading is applicable to all applications and is relatively simple to test in laboratory conditions. In dynamic support conditions, the ground support must contend with static loading as well as possible ejection of the rock at high speed, bulking of a fractured rock mass, and shakedown of loosened rock (Potvin & Hadjigeorgiou 2020). Qualification of support response under dynamic loading is inherently more complex than static testing, requiring the development of more specialised testing rigs. Since the construction of the first dynamic test rig in South Africa in 1978, continued research into the performance and development of dynamic ground support has seen a number of dynamic test rigs being built and used for the qualification of ground support (Hadjigeorgiou & Potvin 2011; Knox & Berghorst 2019; Morkel et al. 2023; Player 2012). These dynamic test facilities most commonly fall into one of 2 classifications: direct impact or momentum transfer (Hadjigeorgiou & Potvin 2011; Player 2012). Of these, direct impact is widely accepted as the approach with which a high rate of testing can be more easily repeated.

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The affordability and accessibility of third-party dynamic testing has historically been a constraint for the development of improved or new products by ground support manufacturers. At the time of writing, only 2 test facilities are commercially available to the broader industry for testing: CanMET in Canada and Western Australian School of Mines in Australia, and this has driven industry to establish several in-house dynamic test facilities.

In 2024, Jennmar commissioned a direct impact test facility, named the DIT105Z, as an addition to the company's research and development capabilities. Since its inception, this facility has conducted an extensive number of dynamic tests on a variety of ground support tendons aiding in both product improvement and new product development.

2 The DIT105Z

The DIT105Z (Figure 1) is a high-capacity direct impact testing facility capable of a maximum energy impulse of 105 kJ and a maximum sample length of 3 m. The key capability parameters for the test facility are listed in Table 1. The design of the DIT105Z makes the rig suitable for testing typical industry rockbolts and cables as well as high-capacity tendons. The design of the DIT105Z aligns with the International Society for Rock Mechanics and Rock Engineering (ISRM) suggested method for impact testing (Li et al. 2024) allowing for impact testing of a variety of tendons under direct or indirect, and continuous or split-tube testing configurations, and records all data required to produce reporting in accordance with the recommendations.



Figure 1 The DIT105Z

Table 1 DIT105Z specifications

Parameter	Specification
Maximum impact energy	105 kJ
Impact velocity	4.4–8.6 m/s
Maximum drop mass	3,145 kg
Maximum sample length	3 m
Data acquisition rate	500 kHz

Based on learnings from previous direct impact test rig designs (Li et al. 2024; Plouffe et al. 2007), the DIT105Z comprises the following main components, as shown in Figure 2:

- Host framework: main structure of test rig
- Hoist with magnetic lifter: for lifting and release of impact carriage
- Impact carriage and drop mass: adjustable for height and mass to alter test velocity and energy impulse
- Load cell: measures impact load applied between the carriage and test sample
- Displacement sensor: a laser sensor tracking displacement of the impact carriage
- Arrestor buffers: floor mounted shock absorbers to arrest falling mass after tendon failure
- Sample host tube: simulate rock mass into which the sample is fixed
- Host tube containing test sample.

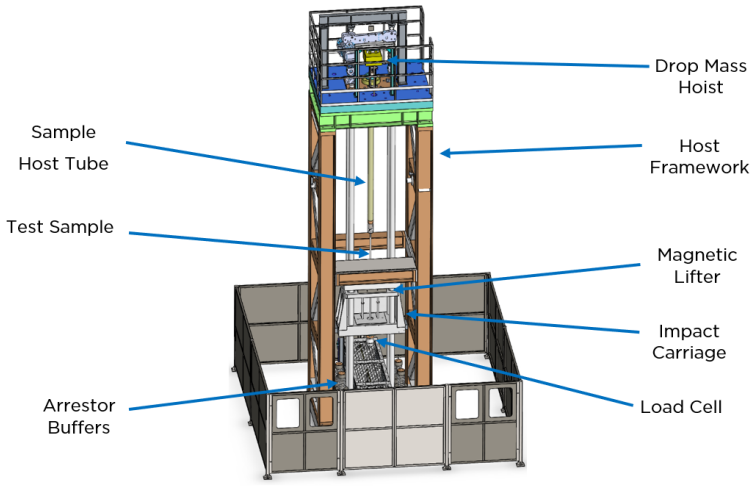


Figure 2 DIT105Z system components

The flexibility of the DIT105Z allows for samples to be tested at varying impulse speeds and energy magnitudes to either induce ultimate failure on a single impact, or to subject samples to multiple lower energy impulses to determine a cumulative dynamic capacity for each tendon type. Figure 3 indicates the envelope of energy, drop mass and drop height and velocity parameters within which the DIT105Z can operate.

