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A comparison between laboratory and in situ dynamic testing on the MDX bolt

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Abstract

As the mining industry moves towards digitalisation, there is an ever-increasing demand for testing information of ground support products. Product testing is typically performed in two environments: laboratory and in situ, each having their place in the design of ground support elements and systems. The difficulty is comparing results from these two quite varied test environments, and how they relate to ground support element performance within a ground support design.

Extensive testing has been conducted on the Sandvik MDX bolt in the Canmet laboratory dynamic testing facility and utilising Sandvik's in situ dynamic test rig. These testing regimes have presented an opportunity for a detailed analysis of the bolt's performance using these different test methods.

This work will establish whether an accurate comparison between the Canmet laboratory facility and Sandvik's in situ dynamic test rig is possible, and reveal any correlation of the MDX bolt performance between laboratory and underground conditions.

Keywords: *dynamic ground support, dynamic testing, laboratory dynamic testing, in situ dynamic testing, MDX bolt*

1 Introduction

The increasing digitalisation trend in mining is prompting the need for ground support suppliers to provide product test results with greater detail. This need for detail is further amplified when publishing and sharing test results obtained from different test apparatus and methods. One difficulty when using test results from different test providers is the varied recorded and reported results between test apparatus and providers. Li et al. (2021) presented a study of the results from testing a mining resin bolt bar in four different test apparatus with a consistent reporting terminology to allow an easier comparison.

Testing ground support products is essential for ground support suppliers to provide accurate product performance characteristics. Traditionally there are two test environments utilised to determine product performance: laboratory and in situ/underground. Each of these test methods provides insight into how the test specimen responds to the selected loading mechanism. When considering rockbolt testing, the axial loading mechanisms are quasi-static and dynamic. Both loading mechanisms entail test assumptions and compromises to allow testing in laboratory and in situ environments.

Laboratory testing provides an opportunity for intense monitoring of test specimens before, during and after the testing regime. This provides an insight into the response of the test sample to varying factors during installation and testing. Another possibility arising from laboratory testing is the ability for dissection and detailed sample analysis post testing. However, it is difficult to replicate some in situ factors, such as operator and machine variability, installation method, variabilities in rock conditions and rock confinement from a massive rock mass.

In contrast, in situ testing subjects test specimens to these variability factors, which gives a better understanding of the product performance in the final use environment. Operator and machine variability can have a large effect on the installation quality of a rockbolt, which can prove the difference between a successful or failed test. Rock conditions can vary from hole to hole, and can even vary within the length of a specific borehole. These variations in rock conditions affect the interaction between the rockbolt and the rock mass, and will influence product performance. Borehole confinement influences all rockbolts but can have more influence on friction mechanical style bolts as frictional engagement is critical for full bolt functionality.

To assess a product’s true performance, both laboratory and in situ testing are often employed. Performing laboratory testing initially allows designers to obtain test results for products in a controlled environment with a greater level of monitoring. This approach also minimises the variables of the testing regime, which simplifies the design approval process. Once laboratory testing is completed, the product is then subjected to the rigours of in situ testing, introducing the variables of the underground environment.

In order to assess the performance of Sandvik’s MDX bolt range, the D39 and D47 MDX bolts were subjected to dynamic testing in both laboratory and in situ environments. The laboratory dynamic testing was conducted at Canmet’s dynamic test facility, and the in situ dynamic testing utilised the Sandvik dynamic test rig. The test results were then compared to assess the performance of the MDX bolts in the two test environments and to assess any variations between the two test apparatus.

2 The bolt

This testing regime was conducted on the Sandvik D47 and D39 MDX bolts, which have a 47 and 39 mm diameter, respectively. The MDX bolt is a friction mechanical bolt employing a 20 mm rebar enclosed within a split tube with a point anchor at the toe end of the bolt (Figure 1). The MDX bolt has been designed for increased performance during dynamic loading events, with a rebar disconnected from the bolt tube. This disconnection ensures all load is applied through the rebar, which has a long free length, allowing controlled elongation throughout load application. The free length is the distance between the wedge mechanism and the radiused washer, which allows the rebar to stretch uniformly through the loading cycle, thereby dissipating greater energy when subjected to dynamic loads.

