Ground Support 2023 – J Wesseloo (ed.)
© 2023 Australian Centre for Geomechanics, Perth, ISBN 978-0-6450938-5-8
doi:10.36487/ACG_repo/2325_27

A laboratory-scale dynamic test of load distribution elements at Rancagua testing facility

M Hinojosa *Universidad de Chile, Chile*

JA Vallejos *Universidad de Chile, Chile*

E Marambio *Universidad de Chile, Chile*

K Suzuki *Universidad de Chile, Chile*

G Fischer *Geobrugg, Chile*

G von Rickenbach *Geobrugg, Chile*

Abstract

Ground support systems must provide safe and effective designs for underground excavations under high-stress conditions. These systems must be capable of resisting dynamic impacts and yielding during the loading process. In this context, dynamic testing of the reinforcement and load distribution (retention) elements that compose the ground support system are required. In the last decade, Geobrugg has been working on the improvement of ground support systems, by testing them in a large-scale impact test facility located at Walenstadt, Switzerland. During the last years, this innovative facility has been used to test several configurations of ground support systems. The results of those tests have improved the understanding of the behaviour of ground support systems under dynamic loads. Inspired by those results, Geobrugg has built a new testing facility for load distribution elements (in its first stage of implementation: calibration) at Rancagua, Chile. The facility is composed of a loading mass that is released in freefall onto a test sample of a load distribution element (mesh). In this paper, the arrangement, measurement, result, and analysis of a preliminary laboratory-scale dynamic test for a load distribution element carried out in this new facility is presented.

Keywords: *ground support capacity, high-stress conditions, rockburst, dynamic testing, underground excavations*

1 Introduction

Mining conditions are becoming increasingly difficult as access to ore deposits getting more complex due to its deepness, and the high-stress environments cause many challenges to continued resource exploitation. One of the main issues is related to the occurrence of seismic events and the associated rockburst phenomenon, that leads to operational and safety problems.

The amount of energy released during seismic events requires mitigation by ground support systems (reinforcement plus retainment systems) that are able to control large displacements and high strain rates. These dynamic systems are composed of reinforcement elements (e.g. rockbolts, cablebolts) able to absorb a large amount of energy and surface support (e.g. mesh) that provide containment to the rock mass. Recent work developed by Kaiser & Moss (2022) provides a comprehensive understanding on how these concepts are implemented to design effective support in high-stress environments.

The design of ground support systems requires research into the behaviour of each support element under dynamic loading. Previously, several tests have been carried out to individual bolts, cables, and mesh, but in practice, all components must fit and work together (Brändle et al. 2021, 2020, 2017; Brändle & Luis Fonseca 2019; Bucher et al. 2013; Cala et al. 2013; Muñoz et al. 2017; Roth et al. 2014). Thus, tests on ground support elements/sytems are relevant to assess and increase their performance and offer industry improved designs. Some institutions in Canada, South Africa and Australia have been testing reinforcement and support elements under dynamic loads. However, the facilities that can test the combinations (reinforcement or ground support systems) of rockbolts, cablebolts, and mesh as a system are limited.

Over the years, large-scale tests have been conducted in the rockfall testing facility at Walenstadt, Switzerland, that have contributed to improving knowledge as well as trying different types of test configurations and sample configurations (Brändle et al. 2021, 2020, 2017; Brändle & Luis Fonseca 2019; Bucher et al. 2013; Cala et al. 2013; Muñoz et al. 2017; Roth et al. 2014). Since 2018, Geobrugg and the Advanced Mining Technology Center at the University of Chile have been collaborating to improve the performance of ground support systems under dynamic loads (rockburst prone), considering large-scale tests, back-analysis, numerical modelling, and design. Inspired by the work done previously, Geobrugg has built a new testing facility for load distribution elements (in its first stage of implementation and calibration and contemplating a second stage of validation and third stage of operation) at Rancagua, Chile. This paper presents the testing arrangement, measuring system, results, and preliminary analysis of a laboratory-scale dynamic test performed on a load distribution element in 2022.

Henceforth, surface retention elements will be referred to as load distribution elements. This change is due to the main contribution of these elements, i.e. the load distribution to the reinforcement elements, which is not recognised by using common terminology.

2 Dynamic laboratory tests

During the last 30 years, significant effort has been made to obtain and quantify the dynamic response of a complete ground support system to provide solutions for rockburst control in high-stress mining environments. Testing and measurement of dynamic response of isolated components that compose the ground support system, such as rockbolts, cablebolts or load distribution elements (mesh or mesh plus shotcrete), have been conducted by a number of institutions including CanMet-MMSL, WASM and New Concept Mining (Crompton et al. 2018; Kaiser et al. 1996; Player et al. 2004). In addition, simplified load distribution elements (retention) and ground support systems have been tested by projects such as SIMRAC/SRK or GRC (Cai & Kaiser 2018; Kaiser et al. 1996; Ortlepp 2001; Ortlepp & Stacey 1998, 1997) using the impact principle and the momentum transfer concept (WASM). Figures 1a, b and c illustrate the dynamic facilities of CanMet-MMSL, WASM and New Concept Mining, respectively. Figures 2a and b show the SIMRAC/SRK apparatus and the GRC apparatus, respectively. Table 1 illustrates a summary of the facilities that are able to test configurations of ground support or load distribution elements (retention) systems.

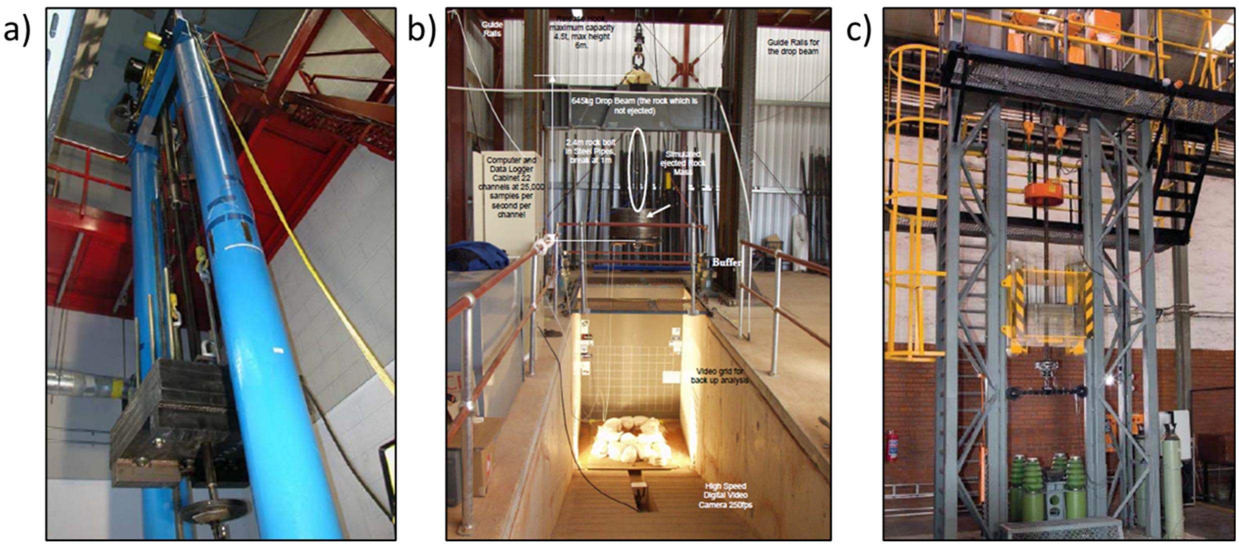


Figure 1 **(a) CanMet-MMSL facility (Cai & Kaiser 2018); (b) WASM facility (Player et al. 2004); (c) New Concept Mining facility (Crompton et al. 2018)**

