DOI: https://doi.org/10.68732/3885be6184315507

ISBN: 978-9989-2053-7-8

Energy absorption capacity of cable bolts under impact loading for the stability of underground excavations

A. Mottahedi, N. Aziz & A. Remennikov
University of Wollongong. Wollongong, Australia
am3887@uowmail.edu.au
0000-0001-7826-6181

A. Mirzaghorbanali
University of Southern Queensland, Toowoomba, Australia

Abstract

Underground mining and tunnelling operations face major safety risks from dynamic events such as rockbursts. In this regard, cable bolts are essential reinforcement elements, yet their behaviour under impact loading, especially for high-strength designs, remains insufficiently understood.

This study examined the pull-out performance of high-strength cable bolts using controlled laboratory impact tests. A Reverse Pull-out Test Machine (RPTM) integrated with a drop hammer system was used, enabling direct measurement of axial load and displacement at the cable bolt for precise energy evaluation. Tests were performed on 70-t SUMO bulbed and non-bulbed cable bolts with a 300 mm encapsulation length, each subjected to an impact energy of 14.52 kJ.

The results show that non-bulbed cable bolts absorbed more energy (average 11.26 kJ versus 8.75 kJ) and showed greater displacement capacity (average 48.40 mm versus 36.25 mm) compared with bulbed cable bolts. The dominant failure mode was debonding at the cable-grout interface, characterised by frictional sliding and some cable rotation. Cable elongation was also observed, particularly in bulbed bolts, attributed to the mechanical anchorage created by the bulbs.

Overall, the findings suggest that non-bulbed cable bolts, due to their higher deformability, greater energy absorption, and extended energy dissipation capability, may offer superior performance in dynamically active ground conditions. These insights can support the development of more resilient, integrated support systems for excavation environments prone to rockburst hazards.

Keywords

Pull-out, Rock burst, Cable bolt, Underground Excavation, Rock reinforcement.

1 Introduction

Ensuring safe working conditions is a fundamental priority in underground mining and tunnelling. To enhance stability, cable bolts, flexible stranded steel tendons, are widely used as rock reinforcement systems (Mottahedi et al. 2025). A cable bolt consists of multiple steel wires twisted into strands and grouted within a borehole (Hutchinson and Diederichs 1996). Typical cable lengths range from 3-15 m, significantly longer than conventional rock bolts, which are usually under 3 m (Jodeiri Shokri et al. 2024).The main role of cable bolts is to reinforce the rock mass, prevent strata separation, and manage post-failure deformations (Galvin 2016). As ground movement occurs, cable bolts mobilize load and transfer the weight of unstable rock blocks to surrounding competent rock (Goris et al. 1996; Thompson and Villaescusa 2014). Because they resist both axial loads from gravity and shear loads along discontinuities (Hutchinson and Diederichs 1996; Windsor 1997), evaluating their performance under both loading modes is essential.

Existing studies have mainly examined static axial and shear behaviour, simulating long-term ground deformation without impact loading (Mottahedi, Aziz, Mirzaghorbanali, et al. 2024; Mottahedi et al. 2025). However, tendons can also experience impact forces in seismically active environments (Hadjigeorgiou and Potvin 2011; Li et al. 2025). Seismic events such as coal or rock bursts and large-scale blasting may induce ejection velocities of 3–10 m/s and energy levels of 10–50 kJ/m², causing significant damage m^2 (Player et al. 2008; St-Pierre et al. 2009). To ensure safety, tendons must therefore absorb impact energy and accommodate large displacements after failure (Player et al. 2008; Cai 2013).Impact testing of reinforcement systems began with small-diameter bolts in North America by Yan (1992). While numerous studies have evaluated the dynamic performance of rock bolts, only limited research focuses on cable bolts under impact loading (Mottahedi, Aziz, Remennikov, et al. 2024). Reported studies have used either Drop Weight (DW) or Momentum Transfer (MT) testing methods (Li et al. 2021, 2025). Most prior work, however, examined low-strength, small-diameter cables, with only a few investigations involving higher-strength, larger-diameter systems (S Anzanpour et al. 2021, 2022).

Anzanpour et al. (2021) performed preliminary impact tests on an MW9 cable bolt, applying 14.7 kJ of input energy. They observed that the normalized energy required for cable pull-out under impact loading was roughly 30% lower than under static loading, likely due to reduced friction effects during rapid loading. Later, Anzanpour et al. (2022) conducted six tests on 63-t SUMO non-bulbed and bulbed cables, showing that bulbed cables absorbed more impact energy (avg. 10 kJ) than non-bulbed ones (avg. 8.53 kJ). However, the energy measurements are uncertain because loads were recorded on the drop hammer rather than directly at the cable, underscoring the need for more accurate experimental studies.Since the dynamic behaviour and energy absorption capacity of high-strength cable bolts remains insufficiently explored, their performance in seismically active environments is still not well understood. The present research aims to help close this knowledge gap by conducting controlled laboratory impact tests and comparing results with existing studies to support safer and more productive underground operations.