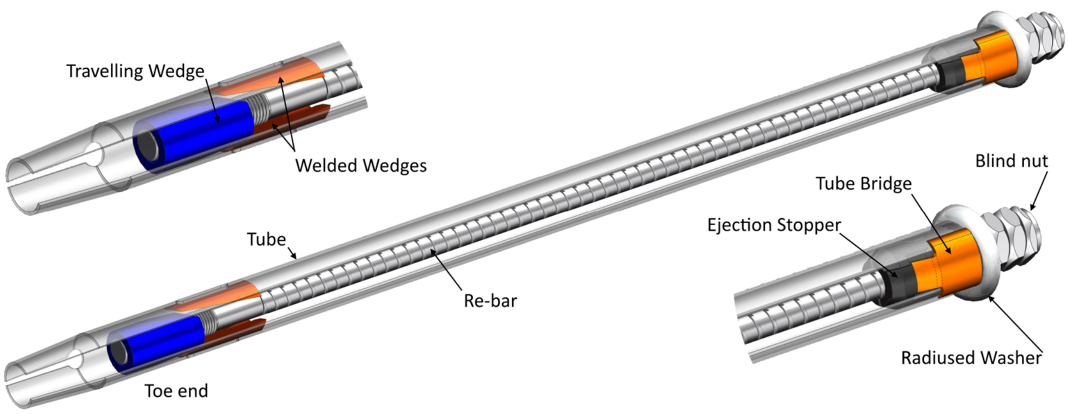

Figure 1 MDX components

The 20 mm diameter rebar has an ultimate tensile strength of 225 kN and is capable of elongation up to 200 mm (when testing a 2.4 m bolt), which lends itself well to dynamic loading conditions. The rebar is secured at the toe end of the bolt with a wedge mechanism capable of expanding the tube’s outside diameter up to 60 mm (from a 47 mm split tube outside diameter). This wedge mechanism is activated during bolt installation through rotation of the rebar, providing initial wedge expansion and bolt anchorage. When the bolt is loaded, the wedges have the capability of additional expansion, further anchoring the toe of the bolt in the rock.

The bolt tube thickness has been reduced from that of the MD bolt (previously released to the market in 2011), which has reduced the product mass. This reduction in bolt mass improves the ergonomics of the bolt and reduces the CO_2 emissions related to manufacture and transportation. The reduced tube thickness has not reduced the performance of the bolt as the MDX design does not rely on the tube to provide tensile load capacity. The tube maintains the wedge mechanism location at the bolt toe end and contains the stopper mechanism and the bolt head end. The stopper mechanism arrests an ejected rebar if failure occurs from tensile overload or bolt shearing.

At the head of the bolt, a blind nut with external thread allows attachment of accessories and a radiused washer provides an adaptable connection to surface support. When coupled with the X-plate, the bolt system has been optimised for dynamic performance by transferring dynamic energy from the rock to the MDX bolt.

3 Test apparatus

When comparing different dynamic test apparatus it is important to first understand the different energy application methods. There are two energy application methods currently utilised by test apparatus: the momentum transfer method employed by DSI Australia (Evans 2022), Swerim (Vallati et al. 2020) and WASM (Villaescusa et al. 2008); and the direct impact method employed by several laboratory apparatus including Canmet (Player et al. 2008) and the Sandvik in situ test rig (Darlington et al. 2018). Li et al. (2021) provided a comparison of several apparatus utilising the direct impact test method, and developed a new method to present and compare results from different test apparatus.

The direct impact method has been more widely implemented in laboratory and in situ test apparatus due largely to the simplicity of test apparatus design. As such, two different direct impact apparatus will be used to compare the performance of the Sandvik MDX bolt in both laboratory and in situ conditions.