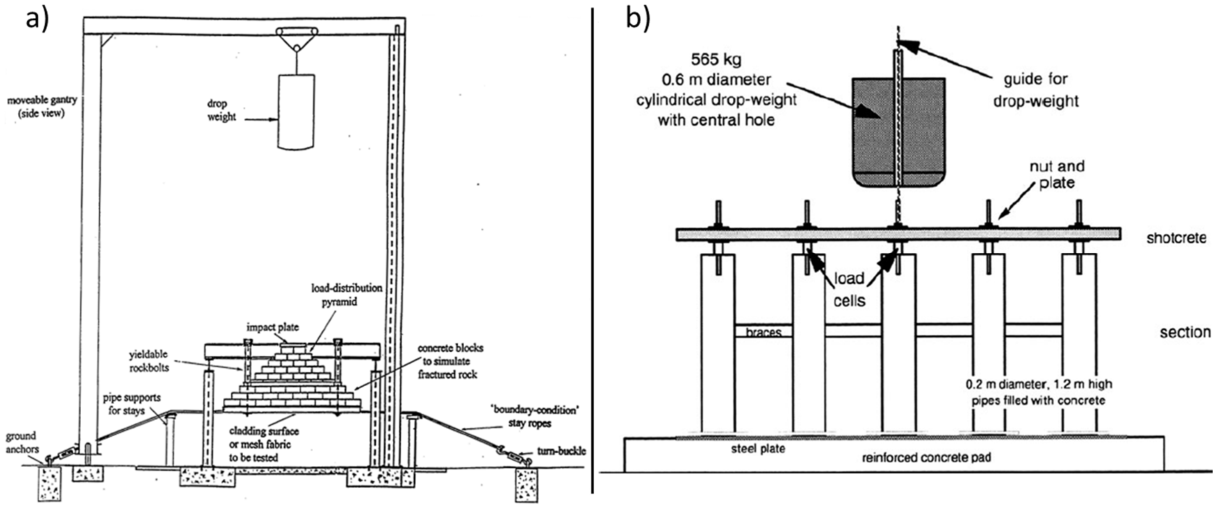


Figure 2 (a) SIMRAC/SRK apparatus (Ortlepp & Stacey 1997); (b) GRC apparatus (Kaiser et al. 1996)

Table 1 Summary of the facilities that test ground support or retainment systems (modified from Hadjigeorgiou & Potvin 2011)

Facility	Configuration /element tested	Loading mass (kg)	Drop height (m)	Impact velocity (m/s)	Impact energy (kJ)	Test area	Measurement instruments
WASM dynamic facility	Reinforcement elements and load distribution elements (surface support)	Up to 4,500	Up to 6	Up to 10	Up to 225	1 × 1 m	High-speed cameras, photographs, load cells, accelerometers and reference tapes
SRK drop weight test	Support system	Up to 2,700	3.3	8.1	Up to 80	2 × 2 m	High-speed cameras, photographs and reference tapes
SIMRAC dynamic testing rig	Support system	1,000					Telescopic bars and geophones
SIMRAC dynamic stope test	Stope support system	10,000	3	7.7	Up to 294	3 × 3 m	High-speed cameras, photographs and reference tapes
GRC support element test	Reinforced shotcrete	565	4	8.8	22		Load cells and photographs
Geobrugg Walenstandt test	Support system	Up to 9,640	5	10	Up to 500	3.6 × 3.6 m	High-speed cameras, photographs, accelerometers, load cells and reference tapes
Geobrugg Rancagua test	Load distribution elements (first stage of implementation)	1,009 currently	Up to 2.5	Up to 7	24	1.8 × 2 m	High-speed cameras, photographs, accelerometers, load cells and reference tapes

The dynamic testing of load distribution elements and ground support systems have been limited due to the difficulty in representing the in situ conditions of a seismic event, quantifying the damage, measuring, and validating the response of each element and the interaction among them. Geobrugg has been performing real-scale dynamic tests on load distribution elements and ground support systems using the impact principle (drop weight test) since the research program started by Cala et al. (2013) through its facility at Walenstadt, Switzerland. The Walenstadt facility has been improved over the years to better represent and understand the damage process that occurs to a complete ground support system during a dynamic impact that represents the in situ conditions of a seismic event (Brändle et al. 2021, 2020, 2017; Brändle & Luis Fonseca 2019; Bucher et al. 2013; Cala et al. 2013; Muñoz et al. 2017; Roth et al. 2014).

Figure 3a illustrates the dynamic testing facility at Walenstadt used in a double impact test (Brändle et al. 2020).

Inspired by the results obtained by the research program performed at Walenstadt, Geobrugg has built a new testing facility for load distribution elements (in its first stage of implementation) at Rancagua, Chile. The facility is composed of a loading mass that is released in freefall onto a square test sample of a load distribution element (mesh). A square pattern of rockbolts (four threadbars) is attached to the load distribution element which serve as boundary condition for the sample tested.

Figures 3b and 3c illustrate the current facility at Rancagua, Chile.