2 Methodology

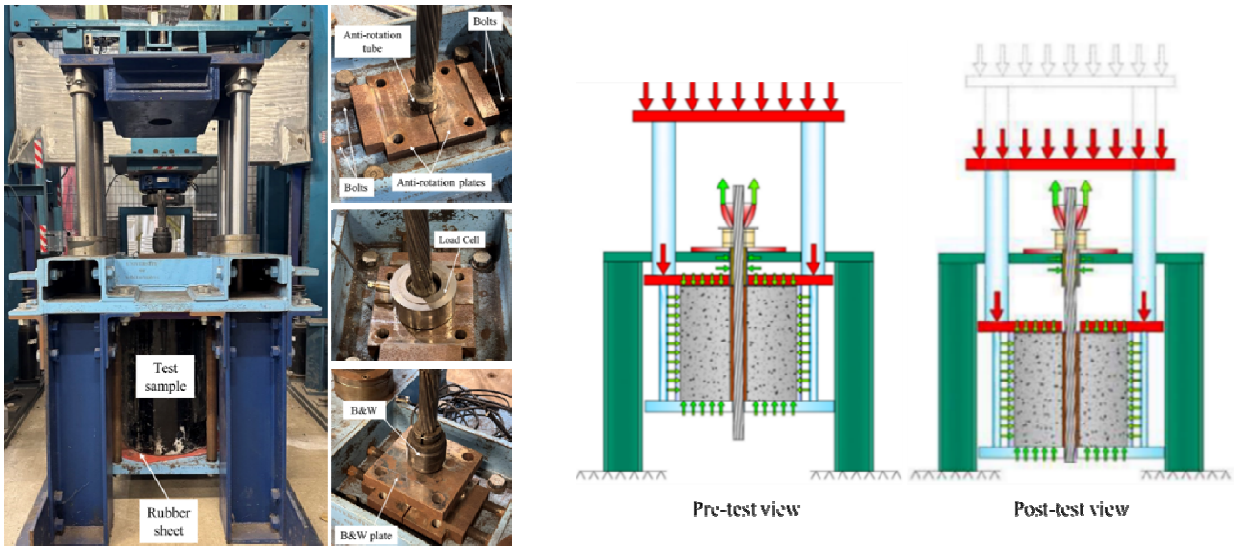
2.1 Materials

In this research, 12-wire 70-tonne SUMO cable bolts with two distinct surface geometries (non-bulbed and bulbed) were used as high-strength tendons for the impact pull-out testing program. All 31-mm diameter cable bolts were manufactured and supplied by Jennmar Australia and have a typical ultimate tensile load of 705 kN. For the required test configuration, the bulbed cable variant included a single bulb (ex-clip) positioned 150 mm from one end to facilitate the intended loading arrangement.

2.2 Method

Anzanpour et al. (2021)developed the Reverse Pull Out Test Machine (RPTM) (see Fig. 1a) at the University of Wollongong, enabling pull-out testing through a push-to-pull mechanism while preventing cable rotation using an anti-rotation confining tube (Sina Anzanpour 2022). This apparatus is worked based on the Laboratory Short Encapsulation Pull Test (LSEPT) method, where the cable's free length is encapsulated to represent the section distant from the excavation boundary, while the embedded end simulates the rock mass sliding along the cable(J. Chen et al. 2018; Rastegarmanesh et al. 2022). As shown in Fig. 1, load is applied downward through the reinforced loading platform and

transferred via four load-transferring shafts to the confinement system, which includes the host medium, confinement plates, and radial confinement cylinder. The cable is held in position by the B&W assembly, and axial load is directly recorded using a hollow load cell mounted beneath it. During loading, the host medium and movable rig components displace downward while the cable remains fixed, allowing typical failure modes such as cable tensile rupture and interface failures (S Anzanpour et al. 2021). The RPTM accommodates both static and impact loading and can test various tendon profiles, borehole diameters, and grout types. Chen et al. (2017) reported that cable load-bearing capacity increases with sample diameter up to 300 mm under confinement, beyond which it stabilises. Accordingly, the RPTM employs concrete cylinders of 300 mm diameter and 450 mm height, enabling controlled investigation of the effects of host medium strength and embedment length (Sina Anzanpour 2022).



(a) (b)

Fig. 1 (a) The RPTM setup and (b) thesetup before and after the test.