3.1 Canmet

The Canmet dynamic test apparatus is at the CanmetMINING ground support testing laboratory in Ottawa, Canada, and has been improved over recent years to expand the test capabilities to include friction mechanical bolts. The test specimens are installed utilising a hydraulic ram to push the test specimen into the pre-drilled borehole in granite cores which were previously inserted into welded steel tube halves to create sufficient confinement. Once the samples are sufficiently inserted into the granite cores they are tightened to the required MDX torque of 400 Nm. This method provides a consistent test medium. The Canmet test apparatus shown in Figure 2 enabled the drop mass to be maintained consistently and the drop height was changed to modify the impact energy. The Canmet test apparatus directly measures the load applied to the lower end of the test specimen and uses vision-based displacement measuring technology.

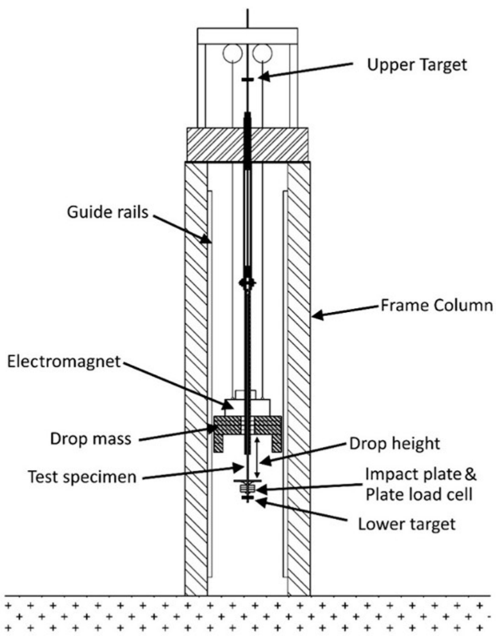

Figure 2 Canmet dynamic test facility

A typical sample installed and prepared for dynamic testing in the Canmet facility is shown in Figure 3, and includes the X-plate in the test assembly. The X-plate (BXPG1550, Darlington et al. 2022) was included in the Canmet test to better understand the behaviour of the complete system under dynamic conditions.

Figure 3 Sample set-up in Canmet apparatus

3.2 Sandvik in situ dynamic test rig

The Sandvik in situ dynamic test rig is a portable dynamic testing apparatus utilised to test specimens in the underground environment. The test rig underwent an audit by the Australian Centre for Geomechanics (ACG) team during 2019, which verified the accuracy and validity of the test method, data recording techniques and data analysis methods. This audit involved members from the ACG attending an in situ dynamic test regime to witness the test method, then processing the data concurrently with the Sandvik team to confirm the validity and accuracy of the data processing methods. The ability to test in the underground environment allows the testing to include variations in operator practices, installation machines and ground conditions. This provides the mine site with an added depth of test results for their mine-specific ground conditions.

The in situ dynamic test rig uses both a variable drop mass and drop height to alter the impact energy, which allows a varied impact velocity without necessarily varying the impact energy. The in situ test rig measures the load applied to the test sample and the acceleration of the claw component, which is used to calculate the displacement of the claws.

The in situ dynamic test rig varies from the Canmet laboratory apparatus with an additional load transfer element (the drop rod), which transfers the impact energy from the impact plate to the test specimen through the claws (Figure 4). This additional element is required to allow testing of a bolt that is entirely embedded into the rock mass. The claw and bell-shaped collar also facilitate the testing of bolts that are not installed perfectly vertical, with the ability to test bolts up to 10° from vertical. This axial misalignment can alter the load application as an element of bending is introduced to the test sample. However, this is not reflected in the measured load as the load is measured below the point of axial misalignment.