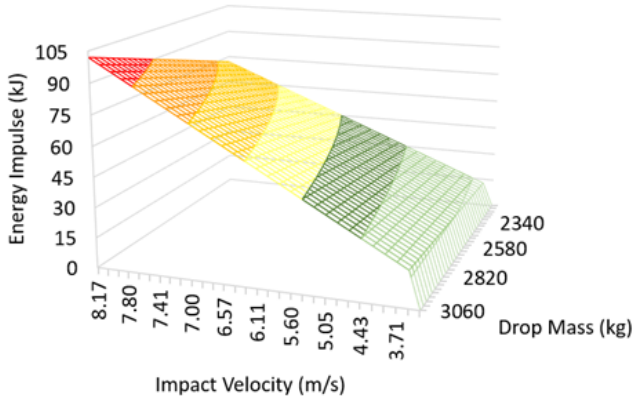


Figure 3 DIT105Z test envelope

3 Dynamic testing

Sample testing can be conducted on mechanically anchored, resin encapsulated, or grout encapsulated rockbolts and cables. These can be tested under direct or indirect impact loading and embedded in continuous or split-tube host tubes.

3.1 Sample preparation

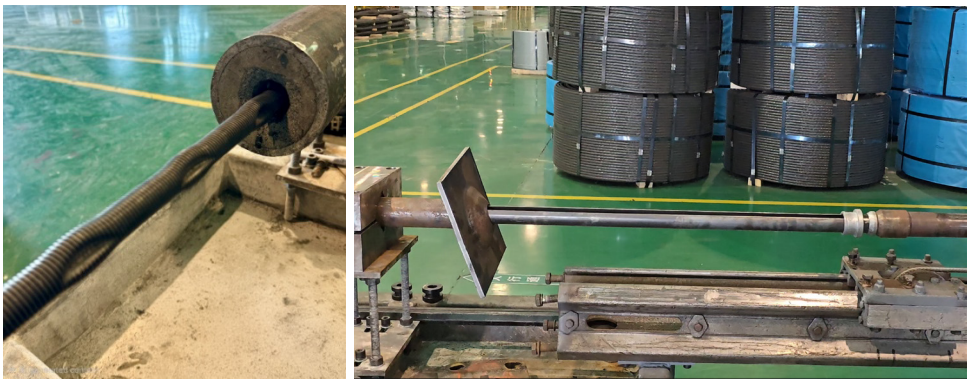
Test samples are prepared in the test laboratory using a standard hydraulic rockdrill and jumbo boom that are mounted to a rigid frame. Using a typical jumbo rockdrill for preparation ensures samples are installed in a manner similar to underground application. Testing of resin or grout anchored rockbolts can be conducted in either thick-walled steel tubes or larger diameter steel tubes filled with high strength cement to simulate host rock. Friction-anchored and mechanically anchored rockbolts are only tested in cement filled tube.

The steel tubes used for resin bolt tests are Ø72 mm outer diameter with an Ø36 mm internal diameter, and the steel tubes used for grouted tube tests are Ø108 mm outer diameter Ø90 mm internal diameter. The grouted host tubes are filled with a cement mix with minimum 80 MPa compressive strength.

In cement-filled tubes, a central hole is drilled into the cement using the same diameter drill bits with which support elements would be installed underground (Figure 4). Once the steel tube is prepared, the sample rockbolts can be installed as per standard process (Figure 5).



Figure 4 Sample preparation with rockdrill



(a) (b)

Figure 5 Installing D-Tech Bolt (a) and Dynamic Mech-Lok Bolt (b) into host tubes

Host tubes can be either a continuous tube or a split-tube configuration depending on the desired testing to be conducted.

3.2 Test preparation

Once sample preparation is complete, the samples are transferred to the DIT105Z for testing. Each sample is fed through the impact carriage and fixed to the top of the test frame (Figure 6). Dynamic testing parameters

for each test are then set by adjusting the mass of the impact carriage and the carriage drop height to achieve the desired impact velocity and energy impulse for each test.