To apply impact loads, the RPTM is used in conjunction with a drop hammer rigbuilt on a 5.0 × 3.0 × 2.5 m³ concrete foundation in the UoW Hi-Bay laboratory.The rig stands 6 m tall and includes a 592 kg free-fall hammer capable of dropping from heights up to 4 m, corresponding to impact velocities of up to 9 m/s and 23 kJ of input potential energy. The hammer is suspended by a hydraulic brake and chain system, and moves along guided columns with roller assemblies. A 1200 kN dynamic load cell (Interface Model 1200) is mounted beneath the impactor to record applied forces. Meanwhile, as shown in Fig. 2, the RPTM is positioned beneath and anchored to the drop hammer rig. The hammer is then raised to the desired drop height**.**

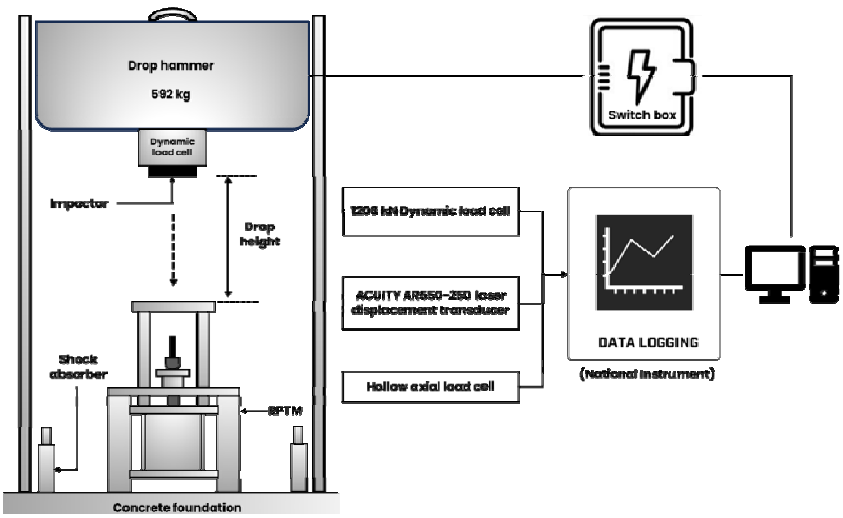


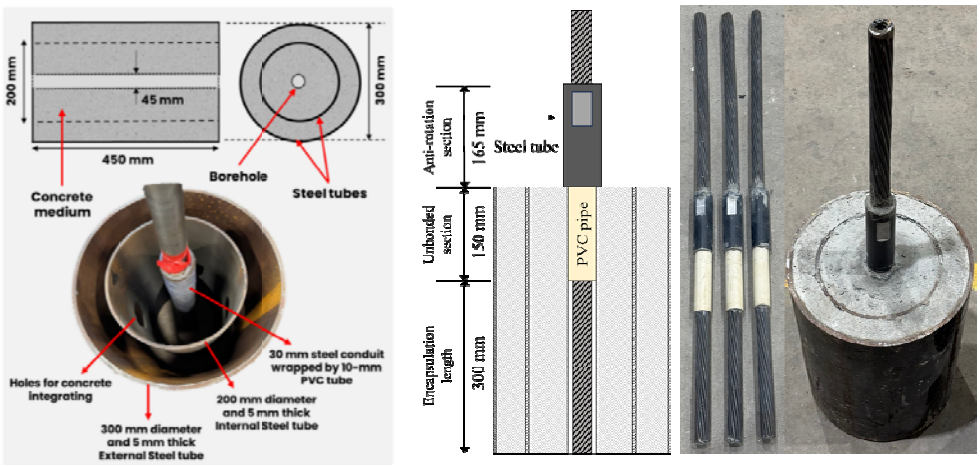
Fig. 2 A schematic view of the pull-out rig test arrangement under the drop hammer rig.

2.3 Sample Preparation

Concrete cylinders were prepared to serve as the host medium for pull-out testing, following the requirements of the RPTM setup (see Fig. 3). Due to difficulties in obtaining large natural rock

samples, 300 mm diameter and 450 mm long concrete specimens were cast to simulate rock conditions (Mottahedi et al. 2025). Constant radial stiffness (CRS) confinement was applied to represent the restraining effect of surrounding ground (Y. Chen and Li 2015; Thenevin et al. 2017). Based on prior research showing steel tubes provide superior confinement compared with copper, PVC, or aluminium (Hyett et al. 1992; Moosavi et al. 2002; Klar et al. 2023), each specimen was cast inside 300 mm × 5 mm external steel tubes and further reinforced with 200 mm × 5 mm internal steel tubes to prevent cracking during testing (Sina Anzanpour 2022).As shown in Fig. 3a, central conduits wrapped in PVC hoses created 45-mm diameterrifled boreholes that improved grout-rock bonding (Blanco Martín et al. 2013; Aziz et al. 2019). After casting, conduits were removed, leaving spiral grooves, and specimens were cured for 28 days.

Cable bolt encapsulation was then conducted using 31 mm cable bolts grouted with TD80 cement at a 0.35 w/c ratio, as recommended by the manufacturer. As shown in Fig. 3b, To satisfy encapsulation requirements while fitting the RPTM geometry, a bonded length of 300 mm was used, leaving the upper 150 mm unbonded. This unbonded region was formed using 40 mm × 1.5 mm PVC pipes, while anti-rotation sections were created with 40 mm × 4 mm steel tubes with flattened faces. Grout was poured into the rifled boreholes, and cables were installed with sealed borehole bases to prevent leakage. Both the cable bolts and concrete samples were vibrated to remove air pockets and enhance grout density. Prepared specimens were cured for 7 days before impact testing.