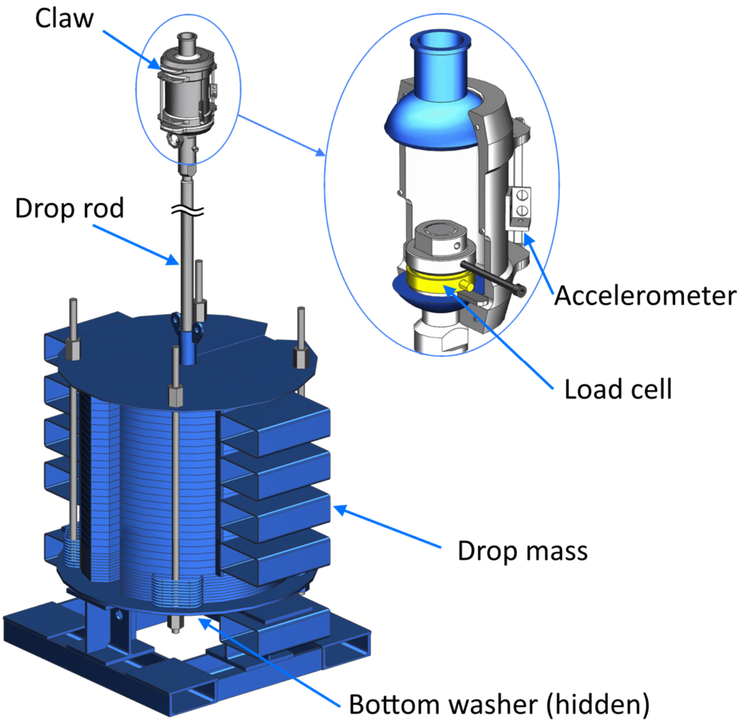

Figure 4 Sandvik in situ dynamic test rig

The in situ test rig currently does not have the capacity to test the rock plate in line with the bolt. Therefore, the MDX bolts were tested without a rock plate in the load transfer system. As shown in Figure 5, the rock plate is against the rock face and the dynamic testing collar is below the rock plate. The dynamic collar is the connection point for the dynamic test rig, which, as shown, has a domed surface to allow testing of non-vertically installed bolts. Testing without the rock plate isolates the rockbolt performance, and auxiliary dynamic laboratory testing on the X-plate can provide an indication of the expected performance of the X-plate (Darlington et al. 2022).

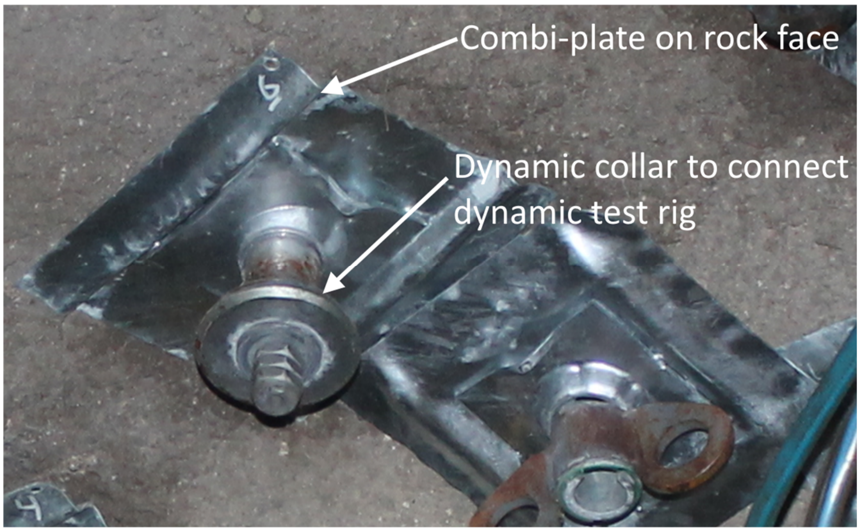

Figure 5 Bolt installed for in situ dynamic testing

4 Test results

The tests were conducted on both 2.4 m-long D47 (47 mm tube outside diameter) and D39 (39 mm tube outside diameter) MDX bolts in both test apparatus, with a nominal rebar length of 2.3 m. For comparison purposes, only single impacts were analysed. Several samples were subjected to secondary impacts but that is outside the scope of this paper. Each bolt size was subjected to two tests with each test apparatus, which will assist in checking for repeated results between samples. This type of testing is commonly known to have variability as, as with the well-established Charpy impact testing and in accordance with ASTM A23, the test must be conducted on a minimum of three samples to eliminate sample variability.