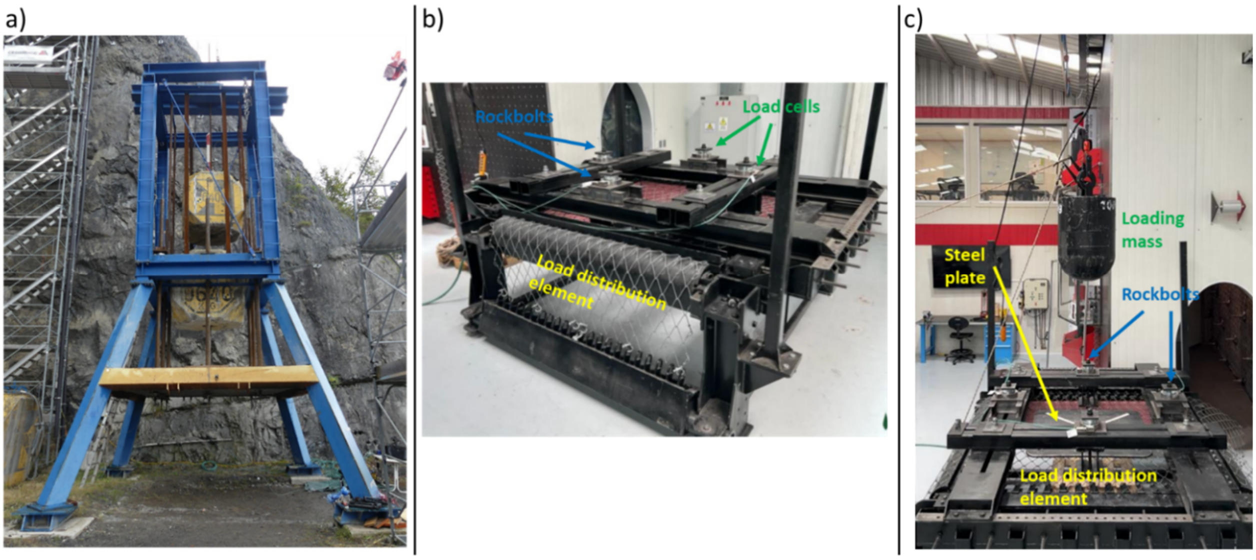


Figure 3 (a) Dynamic test facility at Walenstadt (double impact test); (b) Dynamic test facility at Rancagua: isometric view; (c) Dynamic test facility at Rancagua: front view

2.1 Test arrangement

The testing setup to perform and record the dynamic tests comprises the following components:

- A loading mass (Figure 3b) of 1,009 kg released in a freefall from a height of 1.30 m. The mass leads to a nominal input energy of 12.8 kJ.
- A steel impact plate (Figure 3b and shown later in Figure 6d) of 1 × 1 m (20 mm of thickness) located in the centre of the sample (mesh) and between the sample and the loading mass. In the test, the steel plate is directly impacted by the loading mass improving the load distribution on the sample.

2.2 Ground support system

The test setup was built to be as simple as possible to evaluate the performance of the load distribution elements, considering:

- A load distribution element (sample to be tested) with a test area of 2 × 1.8 m composed by a Geobrugg chain link mesh made of high-tensile steel wire with a diameter of 4 mm (MINAX 80/4).

Figure 4 illustrates a scheme of the MINAX 80/4 high-tensile mesh and Table 2 shows the properties of the MINAX 80/4 high-tensile mesh.

- A reinforcement system composed by four threadbars (rockbolts) with a diameter of 22 mm, a length of 0.6 m and made of A630 steel grade (ultimate strength 630 MPa; yielding strength 420 MPa). The rockbolts were located in a square pattern of 1 × 1 m. Each rockbolt was attached to the retainment system using a plate (150 × 150 × 6 mm) and a nut. Note that the main reason to include this rockbolt pattern is to pin the mesh as it is typically installed in situ. Figure 5 illustrates the test configuration with each rockbolt identified (ID number) from a lower view of the load distribution system.

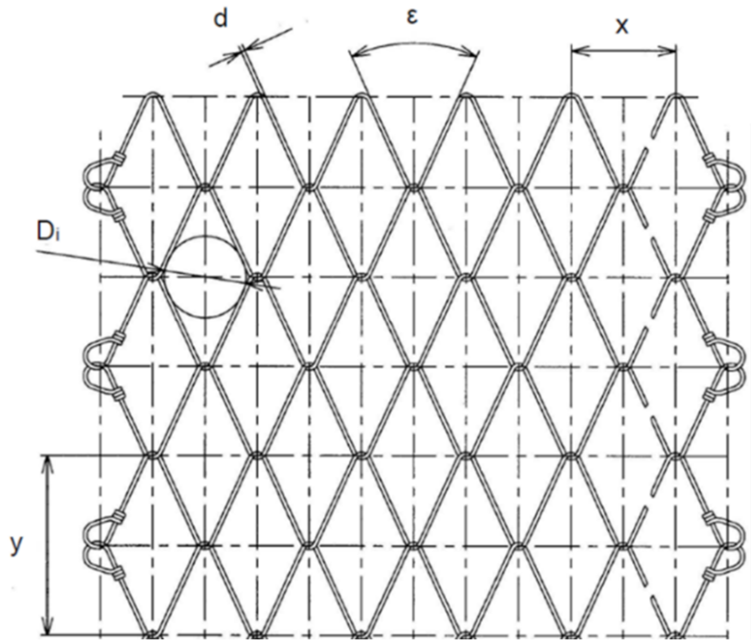


Figure 4 Diamond-shaped high-tensile mesh (Geobrugg's MINAX 80/4): plan view scheme

Table 2 Diamond-shaped high-tensile mesh (Geobrugg's MINAX 80/4): properties

Properties	**MINAX 80/4**
Mesh width (D_i)	80 (mm)
Diagonal ($x \cdot y$)	102 × 177 (mm)
Wire diameter (d)	4 (mm)
Wire strength (f_i)	1,770 (MPa)
Tensile resistance of a wire (z_w)	22 (kN)
Tensile strength of mesh longitudinal (z_l)	190 (kN/m)
Weight per m^2	2.6 (kg/m^2)