(a) (b)

Fig. 3(a) The details of the assembled mould and (b) the details of the cable bolt encapsulation in the concrete samples.

3 Results and Discussion

3.1 Impact loading profile characteristics

A total of six impact pull-out tests were performed using drop height of 2.5 m, with three tests conducted on each cable type.The recorded time-history curves of impact load, displacement, and pull-out load demonstrate that the loading process consists of multiple stages. Consistent with the classification by St-Pierre et al. (2009), the loading signal can be divided into three parts: the first impact, elastic rebounds, and system equilibrium, as shown in Fig. 4. During the initial impact, the potential energy of the falling mass is converted into kinetic energy and transferred to the loading platform, generating a high-amplitude load. Because the specimen and test rig cannot fully absorb this energy, a portion is returned to the impactor, causing it to rebound. These rebounds, which form a sequence of progressively smaller bounces, occur because the impactor loses energy in each cycle until the system gradually settles through damped oscillations.

Among all stages, the first impact is the most critical, as it governs the maximum loading amplitude, impact duration, and resulting permanent displacement. The results confirm that subsequent rebounds do not significantly affect permanent displacement, which is consistent with previous studies (St-Pierre et al. 2009; Li et al. 2021; Knox and Berghorst 2018). Energy recorded during later bounces is considered an artefact arising from the stiffness of both the testing apparatus and the bolt (Li et al. 2021). Consequently, cable bolt debonding and displacement are primarily governed by the initial impact. For this reason, Fig. 5 presents only the curves from the initial loading event up to the point where the load returns to zero, excluding the secondary rebounds.

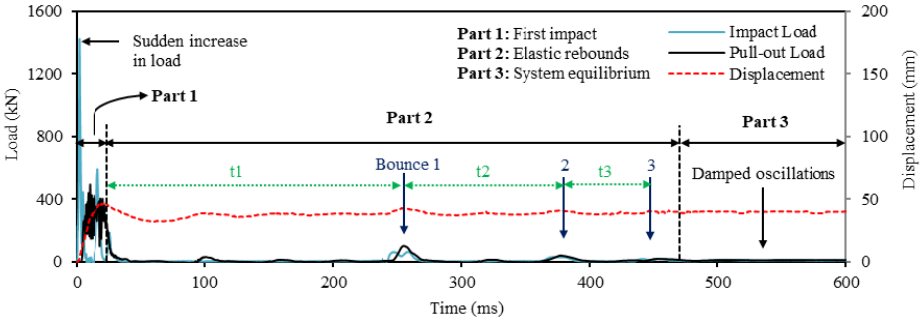
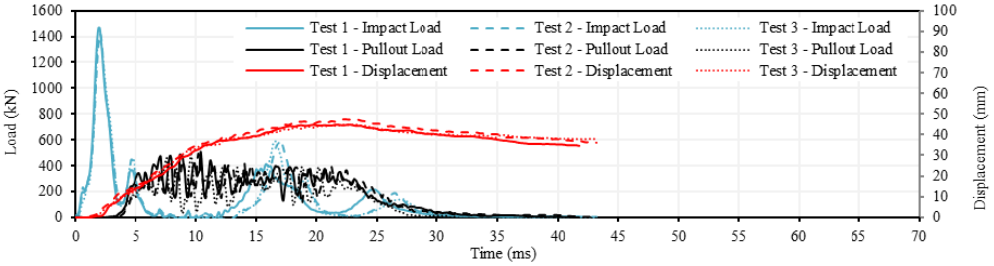
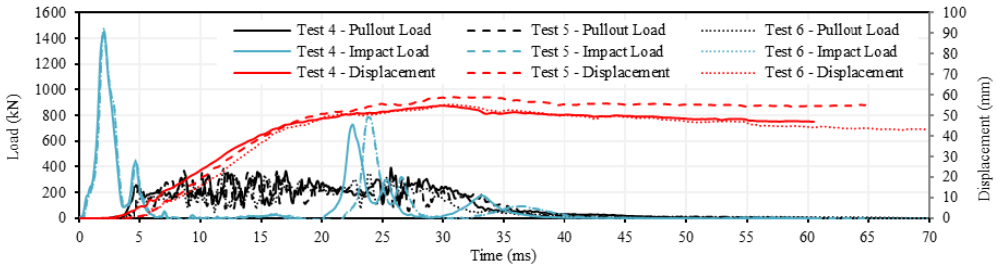


Fig. 4 The classification of the loading signal (Test 2).



(a)



(b)

Fig. 5 The load and displacement as a function of time during the first impact: (a) bulbed cables and (b) non-bulbed cables.