The impact energy levels were selected based on the minimum published data of the MDX bolts (Sandvik 2021), which are 24 and 28 kJ for the D39 and D47 MDX bolts, respectively. For the purpose of this analysis equal samples of both laboratory and in situ test results were compared, with the summary of test results shown in Table 1. Due to a limited library of D39 MDX in situ test results, two samples were selected with input energy of 26.1 kJ rather than the desired 24 kJ.

Table 1 Dynamic testing input parameters

Sample ID	Test method	Bolt type	Loading mass (kg)	Drop height (m)	Theoretical impact velocity (m/s)	Theoretical input energy* (kJ)
D39 LAB-1	Laboratory	D39	1,783	1.38	5.2	24.1
D39 LAB-2	Laboratory	D39	1,783	1.38	5.2	24.1
D39 UG-1	In situ	D39	1,832	1.45	5.3	26.1
D39 UG-2	In situ	D39	1,832	1.45	5.3	26.1
D47 LAB-1	Laboratory	D47	2,006	1.43	5.3	28.2
D47 LAB-2	Laboratory	D47	2,006	1.43	5.3	28.1
D47 UG-1	In situ	D47	1,832	1.56	5.5	27.9
D47 UG-2	In situ	D47	1,832	1.57	5.6	28.3

* Potential energy to the point of mass impact with load plate

From the analysis performed on various test apparatus by Li et al. (2021), several additional items can be used to provide a clearer comparison between the two test apparatus. These include first peak load (FPL), initial stiffness (K), plastic energy dissipation (PE), permanent plastic displacement (D), average impact load (AIL) and specific plastic energy dissipation (SPE) as shown in Figure 6, with results presented in Table 2.

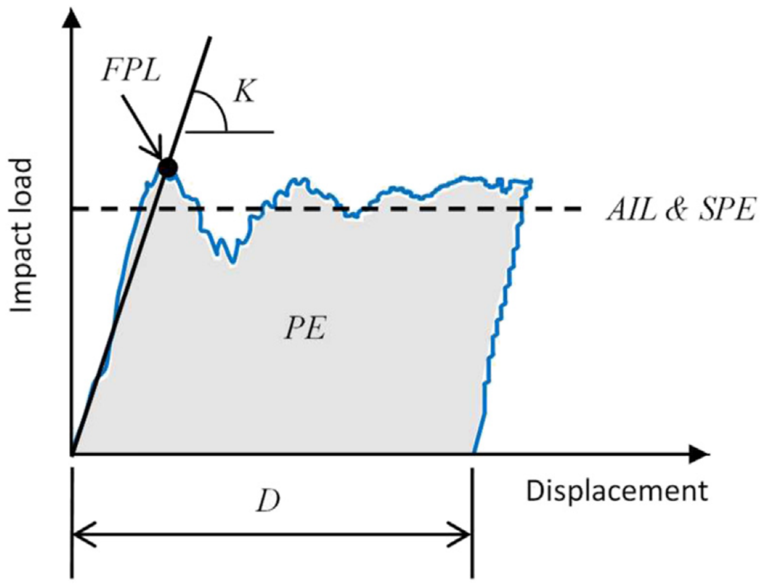

Figure 6 Test parameter reporting (from Li et al. 2021)

As stated in Li et al. (2021), the K is dependent primarily on the elasticity of the specimen and partially on the test apparatus frame stiffness. Furthermore, the calculation used to find AIL and SPE is as shown in Equation 1.