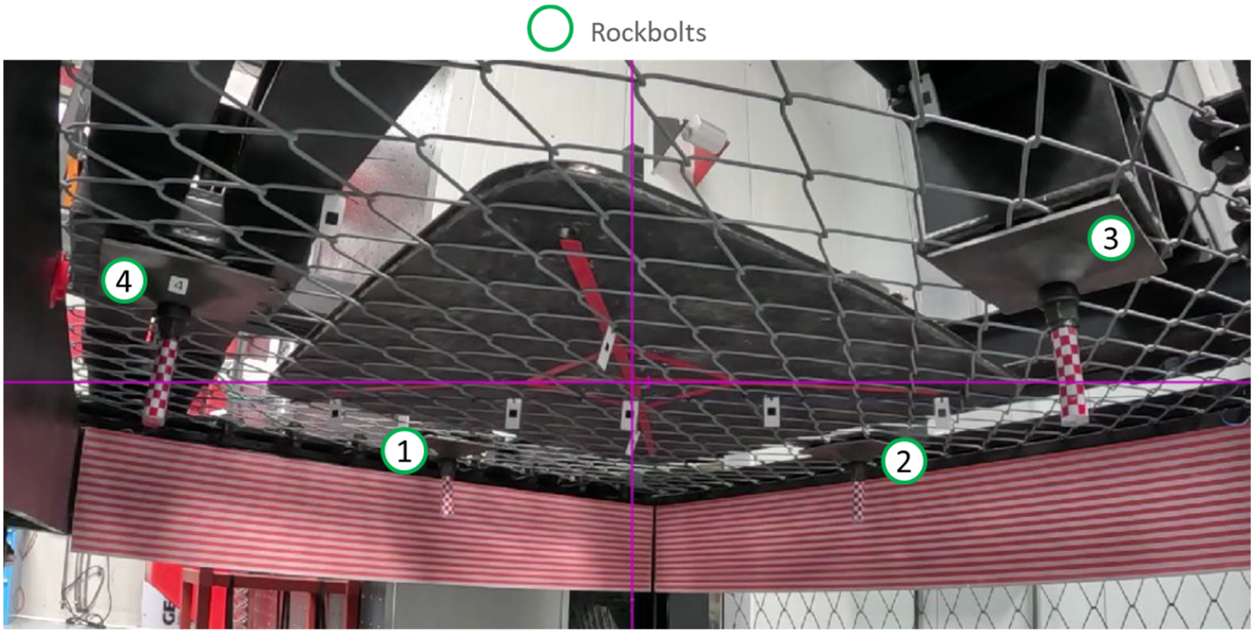


Figure 5 Lower view of the test configuration with each rockbolt identified (ID number) and the coordinate reference system

2.3 Measuring system

The measuring system used for the test included:

- Three high-speed cameras: two cameras (in perpendicular directions) pointing to the lower area (internal face) of the load distribution system as shown in Figure 5, and a third camera pointing to the whole test (upper area of the load distribution system and loading mass), as shown in Figure 3c.
- One accelerometer was located at the top of the loading mass. Figure 6a shows the accelerometer.
- Four load cells were used, one per rockbolt. They were located at the collar (external zone) of the rockbolts. Figure 6b illustrates the load cells used in the test.

Reference tapes were located in each rockbolt, reference points were located in the load distribution element, and reference rulers were used to support the measurement of the high-speed cameras. Figure 6c shows an example of the reference tapes located in each rockbolt, reference points (each square represents an area of 1 cm^2), and a ruler located at the back of the apparatus for the test.

A coordinate reference system for the test located in the middle of the load distribution system (origin) to support the measurement of the dynamic displacement as was shown in Figure 5.

Table 3 illustrates the properties of the measuring instruments.

Table 3 Properties of the measuring instruments

Measuring instrument	Properties
High-speed cameras	Recording frequency of 240 images per second
Accelerometer	2,000 g triaxial accelerometers with a frequency of 20 kHz
Load cells	750 kN force sensors with a frequency of 4.8 kHz
Reference tapes and rulers	Tapes with a square pattern of 1 cm^2 and rulers

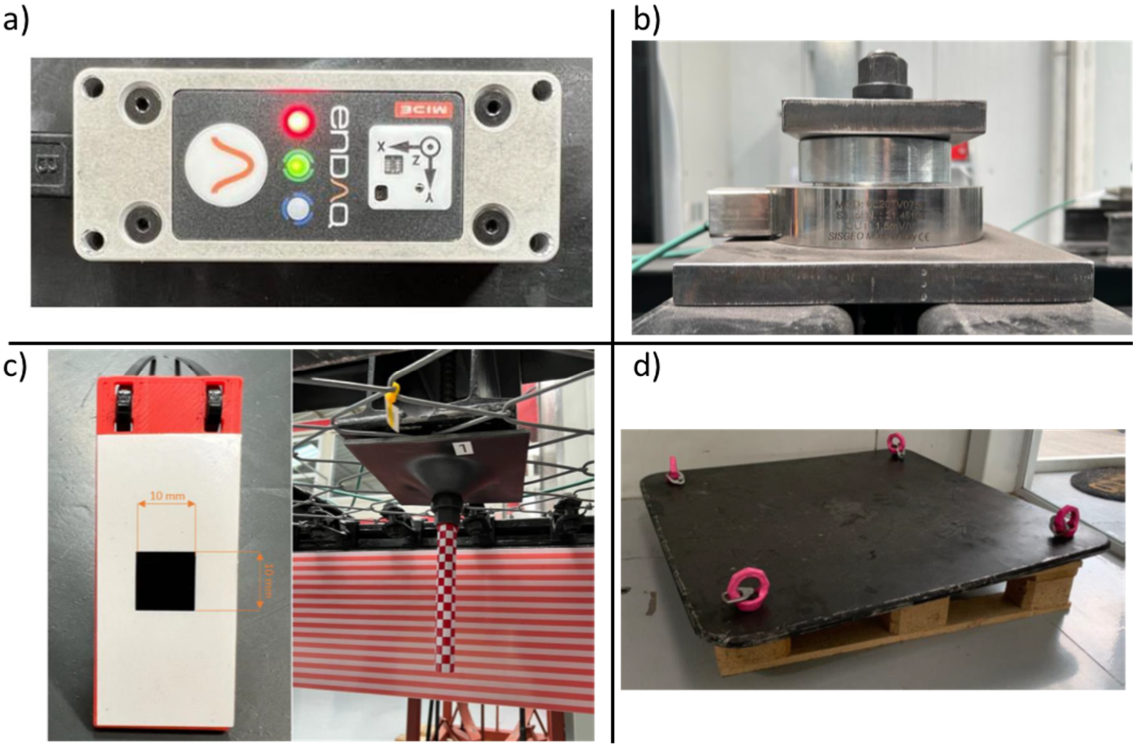


Figure 6 (a) Accelerometer located at the loading mass; (b) Load cells located at the anchor of rockbolt; (c) Example of reference tapes located at rockbolts, reference points located in the load distribution element, and ruler located at the back of the apparatus; (d) Steel plate for load distribution

3 Test results

The behaviour of the test was recorded and analysed using the information collected by the measuring system.

In the case of the test, the impact loading mass was arrested to an equilibrium state by the tested system; however, the load distribution element (element of interest) was led to failure (local rupture). The impact of the loading mass caused that one plate of the rockbolts (rockbolt 2) to cut the load distribution element (mesh) leading to local rupture. The damaged area located at the edge of the rockbolt plate (final state) is illustrated in Figure 7.

Figure 8 illustrates the dynamic process recorded by the high-speed cameras at different instants of time for the test.