3.2 Stages of the first impact load

The impact load-time curves can be divided into three distinct stages, shown schematically in Fig. 6. At Stage 1 (Inertia Effect Stage), the impactor strikes the loading platform at time zero, causing the load to rise sharply, reaching a first peak of 1470 kN within 1.9 ms, due to the inertial resistance of the stationary pull-out rig. This initial spike reflects the transfer of momentum from the moving impactor to the system and does not represent the cable's pull-out resistance. At Stage 2 (Load-Bearing Stage), the impactor and the test specimen begin moving downward together. Once the specimen starts displacing (around 2.3 ms), the applied load is transferred into the cable bolt, initiating pull-out behaviour. The axial load cell captures this transition, showing the onset of load bearing followed by a load drop, which indicates debonding or failure at the cable–grout interface. Stage 3 (Unloading Stage) begins as the displacement reaches its maximum (44.80 mm at 21.8 ms) and then decreases as the impactor rebounds due to release of stored elastic energy in both the specimen and the rig. The stage concludes when the load returns to zero at 41.9 ms, leaving a permanent displacement of 34.60 mm, which characterises the irreversible deformation generated by the first impact.

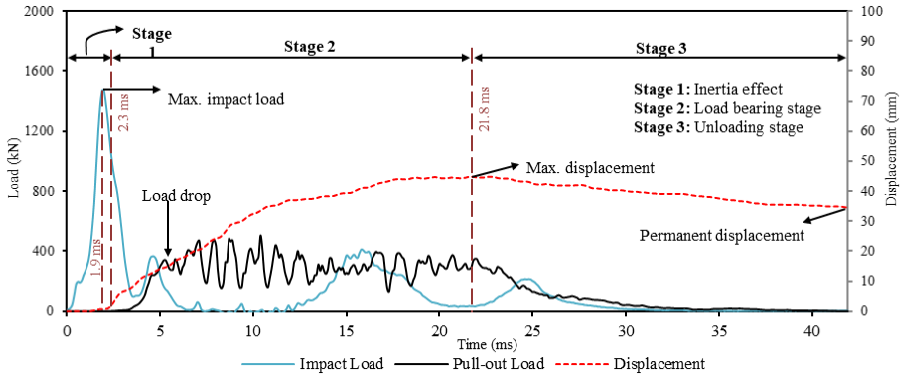


Fig. 6 The stages of the loading signal during the first impact (Test 1).

3.3 Energy absorption capacity

At the drop height of h, the input energy or the potential energy of the impactor ($E_{im,p}$) is (Yan 1992):

$$E_{im,p} = m_{im}gh \tag{1}$$

Where m_{im} is the drop hammer weight and g is the gravitational acceleration (9.81 m/s^2). Besides, according to the energy equilibrium, the theoretical velocity ($V_{im,0}$) of the impactor just before the strikes is equal to $\sqrt{2gh}$ (Li et al. 2025; Pytlik 2016). However, it was reported that during the hammer free fall, due to the friction of the guiding runner, the actual velocity of the impactor ($v_{im,0}$) is 0.98 of its theoretical velocity (Kaewunruen 2009). Hence, the kinetic energy of the impactor ($E_{im,k}$) immediately prior to the strike onto the loading platform can be calculated by Eq. 2(Khaleghparast et al. 2023). Furthermore, the loss of energy due to the friction ($E_{im,fr}$) is given as Eq. 3.

$$E_{im,k} = \frac{1}{2}m_{im}{v_{im,0}}^2 = \frac{1}{2}m_{im}[0.96(2gh)] \tag{2}$$

$$E_{im,fr} = E_{im,p} - E_{im,k} = 0.04m_{im}gh \tag{3}$$

In addition, the absorbed kinetic energy by the cable bolt, which is consumed for pulling the cable bolt out of the host medium, may be estimated by integrating the area under the pull-out load-displacement curves as given by Eq. 4. PE can be referred to as the pull-out energy dissipated through the plastic deformation.

$$PE = \int_0^d P.\mathbf{d}d \tag{4}$$

where P refers to the pull-out load monitored by the hollow axial load cell at permanent displacement d. The obtained pull-out energies are introduced in Table 1. The test results show that non-bulbed cable bolts absorbed more energy (11.26 kJ) than bulbed cable bolts (8.75 kJ). Additionally, the energy dissipated by the various test system's parts (E_{sys}) was also estimated. The results indicate that the bulbed cable bolts exhibited greater energy loss during testing (5.19 kJ) compared with the non-bulbed bolts (2.69 kJ). The higher total energy absorption measured in the non-bulbed cables is linked to their greater axial deformability and more distributed bond mobilisation along the cable-grout interface. Because non-bulbed cables rely primarily on frictional resistance rather than discrete mechanical interlock, they undergo a more gradual and extended slip process, enabling larger displacements and greater dissipation of impact energy. In contrast, bulbed cables concentrate stresses at the bulbed sections, which can lead to localised grout crushing and reduced ductility. Consequently, non-bulbed cables demonstrate superior overall energy absorption under impact loading.