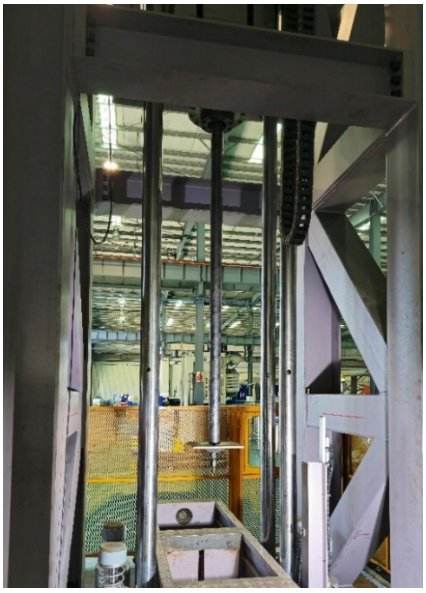


Figure 6 Test sample installed in DIT105Z

3.3 Data collection and storage

The duration of the impact is captured in 0.002 ms intervals by the impact loadcell and laser displacement sensor. High-speed video footage is captured to allow for post-test visual analysis of the tests for which the typical impact duration is less than 0.08 s (Figure 7). The recorded load and deformation data are stored directly into a custom test database and processing platform. Test data is processed in real-time to determine incremental energy absorption and to produce load–deformation and energy–deformation plots immediately after each test to allow for immediate analysis of test results before a sample is re-tested or removed from the DIT105Z (see Figure 8a). Each test result is stored on the system as both a one-page test summary (Figure 8b) and as raw Excel data, allowing for quick review of each test as well as more detailed analysis of test data. Although not yet implemented, the data processing and reporting system is to be upgraded to present the results in accordance with the ISRM suggested method (Li et al. 2024) so that the results from this facility are standardised to anticipated industry practise.

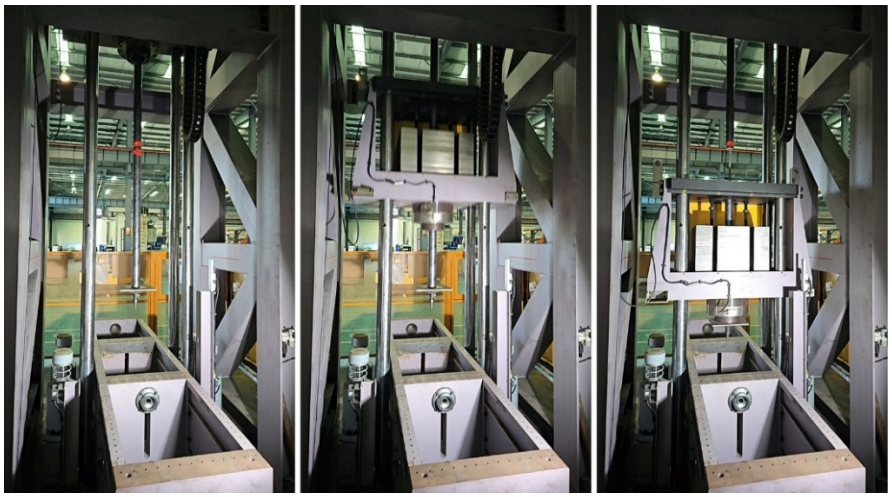


Figure 7 Frames from high-speed video



Figure 8 (a) Test result master database showing latest test result; (b) One-page test summary for test

3.4 Data processing and reporting

The raw test data is post-processed to present results in line with industry practice (Li et al. 2024; Player 2012), and this process entails the following steps.

3.4.1 Filtering individual test data

The raw data for each test is post-processed and filtered to reduce noise associated with high-frequency data sampling and provides a smoother output result for analysis. The custom processing software allows for an adjustable filtering frequency to be set. This is typically 100–200 Hz which is within the filtering range commonly applied by a number of dynamic test facilities (Darlington et al. 2018; Knox 2023; Player 2012; St-Pierre et al. 2007) allowing for easier comparison of test results from different test rigs. Figure 9 illustrates the effect of filtering data at various frequencies on reported dynamic load using dynamic test data from continuous tube, direct impact testing of a 2.4 m long Ø47 Dynamic Mech-Lok Bolt. Whilst this process slightly alters the reported initial response, there is a negligible smoothing of the average yield load for the majority of the rockbolts deformation. It is noted that due to the absorbed energy being incrementally calculated at each data point during testing, the energy result is not affected by the filtering process.