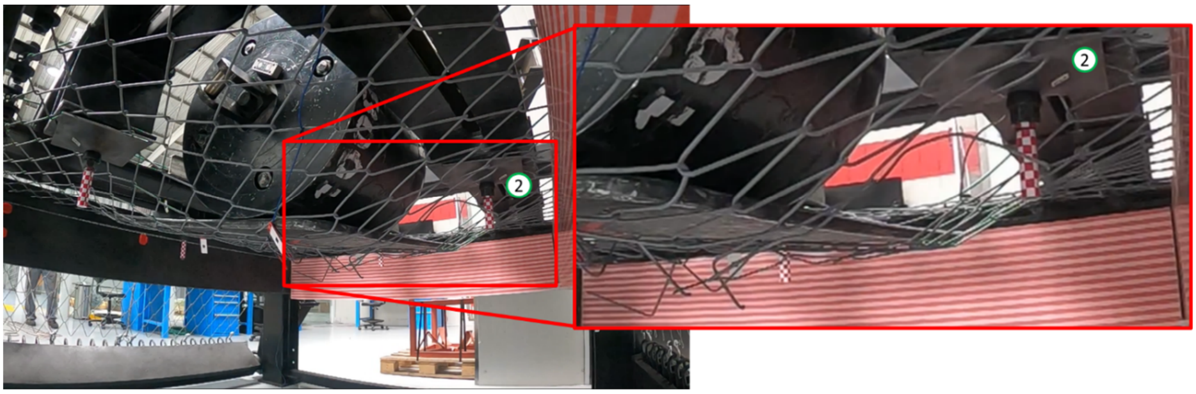


Figure 7 Final dynamic state of the load distribution system tested with damaged area (edge of Rockbolt 2 zoomed)

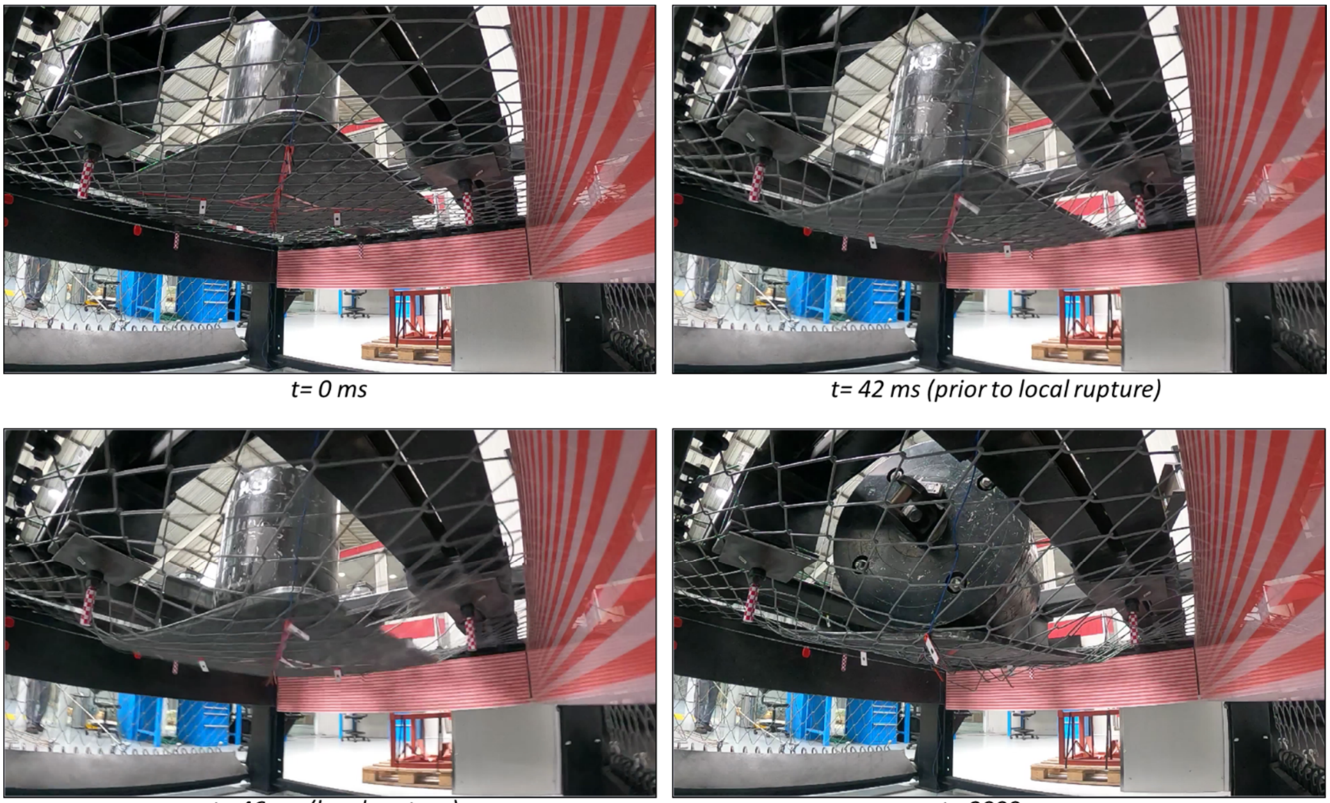


Figure 8 Dynamic loading process of the test recorded by the high-speed cameras as a function of time

3.1 Analysis

As mentioned previously, the nominal input energy of the test performed was 12.8 kJ. In this case, the local rupture of the load distribution element tested occurred at the time of 46 ms, as shown in the acceleration record of Figure 9.

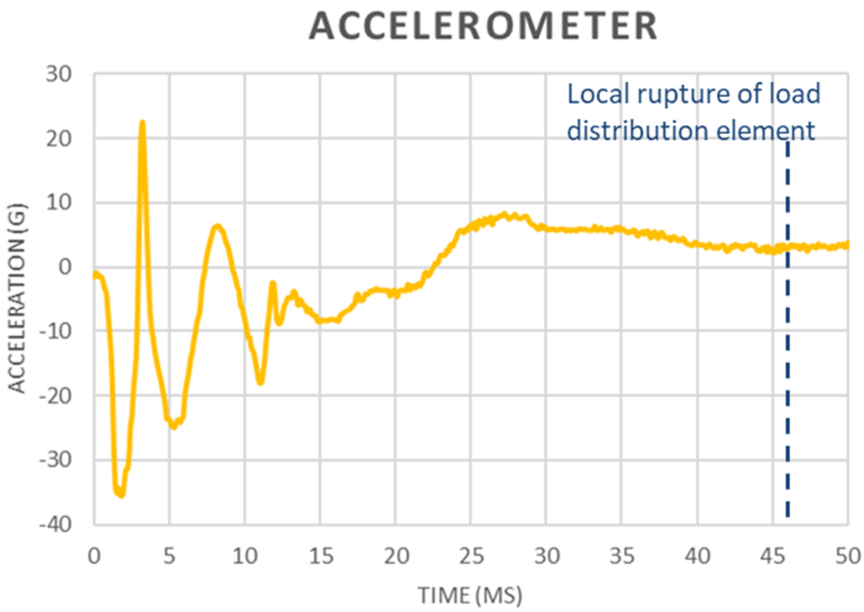


Figure 9 Acceleration of the loading mass as a function of time. Dotted line illustrates the point of local rupture of the load distribution element (mesh)

For the test, the load capacity of the rockbolts during the impact of the loading mass was recorded by the load cells. The records of the load cells located at the anchor of the rockbolts are shown in Figure 10. Note that the local rupture of the load distribution element can be visualised by the sudden drop in load in Cell 2 a few milliseconds before the wire steel was cut by the plate.