In addition, the calculated Unit Pull-out Energy (UPE), defined as the absorbed energy divided by the corresponding displacement, indicates the energy required to pull the cable bolt by 1 mm and reflects the system's resistance to dynamic loading. The highest UPE value was recorded for bulbed cable bolts (0.243 kJ/mm), highlighting their strong initial anchorage capacity. However, in burst-prone ground conditions, energy absorption and deformation capacity are more critical than peak resistance alone (Cai 2013). Although non-bulbed cables exhibited lower UPE, they demonstrated greater total energy absorption and displacement, making them better suited for dynamic environments where large post-failure movements must be accommodated.

Rockburst events in deep mining can release 10-50 kJ/m² of energy and generate ejection velocities of 3–10 m/s(Player et al. 2008; St-Pierre et al. 2009). The tested impact velocity of 6.86 m/s and energy level of 14.52 kJ therefore fall within moderate to severe rockburst scenarios typically encountered in deep coal and hard-rock mines. In such highly stressed geological settings, such as quartzite, dolomite, or stiff coal roofs, support systems must accommodate substantial deformation while dissipating high levels of energy. The greater displacement and absorption capacity measured for non-bulbed cables indicates their suitability for these high-energy, high-deformation conditions. Conversely, bulbed cables, which provide higher peak loads, may be more effective in brittle, low-deformation rock masses where immediate anchorage strength is essential. These findings support performance-based selection of cable bolt types based on expected rockburst severity and geological conditions, contributing to safer and more resilient ground-support design.

Table 1. The summary of the energy dissipation in the impact tests.

Test No.	Bolt type	$E_{im,p}$ (kJ)	$E_{im,k}$ (kJ)	$E_{im,fr}$ (kJ)	Pull-out energy, PE (kJ)		Total energy loss, E_{sys} (kJ) [a]		Unit pull-out energy, UPE (kJ/mm) [b]	
					Value	Ave.	Value	Ave.	Value	Ave.
1	Bulbed	14.52	13.94	0.58	9.84	8.75	4.10	5.19	0.284	0.243
2	Bulbed	14.52	13.94	0.58	8.64		5.30		0.240	
3	Bulbed	14.52	13.94	0.58	7.77		6.17		0.204	
4	Non-bulbed	14.52	13.94	0.58	11.15	11.26	2.79	2.69	0.237	0.233
5	Non-bulbed	14.52	13.94	0.58	12.36		1.58		0.225	
6	Non-bulbed	14.52	13.94	0.58	10.26		3.69		0.237	

[a] $E_{sys} = E_{im,k} - PE$ and [b] $UPE = PE/d$

4 Limitations

Although the RPTM provides a controlled and repeatable setup, it cannot fully reproduce the complexity of in-situ rock masses. Concrete specimens lack the natural heterogeneity, jointing, and anisotropy of real rock, and laboratory confinement conditions do not capture true underground stress redistribution. As a result, laboratory findings should be interpreted cautiously, and future work should incorporate in-situ testing, calibrated numerical modelling, and alternative host media to improve field applicability.

In addition, despite the use of an anti-rotation system, some cable rotation occurred during impact testing. This movement may reduce the measured load-bearing capacity, as rotation interacts with axial loading, frictional behaviour, and cable deformation. Since the quantitative effect is difficult to isolate, future studies should compare free-rotation and restricted-rotation conditions to better understand, and account for its influence.

Also, a single impact energy level (14.52 kJ) was used to represent moderate to severe rockburst conditions. However, underground dynamic loads span a wide range, and a fixed energy level limits understanding of cable bolt behaviour under varying seismic intensities. Future research should apply multiple energy levels and velocities to capture the full spectrum of field conditions.

5 Conclusions

This study investigated the impact pull-out behaviour of high-strength 70-t SUMO cable bolts using a controlled laboratory setup combining the RPTM and a drophammer impact rig. The results showed that non-bulbed cable bolts demonstratedgreater total energy absorption and larger displacement capacity than bulbed cables, despite their lower peak resistance. This enhanced performance is attributed to their higher deformability and more distributed bond mobilisation, which favour gradual frictional slip and sustained energy dissipation under dynamic loading. In contrast, bulbed cables provided higher initial anchorage capacity, reflected in their higher UPE, making them more suited to conditions where immediate load resistance is required.

Overall, the findings indicate that non-bulbed cable bolts may offer superior performance in burst-prone, high-deformation environments, while bulbed bolts may be preferable in brittle, low-deformation rock masses requiring strong initial anchorage. These insights highlight the importance of selecting cable bolt types based on expected rockburst severity, geological conditions, and system-level support demands. Future research incorporating variable impact energies, broader encapsulation lengths, and in-situ testing will further improve the applicability of laboratory-based assessments for dynamic ground-support design.