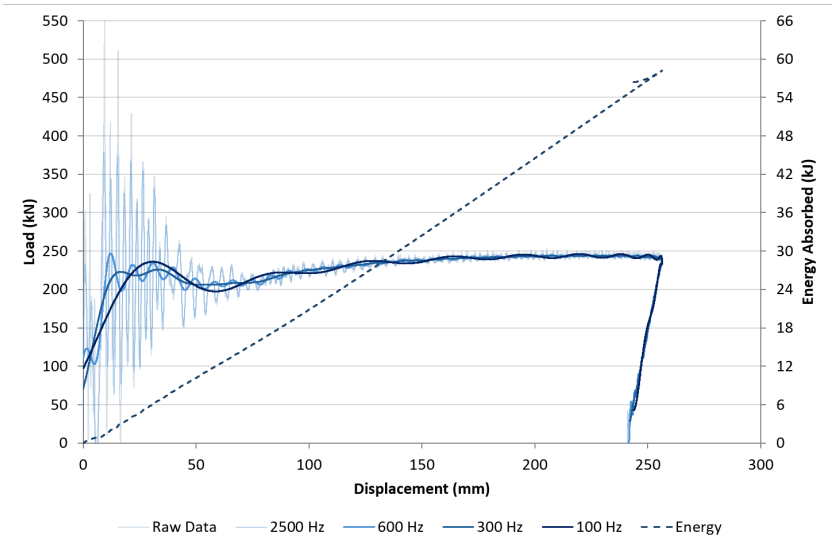
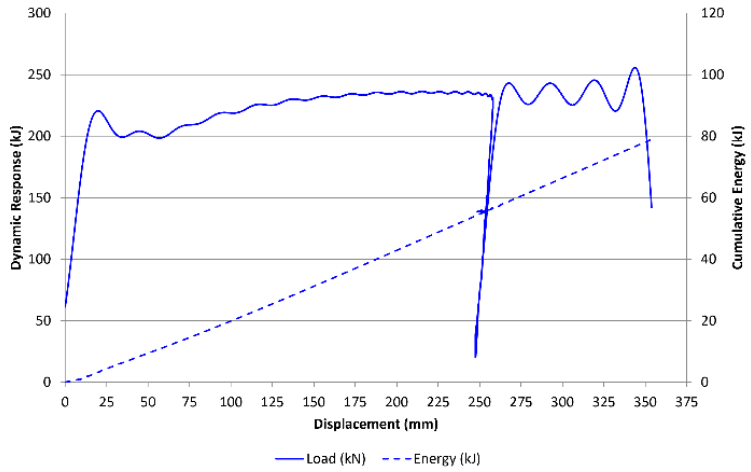


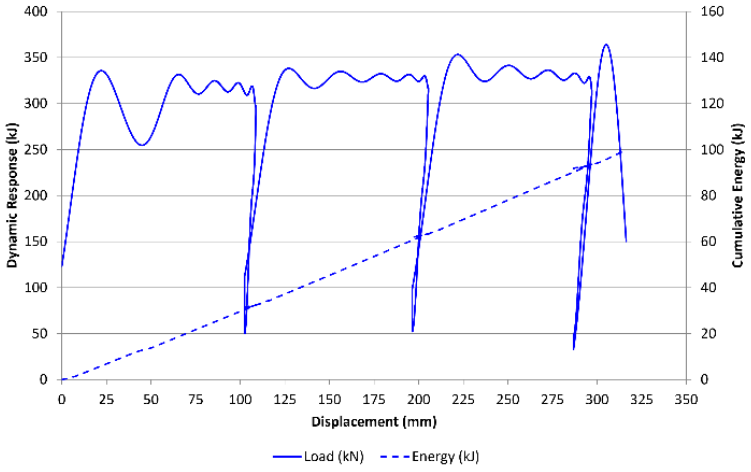
Figure 9 Effect of filtering dynamic response data

3.4.2 Combining multiple impacts on a sample

When samples are subjected to multiple cumulative impacts, these individual impact results are combined to generate a cumulative result for each sample tested. In line with industry practice, successive impacts are adjoined to preceding plots at the equilibrium point concluding each impact, at the end of the spring-back tail of each plot (Knox & Berghorst 2019). The resultant plot for a double impact test for a 2.4 m Ø47 mm Dynamic Mech-Lok Bolt is presented in Figure 10a and the plot for a 4-impact test on a resin anchored Ø25 mm J-Tech Bolt in Figure 10b. Whilst this spring-back is not likely to occur in actual use, this method of conjoining consecutive test results is considered to be a more conservative approach than conjoining successive graphs at the maximum elongation point for each impulse, with the reported cumulative displacement and energy capacities being lower than the summation of the individual results for each impact applied to a test sample.