The maximum measured capacities of the rockbolts in the test are illustrated in Table 4.

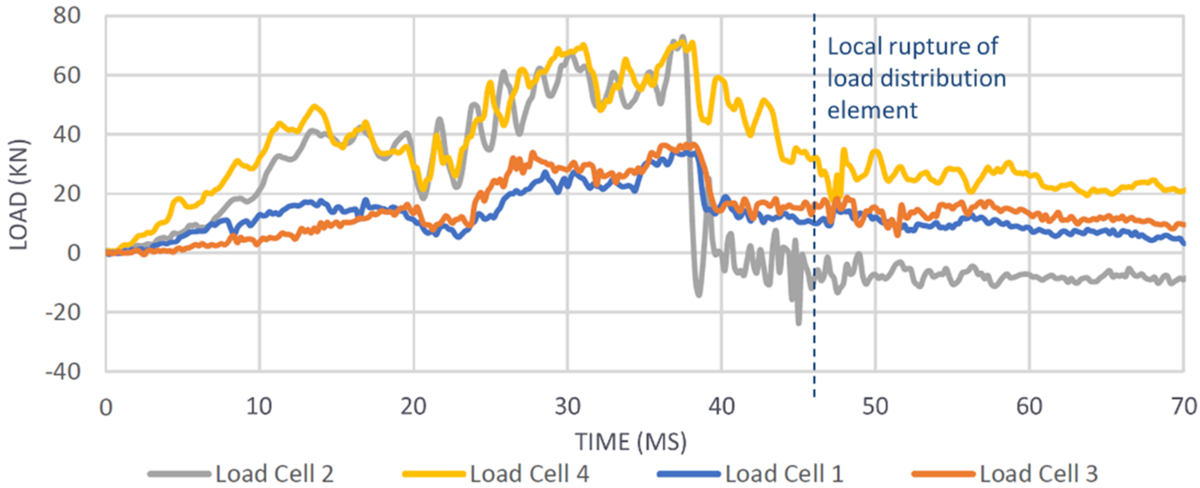


Figure 10 Measured load capacity on the four rockbolts by the load cells through the dynamic test. Note that the dotted line shows the point of local rupture of the load distribution element (mesh)

Table 4 Maximum load capacity measured by the load cells at the rockbolts

Rockbolt ID	Max. force at collar (kN)
1	34
2	73
3	36
4	71

A back-analysis was performed for the test after measuring load capacities (accelerometer and load cells) and movement (high-speed cameras). Therefore, the load response and the energy response for the load distribution element tested were determined as illustrated in Figures 11a and b, respectively. In this sense, the maximum load response and energy response for the load distribution tested were 247 kN and 10.2 kJ, respectively at the time of the local rupture.

For the calculation, a match is performed between the accelerometer (loading mass) and the movement (high-speed cameras), assuming an inelastic collision between the loading mass and the load distribution element. Then, the load–displacement response can be obtained. Finally, the energy–displacement response is obtained by simple integration.

Note that Figures 11a and b also illustrate the previous response of the load distribution element (Geobrugg's MINAX 80/4) for comparison with the new test result.

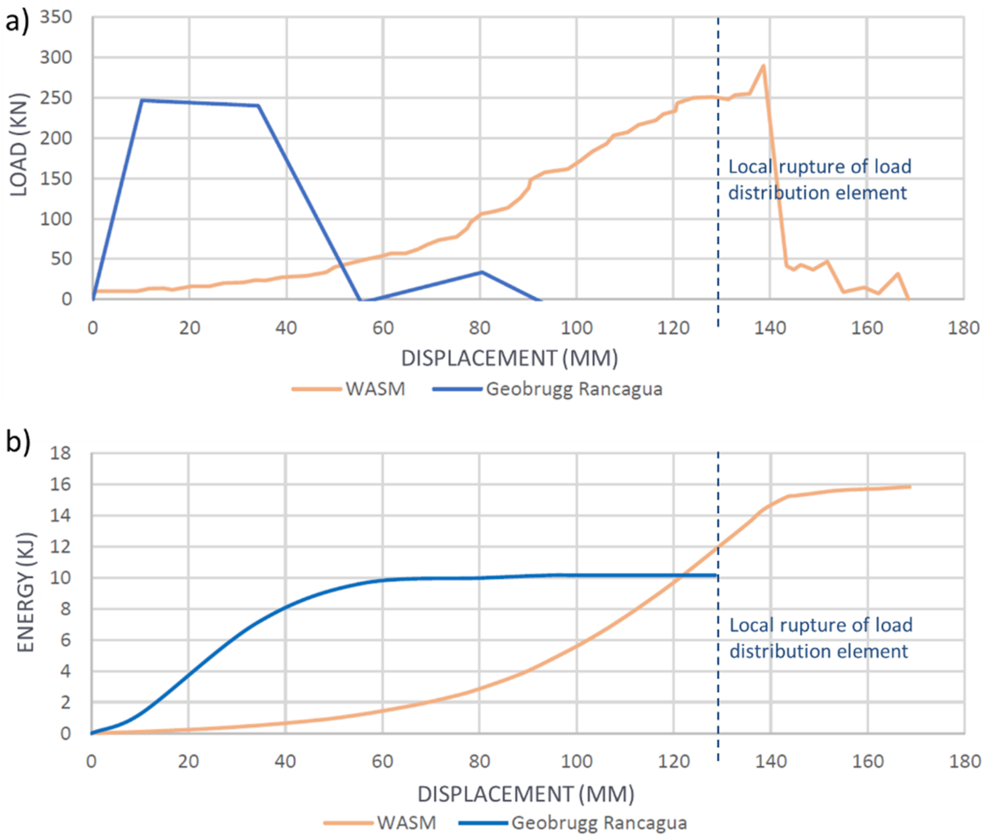
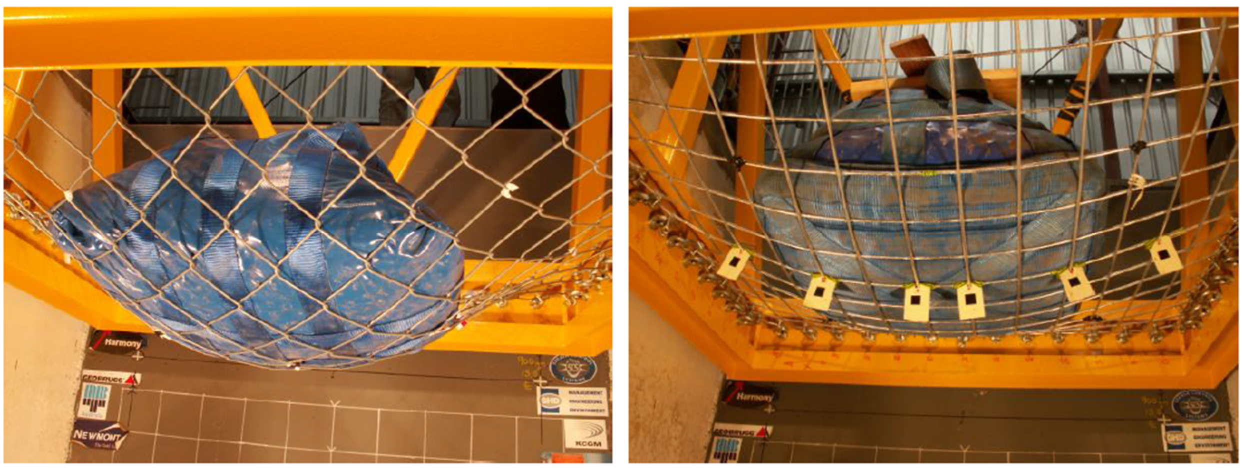