$$AIL = SPE = \frac{PE}{D} \quad (1)$$

Table 2 Dynamic testing input parameters results' summary

Sample ID	Theoretical input energy* (kJ)	Plastic energy dissipation (kJ)	First peak load (kN)	Peak load (kN)	Initial stiffness (MN/m)	AIL (kN) amd SPE (J/mm)	Permanent plastic displacement (mm)
D39 LAB-1	24.1	21.3	115.8	218	24.8	166.0	128
D39 LAB-2	24.1	24.4	173.6	217	60.1	196.5	124
D39 UG-1	26.1	25.3	164.8	267	13.0	219.8	115
D39 UG-2	26.1	23.6	180.0	296	13.1	218.8	108
D47 LAB-1	28.2	25.4	163.9	246	82.4	244.1	104
D47 LAB-2	28.1	30.1	227.4	263	43.3	261.9	115
D47 UG-1	27.9	28.8	191.8	256	15.0	221.7	130
D47 UG-2	28.3	28.1	246.1	284	61.5	228.2	123

* Potential energy to the point of mass impact with load plate

The test specimens all withstood the dynamic impact without rupture of the rebar. However, to better understand the bolt responses to the two test apparatus, the D39 and D47 MDX bolt load displacement behaviours have been plotted individually in Figures 7 and 8.