(a)



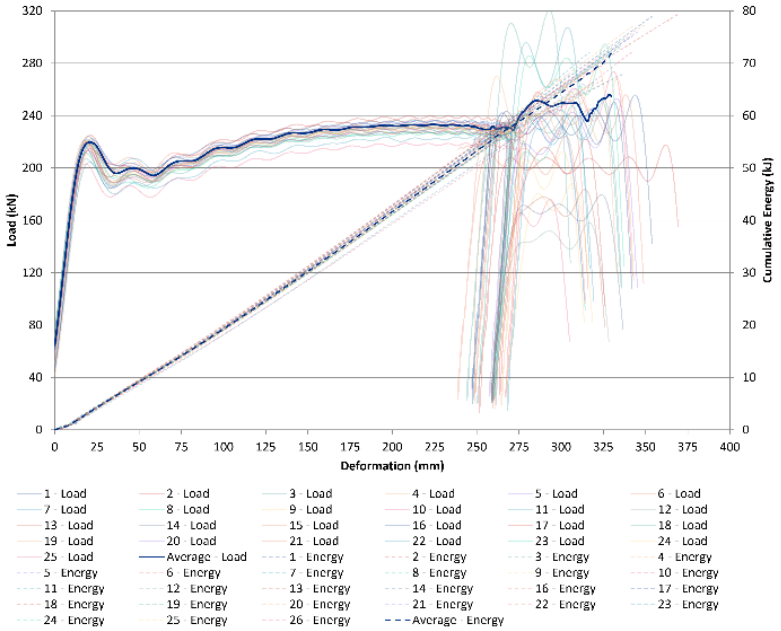
(b)

Figure 10 Cumulative test result for (a) 2.4 m Dynamic Mech-Lok Bolt and (b) 2.4 m J-Tech Bolt

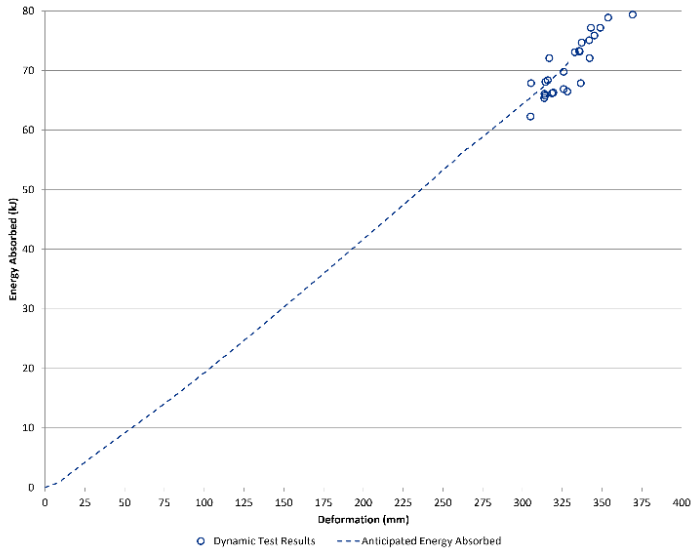
3.4.3 Combining multiple test results

Once the results for all samples have been filtered and combined into cumulative test results, the results for all samples within a testing program can be consolidated into single plots and tables for analysis of the consistency and reliability of various tendons under dynamic loading conditions. Figure 11a presents the dynamic load response and energy absorbed for cumulative dynamic testing conducted on 25 samples of the Ø47 mm × 2.4 m Dynamic Mech-Lok Bolt during a recent testing campaign. The figure includes average dynamic response and average energy absorption curves. In this instance, it is evident that there was a

consistent response from all test samples to the first impulse of 50 kJ, and the responses to the second 25 kJ impulse applied to each sample were more varied. Additionally, the cumulative energy–deformation result from each test are presented on a separate plot (Figure 11b), together with an anticipated dynamic energy response curve. This information is useful to quickly assess the likely deformation required by a tendon to absorb an imparted dynamic energy.