References

Anzanpour, S, Aziz, N., Memcik, J., Mirzaghorbanali, A., Wallace, J., Marshall, T., & Khaleghparast, S. (2021). Introduction to new methods of static and dynamic pull testing of rock bolts and cable bolts. In N. Aziz & A. Mirzaghorbanali (Eds.), *Proceedings of the 2021 Resource Operators Conference* (pp. 210–217). University of Wollongong, NSW, Australia: University of Wollongong. https://ro.uow.edu.au/coal/811

Anzanpour, S, Aziz, N., Nemcik, J., Remennikov, A., Mirzaghorbanali, A., & Wallace, J. (2022). Static and dynamic tendon pull-out test research at the University of Wollongong. In N. Aziz & A. Mirzaghorbanali

(Eds.), *Proceedings of the 2022 Resource Operators Conference* (pp. 182–189). University of Wollongong, NSW, Australia: University of Wollongong. https://ro.uow.edu.au/coal/844

Anzanpour, Sina. (2022). *The Load Transfer Mechanism of Ground Tendons Subjected To Static and Dynamic Loading Conditions* (PhD). University of Wollongong, Wollongong, NSW, Australia. Retrieved from https://ro.uow.edu.au/theses1/1608/

Aziz, N., Yang, G., Khaleghparast, S., & Marshall, T. (2019). Development of double shear testing of tendons. In N. Aziz & B. Kininmonth (Eds.), *Proceedings of the 2019 Coal Operators' Conference* (pp. 150–161). University of Wollongong, NSW, Australia: University of Wollongong. https://ro.uow.edu.au/coal/732/

Blanco Martín, L., Tijani, M., Hadj-Hassen, F., & Noiret, A. (2013). Assessment of the bolt-grout interface behaviour of fully grouted rockbolts from laboratory experiments under axial loads. *International Journal of Rock Mechanics and Mining Sciences*, *63*, 50–61. https://doi.org/10.1016/j.ijrmms.2013.06.007

Cai, M. (2013). Principles of rock support in burst-prone ground. *Tunnelling and Underground Space Technology*, *36*, 46–56. https://doi.org/10.1016/j.tust.2013.02.003

Chen, J., Hagan, P. C., & Saydam, S. (2017). Sample diameter effect on bonding capacity of fully grouted cable bolts. *Tunnelling and Underground Space Technology*, *68*, 238–243. https://doi.org/10.1016/j.tust.2017.06.004

Chen, J., Hagan, P. C., & Saydam, S. (2018). A new laboratory short encapsulation pull test for investigating load transfer behavior of fully grouted cable bolts. *Geotechnical Testing Journal*, *41*(3), 435–447. https://doi.org/10.1520/GTJ20170139

Chen, Y., & Li, C. C. (2015). Influences of loading condition and rock strength to the performance of rock bolts. *Geotechnical Testing Journal*, *38*(2), 208–218. https://doi.org/10.1520/GTJ20140033

Galvin, J. M. (2016). Support and Reinforcement Systems. In *Ground Engineering - Principles and Practices for Underground Coal Mining* (pp. 211–269). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-25005-2_6

Goris, J. M., Martin, L. A., & Curtin, R. P. (1996). Shear behaviour of cable bolt supports in horizontal bedded deposits. *CIM Bulletin*, *89*(1001), 124–128. https://www.scopus.com/inward/record.uri?eid=2-s2.0-0030159490&partnerID=40&md5=e1b247ed1bdb7e4b637ca6b5ce0e9f62

Hadjigeorgiou, J., & Potvin, Y. (2011). A Critical Assessment of Dynamic Rock Reinforcement and Support Testing Facilities. *Rock Mechanics and Rock Engineering*, *44*(5), 565–578. https://doi.org/10.1007/s00603-011-0155-4

Hutchinson, D. J., & Diederichs, M. S. (1996). *Cablebolting in underground mines*. Richmond, B.C.: BiTech Publishers.

Hyett, A. J., Bawden, W. F., & Reichert, R. D. (1992). The effect of rock mass confinement on the bond strength of fully grouted cable bolts. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, *29*(5), 503–524. https://doi.org/10.1016/0148-9062(92)92634-O

Jodeiri Shokri, B., Mirzaghorbanali, A., Nourizadeh, H., McDougall, K., Karunasena, W., Aziz, N., et al. (2024). Axial Load Transfer Mechanism in Fully Grouted Rock Bolting System: A Systematic Review. *Applied Sciences*, *14*(12), 5232. https://doi.org/10.3390/app14125232

Kaewunruen, S. (2009). Experimental and numerical studies for evaluating dynamic behaviour of prestressed concrete sleepers subject to severe impact loading. https://ro.uow.edu.au/articles/thesis/Experimental_and_numerical_studies_for_evaluating_dynamic_behaviour_of_prestressed_concrete_sleepers_subject_to_severe_impact_loading/27830106

Khaleghparast, S., Aziz, N., Remennikov, A., & Anzanpour, S. (2023). An experimental study on shear behaviour of fully grouted rock bolt under static and dynamic loading conditions. *Tunnelling and Underground Space Technology*, *132*. https://doi.org/10.1016/j.tust.2022.104915

Klar, A., Nissim, O., & Elkayam, I. (2023). A hardening load transfer function for rock bolts and its calibration using distributed fiber optic sensing. *Journal of Rock Mechanics and Geotechnical Engineering*, *15*(11), 2816–2830. https://doi.org/10.1016/j.jrmge.2022.12.027

Knox, G., & Berghorst, A. (2018). Increased agility for the research and development of dynamic roof support products. In *Rock Dynamics and Applications 3* (pp. 373–378). CRC Press.