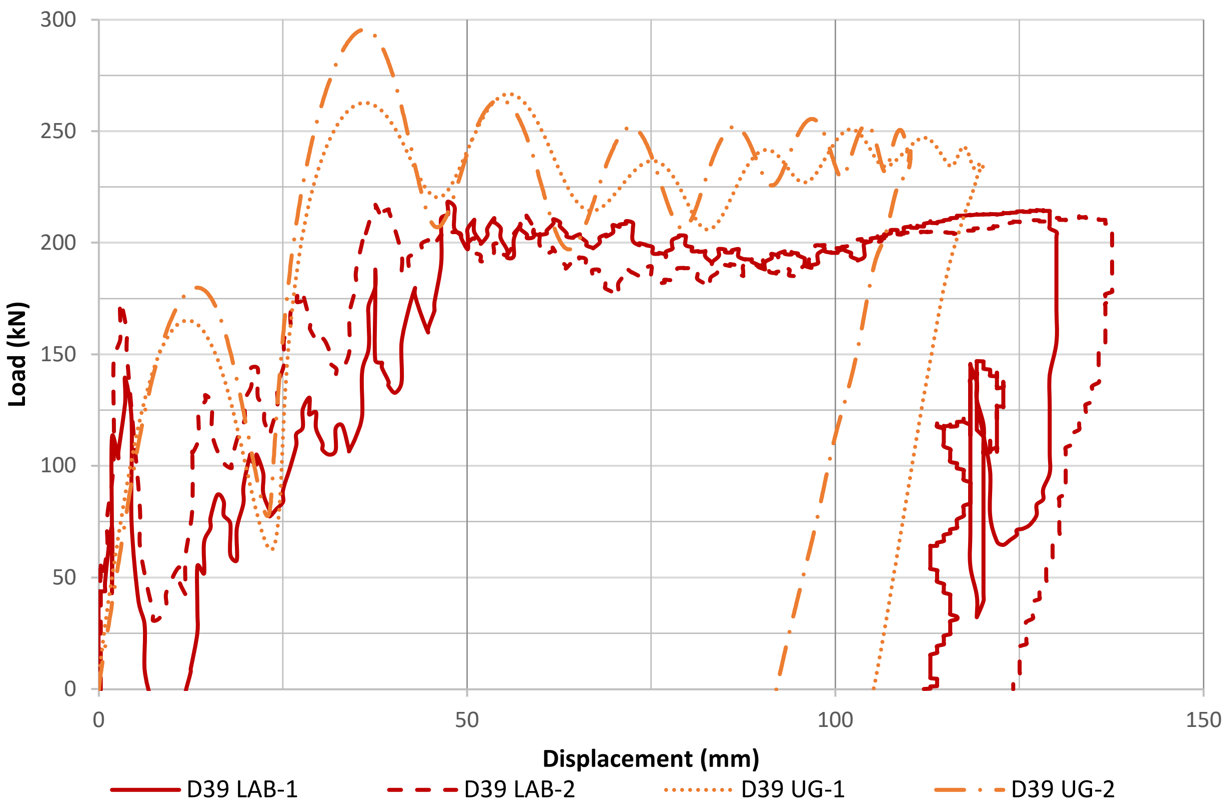

Figure 7 D39 MDX dynamic testing load versus displacement

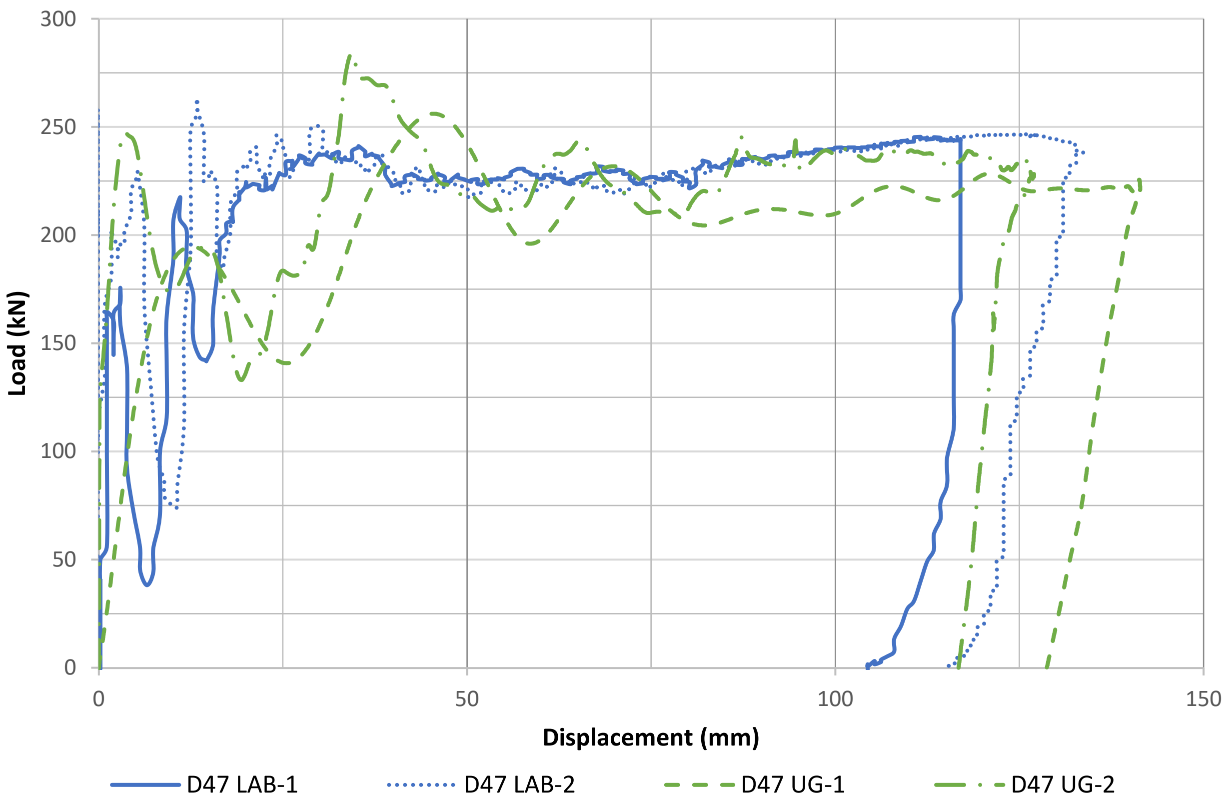

Figure 8 D47 MDX dynamic testing load versus displacement

Sample D39 LAB-1 showed an irregularity at the end of the load response. Upon further investigation of the motion capture and support graphs, this was shown to be a function of the collapse of the rock plate at the end of the load cycle. The rock plate collapse caused the end of the bolt to bend, as shown in Figure 9. This altered the position of the displacement measuring data.