(a)



(b)

Figure 11 (a) Cumulative dynamic response; (b) Energy absorption for multiple test samples

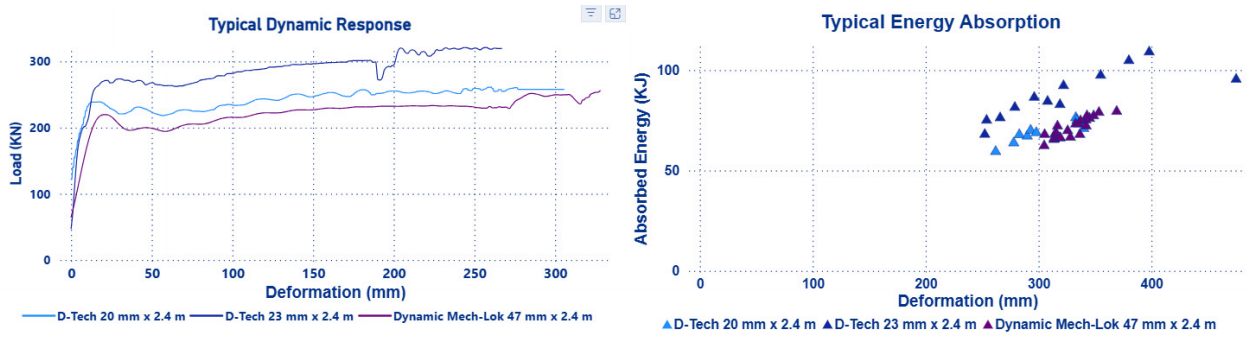
For completeness of reporting, the individual and cumulative results for all test results are provided in Table 2. During review, the variation between the sum of the individual test results and the calculated cumulative result shown below are compared for each test sample. Although these figures differ slightly due to the conservative approach adopted for conjoining successive dynamic results, review of this variance provides an indication of test results which may have been incorrectly calculated during the analysis process.

Table 2 Summary of results from cumulative testing on multiple samples

No.	Impulse 1		Impulse 2		Cumulative	
	Energy absorption (kJ)	Deformation (mm)	Energy absorption (kJ)	Deformation (mm)	Energy absorption (kJ)	Deformation (mm)
1	56.5	258.1	24.1	109.6	78.9	353.8
2	58.1	264.2	23.5	126.8	79.4	369.2
3	54.6	256.1	20.1	91.7	73.2	335.9
4	55.8	258.4	22.5	94.3	77.2	342.9
5	58.7	270.5	18.3	84.0	75.9	345.2
6	58.2	267.5	20.0	89.9	77.2	348.8
7	59.1	271.2	14.4	56.5	72.1	316.8
8	56.8	268.4	10.2	55.4	65.8	314.2
9	59.5	277.3	8.0	51.3	66.2	318.6
10	57.2	270.7	6.5	45.7	62.3	305.0
11	58.1	270.8	16.6	76.6	73.3	335.5
12	58.4	270.2	9.3	68.6	66.5	328.2
13	57.7	269.8	10.5	66.9	66.9	325.8
14	57.0	269.2	12.1	77.6	67.9	336.6
15	55.4	252.2	14.5	75.9	68.1	314.4
16	55.8	258.1	20.7	94.8	75.1	341.9
17	59.6	275.5	11.7	62.3	69.8	325.8
18	55.1	261.6	14.1	55.1	67.9	305.4
19	58.5	275.6	15.9	68.3	73.1	332.9
20	56.8	267.9	10.6	56.2	66.1	313.8
21	55.8	261.6	14.2	67.1	68.4	315.9
22	57.2	278.9	10.3	51.2	66.3	319.3
23	56.7	269.6	18.9	76.1	74.7	337.2
24	57.4	271.1	9.1	52.9	65.4	313.7
25	55.8	275.5	17.3	75.3	72.1	342.2
				Minimum	**62.3**	**305.0**
				Average	**70.8**	**329.6**

3.5 Application of data

Application of the test data is simplified by the use of an interactive online database of all dynamic testing conducted. This database allows users to select particular product types, configurations and lengths, and the database then presents an overview of the dynamic behaviour for the selected ground support products. This simple to use interface is available to aid practitioners in the selection of appropriate ground support for their specific needs. An example of this platform comparing two dynamic resin and a dynamic hybrid bolt is shown in Figure 12.



(a) (b)

Figure 12 Online interactive database for test results showing (a) dynamic response and (b) energy absorption

4 Conclusion

This paper introduces a new dynamic test rig capable of high dynamic energy and velocity impact testing on rockbolts and cable anchors. At the time of writing, the test rig had completed a high volume of dynamic tests on a wide range of rockbolts and cable anchors including resin rockbolts, grouted rockbolt, hybrid rockbolts and cable anchors under varying loading conditions. Continued testing on the DIT105Z aids in increasing the knowledge base for dynamic ground support and will assist with the development of new and improved support elements to further improve safety and increase mining efficiencies.

Acknowledgement

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