Figure 11 Back-analysis for the test and comparison with previous response at WASM (MINAX 80/4). (a) Load–displacement response; (b) Energy–displacement response

An explanation on the differences in the responses illustrated in Figure 11 is due to the stiffness and boundary conditions applied to the load distribution element to be tested (arrangement) in both tests. In WASM, the load distribution element (mesh) is not tensioned when it is installed in the frame. Also, the load distribution element is loaded prior to testing, adding more deformation and some tension to the element. Whereas, at the Rancagua facility, the load distribution element to be tested is tightened (tensioned) to the frame prior to testing as it is installed in situ and then fastened using the rockbolt pattern. Therefore, the Rancagua arrangement has a higher stiffness compared to the WASM test and includes interaction with bolts and plates. Figure 12 illustrates the arrangement at WASM (Villaescusa 2009).



(a) (b)

Figure 12 Arrangement at WASM. (a) Chain link mesh; (b) Welded mesh (Villaescusa 2009)

Regarding the energy, in theory, the linear energy capacity (E_c) of the ground support system (reinforcement system plus load distribution system) can be estimated according to Kaiser et al. (1996) and Muñoz (2019) by Equation 1. In this case, E_r is the energy absorption capacity of threadbars (A630 – 22 mm diameter, assumed to be equal to A440 – 22 mm diameter) in a square pattern of 1 × 1m, and $E_m^{80/4}$ is the energy absorption capacity of the load distribution element (chain link mesh G80/4 according to Geobrugg). Therefore, the theorical energy capacity of the ground support system is 34 kJ/m^2. Cai & Kaiser (2018) provide reinforcement and load distribution element datasheets where some of these values are illustrated.

$$E_c = E_r + E_m^{80/4} \tag{1}$$

$$E_c = 22[kJ/m^2] + 12[kJ/m^2] = 34\ [kJ/m^2]$$

However, after measuring the test results and focusing on the response of the load distribution element (chain link mesh G80/4), a new analysis was performed. Through an energy balance, the input energy (E_i) can be equated to the energy responses measured in the test for each element, as shown in Equation 2. Note that E_m^r, $E_{m-m}^{80/4}$, and E_l represent the energy measured for the rockbolts, load distribution element (mesh), and energy losses, respectively. In addition, an impact area of 1 m^2 is considered for the test (area among rockbolts – note that it is equal to the steel impact plate area), which leads to a normalised energy as shown in Equation 2.

$$E_i = E_m^r + E_{m-m}^{80/4} \ + E_l \tag{2}$$

$$12.8[kJ/m^2] = 0.2[kJ/m^2] + 10.2[kJ/m^2] + 2.4[kJ/m^2]$$

The difference evidenced between Equations 1 and 2 can be explained mainly by the responses of the rockbolts. Theoretically, when looking at Equation 1, each rockbolt can have an energy capacity of 22 kJ/m^2; however, this capacity is only achieved by considering the rockbolt as an isolated element and loading it to the point of failure. The focus of the dynamic test performed is not to measure the energy capacity of the rockbolts. Thus, the rockbolts are intended to be loaded in a minimum range (elastic range) while serving at the same time as boundary condition for the real focus of the test, the load distribution element. Note that in this case the rockbolts only absorb 0.2 kJ/m^2 (measured by back-analysis in Equation 2).

Therefore, analysing the value of the load distribution element illustrated in Equations 1 and 2, it can be seen that their energy response estimations are very similar (12 kJ/m^2 and 10.2 kJ/m^2, repectively). In this context, the value exposed in Equation 1 is an energy estimation after a test perfomed at WASM facility for the isolated element (according to Geobrugg), whereas the value exposed in Equation 2 is the one measured in this test. In addition, note that in Equation 2, the energy losses are calculated indirectly by the energy balance.

Based on the above, the theoretical energy capacity of the ground support system (reinforcement plus load distribution element) is greater than the input energy of the test. However, the test is focused on the behaviour of the load distribution element. In this sense, and neglecting the influence of the rockbolts, the performance of the load distribution element was acceptable, bringing the loading mass to an equilibrium state even after the local rupture of the element.

The local rupture of the loaddistribution element in this case is associated with the thrust of the same element against the rockbolts (boundary condition), which caused the plates to cut the mesh at one of the edges (rockbolt 2). As the loading mass was retained and the damage occurred around one plate, thus, it is reasonable to conclude that the load distribution element could have absorbed more energy. In this context, and despite the falocal ruptue, the previous estimation of the energy response for the load distribution element tested (12 kJ/m^2 from WASM facility) agrees with that obtained in this test (10.2 kJ/m^2) before failure (local rupture).

The aim of this study is to improve the understanding of the interaction between different elements that conform the groud support systems, in the different requirements and scenarios contributing to the research and development of rock mass stability. However, in order to enhance our understanding of the energy transfer process and the dynamic response of load distribution elements and ground support systems, further developments are being undertaken at the Rancagua testing facility in Chile and also at the Walenstadt testing facility in Switzerland.

4 Conclusions

Laboratory-scale dynamic tests contribute to the knowledge, standardisation, and certification of different configurations of ground support systems. The test arrangement on this occasion allowed the authors to study the damage process on a load distribution element in a recreated dynamic impact under laboratory-scale conditions.

The results of the test performed quantified the potential energy absorption capacity of the load distribution element tested under dynamic load (focus of the test). In the case of the test performed, the load distribution element could absorb almost all of the total input energy, stopping the loading mass, but failing locally around the plate in the process. The reinforcement system absorbed a minimum part of the input energy, without plastic deformation (elastic range without fail). The load distribution system begins to work after the impact, bringing the loading mass to an equilibrium state, deforming and failing in the process. In this sense, the boundary condition given by the rockbolts (plates) led to the cut of the load distribution element (mesh).