Figure 9 D39 LAB-1 collapsed plate and bent rebar

It is apparent from these results that the MDX bolts have consistent responses in the two samples tested with each test apparatus, which shows test repeatability. This repeatability demonstrates the consistency of bolt response to each test method. However, there are variations between results from each test method: on average, the in situ specimens show a higher peak load (kN); the D39 laboratory specimens show greater peak load and permanent plastic displacement (D) than the D39 in situ samples; and the D47 laboratory specimens showed lower average D than the in situ samples. Additionally, the load response for the in situ specimens appeared to have a greater oscillatory nature, which is attributed to the displacement measurement and calculation process.

The two test apparatus both showed a FPL followed by a reduction in recorded load, which is theorised to be from further wedge engagement. After this reduction in load, each sample proceeded to increase the load and hold a consistent load for the remainder of the displacement. This consistent load demonstrates an effective yielding mechanism and it is predicted that higher energy input would result in higher displacement with a comparable load magnitude.

As the oscillations in load response are more evident in the in situ samples, this suggests they are a function of the data capture and processing method rather than the response of the MDX bolt. As described previously, the in situ test method requires a drop rod to transfer the dynamic energy into the test sample via a non-rigid connection between the drop rod and the test sample, utilising a claw assembly as shown in Figure 10. This claw assembly has radiused connections on both top and bottom surfaces, which accommodate testing of non-vertically installed bolts.

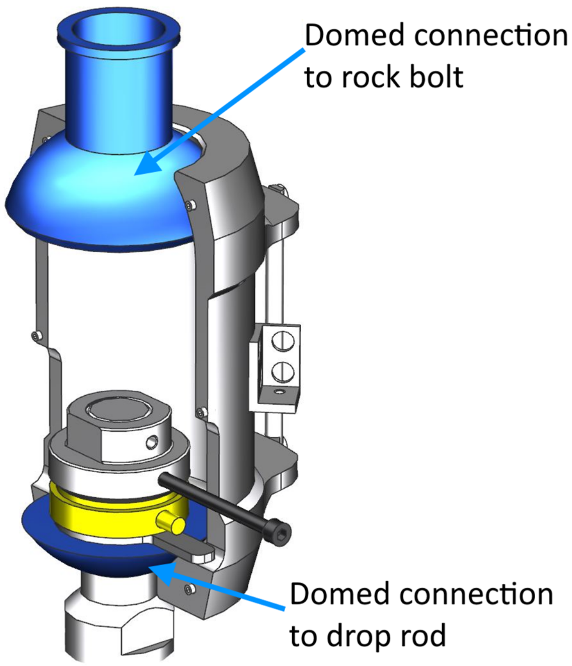

Figure 10 In situ dynamic test rig claws

Further testing could be conducted utilising the in situ apparatus to test a bolt installed under laboratory conditions. This test regime could assist to further understand the effect of installation medium (concrete core or massive rock) on bolt response.

5 Conclusion

Product testing is incredibly important for both product designers and end users to ensure accurate product performance characteristics are known. Dynamic testing of the Sandvik MDX bolts was conducted using two different test apparatus: Canmet laboratory dynamic test apparatus and Sandvik in situ dynamic test apparatus. The testing demonstrated consistent bolt performance for each sample set on each test method, exhibiting consistent performance of the MDX bolts. However, several variations were evident between the results from each test method. These variations can be attributed to the different load transfer mechanism for each test method.

The variations shown between the results from the two test apparatus demonstrate the potential for further research into this area, utilising the in situ apparatus to test samples installed in laboratory conditions. This test will provide a better understanding of the bolt performance when installed in granite cores and massive rock, and will answer several questions raised during this testing regime.

The comparison between the bolt performance from the Canmet and in situ apparatus shows the two test methods yield comparable results for the MDX bolt. There is some variability in final displacement and energy absorption, but this is to be expected when performing testing of this nature. The test samples were prepared with as much care as possible, but sample variability exists between different production batches and the variability is acceptable.

The test comparison showed the MDX bolt successfully absorbed the impact energy with a maximum permanent plastic displacement of 128 mm and 130 mm for the D39 and D47 MDX bolts, respectively. Therefore, the results from both laboratory and in situ testing accurately reflect the true performance of the MDX bolts and can be used to determine expected bolt performance.

Acknowledgement

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