Li, C. C., Hadjigeorgiou, J., Mikula, P., Knox, G., Darlington, B., Royer, R., et al. (2021). Performance of identical rockbolts tested on four dynamic testing rigs employing the direct impact method. *Journal of Rock Mechanics and Geotechnical Engineering*, *13*(4), 745–754. https://doi.org/10.1016/j.jrmge.2021.01.003

Li, C. C., Mikula, P., Hadjigeorgiou, J., Simser, B., He, M., Canbulat, I., & Joughin, W. (2025). ISRM Suggested Method for Determining the Properties of Rock Bolt Assemblies by Mass Freefall Impact Testing in the Laboratory. *Rock Mechanics and Rock Engineering*, *58*(1), 165–179. https://doi.org/10.1007/s00603-024-04159-z

Moosavi, M., Bawden, W. F., & Hyett, A. J. (2002). Mechanism of bond failure and load distribution along fully grouted cable-bolts. *Institution of Mining and Metallurgy. Transactions. Section A: Mining Technology*, *111*(JAN/APR), A1–A11. https://doi.org/10.1179/mnt.2002.111.1.1

Mottahedi, A., Aziz, N., Mirzaghorbanali, A., Remennikov, A., & Anzanpour, S. (2024). Aspects of testing tendon supports for strength, effective installation, and performance in different ground formation. In *Proceedings of the 2024 Coal Operators' Conference* (pp. 146–169). University of Wollongong, NSW, Australia: University of Wollongong. https://ro.uow.edu.au/coal/914/

Mottahedi, A., Aziz, N., Remennikov, A., Mirzaghorbanali, A., & Marston, K. (2024). Impact Loading of Tendon Reinforcement Systems Used for Ground Control: A Critical Literature Review. *Archives of Mining Sciences*, 711–743. https://doi.org/10.24425/ams.2024.152581

Mottahedi, A., Aziz, N., Remennikov, A., Mirzaghorbanali, A., & Marston, K. (2025). A Critical Review on Development of Laboratory Testing Technologies of Tendons Applied to Stabilize Underground Structures. *Rock Mechanics and Rock Engineering*. https://doi.org/10.1007/s00603-025-04518-4

Player, J., Thompson, A., & Villaescusa, E. (2008). Dynamic testing of reinforcement systems (pp. 597–622). Presented at the 6th International Symposium on Ground Support in Mining and Civil Engineering Construction.

Pytlik, A. (2016). A methodology for laboratory testing of rockbolts used in underground mines under dynamic loading conditions. *Journal of the Southern African Institute of Mining and Metallurgy*, *116*(7), 1101–1110. https://doi.org/10.17159/2411-9717/2016/v116n12a2

Rastegarmanesh, A., Mirzaghorbanali, A., McDougall, K., Aziz, N., Anzanpour, S., Nourizadeh, H., & Moosavi, M. (2022). Axial Performance of Cementitious Grouted Cable Bolts Under Rotation Constraint Scenarios. *Rock Mechanics and Rock Engineering*, *55*(9), 5773–5788. https://doi.org/10.1007/s00603-022-02950-4

St-Pierre, L., Hassani, F. P., Radziszewski, P. H., & Ouellet, J. (2009). Development of a dynamic model for a cone bolt. *International Journal of Rock Mechanics and Mining Sciences*, *46*(1), 107–114. https://doi.org/10.1016/j.ijrmms.2008.05.005

Thenevin, I., Blanco-Martín, L., Hadj-Hassen, F., Schleifer, J., Lubosik, Z., & Wrana, A. (2017). Laboratory pull-out tests on fully grouted rock bolts and cable bolts: Results and lessons learned. *Journal of Rock Mechanics and Geotechnical Engineering*, *9*(5), 843–855. https://doi.org/10.1016/j.jrmge.2017.04.005

Thompson, A. G., & Villaescusa, E. (2014). Case Studies of Rock Reinforcement Components and Systems Testing. *Rock Mechanics and Rock Engineering*, *47*(5), 1589–1602. https://doi.org/10.1007/s00603-014-0583-z

Windsor, C. R. (1997). Rock reinforcement systems. *International Journal of Rock Mechanics and Mining Sciences*, *34*(6), 919–951. https://doi.org/10.1016/S1365-1609(97)80004-4

Yan, C. (1992). *Bond between reinforcing bars and concrete under impact loading* (PhD). University of British Columbia, Canada. Retrieved from https://doi.library.ubc.ca/10.14288/1.0050492