Considering the results, the performance of the load distribution element could be measured in this test. The differences observed in the responses of both tests (WASM and Rancagua) are mainly associated with the stiffness and boundary conditions of the arrangements to be tested, including the interaction with bolts and plates in the Rancagua test. In addition, the measurement system was integrated with the appropriate tools to measure the load capacity, displacement and absorbed energy in the processes. However, there are still some aspects that need to be reconsidered in order to proceed to a validation stage (second stage).

Further studies could be done in the same facility combinig different setups of the systems. The stiffness, shape and size of the plates could also play an important rol in the interaction of the elements and the mode of failure of the system.

In this paper, a preliminary analysis of the observed behaviour and response of the dynamic loading process for load distribution elements was presented. The test revealed that the current dynamic test facility at Rancagua, Chile, which is in its first stage of implementation and calibration, has the potential to be an invaluable tool to test, standardise, certify, enhance, and contribute to the understanding of the behaviour of load distribution elements (and ground support systems in the future) under laboratory-scale dynamic loading. This knowledge also contributes to controlling seismic events and rockburst phenomenon in excavations under high-stress conditions. In this context, a more detailed analysis is under development to obtain an enhanced understanding of load distribution elements and ground support systems.

Acknowledgement

The authors acknowledge Geobrugg's support in allowing use of the dynamic testing facility at Rancagua, Chile, performing the tests, and actively participating during the analysis of data, together with producing this paper. The authors acknowledge the support from the basal CONICYT Project AFB220002 of the Advanced Mining Technology Center at the University of Chile. The opinions expressed in this paper are those of the authors and do not necessarily represent the views of any other individual or organisation.

References

Brändle, R, Luis Fonseca, R, von Rickenbach, G, Fischer, G, Vallejos, J, Marambio, E, … & Cuello, D 2021, 'Single impact dynamic test of a ground support system with a high-tensile steel wire mesh at the Walenstadt testing facility', *Proceedings of the Tenth International Conference on Rockburst and Seimicity in Mines*, Society for Mining, Metallurgy & Exploration, Englewood.

Brändle, R, Luis Fonseca, R, von Rickenbach, G, Fischer, G, Vallejos, J, Marambio, E, … & Castro, D 2020, 'Double impact dynamic test of a ground support system at the Walenstadt testing facility', in R Castro, F Báez & K Suzuki (eds), *MassMin 2020: Proceedings of the Eighth International Conference & Exhibition on Mass Mining,* University of Chile, Santiago.

Brändle, R & Luis Fonseca, R 2019, 'Dynamic testing of surface support systems', in J Hadjigeorgiou & M Hudyma (eds), *Ground Support 2019: Proceedings of the Ninth International Symposium on Ground Support in Mining and Underground Construction*, Australian Centre for Geomechanics, Perth, pp. 243250, https://doi.org/10.36487/ACG_rep/1925_15_Brandle

Brändle, R, Rorem, E, Luis, R & Fischer, G 2017, 'Full-scale dynamic tests of a ground support system using high-tensile strength chain-link mesh in El Teniente mine, Chile', in M Hudyma & Y Potvin (eds), *UMT 2017: Proceedings of the First International Conference on Underground Mining Technology*, Australian Centre for Geomechanics, Perth, pp. 25–43, https://doi.org/10.36487/ACG_rep/1710_01_Luis

Bucher, R, Cala, M, Zimmermann, A, Balg, C & Roth, A 2013, 'Large scale field tests of high-tensile steel wire mesh in combination with dynamic rockbolts subjected to rockburst loading', in Y Potvin & B Brady (eds), *Ground Support 2013: Proceedings of the Seventh International Symposium on Ground Support in Mining and Underground Construction*, Australian Centre for Geomechanics, Perth, pp. 221–232, https://doi.org/10.36487/ACG_rep/1304_14_Bucher

Cai, M & Kaiser, PK 2018, *Rockburst Support Reference Book. Volume I: Rockburst phenomenon and support characteristics*, MIRARCO - Mining Innovation, Laurentian University, Sudbury.

Cala, M, Roth, A & Roduner, A 2013, 'Large scale field tests of rock bolts and high-tensile steel wire mesh subjected to dynamic loading', *Proceedings of ISRM International Symposium-EUROCK 2013*, International Society for Rock Mechanics and Rock Engineering, Lisbon.

Crompton, B, Berghorst, A & Knox, G 2018, '*A new dynamic test facility for support tendons*', Australian Centre for Geomechanics Newsletter, August 2018, pp. 13–15, https://acg.uwa.edu.au/wp-content/uploads/2020/06/ACG_Newsletter_46_web.pdf

Hadjigeorgiou, J & Potvin, Y 2011, 'A critical assessment of dynamic rock reinforcement and support testing facilities', *Rock Mechanics and rock Engineering*, vol. 44, pp. 565–578.

Kaiser, PK, McCreath, DR & Tannant, DD 1996, *Canadian Rockburst Support Handbook*, Geomechanics Research Centre, Laurentian University, Sudbury.

Kaiser, PK, & Moss, A 2022, 'Deformation-based support design for highly stressed ground with a focus on rockburst damage mitigation', *Journal of Rock Mechanics and Geotechnical Engineering*, vol. 14, pp. 50–66.

Muñoz, A 2019, *Ground Support Systems at Codelco, El Teniente Mine*, internal report, Codelco, Santiago.

Muñoz, A, Brändle, R, Luis Fonseca, R & Fischer, G 2017, 'Full-scale dynamic tests of a ground support system using high-tensile strength chain-link mesh in El Teniente mine', in JA Vallejos (ed.), *Proceedings of Ninth Symposium on Rockbursts and Seismicity in Mines*, Editec S.A., Santiago.

Ortlepp, WD 2001, *Performance Testing of Dynamic Stope Support Test Facility at Savuka*, SIMRAC report, GAP 611.

Ortlepp, WD & Stacey, TR 1998, 'Performance of tunnel support under large deformation static and dynamic loading', *Tunnelling and Underground Space Technology*, vol. 13, pp. 15–21.

Ortlepp, WD & Stacey, TR 1997, *Testing of Tunnel Support: Dynamic Load Testing of Rock Support Containment Systems*, SIMRAC report, GAP 221.

Player, JR, Villaescusa, E & Thompson, AG 2004, 'Dynamic testing of rock reinforcement using the momentum transfer concept', in E Villaescusa & Y Potvin (eds), *Proceedings of the Fifth International Symposium on Ground Support*, Balkema, Zutphen.

Roth, A, Cala, M, Brändle, R & Rorem, E 2014, 'Analysis and numerical modelling of dynamic ground support based on instrumented full-scale tests', in M Hudyma & Y Potvin (eds), *Deep Mining 2014: Proceedings of the Seventh International Conference on Deep and High Stress Mining*, Australian Centre for Geomechanics, Perth, pp. 151–163.

Villaescusa, E 2009, 'Ground support research at the WA School of Mines', *International Journal of the JCRM*, vol. 5, pp. 1–10.